HIGHWAY DESIGN MANUAL

COMMONWEALTH OF PUERTO RICO
DEPARTMENT OF TRANSPORTATION AND PUBLIC WORKS
HIGHWAY AUTHORITY

AUTORIDAD DE CARRETERAS

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1979

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INTRODUCTION

This Highway Design Manual includes the basic highway design policies and procedures of the Department of Transportation and Public Works. It will provide guidance to the Department personnel, its outside consultants, and other Commonwealth and Municipal agencies for the design of safe, efficient and attractive highways. The manual incorporates the most recent design concepts and practices developed by the American Association of State Highway and Transportation Officials, the Federal Highway Administration and the Transportation Research Board. Traffic safety aspects are emphasized throughout on such features as geometric design, cross section elements, structures, traffic control devices, safety barriers, location of utilities, highway lighting, and pedestrian facilities.

The manual will aid in obtaining consistency and uniformity in the application of standards and policies to those agencies engaged in highway design. The manual will improve the highway design process from the preliminary stages through the development of final construction plans. It will promote the design of safer highways and appurtenances which will contribute to lower accident rates in the future.

Design procedures and criteria are subject to change or additions which will be incorporated in this manual by revisions issued and signed by the Secretary of the Department of Transportation and Public Works.

ACKNOWLEDGEMENTS

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Acknowledgement is made to the Puerto Rico Traffic Safety Commission and the Federal Highway Administration for their technical and financial assistance and to the American Association of State Highway and Transportation Officials (AASHTO), the Transportation Research Board (TRB) and the National Cooperative Highway Research Program (NCHRP) for permission to use material from their publications.

Finally, much credit for the content of the manual must go to the individuals of the Highway Authority and Public Works Areas who contributed to the working drafts and to those who provided excellent review comments in those drafts.

ORGANIZATION OF THE DESIGN MANUAL

This Manual comprises twenty one (21) chapters, each one subdivided into sections and subsections.

A decimal numbering system is used to identify each chapter, section and subsection. For example:

2-08	identifies section 8 of chapter 2.
3-04.02	identifies subsection 2 of section 4 of chapter 3.

Tables within each chapter are identified by the chapter number and a digit as for example Table 5–1.

Figures within each chapter are identified by the chapter number and a letter as for example Figure 6–A.

Charts within each chapter are identified by chapter number and a Roman number as for example Chapter 4–I.

The pages within each chapter are numbered consecutively and identified by the chapter number and page number within the chapter as for example page 7–8.

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CHAPTER 1

GENERAL DESIGN CRITERIA

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CHAPTER 1

GENERAL DESIGN CRITERIA

1–01 GENERAL

This chapter includes a general discussion of highway types, highway systems, design designation and highway capacity. It also covers the general and geometric design requirements that are specified to insure that the design of a highway facility is consistent with its projected service.

1–02 HIGHWAY TYPES

The term highway, road or street is a general term denoting a public way for purposes of vehicular travel including the entire area within the right-of-way. For rural areas the term highway or road is used, for urban areas highway or street is used.

Control of access is the condition where the right of owners or occupants of abutting land or other persons to access, light, air or view in connection with a highway is fully or partially controlled by public authority.

Full control of access means that the authority to control access is exercised to give preference to through traffic by providing access connections with selected public highways only by prohibiting crossings at grade or private drive-way connections.

Partial control of access means that the authority to control access is exercised to give preference to a degree that, in addition to access connections with selected public highways, there may be crossings at grade and some private drive-way connections.

The following definitions of various highway types apply throughout this manual:

Expressway—An arterial highway with full or partial control of access.

Freeway—An expressway with full control of access.

Autopista—A toll freeway.

Major Highway or Major Street—An arterial highway with intersections at grade and direct access to abutting property, and on which the geometric design and traffic control measures are used to expedite the safe movement of through traffic.

Through Highway or Through Street—Every highway or portion thereof on which vehicular traffic is given preferential right-of-way, and at entrances to which vehicular traffic from intersecting highways is required by law to stop before entering or crossing the same and when stop signs are erected.

Divided Highway—A highway with separated roadways for traffic in opposite directions.

Avenue—A major street, usually a divided multilane highway, designated as such in the urban area master plan.

Principal Street—A through street, usually undivided multilane, designated as such in the urban area master plans.

Local Street or Local Road—A street or road primarily for access to residence, business or other abutting property.

Frontage Road or Street (Also called marginal road or street)—A local road or street auxiliary to and located on the side of an arterial highway for service to abutting property and adjacent areas and for control of access.

Cul-de-sac Street—A local street open at one end only and with special provision for turning around.

Dead-end Street—A local street open at one end only and without special provision for turning around.

1—03 HIGHWAY SYSTEMS

Highways in Puerto Rico have been classified and grouped into designated systems for administrative, financing and other purposes. This manual is primarily concerned with highways designated as Commonwealth highways although the design principles, policies and procedures included herein are applicable to roads and streets which fall under the jurisdiction of the respective municipalities.

1—03.01 COMMONWEALTH HIGHWAY SYSTEM

The Commonwealth Highway System includes all highways designated in the master highway plan and some additional roads and streets which are under the maintenance responsibility of the Department of Transportation and Public Works. This system is shown on an official map published by the Department which is normally updated annually. It includes both rural and urban numbered routes.

The Commonwealth Highway System is divided into three categories:

1. Primary—Includes the principal routes connecting the major population centers and some entirely intra-urban routes in the larger metropolitan areas. Primary routes at present comprise about 14% of the total Commonwealth system mileage. Numbers 1 through 99 have been reserved for primary routes.

2. Secondary—Generally serve intraregional traffic and provide together with the primary routes, and integrated network connecting all the municipal centers of the Island except the offshore municipalities of Vieques and Culebra. Secondary routes comprise about 30% of the total Commonwealth system mileage. Numbers 100 through 299 have been reserved for secondary routes.

3. Municipal—These are local access roads which have been included in the Commonwealth system and comprise about 56% of the total mileage. Numbers 300 through 9999 have been reserved for these municipal routes.

1—03.02 FEDERAL-AID HIGHWAY SYSTEM

The Federal-aid Highway System was established to designate the routes that would be eligible for improvement under the Federal-aid highway program. However, there are at present some special categories of FA highway funds which may be spent, under certain conditions, on routes not included in the FA system.

Routes on the FA highway system are classified as follows:

1. Primary—Includes most of the rural arterial highways of the Commonwealth highway system and their urban extensions. The major exceptions are the toll highways PR-22 and PR-52 which are not eligible for financing under the Federal-aid program.

2. Secondary—Includes most of the rural major collector highways in the Commonwealth highway system and their urban extensions except those in urban areas with population of 5,000 or more persons.

3. Urban—Includes principal urban arterial and collector highways located within urban areas with population of 5,000 or more persons which are not included in another FA system.

4. Forest Highways—These include highways serving the Caribbean National Forest-Luquillo Division. Forest highways may also be in other FA systems. The currently designated FH routes are PR-191 (FAS-191) and a portion of PR-186 (FAS-186).

Federal-aid projects must conform with design standards acceptable to the Federal Highway Administration which are covered in the Federal-Aid Highway Program Manual (Volume 6, Chapter 2). The FHWA accepts the standards, specifications, policies and guides of the American Association of State Highway and Transportation Officials (AASHTO). This manual is in general conformance with AASHTO standards, policies and guides; thus, projects designed under this manual will normally meet Federal-aid design requirements. However, a designer assigned a project to be built under the Federal-aid program should ascertain any special FA design requirements applicable to the projects to insure that the design will meet FHWA approval.

1–04 FUNCTIONAL HIGHWAY CLASSIFICATION

Functional highway classification is the grouping of roads and streets into classes, or systems, according to the character of service they are intended to provide. The classification process recognized that most travel involves movement through a network of roads and/or streets and should be channelized within the network in a logical and efficient manner. Under functional classification, roads and streets having similar functions and importance are grouped into connected systems. Such a classification system provides a foundation for planning and design operations.

Under a functional highway classification system, there are three basic categories of roads and streets: arterials, collectors and local. It is also recognized that urban and rural areas have different characteristics as to density and types of land use, density of street and highway networks, nature of travel patterns, and the way that all these elements are related in the definitions of highway function. Therefore, separate classification of urban and rural functional systems are made.

A complete discussion of concepts, criteria and procedures for functional classification is included in the FHWA publication "HIGHWAY FUNCTIONAL CLASSIFICATION" of July 1974. The following are generalized explanations of the three basic types:

1. Arterials—Include routes serving corridors of substantial traffic density and trip length. They are expected to provide a high degree of mobility and, therefore, should have high operating speeds, minimum interference to through movement and direct routing favoring the longer trip lengths. In rural areas, the arterial system consists of a connected network serving the larger urban areas and major traffic generators. In urban areas, the arterial system will serve the major centers of activity, the highest traffic volume corridors and the longer trips. The arterial system is further divided into principal arterials and minor arterials.

2. Collectors—These are routes intermediate between arterials and locals that serve the dual function of mobility and land access. They accommodate the shorter trip lengths and feed traffic to the arterials, and, thus, must provide some degree of mobility. In rural areas they provide service to the urban centers not directly served by the arterial system. In urban areas the collector system provides both land access service and traffic circulation within residential neighborhoods, commercial and industrial areas.

3. Local—Rural local roads serve primarily to provide access to adjacent land and provide service to travel over relatively short distances. Urban local streets serve primarily to provide direct access to abutting land and access to the higher order systems. Local roads and streets offer the lowest level of mobility and in urban areas through traffic movement is usually deliberately discouraged.

The general design criteria applicable to a particular route are directly related to its functional classification. Principal arterials are designed as freeways with high design speeds and full control of access. Minor arterials are designed for somewhat lower speeds with access to adjacent properties usually minimized through partial control of access measures. On some very high volume multilane minor arterials full freeway standards may be warranted. Since collectors are to provide both mobility and access, the applicable design standards are of a lower level than for arterials and direct access is permitted. Local roads and streets require the lowest design standards since property access is their main function and there is little need for mobility or high operating speeds.

The primary, secondary and municipal classifications of the Commonwealth Highway System, which were established many years ago, were essentially functional. The primary would correspond to principal arterials, the secondary to minor arterials and collectors, and the municipal to local. However, as the Island developed, fundamental changes have ocurred in the service requirements of many routes to the point that the Commonwealth system classification of many routes can not be directly related to their current category under a functional classification system.

Functional classification has been applied to the Puerto Rico highway system but its use has been generally limited to highway needs and transportation studies, islandwide and for the metropolitan areas. However, from such studies, the design standards for many arterial and collector routes have been established.

The general design criteria included in this chapter are presented in such a manner that they can be directly related to the functional classification established for any specific route.

1–05 DESIGN REFERENCES

Although this manual provides specific information on design standards, policies and procedures of the Department, it does not do away with the need to consult and use other accepted design guides and throughout the manual references are made to other publications, particularly those of the American Association of State Highway and Transportation Officials.

The following is a list, by no means all inclusive, of references on geometric and structural design and traffic control features that the designer should have access to and be familiar with. These are approved references for use in conjunction with this manual; however, since some of these policies and guidelines do not always satisfy Puerto Rico conditions, the instructions in this manual shall take precedence over these references, except for Federal-aid projects. For the latter, exceptions to the standards specified in the Federal-aid Highway Program Manual (Vol. 6, Chap. 2) require approval on an individual project basis.

1. AASHTO (formerly AASHO):

(Note—AASHTO publications are subject to updating and/or revisions as changes in concepts and standards develop. Therefore, the designer should ascertain as to the latest edition of the following publications that may be in effect at the time of design.)

a. Geometric Design Standards for Highways Other Than Freeways—1969
b. Geometric Design Guide for Local Roads and Streets—1970
c. Standard Specifications for Highway Bridges—1973, as amended
d. Specifications for Design and Construction of Structural Supports for Highway Signs—1968
e. Specifications for the Design and Construction of Structural Supports for Highway Luminaries.—1970, as amended
f. Standard Specifications for Welding of Structural Steel Highway Bridges—1974
g. A Policy on Geometric Design of Rural Highways—1965

h. A Policy on Design of Urban Highways and Arterial Streets—1973
i. A Policy on the Accommondation of Utilities on Freeway Rights-of-Way—1969
j. A Policy on U-Turn Median Openings on Freeways—1960
k. A Policy on Design Standards for Stopping Sight Distances—1971
l. Highway Definitions—1968
m. Highway Design and Operational Practices Related to Highway Safety—1974
n. A Guide for Bicycle Routes—1974
o. Guide Specifications for Highway Construction—1972
p. Highway Drainage Guidelines, Volumes I, II and III—1973, and IV—1975
q. Interim Guide for Design of Pavement Structures—1972
r. A Guide for Highway Landscape and Environmental Design—1970
s. An Informational Guide for Roadway Lighting—1969
t. A Guide for Accommondating Utilities on Highway Rights-of-Way—1969
u. A Guide for Erecting Mail Boxes on Highways—1969
v. A Guide for Protective Screening of Overpass Structures—1969
w. Guide on Evaluation and Attenuation of Traffic Noise—1974
x. An Informational Guide for Fencing Controlled Access Highways—1967
y. Standard Specifications for Transportation Materials and Methods of Sampling and Testing—1974

2. Federal Highway Administration (FHWA):

a. Manual on Uniform Traffic Control Devices for Streets and Highways—1971
b. Handbook of Highway Safety Design and Operating Practices—1973, as amended
c. Capacity Analysis Techniques for Design of Signalized Intersections—1967
d. Capacity Analysis Techniques for Design and Operation of Freeway Facilities—1974
e. Corrugated Metal Pipe—1970
f. Reinforced Concrete Pipe Culverts—1963
g. Reinforced Concrete Bridge Members—1969
h. Standard Plans for Highway Bridges

Vol 1 — Concrete Superstructures—1968
Vol 2 — Structural Steel Superstructures—1968
Vol 4 — Typical Continuous Bridges—1969

i. Typical Plans for Retaining Walls—1969

3. Others:

a. Highway Capacity Manual, HRB Special Report 87—1965
b. Recommended Practices for Railroad-Highway Grade Crossing Warning Systems, Bulleting 7, Association of American Railroads—1974

Reference to other publications providing design guidance on such specific items as hydraulics, drainage, bridges, traffic barriers, lighting, aerial surveys, etc. are included in other appropriate chapters throughout this manual.

1-06 DETERMINATION OF DESIGN REQUIREMENTS

The determination of the general design requirements for a particular route or project is initially made by the Transportation Planning Area of the Department. The general standards selected result from the planning process which includes the system planning studies, corridor studies, and route location studies. This planning process is covered in detail in the ACTION PLAN which was approved in 1974.

The Transportation Planning Area is responsible for route and project development activities up to the location approval stage. However, the Design Area does participate actively during the corridor and location study stages including the furnishing of very preliminary geometric design data and construction cost estimates. The Design Area also provides during these stages information on soils, geology, drainage areas, structures and other technical data needed for the evaluation of the economic, social and environmental aspects of the alternates under consideration.

The Transportation Planning Area is responsible for route location and selection studies including the development of the alternate routes report and the final Route Location Report. The latter includes the general design criteria for the route which is based on the service to be provided and the traffic estimates that have been made.

The design traffic data is essential to the designer. This is furnished by the Transportation Planning Area in the form of traffic flow and turning movement diagrams for the design year. The normal design period used by the Department is 20 years for primary and secondary highways, both rural and urban. However, for low volume secondary highways a 10 years design period is used if the estimated annual average daily traffic (ADT) will not exceed 1,200 vehicles within that period. Commonwealth system municipal roads are designed for their current traffic volume except where the service they provide warrants a 10 or 20 years design period as determined from the highway planning studies.

After the location has been approved, the project becomes the responsibility of the Design Area and it enters the preliminary and final design phases. During the preliminary design phase the general design criteria provided in the approved Route Location Report are further evaluated and expanded to cover in more detail such items as design speed, geometrics, typical sections and structures. The end product of the preliminary design phase is the Preliminary Engineering Design Report which, after review and approval (including public hearings, if required) provides the basic design for the development of the final construction plans.

Corridor and location studies, and preliminary design reports are discussed in Chapter 18 on Route and Project Planning.

1–07 TRAFFIC ELEMENTS

The following definitions apply to traffic data elements pertinent to design which are used throughout this manual:

ADT– Average daily two-way traffic volume. The aplicable year is specified.

DHV– The design hourly volume. It is normally the estimated 30th highest hour two-way traffic volume for the design year selected. In some special cases it may be other than the 30 HV.

K– The ratio of DHV to ADT expressed as a percentage of ADT.

D– The directional distribution of traffic during the design hour. It is the one-way volume in the predominant direction of travel expressed as a percentage of DHV.

T– The proportion of trucks, exclusive of light delivery trucks, in the traffic stream expressed as a percentage of DHV.

V– The design speed in miles per hour which is determined for the design and correlation of the physical features of a highway that influence vehicle operation. It is the maximum safe speed that can be maintained over specified section of highway when conditions are so favorable that the design features of the highway govern.

When designing interchanges and major intersections it is necessary to know the volumes of all movements ocurring simultaneously. The directional DHV is determined by the use of the following formula:

$$\text{DHV (one way)} = \text{ADT} \times K \times D$$

1–08 DESIGN DESIGNATION

Design designation is an expression indicating the major controls or services for which a given highway is designed. The design designation is concise so that it can be readily understood, but complete enough to show the major design controls aplicable to a project.

The major design controls include traffic volume and composition, design speed, and control of access. These controls determine the principal geometric features to be applied. Other design controls and criteria such as topography, physical features, design vehicles, capacity, safety, parking, pedestrian services, and economics are of primary concern but these are either reflected in the major controls or have to do with the more detailed features of the design which are not considered necessary for inclusion in a concise and simple design designation.

The following items are normally included in the design designation:

Control of access— indicated as full, partial or none.

ADT— for current year.

ADT— for design year.

DHV— this ranges 9-14% of ADT for rural highways and 8-13% for urban highways in Puerto Rico.

D— ranges 50-75% of DHV.

T— ranges 3-18% of DHV for rural highways.

V— ranges 20-70 mph depending on the type of highway and character of terrain.

The design designation of each project is included in the title sheet to provide the plan users with a readily available brief reference of the major design controls applicable to the project.

1–09 DESIGN VEHICLES

There are six design vehicles used as controls in geometric design. These vehicles and their dimensions are summarized in Table 1-1. For design purposes, the largest vehicle which represents a significant percentage of the traffic for the design year is used. The design vehicles to be used on expressways and major highways are specified in the tabulations of general design requirements included in this chapter. The semitrailer-full trailer combination (WB-60) is not legal in Puerto Rico.

On most other highways accomodating truck traffic, one of the design semitrailer combinations should be considered in the design, particularly where turning roadways are bordered by curbs or islands.

TABLE 1-1

DESIGN VEHICLES

DESIGN VEHICLE	DIMENSIONS IN FEET						
TYPE	SYMBOL	WHEEL-BASE	Overhang		Overall Length	Overall Width	Height
			Front	Rear			
Passenger Car	P	11	3	5	19	7	—
Single Unit Truck	SU	20	4	6	30	8.5	13.5
Single Unit Bus	BUS	25	7	8	40	8.5	13.5
Semitrailer Combination, Intermediate	WB-40	13+27=40	4	6	50	8.5	13.5
Semitrailer Combination Large	WB-50	20+30=50	3	2	55	8.5	13.5
Semitrailer-full trailer Combination	WB-60	9.7+20+9.4+ 20.9=60	2	3	65	8.5	13.5

1-10 HIGHWAY CAPACITY

The capacity of a highway is a measure of its ability to serve traffic. Highway capacity is considered in two general categories — uninterrupted flow or open highway conditions and interrupted flow as at intersections. Uninterrupted flow occurs in highways with control of access and to a considerable extent on highways where the influece of intersections and abutting property development is not significant.

The basic guide on highway capacity is the 1965 Highway Capacity Manual published by the Highway Research Board (now the Transportation Research Board) as Special Report 87. However, the AASHTO 1965 Policy on Geometric Design of Rural Highways, commonly referred to as the Blue Book, provides the essential working data on capacity in a more condensed, ready-to-use form. Similarly, the AASHTO 1973 Policy on Design of Urban Highways and Arterial Streets, the Red Book, includes condensed data concerning design capacity of urban highways.

This chapter includes a summary of pertinent factors and design values adapted from the above publications which can be applied by the designer to most design analysis for open highway conditions. Capacity of intersections-at-grade is discussed in Chapter 4, and of interchange ramps and weaving sections in Chapter 5.

1—10.01 DEFINITIONS

The following are definitions and explanations of the major terms and variables used in discussions of highway capacity in this manual.

CAPACITY—The maximum number of vehicles which have a reasonable expectation of passing over a section of a lane or a roadway in one direction (or in both directions for a two-lane highway) during a given time period (usually one hour) under prevailing roadway and traffic conditions. Prevailing roadway conditions refer to those that are established by the physical features of the roadway such as grades, horizontal alignment, lane width, and clearance to obstructions. Prevailing traffic conditions refer to those that are dependent upon the nature of the traffic on the roadway.

TABLE 1-2

LEVEL OF SERVICE CHARACTERISTICS BY HIGHWAY TYPE

LEVEL OF SERVICE	TWO - LANE	MULTI-LANE RURAL w/o ACCESS CONTROL	URBAN AND SUB-URBAN ARTERIALS	CONTROLLED ACCESS HIGHWAYS
A	Operating speeds of 60 m.p.h. or higher. 75% of passing maneuvers can be made with little or no delay. Under ideal conditions, a service volume of 400 passenger vehicles/ hour, two-way, can be achieved.	Operating speed 60 m.p.h. or greater. Under ideal conditions, volume is limited to 600 passenger cars per lane per hour or 30 per cent of capacity. Average speeds are likely to be influenced by speed limits.	Average over-all travel speed of 30 m.p.h. or more. Free flowing with volume/capacity ratio of 0.60. Load factor at intersections near the limit of the 0.0 range. Peak-hour factor at about 0.70.	Free flow. Operating speeds at or greater than 60 m.p.h. Service volume of 1400 passenger cars per hour on 2-lanes, one direction. Each additional lane serves volume of 1000 v.p.h./lane.
B	Operating speeds of 50 m.p.h. or higher. Volumes may reach 45% of capacity with continuous passing sight distance. Volumes of 900 passenger cars per hour, two-way, can be carried under ideal conditions.	Beginning of stable flow area. Volume at which actions of preceding vehicle will have some influence on following vehicles. Volume will not exceed 50% of capacity or 1000 passenger vehicles per lane per hour at a 55 m.p.h. Operating speed under ideal conditions.	Average over-all speeds drop due to intersection delay and intervehicular conflicts, but remain at 25 m.p.h. or above. Delay is not unreasonable. Volumes at 0.70 of capacity and peak-hour factor approximately 0.80. Load factor at intersections approx. 0.1.	Higher speed range of stable flow. Operating speed at or greater than 55 m.p.h. Service volume on 2-lanes in one direction not greater than 2000 passenger vehicles per hour. Each additional lane above two in one direction can serve 1500 v.p.h.
C	Flow still stable. Operating speeds of 40 m.p.h. or above with total volume under ideal conditions equal to 70% of capacity with continuous passing sight distance, or 1400 passenger vehicles per hour, two-way.	Stable flow to a volume not exceeding 75% of capacity or 1500 passenger cars per lane per hour, under ideal conditions, maintaining at least a 45 m.p.h. operating speed.	Service volumes about 0.80 of capacity. Average over-all travel speeds of 20 m.p.h. Operating conditions at most intersections approximate load factor of 0.3. Peak hour factor approximately 0.85. Traffic flow still stable with acceptable delays.	Operation still stable, but becoming more critical. Operating speed of 50 m.p.h. and service flow on two-lanes in one direction at 75% of capacity or not more than 5 min. flow rate of 3000 passenger cars per hour. Under ideal conditions each additional lane above two in one direction would serve 1800 v.p.h.
D	Approaching unstable flow. Operating speeds approx. 35 m.p.h. Volumes, two-direction, at 85% of capacity with continuous passing opportunity, or 1700 passenger cars per hour under ideal conditions.	Approaching unstable flow at volumes up to 90% of capacity or 1800 passenger cars per lane per hour at an operating speed of about 35 m.p.h. under ideal conditions.	Beginning to tax capabilities of street section. Approaching unstable flow. Service volumes approach 0.90 of capacity. Average over-all speeds down to 15 m.p.h. Delays at intersections may become extensive with some cars waiting two or more cycles. Peak hour factor approx. 0.90; load factor of 0.7.	Lower speed range of stable flow. Operation approaches instability and is susceptible to changing conditions. Operating speeds approx. 40 m.p.h. & service flow rates at 90% of capacity. Peak 5 min. flow under ideal conditions cannot exceed 3600 v.p.h. for 2-lanes, 1 direction; 1800 v.p.h. each added lane.
E	Operating speeds in neighborhood of 30 m.p.h. but may vary considerably. Volumes under ideal conditions, two-way, equal to 2000 passenger vehicles per hour. Level E may never be attained. Operation may go directly from Level D to Level F.	Flow at 100% of capacity or 2000 passenger cars per lane per hour under ideal conditions. Operating speeds of about 30 m.p.h. or less.	Service volumes at capacity. Average over-all traffic variable, but in area of 15 m.p.h. Unstable flow. Continuous back-up on approaches to intersections. Load factor at intersections in range between 0.7 and 1.0 Peak hour factor likely to be 0.95.	Unstable flow. Over-all operating speeds of 30-35 m.p.h. Volumes at capacity or about 2000 v.p.h./lane under ideal conditions. Traffic flow metered by design constrictions and bottlenecks, but long back-ups do not normally develop upstream.
F	Forced, congested flow with unpredictable characteristics. Operating speeds less than 30 m.p.h. Volumes under 2000 passenger cars per hour, two-way.	Forced flow, congested condition with widely varying volume characteristics. Operating speeds of less than 30 m.p.h.	Forced flow. Average over-all traffic speed below 15 m.p.h. All intersections handling traffic in excess of capacity with storage distributed throughout the section. Vehicular back-ups extend back from signalized intersections, through unsignalized intersections.	Forced flow. Freeway acts as a storage for vehicles backed-up from downstream bottleneck. Operating speeds range from near 30 m.p.h. to stop-and-go operation.

LEVEL OF SERVICE—A qualitative measure of the effect of a number of factors affecting capacity which include speed, travel time, traffic interruptions, freedom to maneuver, safety, driving comfort, convenience and operational costs. Specific levels of service range from ideal operation (Level A) to complete congestion (Level F). The various levels of service as pertain to types of highways are summarized in Table 1-2. Capacity occurs at Level E.

SERVICE VOLUME—The maximum number of vehicles that can pass over a given section of lane or roadway in one direction (or in both directions on a two-lane highway) for a specified time period (usually one hour) while operating conditions are maintained corresponding to the selected or specified level of service.

DESIGN CAPACITY—Comparable to the term service volume for a given level of service.

AVERAGE HIGHWAY SPEED—The weighted average of the design speeds within a highway section when each subsection within the section is considered to have an individual design speed.

OPERATING SPEED—The highest overall speed at which a driver can travel on a given highway under favorable weather conditions and under prevailing traffic conditions without exceeding the safe speed used for design.

RUNNING SPEED—The speed over a specified section of highway, being the distance divided by the running time. The average for all traffic is the summation of distances divided by the summation of running times.

PEAK HOUR FACTOR (PHF)—The ratio of the volume occurring during the peak hour to the maximum rate of flow during a part of the hour, usually 5 minutes for operation on freeways and 15 minutes on intersections. This factor applies for urban freeways at levels of service C and D and at intersections, but not to rural freeways. Common values are about 0.8 to 0.9.

LOAD FACTOR—The ratio of the total number of green signal intervals that are fully utilized by traffic during the peak hour to the total number of green intervals for that approach. Common values within the design range are 0.2 to 0.6.

1-10.02 UNINTERRUPTED FLOW-GENERAL

The designer should determine by analysis the design characteristics of a highway and the corresponding running speed which in combination will have a design capacity at the selected level of service which is at least as great as the design volume. Normally, highways should be so designed that the designated average running speeds can be maintained during the design hour; that is, when the design hour volume (DHV) is using the highway.

Three ranges of **average running speed** are considered appropriate for use in the design of arterial and collector highways as follows:

45—50 mph—Applicable for most main rural 2-lane, two-way highways and all rural multilane highways in level and rolling terrain. Corresponds approximately to level of service B.

40—45 mph—Applicable to highways approaching urban areas, for multilane highways in mountainous terrain, and where feasible for 2-lane highways in mountainous terrain. Corresponds approximately to level of service C.

35—40 mph—Applicable to 2-lane rural highways in mountainous terrain where design for higher speeds is not feasible, and to controlled access highways in urban areas where it is expected that during the design hour freedom to travel at high speed will be curtailed by DHV traffic. Corresponds approximately to level of service D.

It is generally not economically feasible to provide a facility that will permit running speeds during the design hour higher than those mentioned above. For low volume local roads and streets such as municipal roads in mountainous terrain, economic factors normally require the designing for even lower average running speeds.

Table 1—3 shows the capacities for highways constructed to high standards including 12—foot (3.65 M.) lanes, adequate shoulders, lateral clearances of 6 feet (1.83 M) or more, no trucks, adequate stopping sight distance throughout and no restrictive passing sight distance when the highway is 2—lane, two-way.

TABLE 1-3

POSSIBLE AND DESIGN CAPACITIES OF HIGHWAYS CONSTRUCTED TO HIGH DESIGN STANDARDS IN TERMS OF PASSENGER CARS PER HOUR

Type of Highway	Possible capacity	Design capacity for average running speed* in mph of:		
		35-40	40-45	45-50
	vph	vph	vph	vph
2-Lane, two-way (total)	2,000	1,500	1,150	900
Multilane (per lane)	2,000	1,500	1,200	1,000

*Running speed for the faster vehicles, termed "Operating Speed" in the Highway Capacity Manual, will exceed the average running speeds shown by an amount varying from about 5 mph (in the case of 35-40 mph average) to about 7 mph (in the case of the 45-50 mph average).

However, the values in Table 1—3 are seldom attainable since ideal highway conditions rarely prevail. Adjustment factors are aplied to correct for prevailing roadway and traffic conditions and derive the needed working values. The more important adjustment factors include: lane width, lateral clearance, type of terrain, composition of traffic, alignment and sight distances, and degree of access control or roadside and intersectional interference.

The effect that trucks (and buses) have on capacity is primarily a function of the difference between the average speed of the trucks and the average running speed of the passenger cars on the highway. The disparity between the speeds of the two classes of vehicles increases when the grades are sufficiently long and steep to slow down the trucks but where passenger cars are not impeded by alignment and grades. In addition, the physical dimensions of heavy trucks and their poorer accelerating characteristics also have a bearing on the space they occupy in the traffic stream. For example, the average dual-tired truck occupies about twice the space of the average passenger car when grades are nearly level and trucks can travel almost as fast as passenger cars.

The effect that trucks and buses have on capacity and the adjustment factors to be used are covered in considerable detail in the Highway Capacity Manual. Average generalized factors for converting trucks and buses to equivalent passenger cars are as follows:

Type of Highway and Vehicle	Level	Terrain Rolling	Mountainous
Two—lane Highway			
Truck	2	5	10
Bus	2	4	6
Multilane Highway			
Truck	2	4	8
Bus	1.6	3	5

Separate consideration of buses is not warranted in most capacity analyses, only where bus volumes are a significant portion of the traffic stream.

The following sections provide summarized capacity data and tabulations for direct application by the designer to capacity analyses generally under uninterrupted flow conditions. The information provided will allow the designer to arrive at practical conclusions in most cases that he will encounter. It is doubtful that greater precision will be required particularly in view of the reliability of future traffic volume forecasts. However, if greater precision is required and for more complex cases the designer should refer to the Highway Capacity Manual.

1—10.03 TWO—LANE HIGHWAYS

Tables 1—4 through 1—6 show design capacities for uninterrupted flow under various conditions on 2—lane two-way highways. Since the distribution of traffic by directions is not a factor in determining the capacity of 2—lane highways when flow is uninterrupted, the values given in these tables are in total number of vehicles per hour in both directions of travel.

Two—lane highways have a restriction not found on multilane highways resulting from the need for traffic to occupy the lane of opposing traffic when passing. Thus, the character of alignment and profile of these roads, the design speed, and the extent of restrictive sight distance have a considerable effect on their capacity.

Tables 1—4, 1—5 and 1—6 show design capacities considering five basic variables—terrain, percentage of restricted sight distance under 1500 feet (457 meters), lane width, percentage of trucks in the traffic stream and design speed. The sight distance of 1500 feet is not the safe passing sight distance which varies with design speed but is a value selected in the Highway Capacity Manual as a measurement criteria to evaluate design capacity of 2—lane highways.

Table 1—4 which shows design capacities for average running speeds of 45—50 mph corresponds approximately to volumes for a level of service B. This is the level recommended for use, wherever feasible, in the design of major rural 2—lane highways in level and rolling terrain.

The design capacities in Table 1—5, for average running speeds of 40—45 mph, correspond approximately to service level C. This is the level recommended for major 2—lane highways approaching urban areas and, whenever feasible, on rural highways in mountainous terrain. Service level "C" is also the minimum acceptable for the design of major 2—lane rural highways in level and rolling terrain.

Table 1—6 shows design capacities for average running speeds of 35—40 mph which correspond approximately to service level D. This level is acceptable for 2—lane highways with uninterrupted flow in urban areas and is the minimum acceptable level for the design of major rural roads in mountainous terrain.

Table 1—4, 1—5 and 1—6 are all based on shoulder width and lateral clearances of at least 6 feet (1.8 meters). Table 1—7 includes capacity reduction factors to be applied where shoulders and/or lateral clearances are less than 6 feet.

Tables 1—4 through 1—6, together with Table 1—7, may be used directly in design with interpolation as required to quickly evaluate design capacity. They may also be used in highway planning and in the preliminary stages of design to determine generally the extent of improvenent needed on an existing highway to serve an anticipated traffic load.

TABLE 1-4

DESIGN CAPACITIES OF 2-LANE, TWO-WAY HIGHWAYS FOR AVERAGE RUNNING SPEED OF 45-50 MPH IN VPH
Applicable for most main rural 2-lane highways in level and in rolling terrain

Terrain	Alignment: Percentage of total length of highway on which sight distance is restricted to less than 1500 feet*	Design capacity of 2-lane highway, total both directions L = width of lane and T = percentage of trucks, peak hour					
		L = 12'			L=11'		
		T= 0	T= 10	T= 20	T= 0	T= 10	T= 20
		1. Design Speed 65 or 70 mph					
Level	0	900	780	690	11-foot lanes not appropriate for high design speed with heavy volume		
	20	860	750	660			
	40	800	700	620			
Rolling	20	860	615	485			
	40	800	570	450			
	60	720	510	400			
		2. Design Speed 60 mph					
Level	0	900	780	690	775	670	590
	20	810	705	625	700	605	540
	40	700	610	540	600	525	465
	60	585	510	450	500	440	390
Rolling	20	810	580	450	700	500	390
	40	700	500	390	600	430	340
	60	585	420	325	500	360	280
	80	480	340	270	410	290	230
	3. Design Speed 50 mph						
	Highways with design speed no higher than 50 mph are not capable of providing 45-50 mph running speed except when traffic volume is very low.						

*Sight distance measured from height of eye to road surface, both vertical and horizontal alignment considered.

NOTE: To obtain possible capacity, use values in table for zero sight distance restrictions and multiply by 2.22 for 12-foot lanes and 2.27 for 11-foot lanes. Tabular values are for conditions with no restrictive lateral clearances; with clearance of less than 6 feet, edge of lane to obstruction, or with shoulders narrower than 6 feet, multiply above values by factor from Table 1-7.

TABLE 1-5

DESIGN CAPACITIES OF 2-LANE, TWO-WAY HIGHWAYS FOR AVERAGE RUNNING SPEED OF 40-45 MPH IN VPH.
Applicable for highways approaching urban areas and, wherever feasible, for highways in mountainous terrain

Terrain	Alignment: Percentage of total length of highway on which sight distance is restricted to less than 1500 feet*	Design capacity of 2-lane highway, total both directions L = width of lane and T = percentage of trucks, peak hour								
		L = 12'			L = 11'			L = 10'		
		T = 0	T = 10	T = 20	T = 0	T = 10	T = 20	T = 0	T = 10	T = 20
		1. Design Speed 65 or 70 mph								
Level	0	1150	1000	880	11-foot lanes not appropriate for high design speed with heavy volume			10-foot lanes not appropriate for high design speed with heavy volume		
	20	1120	970	860						
	40	1070	930	820						
Rolling	20	1120	800	630						
	40	1070	760	600						
	60	920	650	520						
		2. Design Speed 60 mph								
Level	0	1150	1000	880	990	860	760	10-foot lanes not appropriate for 60 mph design speed with heavy volume		
	20	1050	910	810	900	780	700			
	40	930	810	720	800	700	620			
	60	810	700	620	700	600	530			
Rolling	20	1050	800	630	960	690	540			
	40	930	660	520	800	570	450			
	60	810	580	450	700	500	390			
	80	680	480	380	580	410	330			
Mountainous	40	930	490	330	800	420	280			
	60	810	430	290	700	370	250			
	80	680	360	240	580	310	210			
		3. Design Speed 50 mph**								
Level	0	1010	880	780	870	760	670	780	680	600
	20	900	780	690	770	670	590	690	600	530
	40	770	670	590	660	580	510	590	520	450
Rolling	20	900	640	500	770	550	430	690	490	380
	40	770	550	430	660	470	370	590	420	330
	60	620	440	350	530	380	300	480	340	270
	80	440	310	250	380	270	220	340	240	190
Mountainous	40	770	410	280	660	350	240	590	320	220
	60	620	330	220	530	280	190	480	250	170
	80	440	230	160	380	200	140	340	180	120

*Sight distance measured from height of eye to road surface, both vertical and horizontal alignment considered.

**Normally 50 mph is the lowest design speed suitable where a running speed of 40-45 is appropriate with volumes approaching design capacity.

NOTE: To obtain possible capacity, use values in table for zero sight distance restriction and multiply by 1.74 for 12-foot lanes; 1.78 for 11-foot lanes, and 1.83 for 10 foot lanes.

Tabular values are for conditions with no restrictive lateral clearances; with clearances of less than 6 feet, edge of lane to obstruction, or with shoulders narrower than 6 feet, multiply above values by factor from Table 1-7.

TABLE 1-6

DESIGN CAPACITIES OF 2-LANE, TWO-WAY HIGHWAYS FOR AVERAGE RUNNING SPEED OF 35-40 MPH IN VPH

Applicable for 2-lane highways with uninterrupted flow in urban areas and to 2-lane rural highways in mountainous terrain where design for higher running speed is not feasible

Terrain	Alignment: Percentage of total length of highway on which sight distance is restricted to less than 1500 feet*	Design capacity of 2-lane highway, total both directions L = width of lane and T = percentage of trucks, peak hour								
		L = 12'			L = 11'			L = 10'		
		T = 0	T = 10	T = 20	T = 0	T = 10	T = 20	T = 0	T = 10	T = 20
1. Design Speed 65 or 70 mph										
Level	0	1500	1300	1160	11-foot lanes not appropriate for high design speed with heavy volume			10-foot lanes not appropriate for high design speed with heavy volume		
	20	1450	1260	1120						
	40	1400	1220	1080						
Rolling	20	1450	1030	820						
	40	1400	1000	780						
	60	1350	960	750						
2. Design Speed 60 mph										
Level	0	1500	1300	1160	1290	1120	990	10-foot lanes not appropriate for 60 mph design speed with heavy volume		
	20	1410	1230	1080	1210	1050	930			
	40	1320	1150	1020	1140	990	880			
	60	1220	1060	940	1050	910	810			
Rolling	20	1410	1000	790	1210	860	680			
	40	1320	940	740	1140	810	640			
	60	1220	870	680	1050	750	590			
	80	1110	790	620	950	680	520			
Mountainous	40	1320	700	480	1140	600	410			
	60	1220	650	440	1050	560	380			
	80	1110	590	400	950	500	340			
3. Design Speed 50 mph										
Level	0	1450	1260	1120	1250	1080	960	1120	990	860
	20	1340	1160	1040	1150	1000	890	1040	910	800
	40	1200	1040	930	1040	900	800	930	810	720
Rolling	20	1340	950	750	1150	820	640	1030	730	410
	40	1200	850	670	1040	740	580	930	660	520
	60	1050	750	590	900	640	500	810	580	450
Mountainous	40	1200	640	430	1040	550	380	930	490	330
	60	1050	560	380	900	480	320	810	430	290
	80	900	480	320	770	410	280	700	370	250
4. Design Speed 40 mph										
Level	0	1200	1040	930	1040	900	800	930	820	720
	20	1070	930	820	920	800	710	820	720	630
	40	900	780	690	770	670	590	700	610	540
Rolling	20	1070	760	600	920	650	520	820	580	460
	40	900	640	500	770	550	430	700	500	390
	60	720	510	400	620	440	350	560	400	310
	80	460	330	260	400	280	220	350	250	200

(continues on next page)

TABLE 1-6 (Cont.)

Mountainous	40	900	480	320	770	410	280	700	370	250
	60	720	380	260	620	330	220	560	300	200
	80	460	240	170	400	210	140	350	180	130

*Sight distance measured from height of eye to road surface, both vertical and horizontal alignment considered.

NOTE: To obtain possible capacity, use values in table for zero sight distance restriction and multiply by 1.33 for 12-foot lanes; 1.36 for 11-foot lanes, and 1.40 for 10-foot lanes.

Tabular values are for conditions with no restrictive lateral clearances; with clearances of less than 6ft., edge of lane to obstruction, or with shoulders narrower than 6 feet, multiply above values by factor from Table 1-7.

TABLE 1–7

CAPACITY REDUCTION FACTORS FOR RESTRICTIVE LATERAL CLEARANCE BETWEEN PAVEMENT EDGE AND OBSTRUCTION ON SHOULDER OR FOR NARROW SHOULDER

(Applies to design or possible capacity values)

Clearance from pavement edge to obstruction in feet	Capacity Reduction Factor			
	Obstruction on one side		Obstruction on both sides	
	Two-lane highway	Two lanes in one direction of a four-lane highway	Two-lane highway	Two lanes in one direction of a four-lane highway
6	1.00	1.00	1.00	1.00
5	0.98	1.00	0.96	0.99
4	0.96	0.99	0.92	0.98
3	0.93	0.98	0.86	0.97
2	0.91	0.97	0.81	0.94
1	0.88	0.95	0.75	0.90
0	0.85	0.90	0.70	0.81

1-10.04 MULTILANE HIGHWAYS

The design capacity of highways with two or more lanes in each direction of travel can be related to the general conditions for 2—lane highways. However, the percentage of length with passing sight distance restriction does not apply but the degree of access control and intersectional or roadside interference assumes greater significance.

Where there is no cross or turning traffic or where crossroads are few and with low volumes that do not impede the smooth flow on the main highway, and the geometrics conform to high standards, the design capacity of multilane highways in terms of passenger cars per hour per lane approach those shown on Table 1—3. As roadside and crossroad interference with through traffic increases, as on major highways without control of access, the design capacity decreases substantially.

1-10.05 FREEWAYS AND OTHER EXPRESSWAYS

Although 2—lane rural expressways are included in the Puerto Rico general design standards, the capacity analyses for these follow the procedures as for other 2—lane highways covered in Section 1-10.04 of this chapter. This section covers the capacity of multilane freeways and other expressways.

As indicated in the Highway Capacity Manual, design volumes may vary over a significant range due to three major variables — number of lanes, peak hour factor, and average highway speed. However, in most current freeway design work, they will vary within a rather narrow range. For this reason the rounded values for design capacity of freeways given in this chapter will fit most desing situations without significant error.

Table 1—8 shows design capacity average per lane under various conditions or terrain, percentage of trucks, and lane width for multilane rural and suburban highways. The values shown for suburban freeways may also be applied to freeways in mountainous terrain. With these volumes most freeways regardless of number of lanes will provide a service level C, unless the design speed is below 60 mph, in which case level D will be attained. The design capacity values for rural freeways and expressways will normally provide a service level B for 4— and 6— lane freeways with 70 mph design speeds.

Table 1-9 shows design capacity average per 12—foot lane for urban (built-up areas) and suburban freeways and other expressways for various conditions of terrain and percentages of trucks. The design capacities shown will normally provide a service level D while for the built-up area condition and a service level C for the suburban or outlying areas.

The average design capacity values per lane given in Tables 1-8 and 1—9 are for one direction of travel. Since during the design hour the directional distribution of traffic is seldom equal, it is necessary to consider the directional distribution of DHV, factor D, to determine the two-way capacity. This may be accomplished by the formula:

$$\text{Capacity (2—way)} = \frac{\text{Average lane capacity x No. of lanes in one direction}}{D}$$

1-10.06 MULTILANE HIGHWAYS WITHOUT ACCESS CONTROL

The design capacities given in the Blue Book for rural multilane highways are the same as those for rural freeways except for reductions in terms of the extent of interference from cross traffic and roadsides. These values are summarized as follows:

Extent of Interference	Maximum Design Capacity per lane — pass. cars/hour
Little or None	1000—1500
Moderate	700— 900
Considerable	500— 700

The first line may be within service level B, C or D, the same as for freeways, depending on the average running speed. The second and third lines reflect the effect of unsignalized intersections at grade and roadside interference with average running speeds of 45—50 mph and 40—45 mph respectively.

Table 1—8 shows the design capacity values for major rural multilane highways with moderate interference for various conditions of terrain, percentage of trucks and lane width.

1—10.07 ARTERIAL STREETS AND URBAN HIGHWAYS

The preceding segments of this section have covered highway facilities operating under uninterrupted flow conditions or under essentialy rural conditions with infrequent traffic interruptions. In urban areas, the adjacent development necessitates a closer control of traffic operations through the use of traffic control signals at intersections and/or low speed limits in relation to alignment. Therefore, intersection approach capacity is generally used as the primary measure of the capacity of urban facilities other than expressways. Occasionally midblock interruptions and interference are so significant that they may govern instead.

Basically, the capacity of an urban street represents the maximum utilization of that portion of the hour during which the street has a green signal indication. Although a high type urban street may carry traffic at flow rates approaching uninterrupted flow values while traffic is moving on a green signal phase, there are many periods when traffic does not move and the capacity in actual vehicles per hour will be far less than for uninterrupted flow.

Table 1—10 gives ranges of design capacity for arterial streets and urban highways which are useful as a general guide in estimating the number of lanes needed to serve the estimated design year traffic on such highways. The capacity of signalized intersections is covered in Chapter 4.

1—10.8 CAPACITY IN TERMS OF ADT

The most useful expression of capacity for design purposes is in terms of vehicles per hour. However, it is sometimes desirable to express capacity in terms of average daily traffic. Hourly design capacities may be converted to equivalent average daily traffic (ADT) through the application of the following formulas:

1. For 2—lane, two-way highways:

$$ADT = \frac{DHV}{K}$$

where DHV is the two-way hourly capacity

2. For multilane highways:

$$ADT = \frac{DHV \times \text{No. of lanes in one direction}}{K \times D}$$

where DHV is the hourly capacity per lane

Chapter II of the Blue Book includes tabulations (II—13 and II—14) showing ADT capacities for 2— lane and 4— lane rural highways for various values of K, D and T.

TABLE 1-8

DESIGN CAPACITY OF THROUGH TRAFFIC LANES ON MULTILANE RURAL AND SUBURBAN HIGHWAYS Uninterrupted Flow							
Width of lane in feet	Percent of trucks during peak hour	Design capacity, average per lane, in vph for:					
		Freeways, Suburban		Freeways and expressways, rural		Major highways*	
		Terrain		Terrain		Terrain	
		Level	Rolling	Level	Rolling	Level	Rolling
12	0	1200	1200	1000	1000	800	800
12	10	1090	920	910	770	730	620
12	20	1000	750	830	630	670	500

NOTE: To obtain possible capacity multiply above values by 1.67 for suburban freeways and by 2 for rural expressways and major highways. For 11-foot traffic lanes reduce capacity by 3 percent; for 10-foot traffic lanes reduce capacity by 9 percent.

* The given values are representative of conditions where there is moderate interference from cross traffic and roadsides. Where there is heavy interference a reduction in these values may be appropriate.

TABLE 1-9

LANE DESIGN CAPACITIES FOR URBAN FREEWAYS AND EXPRESSWAYS				
Percent of dual tire trucks during peak hour	Design capacity 1/, average per 12-foot lane, in VPH for:			
	Built-up area (Running speed 35 to 40 mph)		Suburban or outlying areas (Running speed 40 to 45 mph)	
	Level terrain	Rolling terrain	Level terrain	Rolling terrain
0	1500	1500	1200	1200
5	1430	1300	1140	1040
10	1360	1160	1090	920
15	1300	1030	1040	830
20	1250	940	1000	750

1/ Values are based on passenger car equivalents of 2 and 4, respectively, for level and rolling terrain.

1-11 GENERAL DESIGN STANDARDS

The basic general design standards for rural and urban highways used by the Department are summarized in Tables 1—11 through 1—15. These general standards are to be used in conjunction with other chapters in this manual and with the references included in Section 1-05. These standards are intended to be applied as general design controls based on functional class, level of service and design traffic but regardless of the administrative system of which the highway is a part.

Rural highways are typified by high speed (except for local rural roads), low traffic density operations with shoulders and open drainage channels as elements of the cross section. On the other hand, urban highways are typified by lower speed, high density operation with curb and gutter and underground drainage as elements of the cross section. The choice of rural or urban design shall be made on the basis of the anticipated character of the area being traversed.

Approximate ADT ranges are provided for each design class as an indication of capacity under average conditions for use in planning and project development activities. However, it is stressed that the design standards for any particular highway section shall be selected on the basis of its functional classification, proposed level of service, physical conditions, and a capacity analysis using the projected design hourly volume and traffic characteristics obtained from the highway planning studies. All arterial and collector highways, both rural and urban, are to be designed for the estimated DHV on a 20—year forecast. Design standards for local roads and streets are normally based on a 10—year traffic forecast.

Actually, right-of-way, alignment, grading, bridges and drainage structures are permanent investments which will have a service life expectancy considerably in excess of 20 years unless affected by obsolescence. Therefore, whenever the projected DHV appears to approach the capacity of the proposed design standard for a highway section, consideration should be given to providing an expandable design that will allow for constructing additional traffic lanes in the future without the necessity of acquiring additional rights-of-way and with a minimum of interference to existing traffic.

In the case of 2—lane arterial and collector highways, where it appears that four lanes will be required within 10 years after the design year, a 4—lane design should be provided with initial construction limited to two lanes but with the full 4—lane right-of-way acquired or protected.

In the case of multilane highways, expansion can normally be best accomplished by adding lanes in the median space. An expandable median width should be used on all multilane highway designs whenever feasible and shall be provided on all expressways where the traffic data indicates that the DHV is equal to or greater than 80% of the estimated capacity for a level of service "C" in the case of rural highways and "D" in the case of urban highways.

For a number of design elements, the standards specify minimum values. The use of more liberal values than these minimums is recommended where conditions are favorable and costs are not excessive.

1-11.01 RURAL HIGHWAYS

Design standards for classes R-7 and R-8 are lower than the AASHTO guides and FHWA requirements as to minimum surface widths. These minimum standards are not to be used on Federal-aid projects except when previously authorized by the FHWA on an individual project basis.

Design standards R-9, 10 and 11 are also lower than the AASHTO guides and FHWA requirements. These standards are normally used on low volume municipal and local roads not

on the Federal-aid system. Use of these standards on any Federal-aid project requires prior approval of an exception by the FHWA.

The following notes apply to the general design standards for rural highways shown on Tables 1—11, 1—12 and 1—13.

1. The approximate ADT ranges shown for major highways are based on design capacities for average conditions of K=12%, D=60%, and T=10%; and 40% passing sight distance restrictions on 2—lane highways. Specific highway sections may have capacities outside the ranges shown depending on the variables of traffic characteristics, terrain, roadway conditions and level of service provided.

2. Terrain conditions are defined as follows:

Level (L)—generally flat terrain where sight distances, as governed by both horizontal and vertical restrictions, are generally long or could be made to be so without construction difficulty or major expense.

Rolling (R)—terrain where the natural slopes consistently rise above and fall below the highway grade line and where occasional steep slopes offer some restriction to normal highway horizontal and vertical alignment.

Mountainous (M)—terrain where longitudinal and transverse changes in elevation of the ground with respect to the highway are abrupt and where the roadbed is obtained by frequent benching or side hill excavation.

3. On rural expressways with partial control of access, design classes RE—3 and RE—4, intersections with major highways carrying high traffic volumes should be grade separated to attain essentially uninterrupted flow conditions and retain expressway capacity levels.

4. Desirable lane width for all arterial and collectors is 3.65 meters: therefore, wherever feasible this width should be used on design classes R—7 and R—8 (Table 1—12).

5. The minimum pavement width shown on Table 1—13 for local rural roads, design classes R—9, R—10 and R—11, should be increased by 1.2 meters wherever feasible.

6. Median width is a critical safety item on high-speed multilane highways. The minimum median width values shown are bare minimums and the designer should strive for wider medians whenever economically feasible. Medians wider than 9.0 meters normally do not require a median barrier, see Chapter 8.

7. Minimum surfaced or paved shoulder widths are indicated. Total shoulders width shall be as shown in the typical sections, see Chapter 2.

8. Right-of-way width provided for expressways shall be sufficient to accomodate the full cross section plus an additional two meters (preferably three) on each side when this requirement exceeds the minimum ROW widths shown on Table 1—11. On long structures the minimum right-of-way width may be limited to the out to out width of the structure plus an additional three meters on each side.

9. The minimum curve radius indicated for the main line in Tables 1—11 and 1—12 are based on Table III-5 of the AASHTO Policy on Geometric Design of Rural Highways (Blue Book). The minimum curve radius for interchange ramps and loops for expressways in Table 1—11 and for local rural roads with design speeds of 30 mph or less in Table 1—13, are derived from Table IX—2 of the Blue Book.

10. The maximum superelevation rate for expressways is 8%; however, on interchange down ramps a maximum rate of 10% may be authorized if required by site conditions.

11. Steep long grades have a marked influence on the operating speeds and capacity of highways, particularly 2—lane highways, because of the reduction in truck speeds. Grades of 4% or steeper and in excess of 200 meters in length on major highways should be analyzed for "critical length" as per Chapter 3 procedures to determine the possible need for climbing lanes.

12. Pavement widening on sharp curves shall be provided on all 2—lane rural roads with pavement width of less than 7.30 meters (Design Classes R—7 through R—11) as per Chapter 3 procedures.

1—11.02 URBAN HIGHWAYS

The following notes apply to the general design standards for urban highways shown on Tables 1—14 and 1—15.

1. The approximate ADT ranges shown for multilane highways are based on design capacities for average conditions of K=10%, T=5% and D=67%. Specific highway sections may have capacities outside of the ranges shown depending on the variables of traffic characteristics, roadway conditions, intersectional or roadside interference, and level of service provided.

2. A level of service C should be provided on all urban expressways unless costs are excessive.

3. On urban expressways with partial control of access, design classes UE—4 and UE—5, provision should be made for frontage roads.

4. Minimum design speeds for urban interchange ramps and loops shall be as provided in Table 1—11 for rural expressways.

5. Minimum median widths indicated for urban freeways (Design classes UE—1, 2, 3) in Table 1—14 are bare minimums which provide space for a median barrier (0.6 m) plus the median side shoulder. Whenever right-of-way and cost restrictions permit it, a wider median should be used, preferably 9.0 m for non-expandable and 16.3 m for expandable medians.

6. On non-controlled access urban highways, Table 1—15, the border includes a planting strip and sidewalk; however, in commercial areas the planting strip is normally paved for additional sidewalk width.

7. The width of pavement on local streets, design classes U-9 and U-10, will depend on whether one-way or two-way operation is proposed, and whether parking on one or two sides will be permitted.

TABLE 1-10

DESIGN CAPACITIES FOR ARTERIAL STREETS AND URBAN HIGHWAYS	
Type of Highway	Design capacity, passengers cars per hour per 12-foot lane
Major suburban highway with moderate interference from cross traffic and roadsides; level of service "C"	700-900
Major suburban highway, considerable interference from cross traffic and roadsides; level of service "C"	500-700
Arterial street, traffic signals average one mile or more apart, parking prohibited and refuge provided for stalled vehicles; level of service "C"	400-600
Arterial street, traffic signals average less than one mile apart, parking prohibited	As governed by capacity of critical intersections

TABLE 1-11

GENERAL DESIGN STANDARDS FOR RURAL EXPRESSWAYS[1]

DESIGN CLASS CODE		RE-1			RE-2			RE-3			RE-4		
APPROXIMATE ADT RANGE		OVER 25,000			15,000 - 25,000			5,000 - 15,000			UNDER 5,000		
MIN. LEVEL OF SERVICE		C			C			C			C		
TERRAIN[2]		L	R	M	L	R	M	L	R	M	L	R	M
CONTROL OF ACCESS		FULL			FULL			PARTIAL			PARTIAL		
CROSS ROAD TREATMENT		GRADE SEPARATED			GRADE SEPARATED			AS DETERMINED			AS DETERMINED		
RAILROAD CROSSING		GRADE SEPARATED			GRADE SEPARATED			GRADE SEPARATED			GRADE SEPARATED		
MINIMUM DESIGN SPEED (MPH)	MAIN LINE	70	60	50	70	60	50	70	60	50	60	60	50
	DIR. RAMPS	40	30	30	40	30	30	40	30	30	40	30	30
	LOOPS	30	30	25	30	30	25	30	30	25	30	30	25
	CROSS ROADS	AS REQUIRED			AS REQUIRED			AS REQUIRED			AS REQUIRED		
	FRONTAGE RDS.	40	30	30	40	30	30	40	30	30	40	30	30
NUMBER OF LANES		6			4			4			2		
LANE WIDTH		3.65			3.65			3.65			3.65		
PAVEMENT		SEE CHAPTER 7											
MIN. MEDIAN WIDTH		4.2[3]			4.2[3]			6.0			NONE		
EXPANDABLE MED. WIDTH		11.5			11.5			13.3			—		
MIN. SHOULDER WIDTH (SURFACED)	RIGHT	3.0			3.0			3.0			3.0		
	LEFT	1.8			1.2			1.2			NONE		
MIN. ROW WIDTH[4]		60			50			50			30		
MAX. SUPERELEVATION		8%			8%			8%			8%		
MINIMUM CURVE RADIUS	MAIN LINE	500	350	230	500	350	230	500	350	230	350	350	230
	DIR. RAMPS	140	65	65	140	65	65	140	65	65	140	65	65
	LOOPS	65	65	45	65	65	45	65	65	45	65	65	45
	CROSS ROADS	AS REQUIRED			AS REQUIRED			AS REQUIRED			AS REQUIRED		
	FRONTAGE RDS.	140	75	75	140	75	75	140	75	75	140	75	75
MIN. STOP. SIGHT DISTANCE		185	145	110	185	145	110	185	145	110	145	145	110
MIN. PASS. SIGHT DISTANCE		—			—			—			640	640	550
MAXIMUM GRADE PERCENT (%)	MAIN LINE	3	4	7	3	4	7	3	4	7	3	4	7
	DIR. RAMPS	6	7	7	6	7	7	6	7	7	6	7	7
	LOOPS	6	7	7	6	7	7	6	7	7	6	7	7
	CROSS ROADS	AS REQUIRED			AS REQUIRED			AS REQUIRED			AS REQUIRED		
	FRONTAGE RDS.	5	7	9	5	7	9	5	7	9	5	7	9
MINIMUM GRADE (%)		0.5			0.5			0.5			0.5		
DESIGN VEHICLE		WB-50			WB-50			WB-50			WB-50		
BRIDGES		SEE CHAPTER 6											

(1) ALL DIMENSIONS IN METERS UNLESS OTHERWISE SPECIFIED.
(2) L = LEVEL, R = ROLLING, M = MOUNTAINOUS.
(3) MINIMUM WIDTH FOR PAVED MEDIAN WITH BARRIER, SEE CHAPTER 8.
(4) MINIMUM WIDTH EXCLUSIVE OF ANY ROW REQUIRED FOR FRONTAGE ROADS.

TABLE 1-12

GENERAL DESIGN STANDARDS FOR OTHER RURAL ARTERIALS AND COLLECTORS[1]

(NON-CONTROLLED ACCESS)

DESIGN CLASS CODE	R-5			R-6			R-7			R-8		
APPROXIMATE ADT RANGE	OVER 6,000			2,000 - 6,000			1,000-2,000			UNDER 1,000		
MIN. LEVEL OF SERVICE	C			C			D			D		
TERRAIN[2]	L	R	M	L	R	M	L	R	M	L	R	M
MIN. DESIGN SPEED (MPH)	60	60	50	60	50	40	50	40	30	40	40	30
NUMBER OF LANES	4			2			2			2		
LANE WIDTH	3.65			3.65			3.35			3.05		
PAVEMENT	SEE CHAPTER 7											
MIN. MEDIAN WIDTH	6.0			NONE			NONE			NONE		
EXPANDABLE MED. WIDTH	13.3			—			—			—		
MIN. SHOULDER WIDTH	3.0	3.0	2.4	3.0	3.0	2.4	2.4	2.4	1.8	1.8	1.8	1.8
MIN. ROW WIDTH	50			30			22			20		
MAX. SUPERELEVATION	8%			8%			8%			6%		
MIN. CURVE RADIUS	350	350	230	350	230	140	230	140	75	150	150	70
MIN. STOP. SIGHT DISTANCE	145	145	110	145	110	85	110	85	60	85	85	60
MIN. PASS. SIGHT DISTANCE	—			640	550	460	550	460	335	460	460	335
MAX. GRADE (%)	3	4	7	3	5	8	4	6	9	5	6	9
MIN. GRADE (%)	0.5			0.5			0.5			0.5		
DESIGN VEHICLE	WB-50			WB-50			WB-40			WB-40		
BRIDGES	SEE CHAPTER 6											

(1) ALL DIMENSIONS IN METERS UNLESS OTHERWISE SPECIFIED.
(2) L = LEVEL, R = ROLLING, M = MOUNTAINOUS.

TABLE 1-13

GENERAL DESIGN STANDARDS FOR LOCAL RURAL ROADS[1]

DESIGN CLASS CODE	R-9			R-10			R-11		
APPROXIMATE ADT RANGE	OVER 400			100-400			UNDER 100		
TERRAIN[2]	L	R	M	L	R	M	L	R	M
MIN. DESIGN SPEED (MPH)	40	30	25	35	25	20	30	25	20
PAVEMENT WIDTH	5.5			4.9			4.0		
PAVEMENT	SEE CHAPTER 7								
MIN. SHOULDER WIDTH	1.25			1.25			1.25		
MIN. ROW WIDTH[3]	14.0			13.4			12.5		
MAX. SUPERELEVATION	6%			6%			6%		
MIN. CURVE RADIUS	150	70	50	100	50	30	70	50	30
MIN. STOP. SIGHT DISTANCE	85	60	50	75	50	40	60	50	40
MIN. PASS. SIGHT DISTANCE	460	335	—	400	—	—	335	—	—
MAX. GRADE (%)	7	8	10	8	10	12	8	12	15
MIN. GRADE (%)	0.5			0.5			0.5		
DESIGN VEHICLE	SU			SU			SU		
BRIDGES	SEE CHAPTER 6								

(1) ALL DIMENSIONS IN METERS UNLESS OTHERWISE SPECIFIED.
(2) L = LEVEL, R = ROLLING, M = MOUNTAINOUS.
(3) ABSOLUTE MINIMUM. DESIRABLE MINIMUM IS 20 METERS TO ALLOW FOR FUTURE WIDENING.

TABLE 1-14

GENERAL DESIGN STANDARDS FOR URBAN EXPRESSWAYS[1]

DESIGN CLASS CODE		UE-1	UE-2	UE-3	UE-4	UE-5
APPROXIMATE ADT RANGE		OVER 60,000	40-60,000	UNDER 40,000	OVER 30,000	UNDER 30,000
MIN. LEVEL OF SERVICE		D	D	D	D	D
TOTAL LANES		8	6	4	6	4
CONTROL OF ACCESS		FULL			PARTIAL	
CROSS STREET TREATMENT		GRADE SEPARATED			AS DETERMINED	
MINIMUM DESIGN SPEED (MPH)		60	60	60	50	50
LANE WIDTH		3.65	3.65	3.65	3.65	3.65
MINIMUM MEDIAN WIDTH		6.6	5.4	4.2	6.0	6.0
EXPANDABLE MEDIAN WIDTH		—	13.9	11.5	13.3	13.3
MIN. SURFACED SHOULDER WIDTH	RIGHT	3.0	3.0	3.0	3.0	3.0
	LEFT	3.0	2.4	1.8	1.8	1.2
OUTER SEPARATOR		9.0 FOR 2-WAY FRONTAGE, 6.0 FOR ONE-WAY			6.0	6.0
FRONTAGE STREETS		AS REQUIRED - SEE CHAPTER 2			AS REQUIRED	
RIGHT-OF-WAY WIDTH		AS REQUIRED FOR TOTAL SECTION			AS REQUIRED	
MAXIMUM SUPERELEVATION		8%	8%	8%	8%	8%
MINIMUM CURVE RADIUS		350	350	350	230	230
MIN. STOPPING SIGHT DISTANCE		145	145	145	110	110
MAXIMUM GRADE (%)		4	5	5	5	5
MINIMUM GRADE (%)		0.35	0.35	0.35	0.35	0.35
DESIGN VEHICLE		WB-50	WB-50	WB-50	WB-50	WB-50
BRIDGES		SEE CHAPTER 6				

(1) ALL DIMENSIONS IN METERS UNLESS OTHERWISE SPECIFIED.

TABLE 1-15

GENERAL DESIGN STANDARDS FOR OTHER URBAN HIGHWAYS[1]

(NON-CONTROLLED ACCESS)

DESIGN CLASS CODE	U-6 AVENUE	U-7 PRINCIPAL ST.	U-8 PRINCIPAL ST.	U-9 LOCAL-COMM.	U-10 LOCAL-RES.
APPROXIMATE ADT RANGE	20-30,000	10-20,000	10-20,000	UNDER 8,000	—
MIN. LEVEL OF SERVICE	D	D	—	—	—
TOTAL TRAVEL LANES	6 DIVIDED	4 DIVIDED	4	2	2
MIN. DESIGN SPEED (MPH)	40	40	30	30	30
PAVEMENT WIDTH	2 @ 11.0 (NO PARKING)	2 @ 7.3 W/O PARK. 2 @ 10.3 W. PARK.	14.6 W/O PARK. 20.6 W. PARK.	8.0-12.0	8.0-11.0
MIN. MEDIAN WIDTH	6.0	4.25	NONE	NONE	NONE
MIN. ROW WIDTH	36	FULL ROADWAY PLUS BORDERS			
MAX. SUPERELEVATION	6%	6%	—	—	—
MIN. CURVE RADIUS	150	150	70	70	70
MIN. STOP. SIGHT DISTANCE	85	85	60	60	60
MAX. GRADE (%)	7	7	7	10	12
MIN. BORDER WIDTH	4.0	3.0	2.5	2.5	2.5
SIDE WALK WIDTH	1.5-4.0	1.5-3.0	1.5-2.5	2.5	1.25
DESIGN VEHICLE	WB-50	WB-50	WB-50	SU	SU
BRIDGES	SEE CHAPTER 6				

(1) ALL DIMENSIONS IN METERS UNLESS OTHERWISE SPECIFIED.

CHAPTER 2

TYPICAL SECTIONS

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CHAPTER 2

TYPICAL SECTIONS

2-01 GENERAL

This chapter provides details and guidance on the policies and standards of the Department concerning the major cross section elements of the various classes of highways. The information presented complements the general design criteria data included in Chapter 1.

It is not practical to present and standardize all possible typical sections. However, there is a need for uniformity of format and section treatment, and to specify minimum standards for the basic cross section elements. It is intended that the designer use these criteria and aids in developing the typical sections for individual projects. Each project is to be carefully evaluated and problems peculiar to it are to be considered. The goal is to develop a safe, adequate and pleasing highway section for the projected traffic to be served within reasonable economic limitations.

2-02 TYPICAL SECTION TERMINOLOGY

The general terminology for the typical section elements is illustrated in Figure 2—A and explained in Table 2-1. For other terms not covered in this chapter, the user should refer to the AASHTO Highway Definitions adopted and published in 1968.

2-03 STANDARD TYPICAL SECTIONS

Generalized standard typical sections for the various design classes of rural and urban highways are shown in Figures 2—B through 2—H inclusive.

More specific typical details of various cross section elements are included in Figures 2—I through 2-N inclusive.

A sample completed typical section is illustrated in Figure 2—P.

The completed typical cross section shall show all functional elements and should represent conditions which are typical of the project. It is not necessary to show a separate typical section to delineate relatively minor variations from the basic "typical" conditions. All integral parts of the section between the right-of-way lines shall be included. Chapter 19 covers the information that should be detailed in the typical section sheets to be included in the project plans.

2-04 CROSS SECTION ELEMENTS

The major functional elements of the cross section are discussed below

2-04.01 TRAVELED WAY

1. PAVEMENT TYPE—The type of pavement for the traveled way is determined by the volume and composition of the traffic, the availability of materials, the initial cost, and the extent and cost of maintenance, all of which affect the relation of cost to traffic service.

High type pavements shall provide adequate structural support for the traffic loads and have smooth riding qualities, effective nonskid properties in all weather and ability to retain their shape. Intermediate type pavements have similar characteristics but with somewhat less strength

Chapter 7 of this manual covers the various pavement types, the selection procedures, and guidance on the structural design of both rigid and flexible pavements

TABLE 2–1

TYPICAL SECTION TERMINOLOGY
(Refer to Figure 2-A)

(1) HIGHWAY — The entire strip within the right-of-way lines.

(2) HIGHWAY SECTION — The portion of the highway included between top of slopes in cut and the toe of slopes in fill.

(3) ROADWAY — The portion of the highway for vehicular use included between the outside edges of the shoulders.

(4) TRAVELED WAY — The portion of the roadway provided for the movement of vehicles, exclusive of shoulders and auxiliary lanes.

(5) MEDIAN — The portion of a divided highway separating the traveled ways for traffic in opposite directions.

(6) SHOULDER — The portion of the roadway contiguous with the traveled way for accommodation of stopped vehicles for emergency use, and for lateral support of the base and surface courses. The graded shoulder width is the distance from the edge of the traveled way to the intersection of the shoulder slope and the ditch or fill slope planes.

(7) SURFACED RIGHT SHOULDER — That portion of the right (or outside) shoulder surfaced or paved to provide all-weather load support.

(8) SURFACED LEFT SHOULDER — The portion of the median side shoulder surfaced or paved to provide all-weather load support.

(9) PROFILE GRADE LINE — The point for control of the vertical alignment. Also, normally the point of rotation for superelevated sections.

(10) PAVEMENT CROSS SLOPE — See typical cross sections.

(11) SHOULDER CROSS SLOPE — See typical cross sections.

(12) PAVEMENT COURSE OR COURSES — P. C. Concrete or Bituminous Concrete Surface and Base courses.

(13) SUBASE COURSES — The layer or layers of specified or selected material placed on a subgrade to support a base course. May be identified as a "base course" material in the typical section.

(14) PAVEMENT STRUCTURES — The combination of subbase, base course and surface course placed on a subgrade to support the traffic load and distribute it to the roadbed.

(15) SHOULDER SURFACE COURSE — See Chapter 7.

(16) SHOULDER BASE COURSE — See Chapter 7.

(17) SUBGRADE — The top sufrace of the roadbed upon which the pavement structure and shoulders are constructed.

(18) ORIGINAL (EXISTING) GROUND

TABLE 2–1 (Cont.)

TYPICAL SECTION TERMINOLOGY
(Refer to Figure 2-A)

(19) EMBANKMENT (FILL)

(20) FILL SLOPE — See typical sections and Chapter 12.

(21) CUT SECTION — See typical cross sections and Chapter 12.

(22) CUT SLOPE — Also called back slope.

(23) DITCH WIDTH — See Chapter 11.

(24) DITCH DEPTH — See Chapter 11.

(25) INSLOPE — Also called ditch slope.

(26) SHOULDER BREAK — The intersection of shoulder slope planes with inslope or fill slope planes.

(27) ROUNDING — At the intersection of slope planes.

(28) MEDIAN BARRIER — See Chapter 8.

(29) GUARDRAIL — See Chapter 8.

(30) OUTER SEPARATION — The portion of an arterial highway between the traveled ways of a roadway for through traffic and a frontage street or road.

(31) FRONTAGE ROAD OR STREET — Also called marginal road or street. A local road or street auxiliary to and located on the side of an arterial highway for service to abutting property and adjacent areas and for control of access.

(32) BORDER — The area that separates the roadway from adjacent properties. Also called the roadside in the case of freeways.

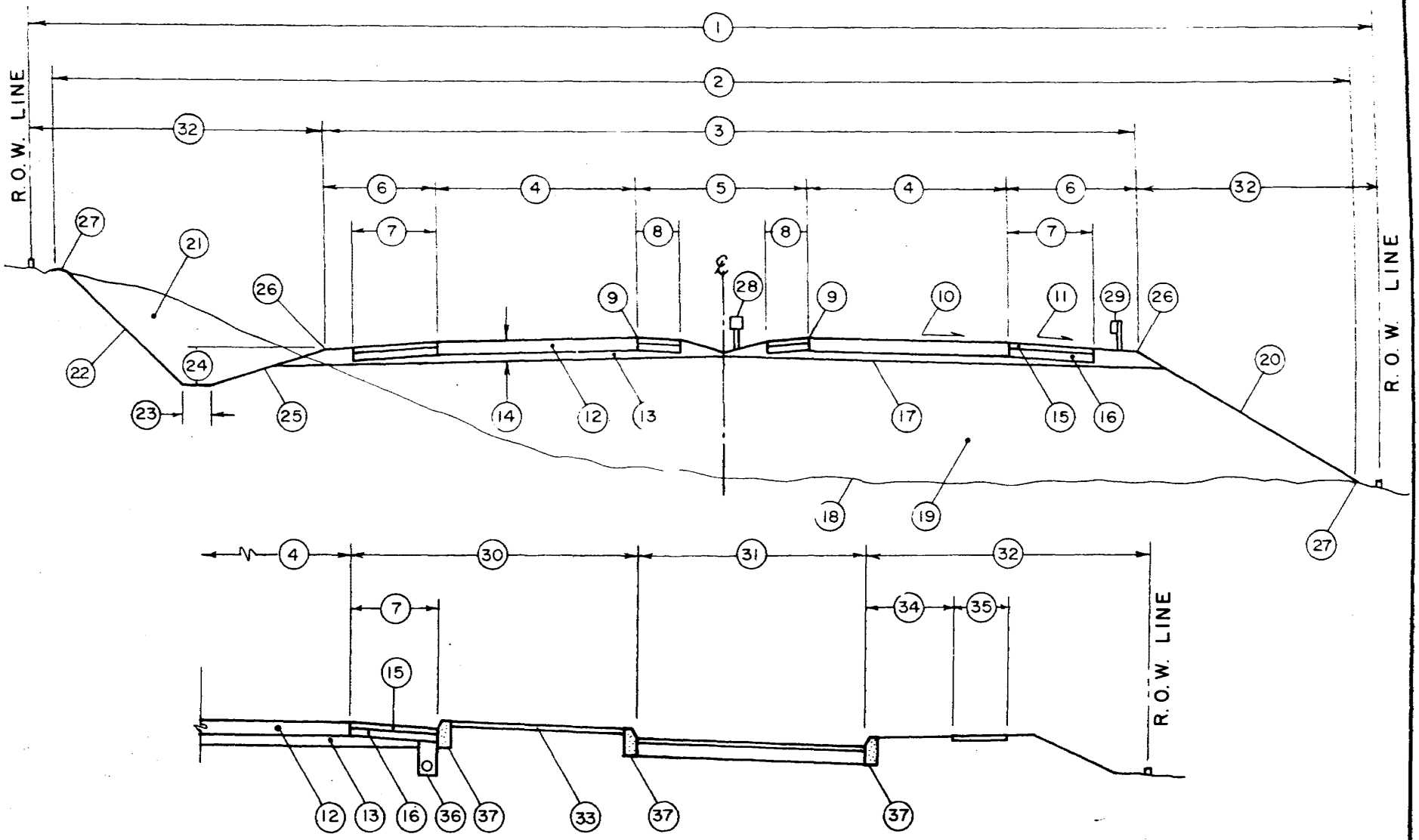
(33) OUTER SEPARATION ISLAND — The space in the outer edge of roadway shoulder and frontage roadway shoulder and frontage road or street which may be landscaped or paved depending on width.

(34) PLANTING STRIP — The space in the border are provided to separate the sidewalk from the vehicular travel facilities.

(35) SIDEWALK — See Chapter 15.

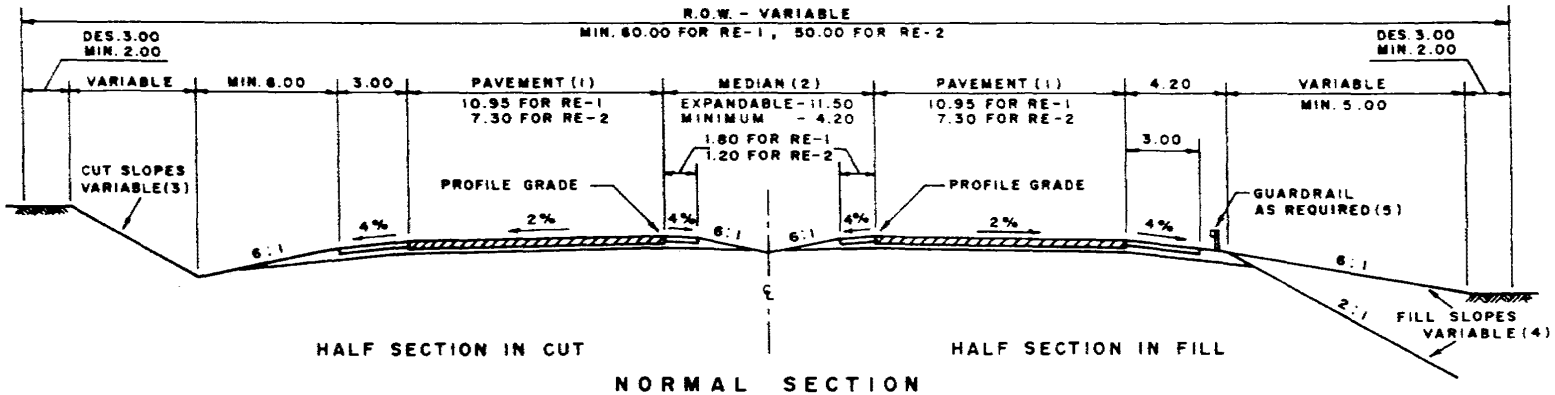
(36) UNDERDRAIN — Where required. See Chapter 12.

(37) CURB — P. C. Concrete or Bituminous Curb.



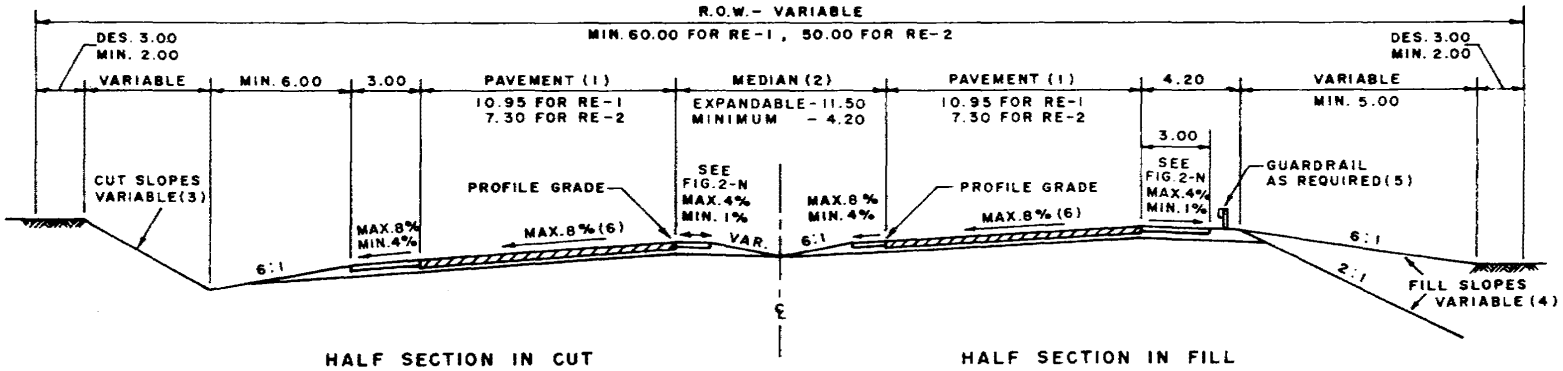
TYPICAL SECTION TERMINOLOGY (REFER TO TABLE 2-1)

FIGURE 2-A



NORMAL SECTION

NOT TO SCALE



SUPERELEVATED SECTION

NOT TO SCALE

NOTES:

(1) THE ELEMENTS OF THE PAVEMENT STRUCTURE ARE TO BE DETERMINED FOR EACH PROJECT, SEE CHAPTER 7.

(2) FOR TYPICAL MEDIAN SECTIONS SEE FIG. 2-I.

(3) FOR TYPICAL CUT SECTIONS SEE FIG. 2-J.

(4) FOR TYPICAL FILL SECTIONS SEE FIG. 2-K.

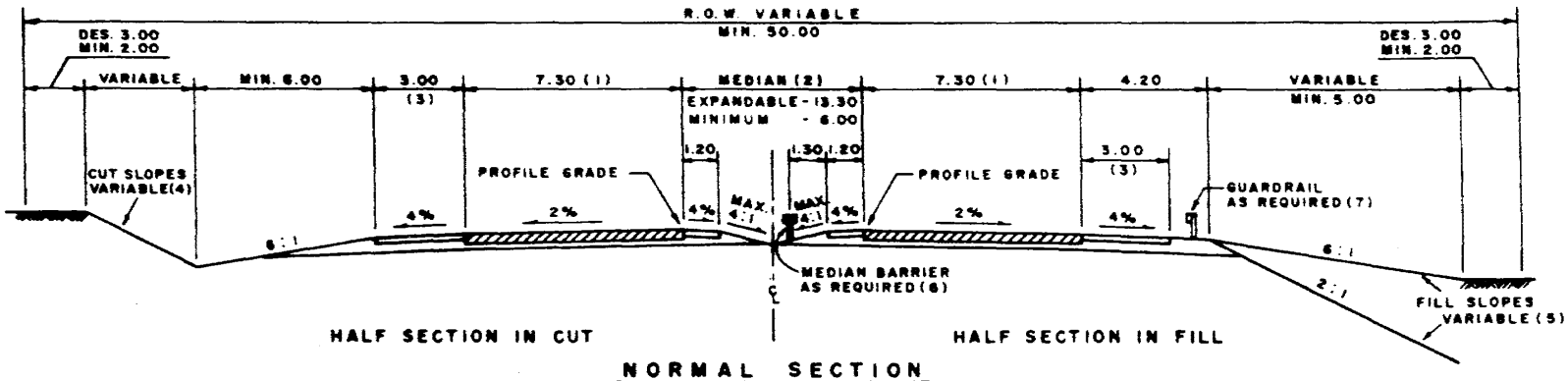
(5) FOR WARRANTS FOR GUARDRAIL USE SEE CHAPTER 8.

(6) FOR SUPERELEVATION RATES AND TRANSITIONS SEE CHAPTER 3.

(ALL DIMENSIONS IN METERS)

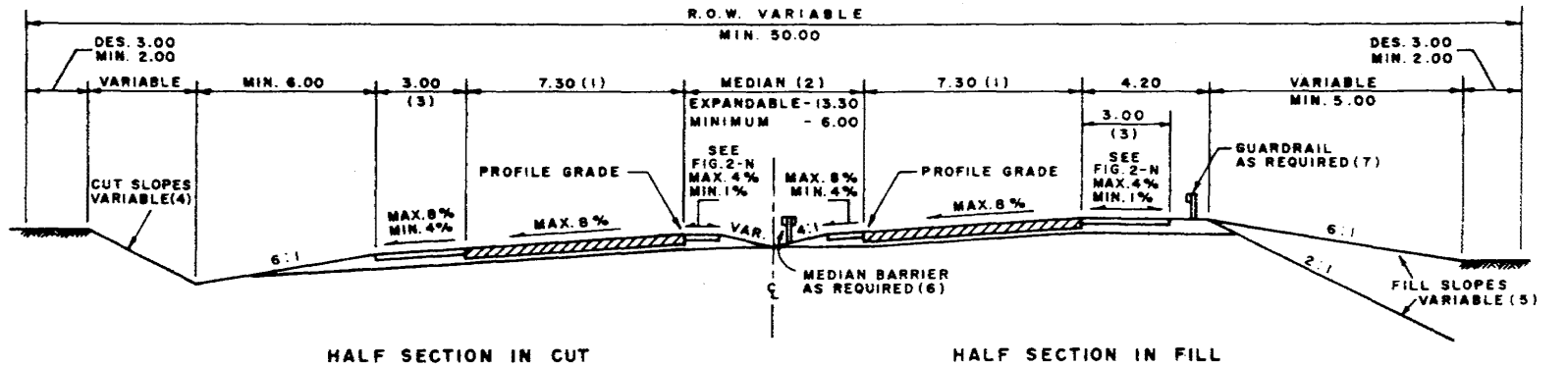
TYPICAL SECTION - RURAL FREEWAYS RE-1, RE-2

FIGURE 2-B



NORMAL SECTION

NOT TO SCALE



SUPERELEVATED SECTION

NOT TO SCALE

NOTES:

(1) THE ELEMENTS OF THE PAVEMENT STRUCTURE ARE TO BE DETERMINED FOR EACH PROJECT, SEE CHAPTER 7.

(2) FOR OTHER TYPICAL MEDIAN SECTIONS SEE FIG. 2-I.

(3) MAY BE REDUCED TO 2.40 M. IN MOUNTAINOUS TERRAIN FOR R-5.

(4) FOR TYPICAL CUT SECTIONS SEE FIG. 2-J.

(5) FOR TYPICAL FILL SECTIONS SEE FIG. 2-K.

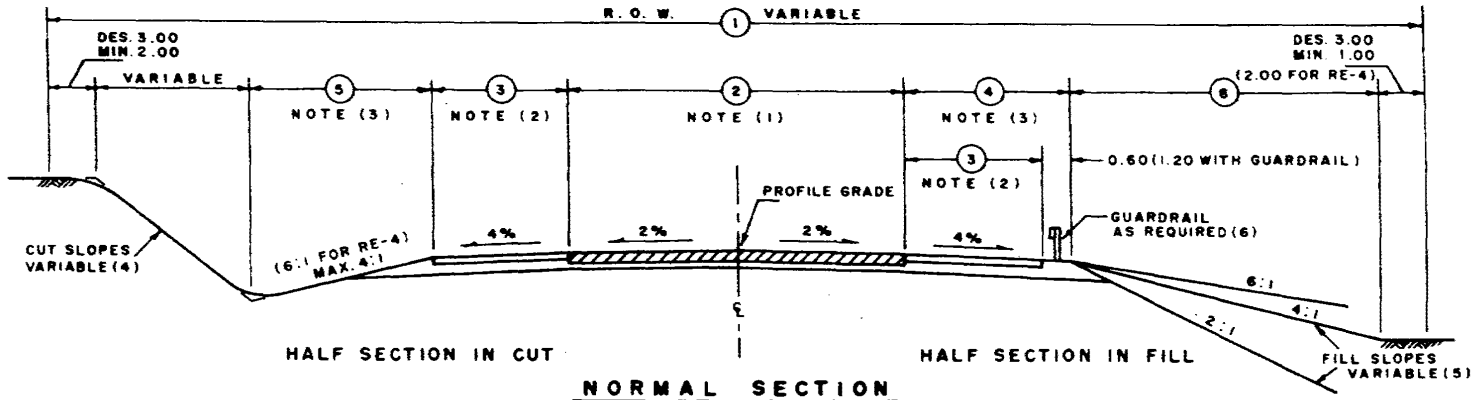
(6) FOR WARRANTS FOR MEDIAN BARRIER USE SEE CHAPTER 8.

(7) FOR WARRANTS FOR GUARDRAIL USE SEE CHAPTER 8.

(ALL DIMENSIONS IN METERS)

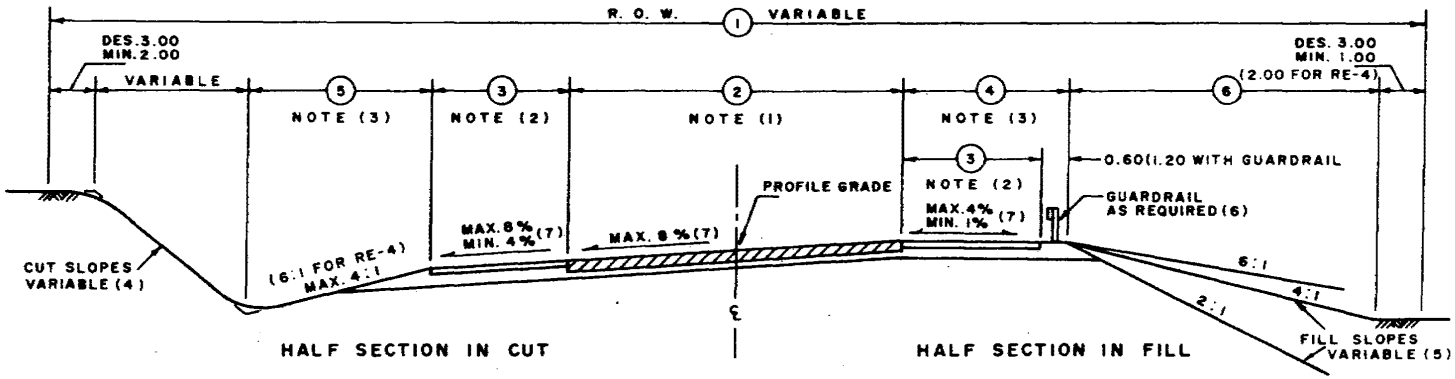
TYPICAL SECTION - OTHER RURAL MULTILANE HIGHWAYS RE-3, R-5

FIGURE 2-C



NORMAL SECTION

NOT TO SCALE



SUPERELEVATED SECTION

NOT TO SCALE

(ALL DIMENSIONS IN METERS)

NOTES:

(1) THE ELEMENTS OF THE PAVEMENT STRUCTURE ARE TO BE DETERMINED FOR EACH PROJECT, SEE CHAPTER 7.

(2) MAY BE REDUCED IN MOUNTAINOUS TERRAIN, SEE TABLE 1-12.

(3) FOR VARIATIONS SEE FIG. 2-N.

(4) FOR TYPICAL CUT SECTIONS SEE FIG. 2-J.

(5) FOR TYPICAL FILL SECTIONS SEE FIG. 2-K.

(6) FOR WARRANTS FOR GUARDRAIL SEE CHAPTER 8.

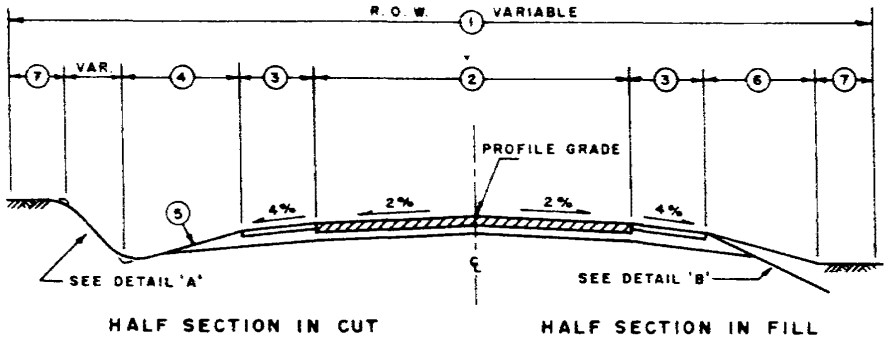
(7) FOR SUPERELEVATION RATES AND TRANSITIONS SEE CHAPTER 3 AND FIGURE 2-N. MAXIMUM SUPERELEVATION FOR DESIGN CLASS R-8 IS 6%.

SECTION ELEMENTS

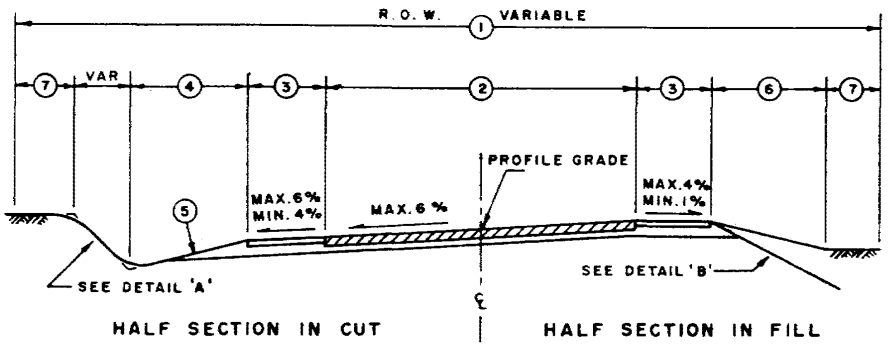
		R-6	R-7	R-8	RE-4
1	MIN. R.O.W	30.00	22.00	20.00	30.00
2	NORMAL PAVEMENTS	7.30	6.70	6.10	7.30
3	SURFACED SHOULDER	3.00	2.40	1.80	3.00
4	SHOULDER ON FILL	3.60	3.00	2.40	3.60
5	NORMAL INSLOPE	4.00	3.00	3.00	6.00
6	MIN. FILL SLOPE	4.00	3.00	3.00	5.00

TYPICAL SECTION — RURAL TWO-LANE HIGHWAYS R-6, 7, 8 AND RE-4

FIGURE 2-D

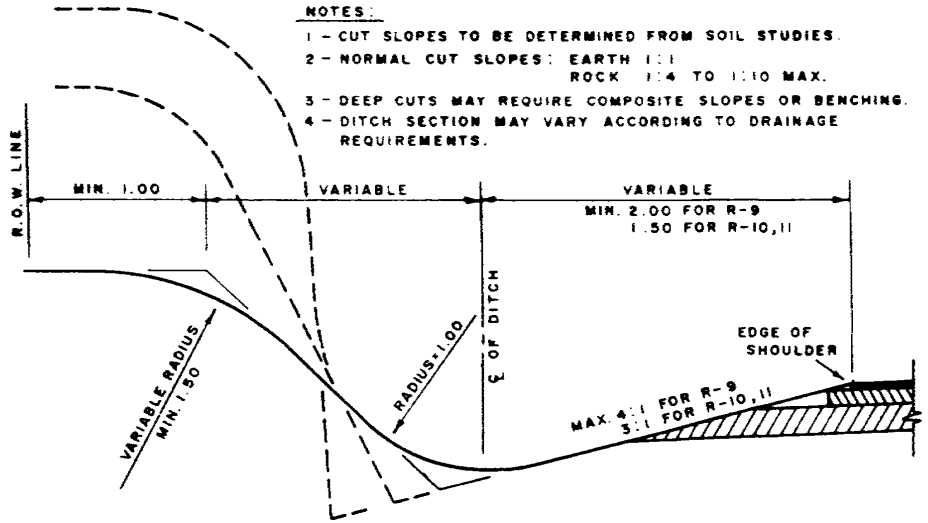


NORMAL SECTION
NOT TO SCALE

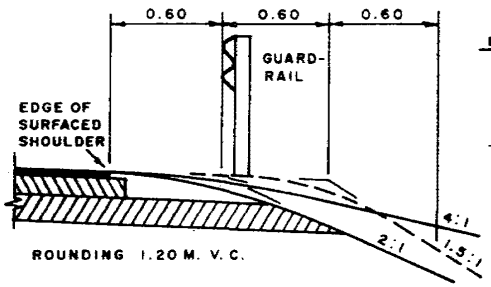


SUPERELEVATED SECTION
NOT TO SCALE

NOTES:
1 - CUT SLOPES TO BE DETERMINED FROM SOIL STUDIES.
2 - NORMAL CUT SLOPES: EARTH 1:1
ROCK 1:4 TO 1:10 MAX.
3 - DEEP CUTS MAY REQUIRE COMPOSITE SLOPES OR BENCHING.
4 - DITCH SECTION MAY VARY ACCORDING TO DRAINAGE REQUIREMENTS.



TYPICAL DETAIL OF CUT SECTION
DETAIL 'A'



NORMAL FILL SLOPES

HEIGHT OF FILL	SLOPE
UP TO 2.00 M.	4:1 MAX.
2.00 M. TO 4.00 M.	3:1
OVER 4.00 M.	1.5:1

NOTES:
1- GUARDRAIL REQUIRED ON FILLS OVER 4.00 M. UNLESS FLATTENED. SEE CHAPTER 8.
2- ADD 0.60 M. FOR GUARD RAIL AS SHOWN FOR 1.5:1 SLOPES.

TYPICAL DETAIL OF FILL SECTION
DETAIL 'B'

SECTION ELEMENTS

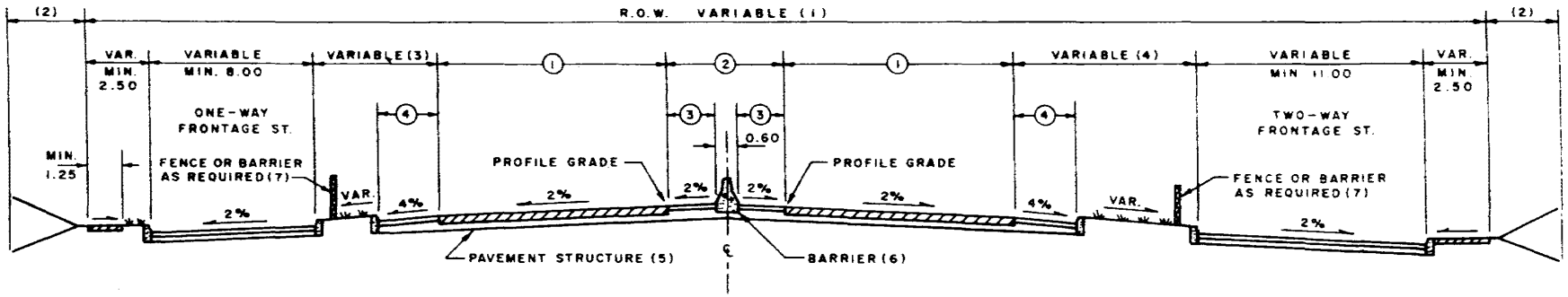
	R-9	R-10	R-11
(1) MINIMUM R.O.W.	14.00	13.20	12.50
(2) NORMAL PAVEMENT WIDTH	5.50	4.90	4.00
(3) SURFACED SHOULDER	1.25	1.25	1.25
(4) MINIMUM INSLOPE LENGTH	2.00	1.50	1.50
(5) MAXIMUM INSLOPE	4:1	3:1	3:1
(6) MIN. FILL SLOPE	2.00	2.00	2.00
(7) MIN. ADDITIONAL BORDER	1.00	1.00	1.00

GENERAL NOTES:
1- FOR PAVEMENT STRUCTURE DESIGN SEE CHAPTER 7.
2- FOR PAVEMENT WIDENING DETAILS SEE CHAPTER 3.
3- FOR SUPERELEVATION RATES AND TRANSITIONS SEE CHAPTER 3.

(ALL DIMENSIONS IN METERS)

TYPICAL SECTION - LOCAL RURAL ROADS R-9, 10, 11

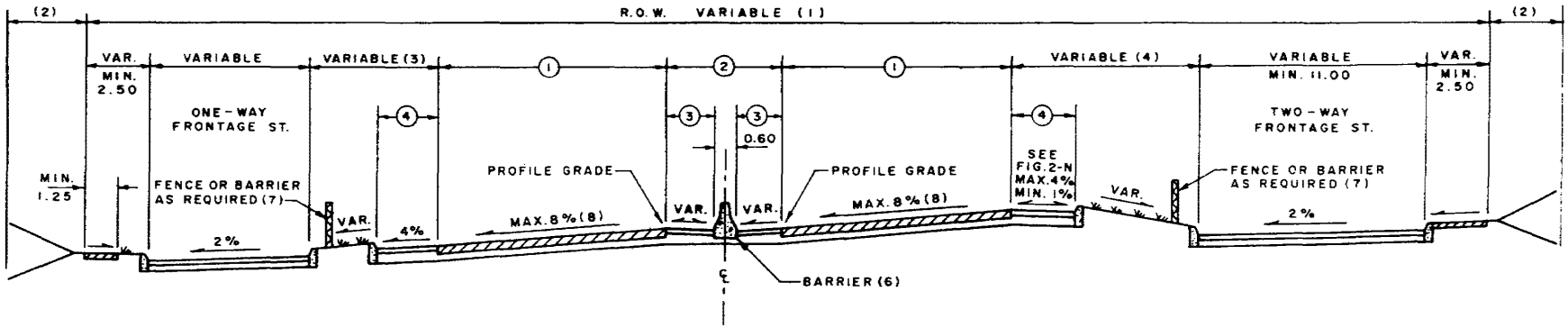
FIGURE 2-E



NORMAL SECTION

(WITH ADJACENT FRONTAGE STREETS)

NOT TO SCALE



SUPERELEVATED SECTION

(WITH ADJACENT FRONTAGE STREETS)

NOT TO SCALE

NOTES:

(1) R.O.W. AS NEEDED FOR TOTAL SECTION INCLUDING FRONTAGE STREETS WHEN REQUIRED.

(2) ADDITIONAL ACQUISITION OR EASEMENT AS MAY BE REQUIRED FOR FILL OR CUT SECTIONS.

(3) MIN. WIDTH OF 6.00 M. FOR AT GRADE CONDITIONS, MAY VARY WHERE WALLS ARE USED.

(4) MIN. WIDTH OF 9.00 M. FOR AT GRADE CONDITIONS.

(5) PAVEMENT STRUCTURE AS DESIGNED FOR EACH PROJECT. SEE CHAPTER 7.

(6) BARRIER REQUIRED ON NARROW MEDIANS. FOR WARRANTS SEE CHAPTER 8.

(7) FOR WARRANTS FOR FENCING SEE CHAPTER 8.

(8) FOR SUPERELEVATION RATES AND TRANSITIONS SEE CHAPTER 3.

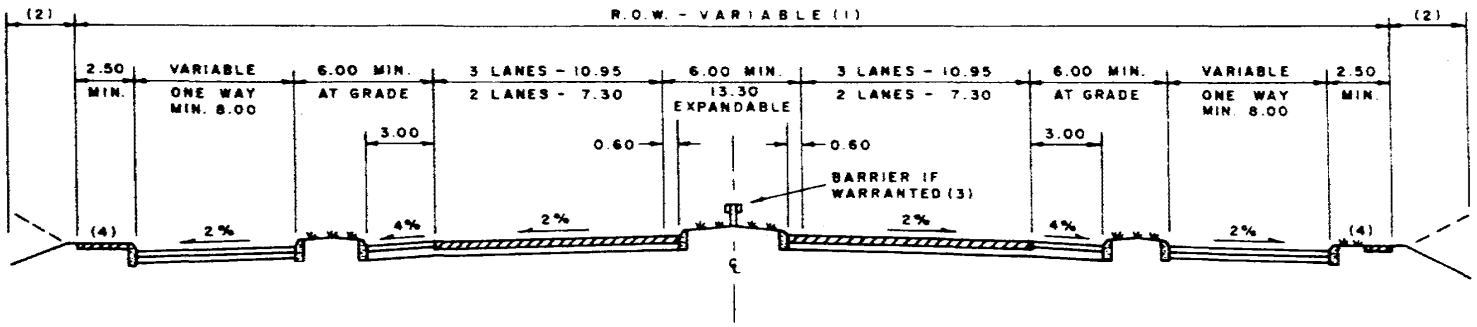
SECTION ELEMENTS

	UE-1	UE-2	UE-3
(1) PAVEMENT WIDTH	14.60	10.95	7.30
(2) MEDIAN WIDTH - MINIMUM	6.60	5.40	4.20
- EXPANDABLE	—	13.90	11.50
(3) LEFT SHOULDER	3.00	2.40	1.80
(4) RIGHT SHOULDER	3.00	3.00	3.00

(ALL DIMENSIONS IN METERS)

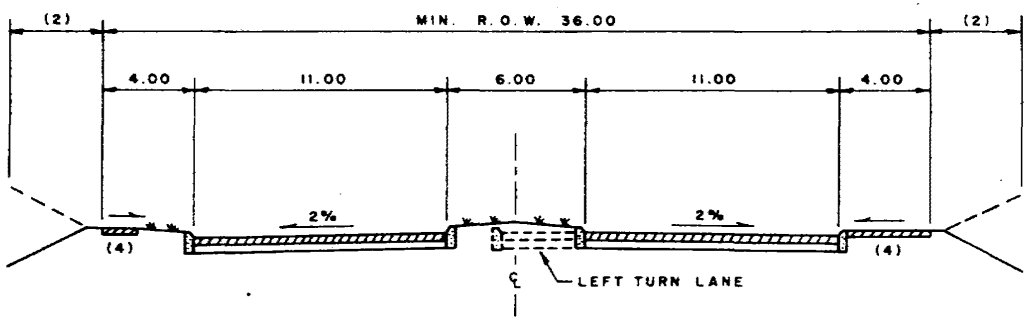
TYPICAL SECTION – URBAN FREEWAYS UE-1, 2, 3

FIGURE 2-F



EXPRESSWAY - AT - GRADE UE - 4, 5

(WITH ADJACENT FRONTAGE STREETS)



6-LANE AVENUE U-6

NOTES:

(1) R.O.W. AS NEEDED FOR TOTAL SECTION INCLUDING FRONTAGE STREETS WHEN REQUIRED.

(2) ADDITIONAL ACQUISITION OR EASEMENT AS REQUIRED FOR FILL OR CUT SECTIONS.

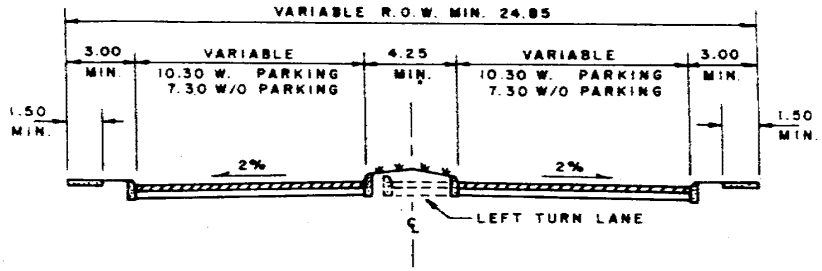
(3) FOR BARRIER WARRANTS SEE CHAPTER 8.

(4) SIDEWALK WIDTH AS REQUIRED FOR ADJACENT RESIDENTIAL OR COMMERCIAL DEVELOPMENT. MINIMUM 1.25 M.

(ALL DIMENSIONS IN METERS)

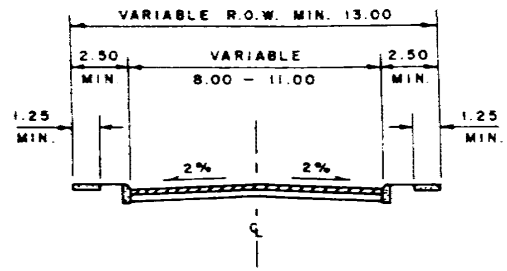
TYPICAL SECTION - URBAN HIGHWAYS UE-4,5 AND U-6

FIGURE 2-6

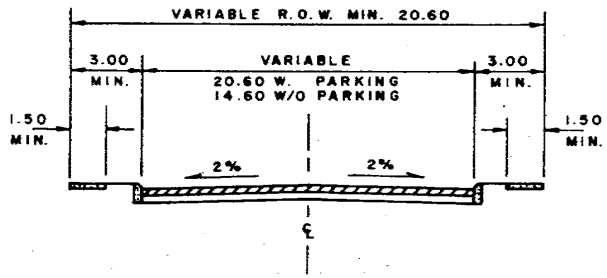


PRINCIPAL STREET - DIVIDED U-7

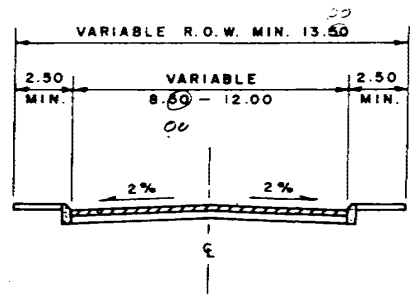
(WITH RAISED MEDIAN)



LOCAL STREET - RESIDENTIAL U-10



PRINCIPAL STREET - UNDIVIDED U-8



LOCAL STREET - COMMERCIAL U-9

(ALL DIMENSIONS IN METERS)

TYPICAL SECTION - PRINCIPAL AND LOCAL STREETS U-7, 8, 9, 10

FIGURE 2-H

The Department's policy is to provide high type pavements for all rural arterial and collectors except for low volume highways in design class R—8 where intermediate type pavements may be used if heavy truck traffic is not a factor. For local rural roads (R—9, 10, 11), intermediate or low type pavements are provided.

For urban facilities, the Highway Authority design policy calls for high type pavement for all except local residential streets (U—10) for which intermediate type pavement may be used.

2. WIDTH—The pavement width for the various design classes are indicated in Tables 1—11 through 1—15 of Chapter 1 and illustrated in Figures 2—B through 2—H of this chapter.

The standard lane width for high-volume, high-speed rural and urban highways is 3.65 meters. For multilane rural and urban expressways the width of the traveled way in each direction is determined as a multiple of this standard lane width.

Pavement width of 6.70 meters for rural design class R—7 and 6.10 meters for R—8 are indicated. However, when a significant percentage of large trucks, say in excess of 5%, are expected in the traffic stream, a pavement width of 7.30 meters should be used to provide two standard 3.65 M. lanes. In addition, provision is made for widening these pavements less than 7.30 meters in width at sharp curves as discussed in Chapter 3.

Travel lanes for all urban facilities shall be designed with the 3.65 M. standard width except for local streets U—9 and U—10 for which reduced widths are allowed as shown in Table 1—15 and Figure 2—H.

3. CROSS SLOPE—The normal cross slopes of the traveled way is 2% for all highway classes and pavement types as shown in the typical section. However, the following variations apply:

a. In rolling and mountainous terrain a minimum of 1—1/2% may be used for high type pavements.

b. On multilane highways with three or more lanes inclined in the same direction, the two lanes nearest the median may have a cross slope of 1-1/2% while the outside lanes may slope 2%.

4. SUPERELEVATION—The maximum rate of superelevation shall be 8%. The superelevation of pavements is covered in Chapter 3 including the rate-curvature-speed relation, methods of attainment, runoff requirements and transition curves.

2—04.02 SHOULDERS

Outside or right shoulders are provided on all rural highways for the accomodation of stopped vehicles, emergency use, and for lateral support of the base and surface courses. In urban facilities, other than expressways, a parking lane may be provided in lieu of a shoulder and, when not provided, the outside lane has to serve for stops and emergency use.

In multilane, divided rural highways and in urban expressways a left or median shoulder is normally provided.

1. RIGHT (OUTSIDE) SHOULDER

a. WIDTH—The shoulder widths for the various design classes are shown in the typical sections, Figures 2—B through 2—G. The total shoulder is normally wider in fill sections than in cut sections as shown in the figures because of the steeper fill slopes when these exceed 2.00 meters in height. Furthermore, an additional 0.60 meters in the shoulder width must be provided whenever a guardrail is required. However, the surfaced or paved shoulder width is the same whether in the cut or fill side.

The standard paved width of right shoulders for all rural and urban expressways is 3.00 meters. When problems with vegetation growth and moving under the guardrail are expected, the shoulder surface may be extended 0.15 meters back of the guard as shown in Detail C of Figure 2—N.

The right shoulder width may be reduced to a minimum of 1.20 meters when there are auxiliary lanes next to the traveled way as in the case of climbing lanes (Figure 2—M) and speed-change lanes. The paving may also be omitted but at least a crushed aggregate or stabilized surface should be provided.

The right shoulder width of rural arterial and collectores of design classes R—5, 6 and 7 may be reduced by 0.60 M. in mountainous terrain as shown in Table 1—12 of Chapter 1 if appreciable savings in earthwork costs can be obtained.

b. SURFACE OR PAVEMENT—The policy of the Department is to provide a pavement structure for the right shoulders with an all weather bituminous surface and capable of supporting intermittent heavy loads. However, these shoulders are not required to have the same structural strength as the pavement of the adjacent traveled way.

The surface course of the shoulder should provide a recognizable contrast in texture and, if possible, color with the travel lanes. The shoulder texture should be sufficiently coarse in appearance and riding quality to discourage its use as a traffic lane.

c. CROSS SLOPE—The normal outside shoulder cross slope on tangent sections shall be as follows:

Type of Surface	Slope
Bituminous	4%
Gravel or Crushed Stone	6%
Turf	8%

On superelevated sections, the cross slope of bituminous surface shoulder may be transitioned as shown in Detail "E" of Figure 2—N. This type of transition has the advantage that the algeabric difference in pavement and shoulder slopes or "roll-over" effect at the edge of the traveled way on the high side does not exceed 5% but it has the disadvantage that for pavement superelevation in excess of 4% the high side shoulder drains towards the traveled way.

An alternate method of shoulder slope transition thay may be used when the maximum superelevation rate "e" does not exceed 6% is as follows:

High Side— For "e" up to 3% retain normal 4% shoulder cross slope. For "e" greater than 3% use a shoulder cross slope equal to the difference of 7% minus "e".

Low Side— Same as "e" but in no case less than 4%.

The above alternate method reaches the maximum acceptable roll-over of 7% but provides for the shoulders to drain away from the traveled way under all conditions.

Since turf or aggregate shoulders require a higher rate of cross slope for adequate drainage, the high side shoulders on superelevated sections shall be rounded as illustrated in Figure 2—M for climbing lane shoulders.

2. MEDIAN (LEFT) SHOULDER—On all divided rural highways and all urban freeways a left or median shoulder is provided as shown in Figures 2—B, 2—C and 2—F.

a. WIDTH—Median shoulder are not intended to serve the same purpose as the outside or right shoulder. The outside shoulder is the accepted refuge space for stops. The median shoulders is primarily intended to allow a driver to encroach or drive on it

momentarily to avoid an accidents, to provide lateral support for the pavement structure and to avoid rutting at the edge of pavement. Normally a 1.20 surfaced width is adequate for this purpose and is the minimum specified for a four-lane highway.

However, as the traffic volumes and number of lanes in one direction increase, the left shoulder takes on added significance as a breakdown lane. Therefore, minimum median surfaced shoulder width of 1.80 meters for six lane freeways and 2.40 meters for eight-lane freeways are specified. Whenever the median shape and width allows it, it is desirable to provide a 3.00-meter surfaced left shoulder on freeways with six or more lanes.

When narrow medians with a barrier are required because of right-of-way restrictions, as is often the case in urban areas, the entire median should be paved to provide left shoulder space as illustrated in Figure 2—F.

Median shoulders are not normally provided on divided urban facilities, other than freeways, when raised or curbed medians are used to control left turn movement such as avenues (Figure 2—G) and divided principal streets (Figure 2—H).

On freeways with independent highway alignment where each roadway is at different level and guardrail is required on the median side, the same principles on extra width and guardrail placing apply as for the outside shoulders. See Figure 2—I and Chapter 8.

b. SURFACE—As in the case of outside shoulders, the median shoulders should be surfaced with materials that will have a definite color and texture contrast with the through traffic lanes.

c. CROSS SLOPES—The same criteria for cross slopes, both for normal and superelevated sections, that applies to outside shoulders is used for median shoulders on depressed and wide medians.

On paved flush medians the median shoulder will drain towards the traveled way in normal sections. In superelevated sections the transition of the shoulder cross slope is handled in a similar manner as for outside shoulders insuring that the roll-over at the pavement edge does not exceed 7%.

2—04.03 MEDIANS

The primary purpose of the median is to increase the operational safety of the highway by separating opposing streams of traffic, providing a recovery area for out-of-control vehicles, providing a stopping area in case of emergencies, and minimizing headlight glare. Medians also provide space for left turn lanes, for drainage facilities, for lighting and other appurtenances, and for future expansion of the highway.

There are three basic general types of medians — depressed, raised, or flush. In addition they can vary considerably as to width, treatment and drainage arrangements. As in the case of shoulders, medians should contrast in color and texture with the through traffic lanes. Typical median sections are shown in Figure 2—I.

1. DEPRESSED MEDIANS—These are the preferred type for all freeways and multilane rural divided highways whenever right-of-way and topographic conditions allow providing the necessary width.

Whenever the depressed median width is less than 6.0 meters it should be fully paved and the slopes limited to no more than 6:1.

Depressed medians 6.0 meters wide or wider may have a turf surface between the paved median shoulders and median ditch slopes no steeper than 4:1. However, if a median barrier is required (See Chapter 8) then the full width shall be paved.

Depressed medians requiere adequate drainage to remove storm waters and prevent ponding. Median inlets shall be provided but these shall be so designed as not to be hazardous to vehicles that run off the roadway. The invert of the ditch of a turf surfaced median on a steep grade should be paved for erosion control.

2. RAISED MEDIANS—These are normally used only in urban expressways-at-grade, avenues and principal streets (Figures 2—G and 2—H) when median widths are normally 6.00 meters or less and more positive control of left turn and cross median movements are required. On urban expressways-at-grade, design classes UE—4 and 5, the curbs of the raised portion of the median shall be offset a minimum of 0.60 meter from the edge of the through lanes.

Raised median curbs should be mountable and the median should be paved when the width is less than 3.00 meters to minimize maintenance. Also the raised median should be crowned to facilitate drainage.

Figure 2—M illustrates the accomodation and cross slopes for left turns in the median. The left turn lane should have a minimum width of 3.65 meters and the median a minimum of 4.90 meters to provide a 1.25 meter refuge for pedestrians. However, on divided principal streets, design class U—7, a minimum median width of 4.25 meters with a 3.00 meter median lane can be accepted.

When a median barrier or guardrail is required on a raised curbed median, care must be exercised in the placement of the barrier because of the vehicle vaulting effect caused by the curb. The face of the barrier shall be at least 3 meters away from the face of the curb. If that space can not be provided, then the face of the barrier shall be no further than 0.23 meters from the face of the curb.

3. FLUSH MEDIANS—These are generally used on multilane highways or streets where it is advantageous or permissible for left turns to be made to abutting properties. They are also used on rural and urban freeways with narrow medians when a median barrier is required.

Flush medians shall be paved, preferably with a surface contrasting in color and texture with the through lanes. As a minimum the through lane edges shall be delineated with pavement markings.

Figure 2—F illustrates the use of paved flush medians with a barrier on urban freeways. A minimum clearance of 1.80 meters from the through lane edge to the face of the barrier is specified. In extreme cases this clearance may be reduced to 0.60 meter as shown in Figure 2—I, subject to the approval of the Design Office.

Flush paved median will normally be designated to drain towards the through lanes except in superelevated section when inlets and storm drain pipes must be provided.

2—04.04 SIDE SLOPES AND DITCHES

Cut and fill slopes shall be flattened and liberally rounded as fitting with the topography and soils, and consistent with the overall type of highway. Effective erosion control, low maintenance cost and adequate drainage of the subgrade are largely dependent upon proper shaping of the side slopes.

Side slopes and back slopes should be sodded or seeded when needed to promote stability and reduce erosion. The use of dikes and/or ditches at the top of long heavy cuts will provide slope protection and reduce the side ditch capacity required.

Side slopes should provide a reasonable opportunity for recovery of an out-of-control vehicle. Ideally, a safety zone at least 9.00 meters in width, clear of obstructions and with slopes no steeper than 6:1, should be provided adjacent to the through lanes of high speed highways.

When a project has an excess of excavated material, the material should be used to flatten slopes rather than being wasted. Similarly, when borrow material is required it should be

obtained, to the extent feasible, by flattening cut slopes. Flattened slopes should be consistent with the existing terrain and the available right-of-way, and should not encroach on stream channels or other drainage features.

The normal fill, cut and inslopes for the various highway design classes are illustrated in Figures 2—E, 2—J and 2—K. The guide values given are subject to modification for any specific project on the basis of the soils study recommendations. As shown in the figures, the intersections of slope planes should be well rounded for safety, erosion control, and pleasing appearance.

Detail A in Figure 2—N shows an alternate cut section which may be used for depressed freeway sections in urban areas and, when authorized, for deep cut sections on freeways in mountainous terrain. Roadside drainage ditches should have a minimum depth of 0.60 meter below the shoulder break and generally should have the invert at least 0.15 meter below the subgrade. Roadside drainage requirements are discussed in Chapter 11.

2—04.05 CURBS

Curbs are used to control drainage, to deter vehicles from leaving the pavement at hazardous points, to delineate the edge of pavement, to act as traffic control devices, to protect pedestrians, to present a more finished appearance, and to assist in the orderly development of the roadside. Although curbs are used extensively on all types of urban highways they are seldom used on rural facilities except for control of drainage. The use of curbs on freeways and other high speed facilities should be avoided for safety, economy and reduced flooding of the pavement. Curbs should not be placed adjacent to high speed lanes.

The two general classes of curbs are "barrier" and "mountable" and each has numerous types and details of design. They may be designed with a gutter to form a combination curb and gutter section. Various types of typical curbs are illustrated in Figure 2—L.

1. MOUNTABLE CURBS—These are designed so that vehicles can cross them with varying degree of ease as may be required. They are 0.15 meter or less in height and have well rounded or flat sloping faces. When the face slope is steeper than 1:1 and a mountable curb is desired, the height should be no greater than 0.10 meter.

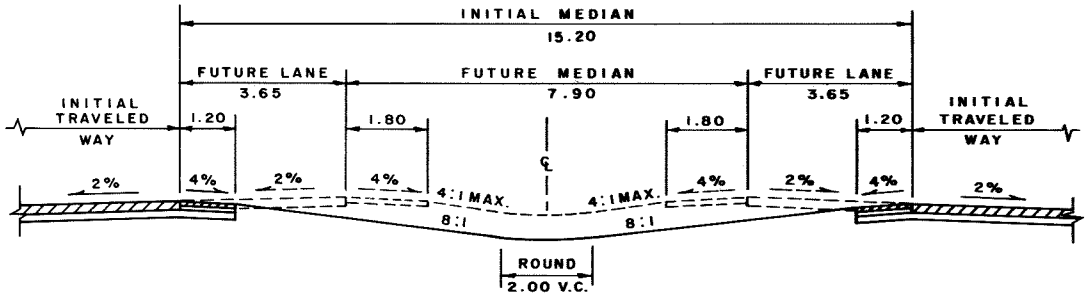
For the most part, mountable curbs are used along median and inside shoulder edges or to outline channelizing islands at intersections. They may also be used at the outer edge of outside shoulders and along the pavement edges of ramp on embankment slopes steeper than 4:1 if essential for drainage and erosion control.

2. BARRIER CURBS—These are generally 0.15 meter high or higher and steep faced, and designed to inhibit, or at least discourage, vehicles from leaving the roadway. When vehicles are expected to stop parallel to the curb, its height should not exceed 0.15 meter to prevent scraping of bumbers, fenders or doors.

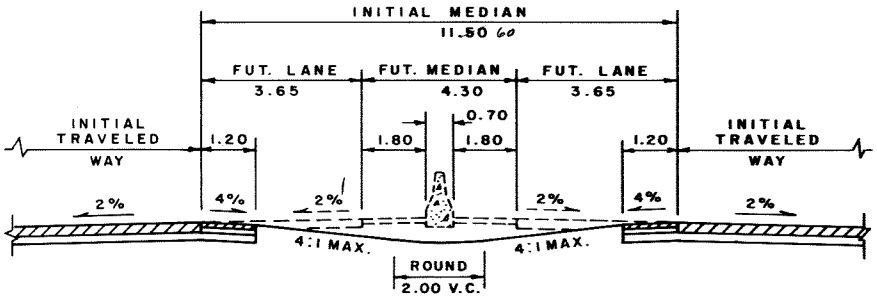
Barrier curbs should not be used on freeways and are considered undersirable on other arterials where design speeds are above 50 mph. When accidentally struck at high speeds, it is difficult for the operator to retain control of the vehicle and also, most barrier curbs are not adequate to prevent a vehicle from leaving the roadway. Where positive protection is required, such as along narrow medians or adjacent to bridge substructures, a suitable median barrier or guardrail should be provided.

Barrier curbs are normally used along the border side of avenues, principal and local streets, and frontage streets when sidewalks are provided.

3. CURB PLACEMENT—When used on expressways, curbs should not be closer than the outer edge of shoulder and in any case no closer than 0.60 meter from the edge of the through traffic lanes.

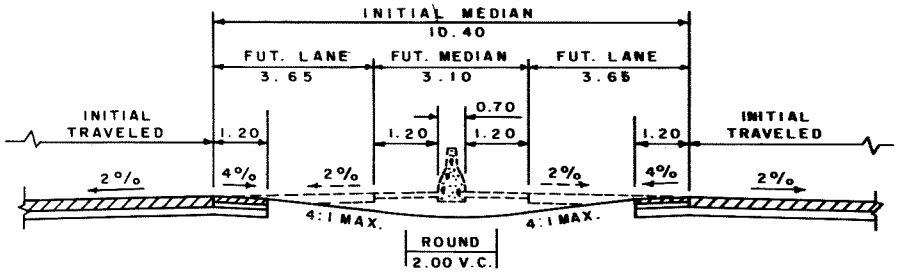


FOR FINAL MEDIANS 7.90 M.



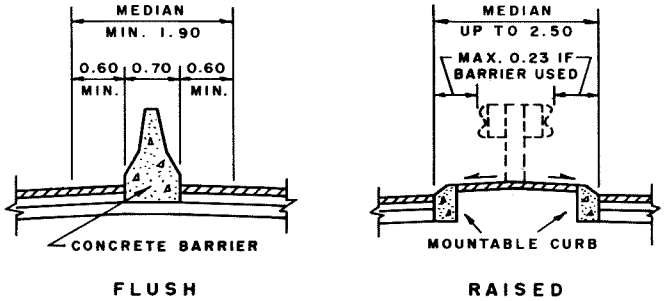
FOR FINAL NARROW MEDIANS WITH BARRIER

MINIMUM MEDIAN FOR EXPRESSWAYS WITH PROVISION FOR LEFT TURN LANE



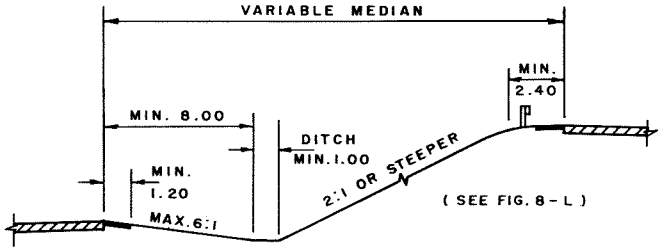
FOR FINAL NARROW MEDIANS WITH BARRIER

MEDIANS WITH PROVISION FOR FUTURE LANES



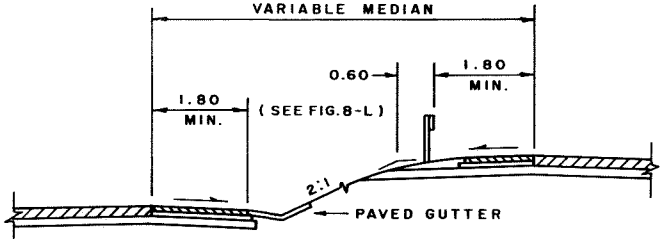
FLUSH RAISED

SPECIAL CASE – NARROW MEDIANS



FREEWAY – INDEPENDENT ALIGNMENT

(WIDE MEDIAN)



FREEWAY – INDEPENDENT ALIGNMENT

INTERMEDIATE MEDIAN

NOTE: MINIMUM MEDIAN FOR FREEWAYS WITH DESIGN CLASS RE-1, RE-2, UE-1, UE-2, UE-3, SHALL BE 3.10 METERS.

(ALL DIMENSIONS IN METERS)

TYPICAL MEDIAN SECTIONS

FIGURE 2-I

On other urban highways and streets, continuous median or border curbs need not be offset provided they are no higher than 0.15 meter. However, on facilities where curbs are intermittently introduced, they should be offset at least 0.60 meter from the edge of traffic lanes.

4. CURB RAMPS—Whealchair ramps shall be provided across curbs at all pedestrian crosswalks. These are detailed in Chapter 15.

2—04.06 CLIMBING LANES

The warrants for the use of and the design of climbing lanes are discussed in Chapter 3. When included in the highway section, climbing lanes shall have the standard 3.65 meter width.

As shown in Figure 2—M, the shoulder on the outer edge of a climbing need not be as wide as the shoulder elsewhere because the climbing lane itself could be used for emergency stops clear of the through lanes. A usable shoulder 1.20 meter wide with an aggregate or turf surface finish is adequate.

The cross slope of a climbing lane should be a continuation of the cross slope of the adjacent through lanes except superelevated sections. Figure 2—M shows how the cross slope of the climbing lane on superelevated sections varies in relation to the through lane slopes. Since vehicles using the climbing lane are expected to travel at lower speed, a maximum "e" of 4% is provided.

2—04.07 FRONTAGE ROADS AND OUTER SEPARATIONS

Frontage roads or streets are provided on expressways to control access to the through lanes, service abutting properties and to maintain local traffic circulation.

1. RURAL FRONTAGE ROADS—The design of frontage roads adjacent to rural expressways will be compatible with the service to be provided. The typical section may range from a gravel surfaced one-way local facility to one of the design classes of the Department.

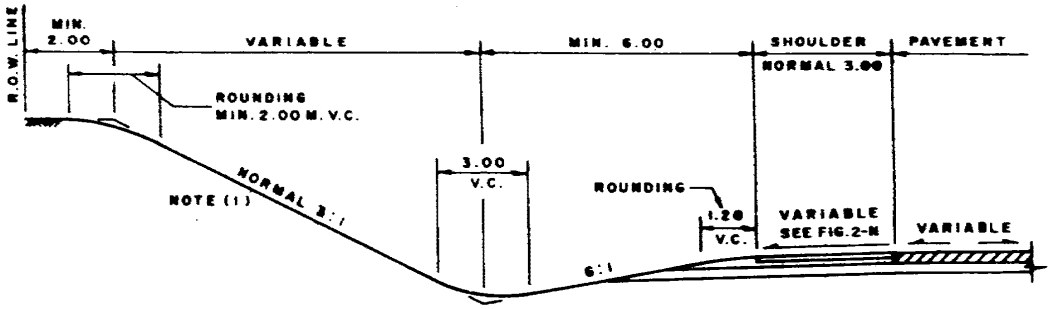
The outer separation between the through lanes and the frontage road will be dependent on the topographic conditions and the highway cross section. The width of the outer separation will be predicated upon the sum of the shoulder widths for both the highway and frontage road, the earth slopes in accordance with the design class typical sections and any required intermediate ditch or channel. However, in no case shall the width of the outer separation be less than 12.00 meters.

2. URBAN FRONTAGE STREET—The design of frontage streets in urban areas will be dependent on the character of the area traversed, the existing street intervals, and the type of service to be provided. It is preferable that, whenever possible, frontage streets located between the expressway and abutting properties be one-way for more efficient and safer traffic operation, particularly at intersections. The minimum pavement and border widths for one-way and two-way frontage streets are shown in Figure 2—F.

Outer separations should be as wide as possible. For at grade conditions, the outer separation on expressways with one-way frontage street shall be at least 6.00 meters wide and with two-way frontage street at least 9.00 meters wide.

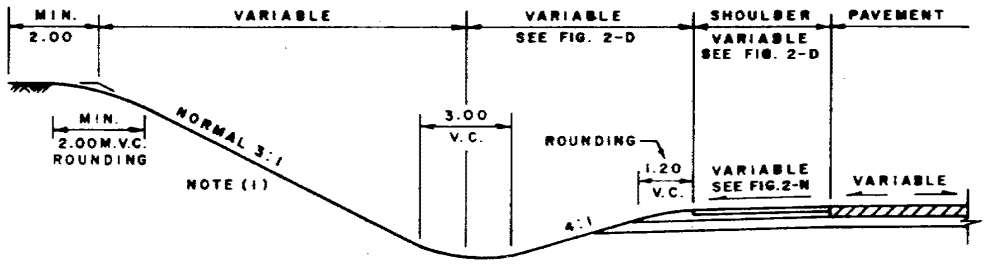
2—04.08 PARKING LANES

Parking lanes are provided only on principal and local streets. Since the need may arise to prohibit parking, at least during peak hours, on principal streets and use the parking lanes as through traffic lanes, they should be designed a minimum of 3.00 meters in width and preferable 3.65 meters. See Figure 2—H.

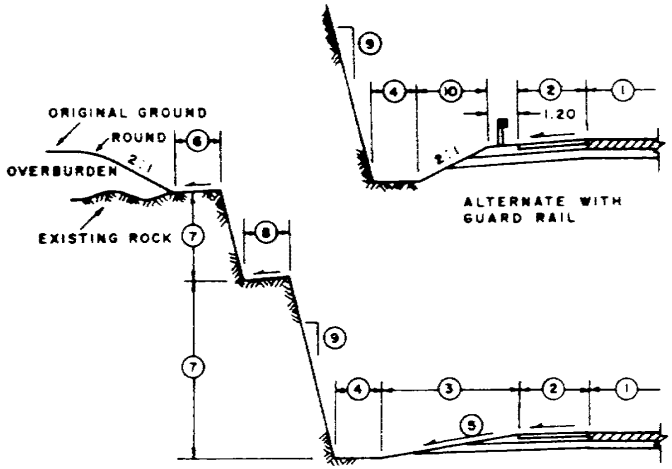


NORMAL EARTH CUT SECTION FOR RE-1,2,3,4 AND R-5

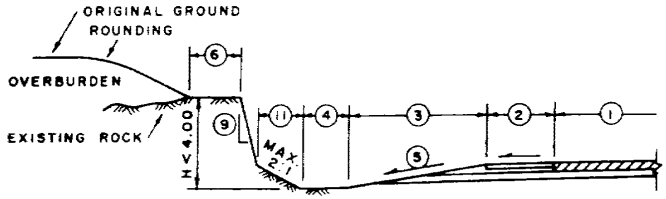
(ALSO FOR UE-1,2,3,4,5 WHERE APPLICABLE)



NORMAL EARTH CUT SECTION FOR R-6,7 AND 8



TYPICAL ROCK CUT SECTION — OVER 4.00 M.



TYPICAL ROCK CUT SECTION — UNDER 4.00 M.

NOTES:

(1) CUT SLOPES SUBJECT TO SOILS STUDY RECOMMENDATION.

(3) FOR ALTERNATES SEE FIG. 2-N.

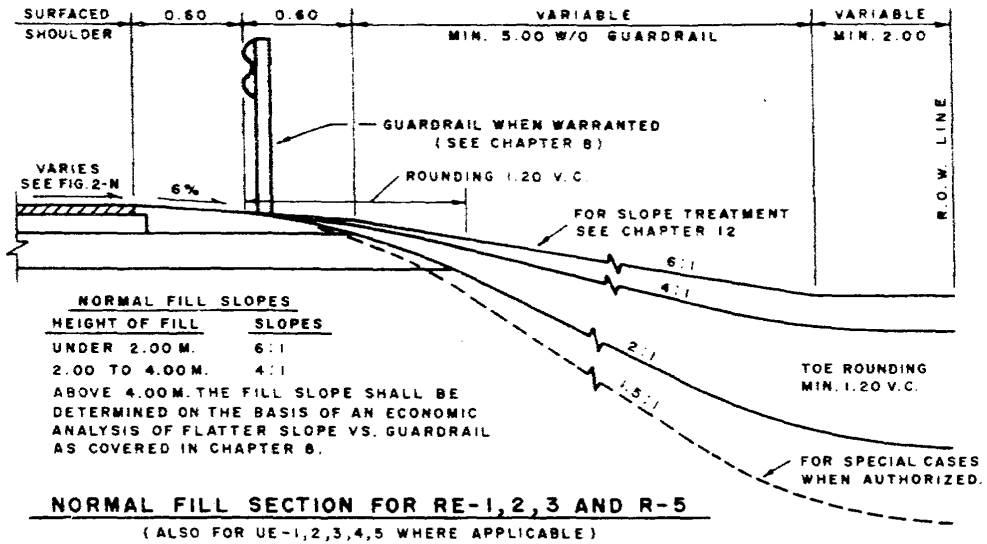
LEGEND

1. TRAVELED WAY
2. SHOULDER - SEE STANDARDS
3. VARIABLE - SEE TYPICAL SECTIONS
4. DITCH TO BE DESIGNED AS REQUIRED - MIN. 1.00 M.
5. INSLOPE VARIABLE - SEE TYPICAL SECTIONS.
6. WIDTH AS RECOMMENDED IN SOILS STUDY - MIN. 1.50 M.
7. - 8. BENCHES, IF USED, AND THESE DIMENSIONS AS RECOMMENDED IN SOILS STUDY.
9. ROCK CUT SLOPES TO BE DESIGNED ON BASIS OF SOILS STUDY. NORMAL SLOPE 1:4
10. VARIABLE - AS REQUIRED FOR DESIGN DITCH DEPTH - MIN. 2.00 M.
11. MIN. WIDTH 2.00 M.

(ALL DIMENSIONS IN METERS)

TYPICAL CUT SECTIONS

FIGURE 2-J



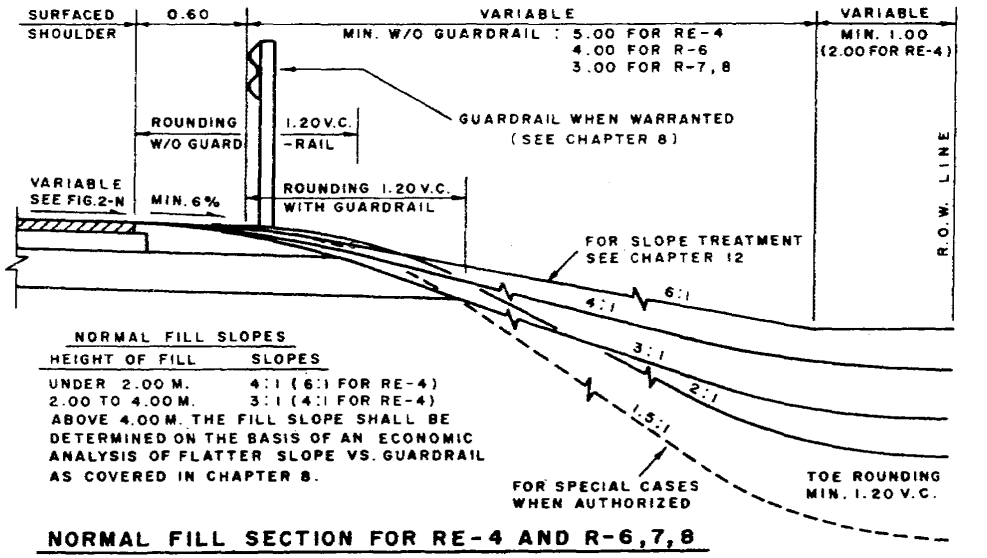
NORMAL FILL SLOPES

HEIGHT OF FILL	SLOPES
UNDER 2.00 M.	6:1
2.00 TO 4.00 M.	4:1

ABOVE 4.00 M. THE FILL SLOPE SHALL BE DETERMINED ON THE BASIS OF AN ECONOMIC ANALYSIS OF FLATTER SLOPE VS. GUARDRAIL AS COVERED IN CHAPTER 8.

NORMAL FILL SECTION FOR RE-1,2,3 AND R-5

(ALSO FOR UE-1,2,3,4,5 WHERE APPLICABLE)

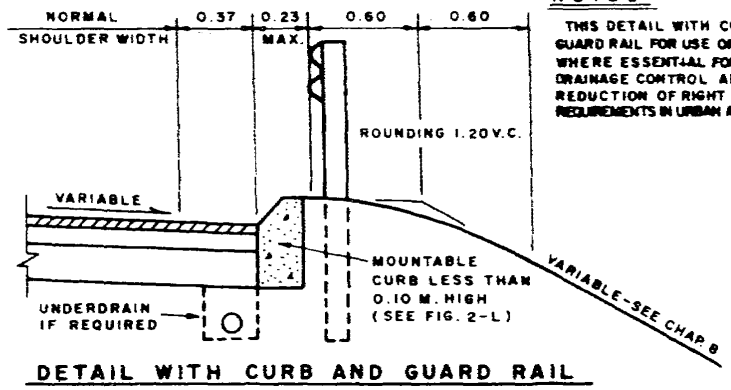


NORMAL FILL SLOPES

HEIGHT OF FILL	SLOPES
UNDER 2.00 M.	4:1 (6:1 FOR RE-4)
2.00 TO 4.00 M.	3:1 (4:1 FOR RE-4)

ABOVE 4.00 M. THE FILL SLOPE SHALL BE DETERMINED ON THE BASIS OF AN ECONOMIC ANALYSIS OF FLATTER SLOPE VS. GUARDRAIL AS COVERED IN CHAPTER 8.

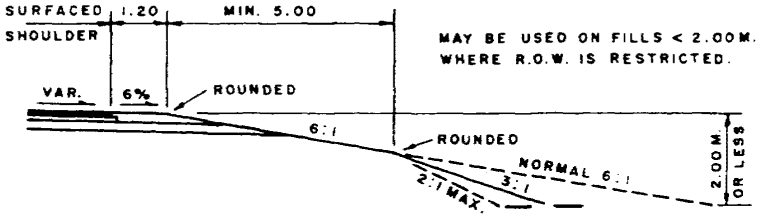
NORMAL FILL SECTION FOR RE-4 AND R-6,7,8



NOTES

THIS DETAIL WITH CURB & GUARD RAIL FOR USE ONLY WHERE ESSENTIAL FOR DRAINAGE CONTROL AND FOR REDUCTION OF RIGHT OF WAY REQUIREMENTS IN URBAN AREAS

DETAIL WITH CURB AND GUARD RAIL



MAY BE USED ON FILLS < 2.00 M. WHERE R.O.W. IS RESTRICTED.

ALTERNATE VARIABLE FILL SLOPE

GENERAL NOTES

1 - FILL SLOPES SUBJECT TO SOILS STUDY RECOMMENDATIONS.

2 - EXCESS EXCAVATION MATERIAL SHOULD BE USED TO FLATTEN SLOPES AND ELIMINATE NEED FOR GUARDRAIL WHEREVER POSSIBLE.

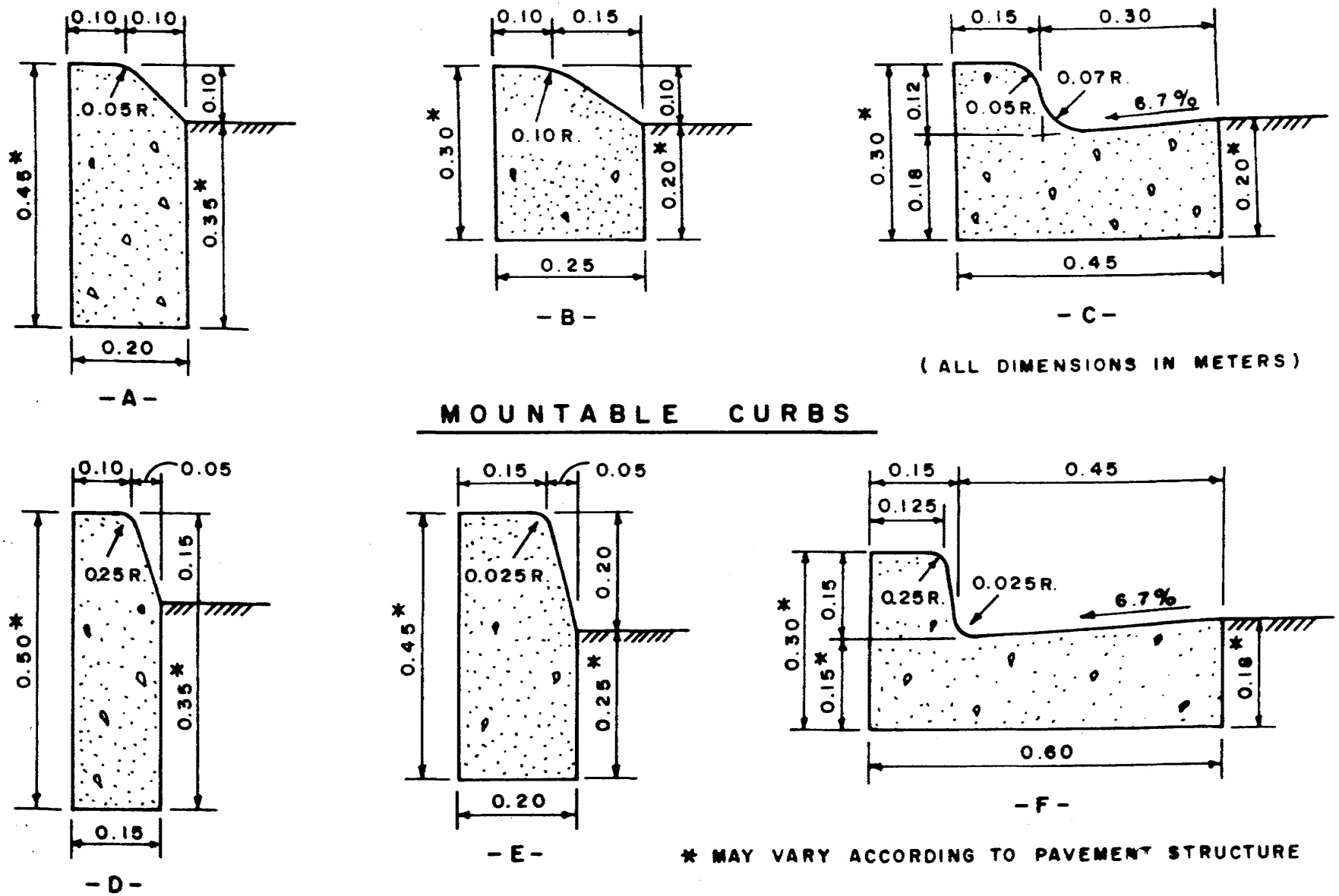
3 - FOR ALTERNATE SHOULDER TREATMENT SEE FIG. 2-N.

4 - THE "GUIDE FOR SELECTING, LOCATING AND DESIGNING TRAFFIC BARRIERS" ISSUED BY AASHTO, 1977 EDITION, SHALL BE USED AS A GUIDE FOR FILL SLOPE CRITERIA.

(ALL DIMENSIONS IN METERS)

TYPICAL FILL SECTIONS

FIGURE 2-K



TYPICAL CURBS

FIGURE 2-L

2—04.09 BORDERS AND SIDEWALKS

1. RURAL HIGHWAYS—The border or roadside area shall be of sufficient width to accommodate the cut and/or fill slopes required by the typical section plus any longitudinal drainage channels and utility installation corridors that may be required. An additional minimum clear space to the right-of-way line is specified in the typical sections to facilitate maintenance operations.

When future frontage roads may be required, the border width should be of sufficient width to provide for an adequate outer separation and the frontage road construction.

Similarly, when future widening is contemplated, the initial border width should be designed to provide for the widening and a final border width meeting the design class requirements.

The typical sections for rural expressways RE-1, 2, 3 and 4 provide for a border width, inslopes and fill slopes which in combination with the shoulder width provide a recovery area outside the traveled way at least 9.00 meters wide.

On non-controlled access rural facilities, sidewalks are required at some locations because of adjacent community development such as schools and industrial plants. In such cases, an urban type section with lower speed controls may be required, otherwise the sidewalks should be well removed from the traveled way.

2. URBAN HIGHWAYS—The main function of the border area in urban facilities is to provide space for sidewalks and utilities. It also serves to provide a green-belt area and as a buffer or insulation strip. Urban expressways without frontage streets should, whenever possible, have border areas similar to rural expressways to provide a clear recovery area.

In residential areas the minimum border width shall be 2.50 meters. The sidewalk shall be no less than 1.25 meters wide and may be wider in school areas, and will be separated from the pavement by a grass or planting strip.

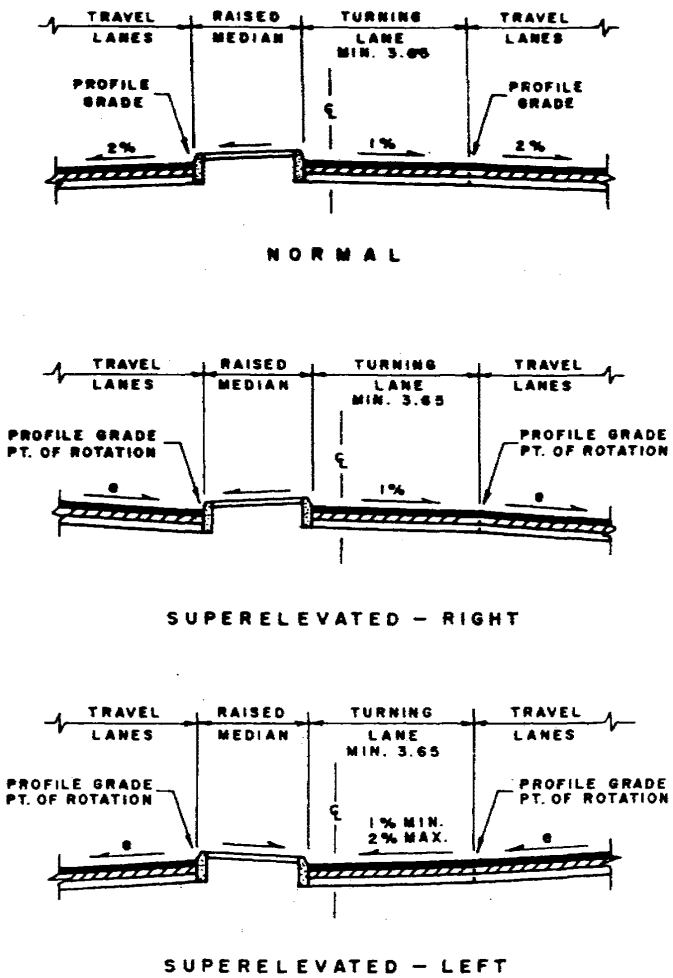
In commercial areas the minimum border width shall also be 2.50 meters but preferably 3.00 meters or wider. The whole border area is usually paved as sidewalk depending on anticipated pedestrian density.

3. SIDEWALK CROSS SLOPES—Sidewalks are normally sloped 2% towards the traveled way. They may be sloped to drain away from the traveled way where the drainage will not adversely affect adjacent properties.

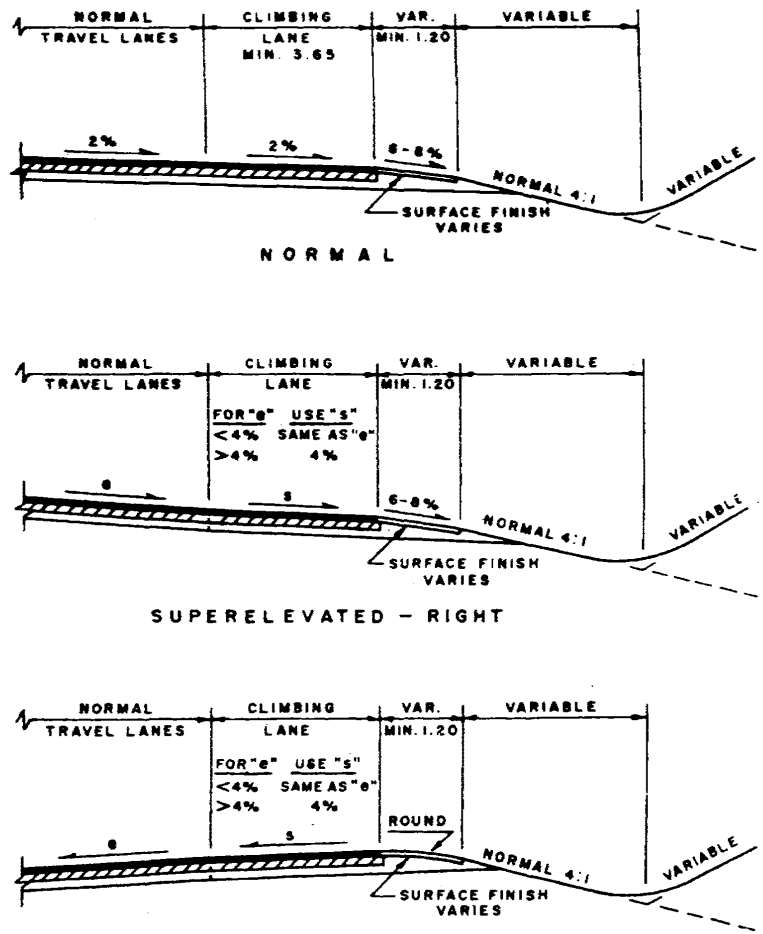
2—04.10 RIGHT-OF-WAY

Right-of-way is a critical item in Puerto Rico, in both urban and rural areas, because of the scarcity and high cost of land, and the intense development caused by our high population density. This is why the minimum values accepted for some of the cross section elements are lower than would be desirable. However, the right-of-way together with the alignment constitute the two most permanent features of a highway. Therefore, providing rights-of-way of such width as will accomodate the construction, adequate drainage, proper maintenance and the development of a safer and more aesthetically pleasing highway is a very important part of the overall design.

Wide rights-of-way permit the construction of gentle side slopes and wider medians resulting in safer highways and providing for more economical maintenance. The acquisition of sufficient rights-of-way at the time of initial improvement permits future widening as traffic increases. In all cases the right-of-way shall be no less than required for all elements of the highway cross section and border areas, including provision for the addition of future lanes when indicated by the highway planning studies.



LEFT TURN LANES IN RAISED MEDIAN

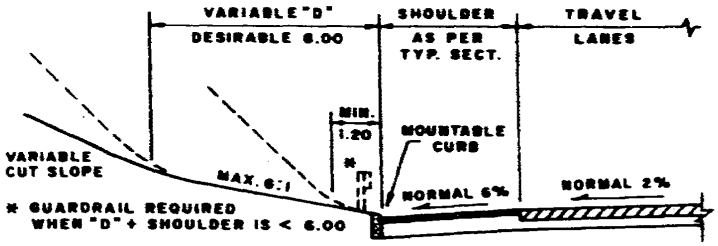


CLIMBING LANE

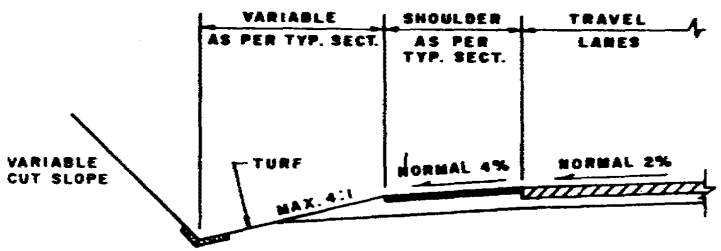
(ALL DIMENSIONS IN METERS)

TYPICAL SECTIONS – MEDIAN AND CLIMBING LANES

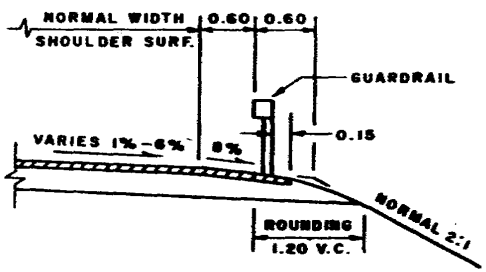
FIGURE 2-M



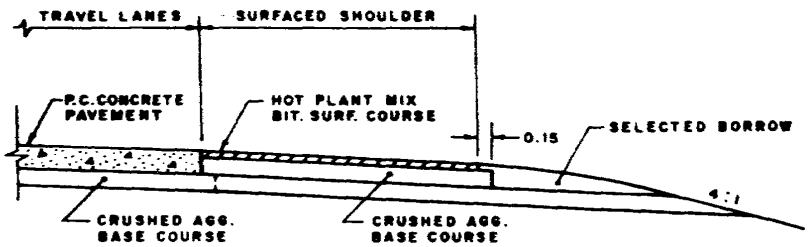
ALTERNATE CUT SECTION
WITH CURB AT EDGE OF SHOULDER
DETAIL A



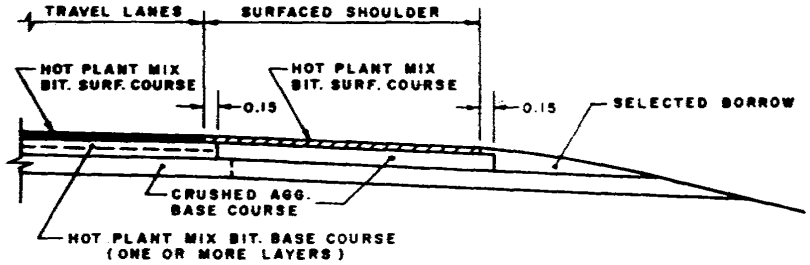
CUT SECTION WITH CONCRETE GUTTER
DETAIL B



SHOULDER SURFACING
EXTENDED BEYOND GUARDRAIL
DETAIL C

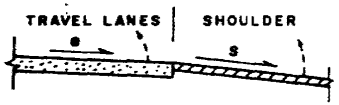


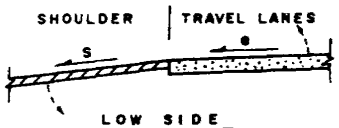
RIGID PAVEMENT



FLEXIBLE PAVEMENT

STEPPING SURFACE AND BASE LAYERS
DETAIL D





HIGH SIDE

θ (%)	S (%)
− 2	− 4
− 1	− 4
+ 1	− 3
+ 2	− 3
+ 3	− 2
+ 4	− 1
+ 5	+ 1
+ 6	+ 2
+ 7	+ 3
+ 8	+ 4

LOW SIDE

θ (%)	S (%)
− 2	− 4
− 3	− 4
− 4	− 4
− 5	− 5
− 6	− 6
− 7	− 7
− 8	− 8

TYPICAL SHOULDER SLOPE TRANSITION
FOR SUPERELEVATED SECTIONS
DETAIL E

(ALL DIMENSIONS IN METERS)

MISCELLANEOUS DETAILS

FIGURE 2-N

TABLE 2—2

DESIGN WIDTHS OF PAVEMENT FOR TURNING ROADWAYS									
R Radius on inner edge of pavement in meters	Pavement width in meters for:								
	Case I One-lane, one-way operation - no provision for passing			Case II One-lane, one-way operation - with provision for passing a stalled vehicle			Case III Two-lane operation - either one-way or two-way		
	Design Traffic Condition								
	A	B	C	A	B	C	A	B	C
15	5.50	5.50	7.00	7.00	7.60	8.85	9.45	10.65	12.80
23	4.90	5.20	5.80	6.40	7.00	8.20	8.85	10.05	11.30
30	4.55	4.90	5.50	6.10	6.70	7.60	8.55	9.45	10.65
45	4.30	4.90	5.20	5.80	6.40	7.30	8.25	9.15	10.05
60	3.95	4.90	4.90	5.80	6.40	7.00	8.25	8.85	9.45
90	3.95	4.55	4.90	5.50	6.10	6.70	7.90	8.55	9.15
120	3.95	4.55	4.90	5.50	6.10	6.70	7.90	8.55	8.85
150	3.65	4.55	4.55	5.50	6.10	6.70	7.90	8.55	8.85
Tangent	3.65	4.55	4.55	5.20	5.80	6.40	7.60	8.25	8.25
	Width modification regarding edge of pavement treatment:								
No paved shoulder	None			None			None		
Mountable curb	None			None			None		
Barrier curb: one side two sides	 Add 0.30 M. Add 0.60 M.			 None Add 0.30 M.			 Add 0.30 M. Add 0.60 M.		
Paved shoulder, one or both sides	None			Deduct paved shoulder width; minimum roadway pavement width as under Case I			Deduct 0.60 M. where paved shoulder is 1.20 M. or wider		

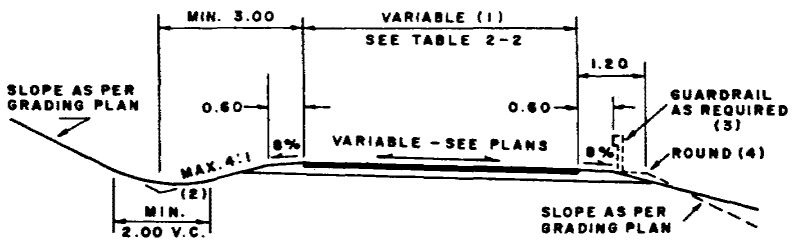
Traffic Condition A - predominately passenger with some consideration for SU vehicles (Small volume of trucks).

Traffic Condition B - SU governs design with some consideration for semi-trailers (moderate volume of trucks, 5% to 10% of total traffic).

Traffic Condition C - Sufficient bus and combination-types of vehicles govern design.

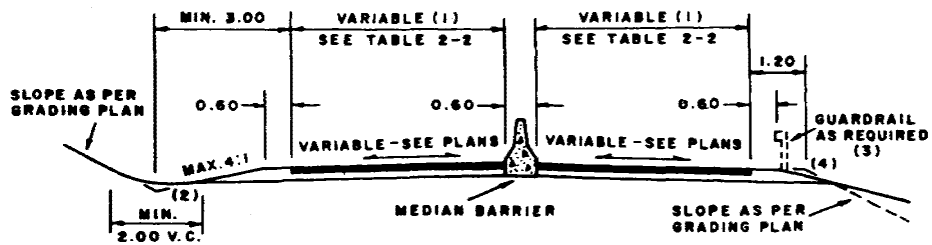
2—04.11 OTHER ELEMENTS

Other elements affecting the cross section are discussed in detail in other sections of this manual. These include structures (Chapter 6), traffic barriers and fencing (Chapter 8), traffic control devices (Chapter 9), lighting (Chapter 10), drainage (Chapter 11), utilities (Chapter 13), landscaping and roadside development (Chapter 14), and pedestrian facilities (Chapter 15).



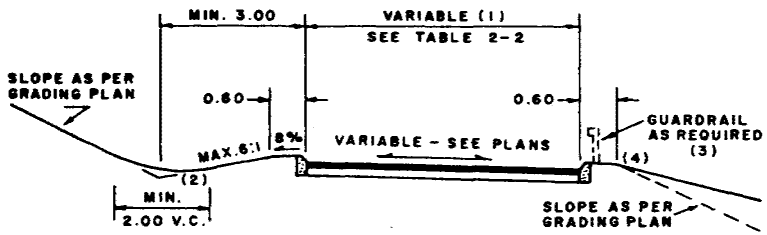
ONE-WAY RAMP - NO CURBS

DETAIL A



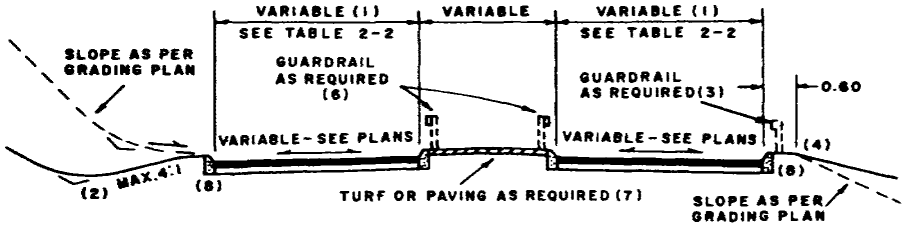
ABUTTING RAMPS - NO CURBS

DETAIL D



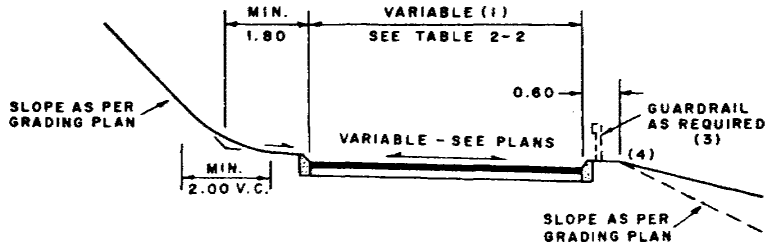
ONE-WAY RAMP - WITH CURBS (5)

DETAIL B



ABUTTING RAMP-WITH RAISED MEDIAN AND CURBS (5)

DETAIL E



ONE-WAY RAMP - WITH CURBS (5)

DETAIL C

NOTES:

(1) TOTAL PAVED WIDTH INCLUDING SHOULDERS, IF PROVIDED.
(2) DITCH SECTION TO BE DESIGNED AS REQUIRED.
(3) FOR GUARDRAIL WARRANTS SEE CHAPTER 8. SEE ALSO FIG. 2-K.
(4) FOR ROUNDING OF FILL SLOPES SEE FIG. 2-K.
(5) CURBS MAY BE USED ON ONE OR BOTH SIDES ONLY AS REQUIRED FOR DRAINAGE CONTROL AND FOR REDUCTION OF RIGHT OF WAY REQUIREMENTS IN URBAN AREAS
(6) GUARDRAIL IF REQUIRED BY RAMP VOLUMES AND CURVATURE.
(7) MEDIAN SHALL BE PAVED WITH CONTRASTING SURFACE WHERE WIDTH IS LESS THAN 5.00 METERS.
(8) SEE DETAIL "D" FOR DESIGN WITHOUT OUTSIDE CURBS.

(ALL DIMENSIONS IN METERS)

TYPICAL RAMP SECTIONS

FIGURE 2-O

2–05 RAMP SECTIONS

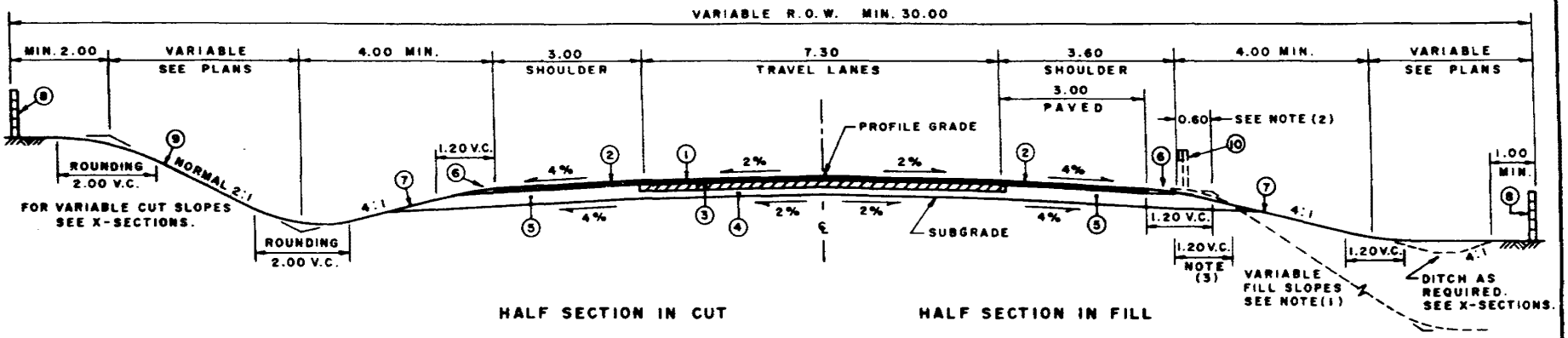
Typical ramp sections are illustrated in Figure 2–0. The required pavement width for various operating conditions, design vehicles and curvatures are given in Table 2–2.

Widths shown for Case I are used for minor turning movements and for moderate turning volumes when the connecting roadway is relatively short. One of the pavement edges should be flush with the shoulder or have a mountable curb.

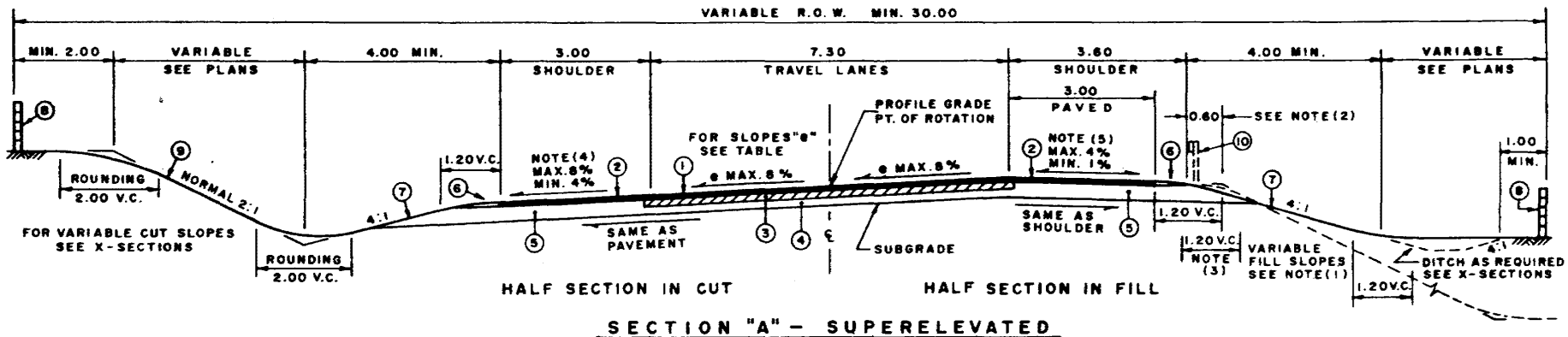
Under Case II, widths are determined so as to allow operation at low speed with restricted clearance past a stalled vehicle. These widths are applicable to turning movements of moderate to heavy traffic volumes that do not exceed the capacity of a single-lane connection.

Case III widths are applicable when operation is two-way, or when operation is one-way but two lanes are needed to handle the traffic volume.

The requiered width to be used shall be based on the shortest radius of the ramp and shall be applicable throughout the full length of curved alignment with the transition to normal pavement width being made on the approaches.



SECTION "A" – NORMAL



SECTION "A" – SUPERELEVATED

LEGEND:

1. 0.05 M. HOT PLANT MIX BIT. SURFACE COURSE – MIX IV-b, SPEC. 401.
2. 0.05 M. HOT PLANT MIX. SURFACE COURSE – MIX II-c, SPEC. 401.
3. 0.15 M. HOT PLANT MIX BASE COURSE – MIX III-d, SPEC. 401.
4. 0.15 M. CRUSHED STONE BASE COURSE – CLASS 2, GRADING B-1, SPEC. 304.
5. 0.30 M. CRUSHED STONE BASE COURSE – CLASS 2, GRADING B-1, SPEC. 304 TO BE PLACED IN TWO LAYERS.
6. SELECTED BORROW – SPEC. 203.
7. TURF ESTABLISHMENT – SPEC. 627, WHERE CALLED FOR ON PLANS.
8. BARBED WIRE FENCE – TYPE A, SPEC. 607.
9. TREATMENT VARIES – SEE PLANS.
10. GUARDRAIL – TYPE I, SPEC. 606 – WHERE CALLED FOR ON PLANS.

NOTES:

(1) FOR FILL SLOPES SEE X-SECTION SHEETS. NORMAL FILL SLOPES ARE:

HEIGHT OF FILL	SLOPE
UNDER 2.00 M.	4 : 1
2.00 TO 4.00 M	3 : 1
OVER 4.00 M.	2 : 1 (WITH GUARDRAIL)

(2) INCREASE SHOULDER WIDTH BY 0.60 M. WHERE GUARDRAIL IS CALLED FOR.

(3) ROUNDING WHERE EXTRA WIDTH AND GUARDRAIL ARE USED.

(4) SLOPE OF LOW SIDE SHOULDER SHALL BE THE SAME AS THE SUPERELEVATION RATE OF TRAVEL LANES BUT NO LESS THAN 4%.

(5) SLOPE OF HIGH SIDE SHOULDER SHALL BE AS FOLLOWS:

e (%)	S (%)	e (%)	S (%)
+ 1	– 3	+ 5	+ 1
+ 2	– 3	+ 6	+ 2
+ 3	– 2	+ 7	+ 3
+ 4	– 1	+ 8	+ 4

(ALL DIMENSIONS IN METERS)

SAMPLE COMPLETED TYPICAL SECTION (DESIGN CLASS R-6) FIGURE 2-P

CHAPTER 3

BASIC GEOMETRIC DESIGN ELEMENTS

CONTENTS

Section	Title	Pages
3—01	GENERAL	1
3—02	SIGHT DISTANCE	1
	3—02.01 Stopping Sight Distance	1
	3—02.02 Passing Sight Distance	2
3—03	HORIZONTAL ALIGNMENT	2
	3—03.01 Curvature	3
	3—03.02 Superelevation	5
	3—03.03 Superelevation Transition	9
	3—03.04 Pavement Widening on Curves	9
	3—03.05 Sight Distance on Horizontal Curves	10
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CHAPTER 3

BASIC GEOMETRIC DESIGN ELEMENTS

3—01 GENERAL

Geometric highway design pertains to the design of the visible features of the highway. It may be considered as the tailoring of the highway to the requirements of the users, to the limitations imposed by the terrain and to other controls of land usage and existing development.

General design criteria covering highway types, highway systems, design vehicles, highway capacity and general design standards are included in Chapter 1. The major cross section elements for the various classes of highways are discussed in Chapter 2.

This chapter covers detailed information and guidance on other basic geometric design elements that have to be considered in the location and design of the various classes of highways. It includes criteria on sight distances, horizontal and vertical alignment, and other features common to the several types of highways.

In applying these criteria it is important to follow the basic principle that consistency in design standards is of major importance on any section of road. The highway should offer no surprises to the driver in terms of geometrics or traffic controls. The violation of driver expectancy is a large factor in accident causation. Problem locations are generally at the point where minimum design standards are introduced on a highway section where otherwise higher standards have been applied. The ideal highway design is one with uniformly high standards applied consistently over a section, particularly on major highways designed to serve large volumes of traffic at high operating speeds.

3—02 SIGHT DISTANCE

Sight distance is the continous length of highway ahead visible to the driver. In design, two types of sight distances are considered, stopping sight distance and passing sight distance. Stopping sight distance is the minimum sight distance that should be provided throughout the continuous length of each highway. Passing sight distance is the sight distance required for safely overtaking and passing a slower moving vehicle on a two-lane highway where the opposing traffic lane must be occupied for the passing maneuver. Two-lane highways should be provided with passing sight distance over as high a proportion of the highway lenght as is feasible.

3—02.01 STOPPING SIGHT DISTANCE

Stopping sight distance is the minimum sight distance required by a driver travelling at a given speed to bring his vehicle to a stop before reaching an object in its path. It is measured from the driver's eyes, assumed to be 1.14 meters above the pavement surface, to an object 0.15-meter high on the road.

Two design values for stopping sight distance have been established for each design speed, a minimum and a desirable value as shown in Table 3—1. The minimum values shown in this table are the absolute minimum sight distances that must be provided in the design for the design speed selected. However, the designer should strive to provide the desirable value whenever costs are not unduly increased. It should be noted that the minimum and desirable values are the same for design speed up to 35 mph.

TABLE 3—1

SIGHT DISTANCES FOR DESIGN

DESIGN SPEED MPH	SIGHT DISTANCE IN METERS		
	STOPPING		PASSING * MINIMUM
	MINIMUM	DESIRABLE	
20	40	40	—
25	50	50	—
30	60	60	335
35	75	75	400
40	85	95	460
50	110	140	550
60	145	195	640
70	185	260	760

* Not applicable to multilane highways.

3—02.02 PASSING SIGHT DISTANCE

The minimum passing sight distance is the minimum lenght of highway required for a vehicle to safely complete a normal passing maneuver under related design conditions and design speed. Passing sight distance is measured from the driver's eyes, assumed to be 1.14 meters above the pavement surface, to an object 1.37—meters high on the road. The minimum passing sight distances to be used for design for the various design speeds are shown in Table 3—1.

As shown in Section 1—10.03, the lack of adequate passing sight distances on a two-lane highway has a marked adverse effect on its capacity, particularly as the percentage of trucks in the traffic stream increases. Therefore, the designer should strive to provide sections with adequate passing sight distance as often as can be done within reasonable costs to present as many passing opportunities as possible.

3—03 HORIZONTAL ALIGNMENT

The horizontal alignment of a highway must permit safe operation and provide continous stoping sight distance for the design speed selected. In the design of highway curves it is necessary to maintain the proper relationship between design speed and curvature and also their joint relationship with superelevation.

3—03.01 CURVATURE

The simple circular curve, illustrated in Figure 3—A, is most frequently used in horizontal alignment for changes in direction; although compound and spiral transition curves are also used. Curve data will generally be processed by electronic computer but may also be computed manually using the GAUNIN tables.

Table 3—2 gives the absolute minimum radius of curve, based on a maximum superelevation rates "e" of 0.06 and 0.08, which may be used for each design speed. Table 3—2 also shows for each speed the minimum radius at which the normal crown section without superelevation may be retained.

The minimum radii given in Table 3—2 are based solely on design speeds and do not reflect the requirements for horizontal sight distance set forth in Table 3—1. The latter may require in some instances a larger curve radius because of topography or other obstructions as discussed in Section 3—03.05.

Curves shall be sufficiently long to avoid the appearance of a kink. On all arterial and collectors, curves should have a minimum length of 150 meters for a deflection angle (Δ) of 5 degrees and this minimum length should be increased by 30 meters for each 1-degree decrease in the deflection angle.

3—03.02 SUPERELEVATION

When a vehicle travels on a circular curve it is forced radially outward by centrifugal force. This effect becomes more pronounced as the radius of the curve is shortened. This is counterbalanced by providing roadway superelevation and by the side friction between the vehicle tires and the surfacing. Safe travel at different speeds depends upon the radius of curvature, the side friction and the rate of superelevation. The basic formula for vehicle operation on a curve is:

Safe side friction factors for use in open highway curve design vary directly with design speed from 0.15 at 40 mph to 0.12 at 70 mph. For design speeds up to 30 mph a value of 0.20 may be used.

The maximum rates of superelevation "e" used by the Department are 0.08 for all expressways and other major rural highways and 0.06 for local rural roads and other urban highways as shown in Tables 1—11 through 1—15 of Chapter 1. Tables 3—3 and 3—4 give the design values for each rate of superelevation to be used for various design speeds and radius of curve. The letters NC (normal crown) designate curves where the normal crown section can be used and the letters RC (remove crown) indicate the curves where it is adequate to eliminate the adverse crown and superelevate the entire traveled way at the normal cross slope.

TABLE 3—2

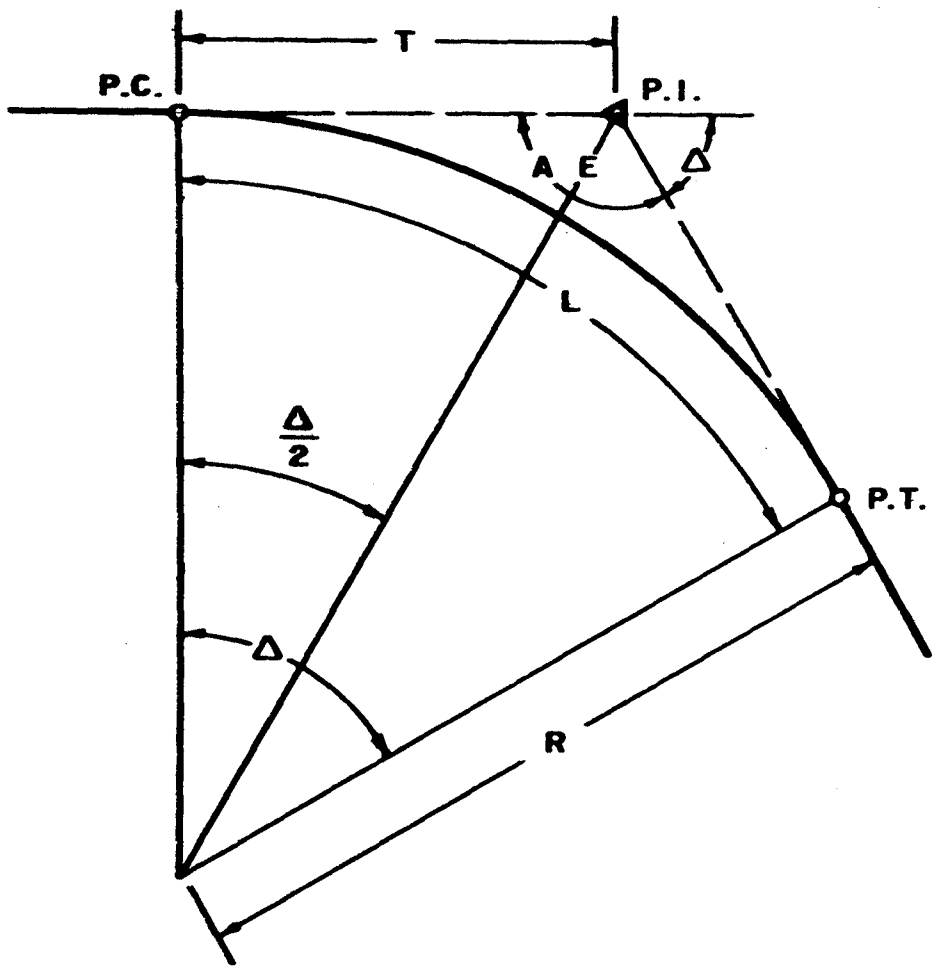
CURVATURE-RADIUS STANDARDS (1)

DESIGN SPEED (MPH)	MIN. RADIUS e = 0.06 (METERS)	MIN. RADIUS e = 0.08 (METERS)	MIN. RADIUS NORMAL CROWN (METERS)
20	30	(2)	500
25	50	(2)	800
30	70	70	1200
35	100	95	1700
40	150	140	2200
50	250	230	3300
60	385	350	4500
70	580	500	5800

(1) Open highway conditions.
(2) Not used for these design speeds.

$$e + f = \frac{V^2}{49\,R}$$

Where e = rate of superelevation in decimals
f = side friction factor
V = vehicle speed in mph
R = radius of curve in meters



LEGEND

P.C. = POINT OF CURVATURE
P.I. = POINT OF INTERSECTION
P.T. = POINT OF TANGENCY
Δ = DEFLECTION ANGLE
A = $180° - \Delta$
R = RADIUS OF CURVE (M.)
T = TANGENT LENGTH (M.)
E = EXTERNAL (M.)
L = LENGTH OF CURVE (M.)

EQUATIONS

GIVEN R AND Δ

$$T = R \left(\text{TANGENT } \frac{\Delta}{2} \right)$$

$$E = R \left(\text{EX. SEC. } \frac{\Delta}{2} \right)$$

$$L = \frac{\Delta}{360} \left(2 \pi R \right)$$

HORIZONTAL CIRCULAR CURVE FIGURE 3-A

3—03.03 SUPERELEVATION TRANSITION

1. GENERAL

Superelevation transition is the general term denoting the change in cross section from a normal crown section to a fully superelevated section, or vice versa. To meet the requirements of comfort and safety, the superelevation transition should be effected uniformly over a length adequate for the travel speeds.

The "tangent runout" is the term denoting the length of highway needed to accomplish the change in cross slope from a normal crown section to a section with the adverse crown removed. The "superelevation runoff" is the term denoting the length of highway needed to accomplish the change in cross slope from a section with the adverse crown removed to the fully superelevated section. The sum of these two lengths provides for the full superelevation transition.

2. TWO-LANE HIGHWAYS

The standard method of attaining superelevation on 2—lane highways is to rotate the pavement about the centerline profile. This is illustrated in detail "A" of Figure 3—B. The centerline profile, drawn as a horizontal line, represents the calculated profile, which may be tangent, a vertical curve or a combination of the two. The cross section rotation is shown in the lower portion of detail "A" with the pavement cross slope condition at each lettered point indicated.

The superelevation runoff length (L.R.) corresponds to that given under "L" for the various design speeds in Tables 3—3 and 3—4. When spiral transition curves are used, the length of spiral shall correspond to the length of superelevation runoff with the spiral T.S. at the beginning and the S.C. at the end. In the design of curves without spirals, two thirds (2/3) of the superelevation runoff will be accomplished on the tangent approach and one third (1/3) on the curve.

The length of the tangent runout (T.R.) will be determined, as shown in figure 3—B, by the formula:

$$\text{T.R.} = \text{L.R.} \times \frac{\text{Normal Slope}}{\text{"e" of curve}}$$

Where the normal pavement cross slope rate is 0.02 the tangent runout length for a curve with the minimum superelevation rate of 0.02 will be equal to the length of runoff. For a curve with a full superelevation rate of 0.08 the tangent runout length will equal one-fourth (1/4) of the length of runoff.

3. LOCAL RURAL ROADS

The minimum length of superelevation runoff on local rural roads of design classes R-9, R-10 and R-11 with design speeds of less than 30 MPH should be 30 meters but may be reduced to 20 meters in mountainous terrain. On these roads it is sometimes not economically feasible in mountainous terrain to obtain sufficient tangent distance between reverse curves to develop the standard superelevation transition. In such instances the length of superelevation runoff required for each curve may be distributed 50% on the tangent and 50% on the curve.

4. DIVIDED HIGHWAYS

On multilane divided highways, the superelevation is normally attained by holding the median on a horizontal plane and rotating each traveled way separately around the median edges as illustrated in detail "B" of Figure 3—B. In special cases of narrow medians, 3 meters or less in width, and moderate superelevation rates, the two traveled ways and the median may be rotated as a plane section about the centerline. In the case of wide medians, 12 meters or more

TABLE 3-3

DESIGN VALUES FOR RATE OF SUPERELEVATION

MAXIMUM e = 0.06

R	V = 30 MPH		V = 40 MPH			V = 50 MPH			V = 60 MPH			V = 70 MPH		
	e	L	e	L		e	L		e	L		e	L	
		2-LANE		2-LANE	4-LANE		2-LANE	4-LANE		2-LANE	4-LANE		2-LANE	4-LANE
7000	NC	—	NC	—	—	NC	—	—	NC	—	—	NC	—	—
3500	NC	—	NC	—	—	NC	—	—	RC	55	55	RC	60	60
2400	NC	—	NC	—	—	RC	45	45	.021	55	55	.027	60	60
1700	NC	—	RC	40	40	.021	45	45	.027	55	55	.034	60	60
1200	RC	30	.020	40	40	.028	45	45	.036	55	55	.044	60	60
900	RC	30	.026	40	40	.034	45	45	.044	55	55	.052	60	70
800	RC	30	.028	40	40	.036	45	45	.046	55	60	.053	60	75
700	.020	30	.031	40	40	.040	45	45	.050	55	60	.057	60	80
600	.023	30	.035	40	40	.044	45	45	.054	55	65	.060	60	85
500	.026	30	.038	40	40	.048	45	50	.057	55	70	.060	60	85
450	.029	30	.040	40	40	.050	45	50	.059	55	75	MIN. R = 580		
400	.032	30	.043	40	45	.053	45	55	.060	55	75			
350	.035	30	.046	40	45	.056	45	60	.060	55	75			
300	.038	30	.050	40	50	.059	45	65	MIN. R = 385					
250	.041	30	.054	40	50	.060	45	70						
200	.045	30	.058	40	55	MIN. R = 250								
180	.047	30	.059	40	55									
160	.050	30	.060	40	60									
140	.053	30	.060	40	60									
120	.056	30	MIN. R = 150											
100	.059	30												
90	.060	30												
80	.060	30												
	.060	30												
	MIN. R = 70													

R - RADIUS OF CURVE (METERS)
V - DESIGN SPEED
e - RATE OF SUPERELEVATION
L - MINIMUM LENGTH OF RUNOFF (METERS)
NC - NORMAL CROSS SLOPE
RC - REMOVE ADVERSE CROSS SLOPE AND SUPERELEVATE AT NORMAL CROSS SLOPE

NOTES:

1 - SPIRAL TRANSITIONS RECOMMENDED FOR "L" BELOW HEAVY LINE.

2 - FOR DIVIDED HIGHWAYS WITH THREE OR MORE LANES IN ONE DIRECTION:
LENGTH OF RUNOFF (L) = 200 x W x e
WHERE W IS THE WIDTH IN METERS OF TRAVELED WAY IN ONE DIRECTION.
MINIMUM L = 60 METERS.

TABLE 3-4

DESIGN VALUES FOR RATE OF SUPERELEVATION

MAXIMUM e = 0.08

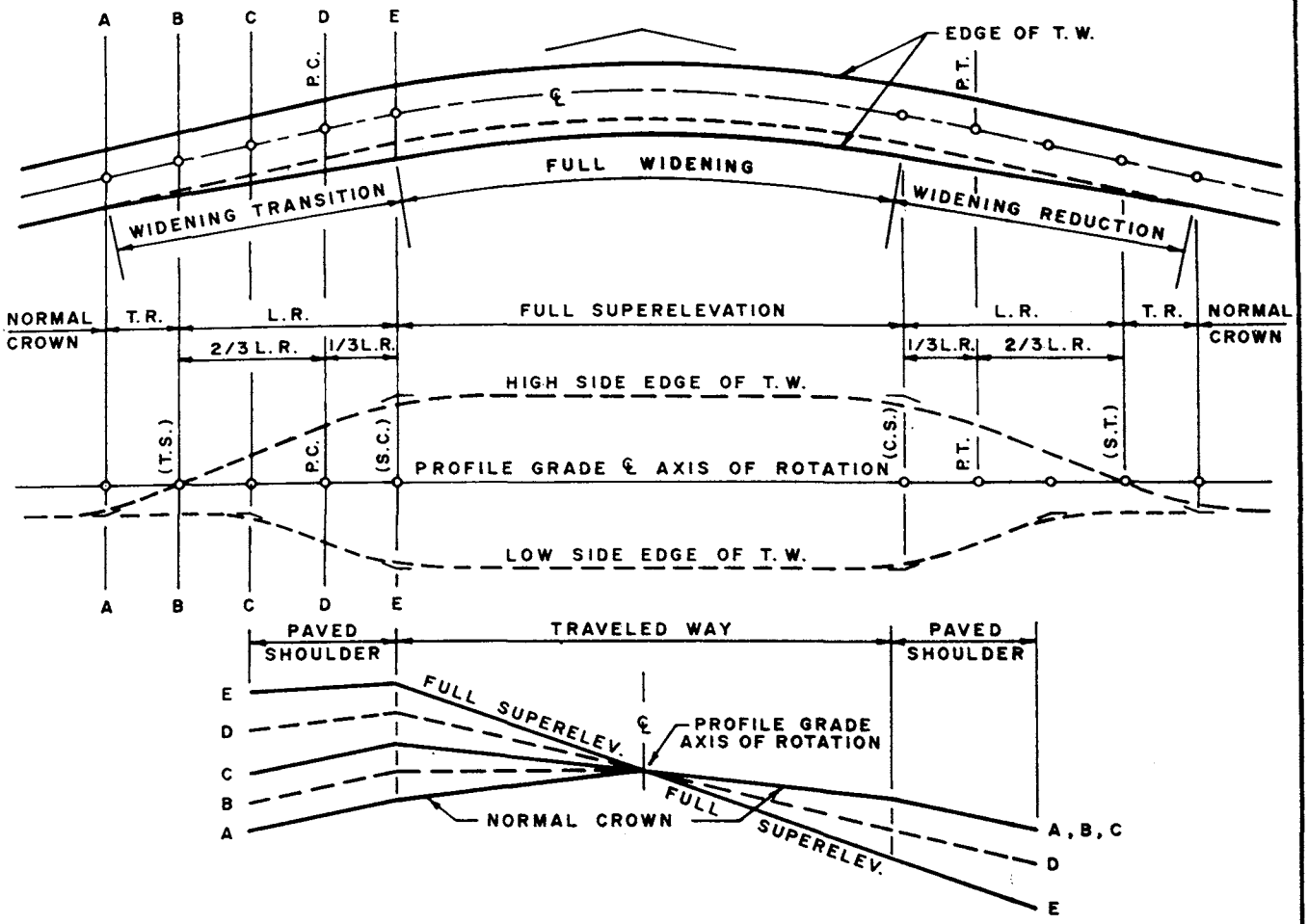
R	V = 30 MPH		V = 40 MPH			V = 50 MPH			V = 60 MPH			V = 70 MPH		
	e	L	e	L		e	L		e	L		e	L	
		2-LANE		2-LANE	4-LANE		2-LANE	4-LANE		2-LANE	4-LANE		2-LANE	4-LANE
7000	NC	—	NC	—	—	NC	—	—	NC	—	—	NC	—	—
3500	NC	—	NC	—	—	NC	—	—	RC	55	55	RC	60	60
2400	NC	—	NC	—	—	RC	45	45	.022	55	55	.027	60	60
1700	NC	—	RC	40	40	.021	45	45	.028	55	55	.038	60	60
1200	RC	30	.021	40	40	.030	45	45	.039	55	55	.052	60	75
900	RC	30	.026	40	40	.038	45	45	.050	55	65	.065	60	90
800	RC	30	.029	40	40	.042	45	45	.055	55	70	.069	60	95
700	.021	30	.033	40	40	.046	45	50	.060	55	75	.073	65	100
600	.024	30	.038	40	40	.052	45	60	.066	55	80	.077	70	105
500	.027	30	.043	40	40	.058	45	65	.073	60	90	.080	75	110
450	.030	30	.047	40	45	.062	45	70	.076	60	95	MIN. R = 500		
400	.034	30	.051	40	45	.066	45	80	.078	65	95			
350	.038	30	.055	40	50	.071	50	80	.080	70	100			
300	.043	30	.061	40	60	.076	55	85	MIN. R = 350					
250	.048	30	.067	40	65	.079	60	85						
200	.055	30	.074	50	70	.080	60	90						
180	.059	30	.077	50	75	MIN. R = 230								
160	.063	35	.079	50	75									
140	.067	35	.080	50	75									
120	.072	35	MIN. R = 140											
100	.077	40												
90	.079	40												
80	.080	40												
	.080	40												
	MIN. R = 70													

R - RADIUS OF CURVE (METERS)
V - DESIGN SPEED
e - RATE OF SUPERELEVATION
L - MINIMUM LENGTH OF RUNOFF (METERS)
NC - NORMAL CROSS SLOPE
RC - REMOVE ADVERSE CROSS SLOPE AND SUPERELEVATE AT NORMAL CROSS SLOPE

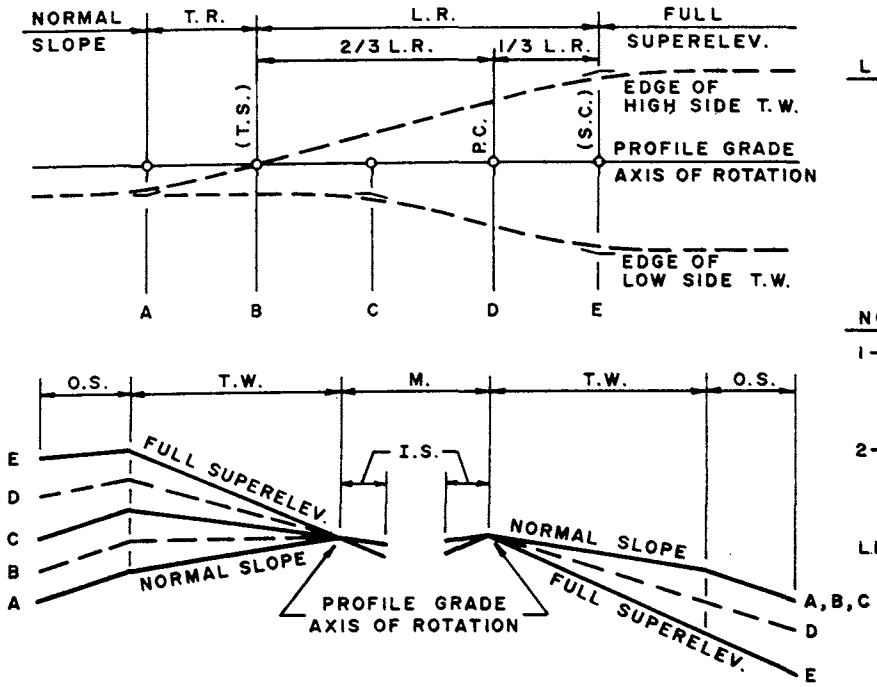
NOTES:

1 - SPIRAL TRANSITIONS RECOMMENDED FOR "L" BELOW HEAVY LINE.

2 - FOR DIVIDED HIGHWAYS WITH THREE OR MORE LANES IN ONE DIRECTION:
LENGTH OF RUNOFF (L) = 200 x W x e
WHERE W IS THE WIDTH IN METERS OF TRAVELED WAY IN ONE DIRECTION.
MINIMUM L = 60 METERS.



A - SUPERELEVATION AND WIDENING TRANSITION - 2-LANE HIGHWAY



LEGEND:

T.R. - TANGENT RUNOUT
L.R. - LENGTH OF RUNOFF
M. - MEDIAN
T.W. - TRAVELED WAY
I.S. - INSIDE SHOULDER
O.S. - OUTSIDE SHOULDER

NOTES:

1 - WHEN SPIRALS ARE USED THE RUNOFF IS TO BE EFFECTED FROM T.S. TO S.C. AND C.S. TO S.T.

2 - FOR PAVED SHOULDER SLOPE TRANSITION SEE SECT. 2-04.02 AND FIG. 2-N.

$$\text{LENGTH T.R.} = \text{L.R.} \times \frac{\text{NORMAL SLOPE}}{\text{"e" OF CURVE}}$$

B - SUPERELEVATION TRANSITION - DIVIDED HIGHWAY

SUPERELEVATION AND WIDENING TRANSITIONS FIGURE 3-B

in width, and/or independent alignment, each traveled way may be treated separately and rotated about its own centerline.

For 4—lane divided highways with medians up to 12 meters in width, the minimum length of superelevation runoff shall be as shown under 4—lane in Tables 3—3 and 3—4. For divided highways with three or more lanes in one direction the minimum length of runoff shall be determined as indicated in note no. 2 of these tables.

The length of tangent runout will be determined as indicated previously for 2—lane highways.

5. PAVEMENT EDGE PROFILES

The change in cross slope to attain the superelevation should be made in a manner that will result in edge-of-pavement profiles which are rounded to smooth flowing lines for safety and general appearance. The angular break that would appear at cross sections A, C and E of Figure 3—B if tangent profile control lines were followed shall be rounded in the finished design by introducing short vertical curves. The length of these curves should be approximately equal to one third (1/3) the length of runoff.

Divided highways warrant special refinement in design and attention to appearance because they are normally designed to serve greater traffic volumes at higher speeds, and because the cost of refinements are usually insignificant compared to the cost of construction. Accordingly, efforts should be made to use longer values for the length of superelevation runoff than those indicated as minimums. There should also be emphasis on the development of smooth flowing pavement edge profiles such as obtained by spline line design methods.

3—03.04 PAVEMENT WIDENING ON CURVES

The standards for rural highways of design classes R—7, 8, 9, 10 and 11 allow minimum lane width of less than 3.65 meters. When such minimum widths are used, the traveled way pavement shall be widened on curves in accordance with the values given in Table 3—5.

The method of attaining pavement widening on curves is shown in detail "A' of Figure 3—B. The following principles should be followed in the design of the pavement widening. These apply to both ends of the highway curves.

1. The widening will be applied on the inside edge of pavement in all cases.

2. The widening shall be attained gradually over the same length as the total superelevation transition including the tangent runout and the length of runoff.

3. The pavement edge through the widening transition should be a smoth graceful curve. A tangent transition and angular breaks at the pavement edge should be avoided.

4. Pavement widening may be fully detailed on construction plans or general controls cited and final details left to the field engineer.

3—03.05 SIGHT DISTANCE ON HORIZONTAL CURVES

Where an object off the pavement, such as a wall, bridge pier, bridge railing, building, guard rail, cut slope or natural growth restricts sight distance on the inside of a curve, the minimum radius of curvature may be controlled by the stopping distance rather than the design speed. Design to provide adequate sight distance may require adjustment in the normal highway cross section or a change in alignment if the obstruction cannot be removed. Specific study is usually necessary for each condition which should be checked using the appropriate design speed and stopping sight distance controls, and making the necessary adjustment to provide adequate sight distance.

For general use in the design of horizontal curves, the sight line is a chord of an arc equal in length to the minimum stopping sight distance measured along the centerline of the inside lane around the curve as illustrated in the sketch in Figure 3—C. For the stopping sight distance criteria of height of driver's eyes at 1.14 meters and height of object of 0.15 meter, the midpoint of the line of sight is about 0.60 meter above the center of the inside lane. The line of sight is assumed to intercept the view obstruction at this midpoint.

The chart in the upper portion of Figure 3—C may be used to graphically check sight distance restrictions on horizontal curves. For graphical solution, the radius (R) is taken at the centerline of the inside traffic lane and the distance (M) to the obstruction is measured from the same line. This permits use of the chart with variable pavement widths. This graphical solution is also aplicable to divided highways on curved alignment where the sight distance in the median lane on the outside of curve may be restricted due to a structure pier or other obstruction in the median.

Guard rail can become an obstruction to stopping sight distance where placed on the inside of curves where minimum permissible radius are used. In such cases the radius of curvature may have to be increased or the fill slopes flattened to eliminate the need for guard rail, or the shoulder widened to increase the distance M.

In designing projects, care must be exercised that proposed signing, bridge abutments and piers, guard rails, landscaping and other appurtenant facilities on curved alignment do not result in stopping sight distance obstructions.

TABLE 3–5

DESIGN VALUES FOR PAVEMENT WIDENING ON OPEN HIGHWAY CURVES (RURAL HIGHWAYS)

RADIUS OF CURVE (METERS)	DESIGN CLASS				
	R-7	R-8	R-9	R-10	R-11
	PAVEMENT WIDENING IN METERS*				
30— 70			1.0	1.0	1.0
71—100			0.8	1.0	1.0
101—150			0.6	1.0	1.0
151—200	0.6	1.0			
201—250	0.6	1.0			
251—300	0.6	1.0			
301—350		1.0			
351—400		0.8			
401—800		0.6			

* When the minumum pavement widths given in Tables 1—12 and 1—13 are used.

3—03.06 GENERAL CONTROLS FOR HORIZONTAL ALIGNMENT

In addition to the specific design elements for horizontal alignment previously discussed, the following general controls should be followed in developing the highway design:

1. The horizontal alignment for the main travel lanes should be as direct as possible but should be consistent with topography. Excessive curvature or poor combinations of curvature generate accidents, limit capacity, increase operating costs and detract from a pleasing appearance.

2. A flowing alignment that conform to the natural contours is preferable to long tangents that slash through the terrain, to avoid deep scars and preserve natural slopes and vegetation. However, on two-lane highways consideration must be given to providing adequate passing sight distance over as great a percentage of the highway as feasible.

3. Flat curves rather than sharp curves are desirable. The use of the minimum radius acceptable for the given design speed should be restricted to the most critical conditions.

4. The alignment throughout a highway section should be consistent. Sharp curves at the end of long tangents and sudden changes from easy to sharp curvature should be avoided.

5. The use of compound circular curves on the main travel lanes should be avoided when a simple circular curve can be utilized at small extra cost. Where topography requires the use of compound curves, the radius of the flatter curve should not be more than 50% greater than the radius of the sharper curve.

6. Abrupt reversal in alignment should be avoided by the use of sufficient length of tangent or spirals between reverse curves to provide adequate superelevation runoff. The length of tangent should be as required to provide the minimum length of superelevation runoff for each curve specified in Section 3—03.03.

7. Broken-back curves (short tangent between two curves in the same direction) should be avoided. Use of a single longer circular curve, a compound curve or spiral transition is preferable. In any case, the minimum length of tangent between succesive curves in the same direction shall be at least equal to the sum of the required minimum length of superelevation runoff for each curve specified in Section 3—03.03.

8. Whenever practical, high fills should have tangent or flat curvature alignment.

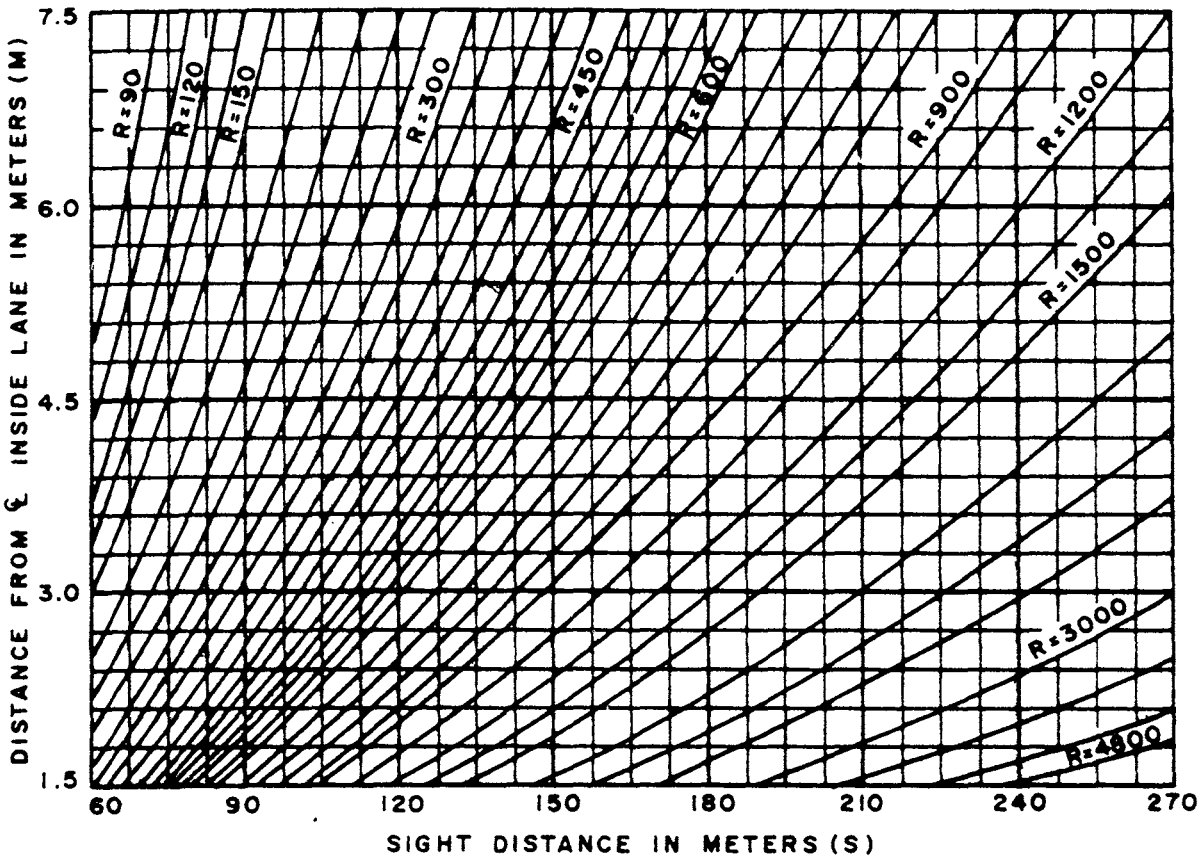
9. Whenever feasible, the locating of any portion of the superelevation transition on a bridge deck should be avoided to simplify the design and construction of the structure. It is preferable to have the bridge either on a tangent with normal cross section or, if on a curve, with a uniform superelevation rate.

10. The horizontal alignment should be carefully coordinated with the profile design. This is discussed in Section 3—05.

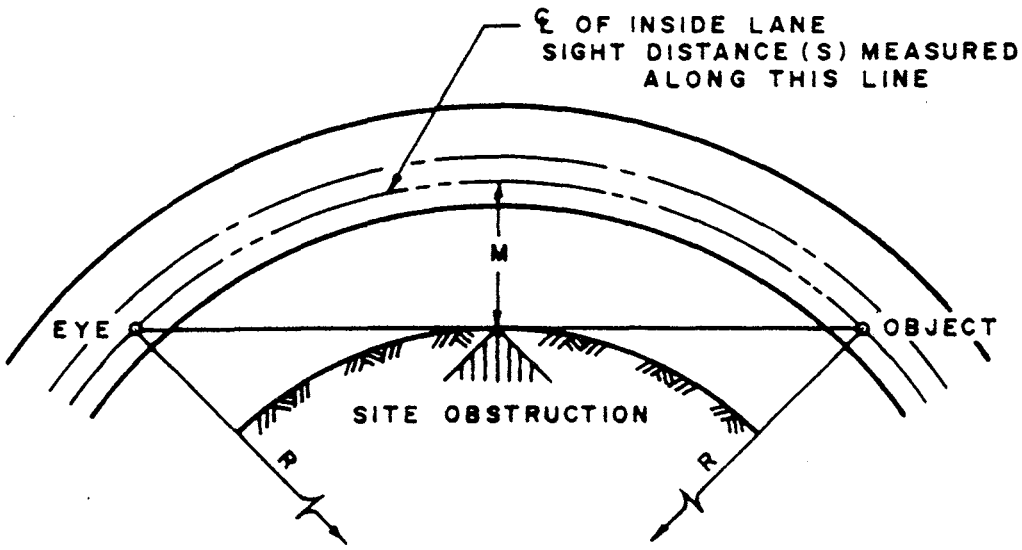
3—04 VERTICAL ALIGNMENT

The profile grade line is a reference line by which the elevation of the pavement and of other features along the highway are established. It is controlled by topography, safety, design speed, vehicle performance, sight distance requirements, horizontal alignment, drainage requirements, adjacent development and construction costs.

Highways should be designed to encourage uniform operation throughout. A selected design speed is used as a means to correlate the various geometric feature of a highway including the vertical alignment. However, the rugged mountainous topography of Puerto Rico imposes severe limitations on the profile design, in other than the coastal areas, to maintain highway construction within reasonable costs.



R = RADIUS IN METERS



STOPPING SIGHT DISTANCE ON HORIZONTAL CURVES

FIGURE 3-C

3—04.01 CONTROL GRADES

1. MAXIMUM GRADES

Table 3—6 summarizes the maximum grades for varying terrain conditions and design speeds for rural main highways and local roads. Table 3—7 provides similar data for urban highways.

The use of the allowable maximum design grades should be avoided whenever feasible. On the other hand, for short grades of less than 200 meters in length, the maximum gradient may be about 1% steeper than shown in Tables 3—6 and 3—7 for main rural and urban highways, and 2% steeper for local roads and streets.

2. MINIMUM GRADES

In general, 0.50% is the desirable minimum grade for the design of all rural highways and 0.35% for urban highways. On high type pavements without curbs in rural areas a minimum grade of 0.35% may be used provided roadside ditches and channels can be designed with the necessary slope for adequate drainage.

Where minimum grades are used with curbed pavements, care must be exercised in the design and spacing of storm water inlets to avoid excessive spread of water on the traveled way. See Chapter 11.

3—04.02 CRITICAL LENGTHS OF GRADE

Maximum grade in itself is not a complete design control. It is also necessary to consider the length of a particular grade in relation to desirable vehicle operation. The term "critical length of grade" is used to indicate the maximum length of a designated upgrade upon which a loaded truck can operate without an unreasonable reduction in speed. The relation between rate and length of tangent grade for several reductions in speed is shown in Figure 3—D.

For a given grade, lengths less than the critical result in acceptable operation in the desired range of speeds. On grades longer than the critical, design adjustments in location and profile or the addition of auxiliary climbing lanes would be required to attain the desired freedom of operation.

Figure 3—D may be used to obtain the critical length of grade for truck speed reductions of 5 to 35 mph for upgrades up to 8% regardless of design speed. A 15-mph speed reduction is the generally accepted design guide. However, in many instances in mountainous terrain, physical controls preclude shortening or flattening grades to meet this criteria and larger speed reductions have to be accepted.

3—04.04 CLIMBING LANES

A climbing lane is an auxiliary lane in the upgrade direction intended for use primarily by slow-moving vehicles to maintain capacity and freedom of operation. Generally, climbing lanes should be provided on two-lane rural highways of design classes RE—4, R—5 and R—6 when both of the following warrants are present:

1. Speed Reduction—On grades where a critical length for a truck speed reduction to below 30 mph can not be avoided.

2. Capacity Reduction—On grades where the design hourly volume (DHV) of the highway will exceed 120% of the design capacity of the individual grade section. The capacity of the grade shall be determined on the basis of the truck equivalent factors given in Chapter 1 and in the Highway Capacity Manual.

TABLE 3-6

RELATION OF MAXIMUM GRADES TO DESIGN SPEED

RURAL HIGHWAY

Type of Terrain	DESIGN SPEED — MPH							
	20	25	30	35	40	50	60	70
	GRADES IN PERCENT							
	EXPRESSWAYS, ARTERIALS AND COLLECTORS							
Level					5	4	3	3
Rolling					6	5	4	4
Mountainous					8	7	6	5
	LOCAL ROADS							
Level	7	7	7	7	7			
Rolling	12	10	9	8	8			
Mountainous	15	12	10	10	10			

TABLE 3-7

RELATION OF MAXIMUM GRADES TO DESIGN SPEED

URBAN HIGHWAYS

Type of Terrain	DESIGN SPEED — MPH					
	20	30	40	50	60	70
	GRADES IN PERCENT					
	EXPRESSWAYS					
Level			5	4	3	3
Rolling			6	5	4	4
Hilly			8	7	6	5
	OTHER ARTERIALS AND COLLECTORS					
Level		7	7	6		
Rolling		8	8	7		
Hilly		10	10	9		
	LOCAL STREETS					
Level	7	7	7			
Rolling	10	9	8			
Hilly	12	10	10			

Climbing lanes on multilane highways are seldom warranted; however, they should be considered on both rural and urban 4-lane expressways if critical length of grade for a 15-mph reduction is exceeded and the directional DHV will exceed 130% of the directional capacity of the grade section.

The beginning warrant for a climbing lane shall be that point where it is estimated that the truck speed has been reduced by 15 mph or to 30 mph, as selected, and is decelerating. However, a transition length of 160 meters should be provided ahead of the climbing with a 60-meter taper and 100 meters of full climbing lane width.

It is desirable to end the climbing lane at a point beyond the crest where a typical truck would have attained again a speed of 30 mph and be accelerating. An additional transition length of 160 meters shall be provided beyond the point of need to include 100 meters of full lane width and a 60-meter taper.

Critical lengths of grade and the location of climbing lanes can be determined graphically from the speed-distance curves included in Figure 3—E. The use of these curves is illustrated by the example problem included in Figure 3—E.

Climbing lanes shall be 3.65 meters wide but where used the usable shoulder width can be reduced to 1.20 meters as shown in Figure 2—M. Pavement markings and adequate warning signs, in advance and near the end, all in accordance with the Manual of Uniform Traffic Control Devices, shall be provided.

3—04.04 VERTICAL CURVES

1. GENERAL

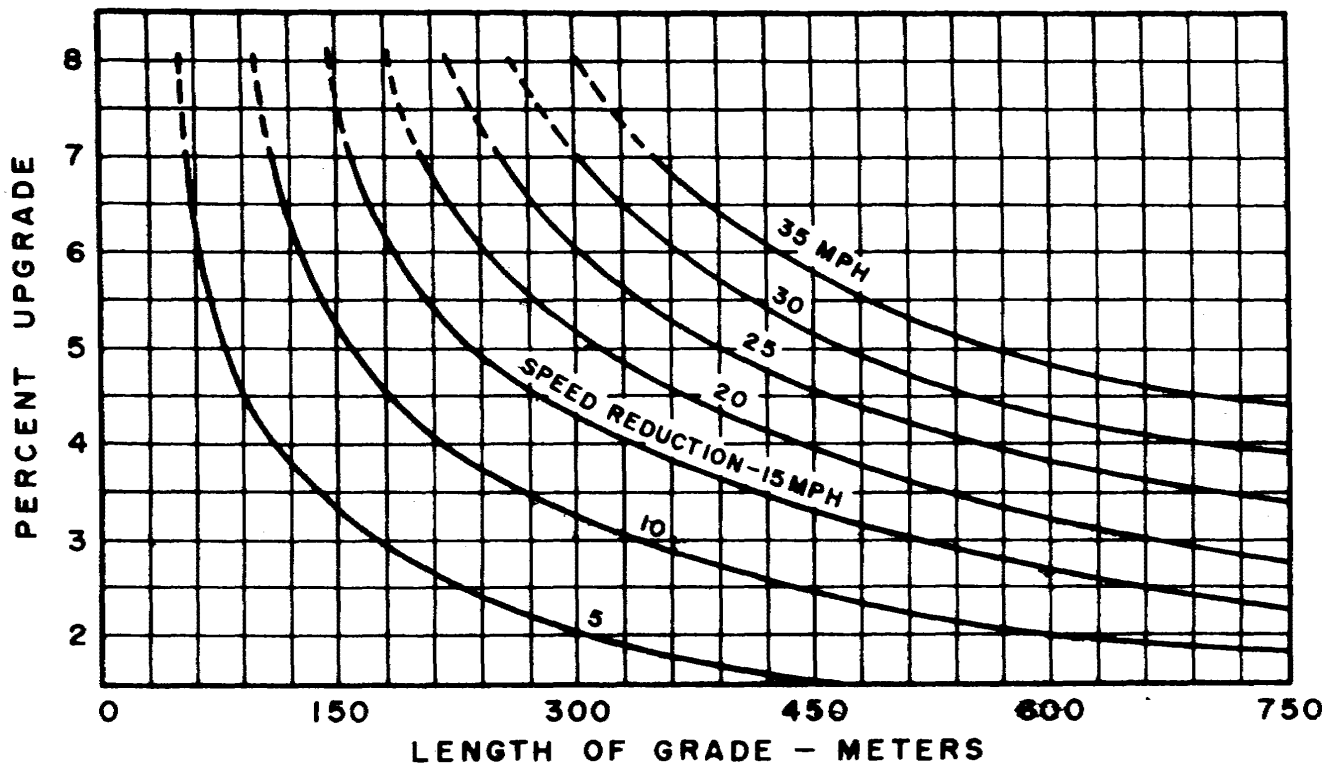
Vertical curves are used to obtain a gradual change between tangent grades. They should result in a design that is safe, comfortable in operation, pleasing in appearance and adequate for drainage. The various types of vertical curves are illustrated in Figure 3—F.

The simple parabolic curve has been adopted for highway profile design because it closely approximates a circular curve and is simple in application. It is illustrated in Figure 3—G which also gives necessary mathematical relations for computations. The vertical offsets from the tangent to the curve vary as the square of the horizontal distance from the curve end. The rate of change of grade to successive points on the curve is a constant amount for equal increments of horizontal distance and equals the algebraic difference (A) between intersecting tangent grades in percent divided by the length of curve (L) in meters, or A/L in percent per meter. The reciprocal, L/A, is the horizontal distance in meters required to effect a 1-percent change in gradient and is a measure of curvature. The expression L/A, termed "K", is used to designate curvatures necessary for a given design speed. The term "K" is a simple and convenient expression for design control and is used in determining the minimum length of vertical curve required for any combination of design speed and algebraic difference in grades through the application of the relation L=KA.

2. CREST VERTICAL CURVES

The major control for safe operation on crest vertical curves is the provision of adequate sight distance for the design speed. Minimum stopping sight distances or greater should be provided in all cases.

Minimum length of crest vertical curves as determined by sight distance requirements are generally satisfactory from the standpoint of safety, comfort and appearance. However, the minimum length of a crest vertical curve in meters shall in no case be less than the value of the

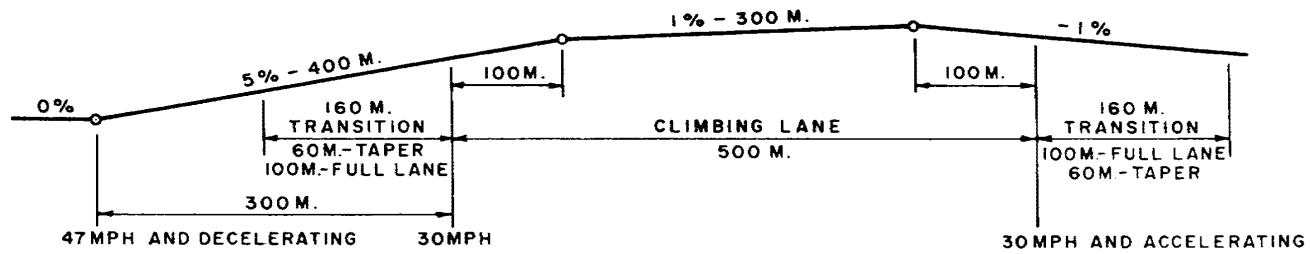


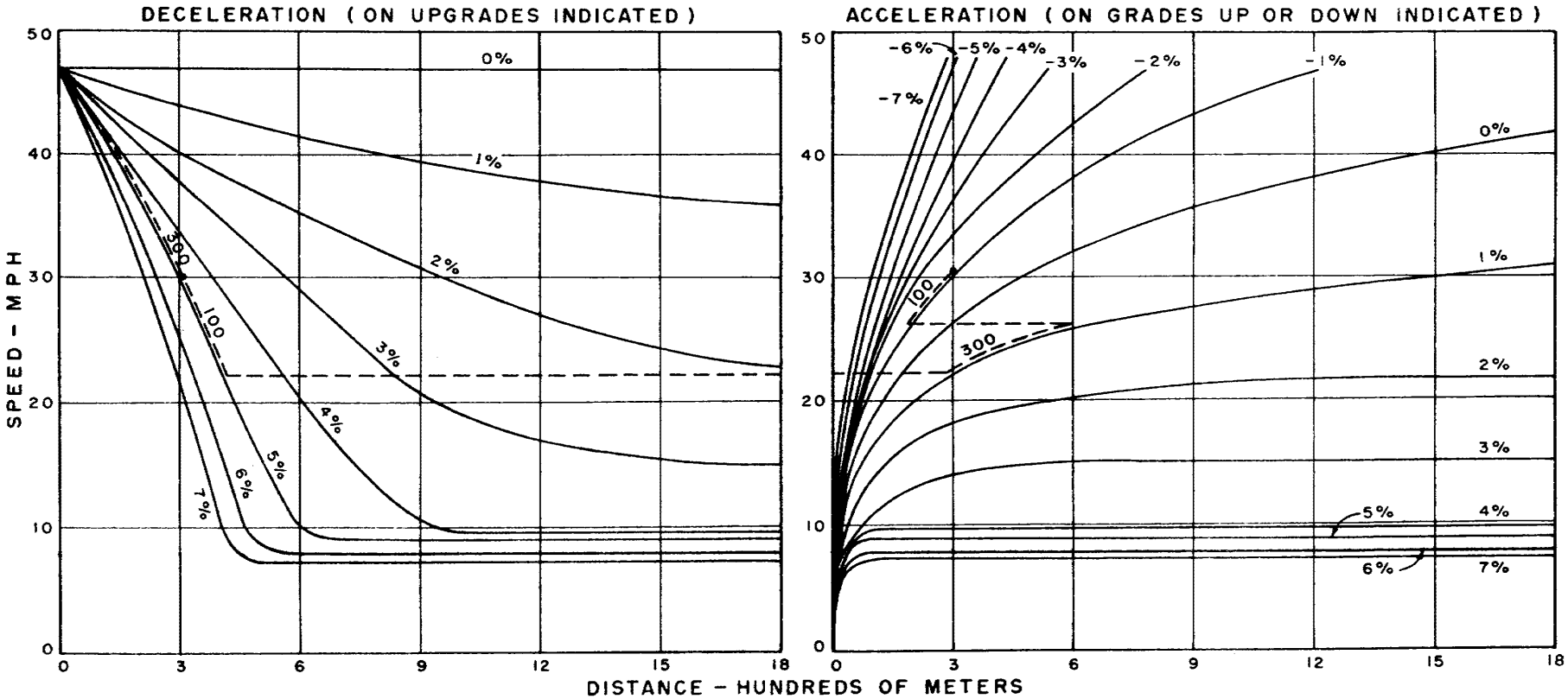
CRITICAL LENGTHS OF GRADE FOR DESIGN

(ASSUMED TYPICAL HEAVY TRUCK OF 400 POUNDS PER HORSEPOWER)

FIGURE 3-D

NOTE:
DASHED LINES ON GRAPH INDICATE STEPS FOLLOWED IN FINDING LOCATION FOR CLIMBING LANE SHOWN ON SKETCH.

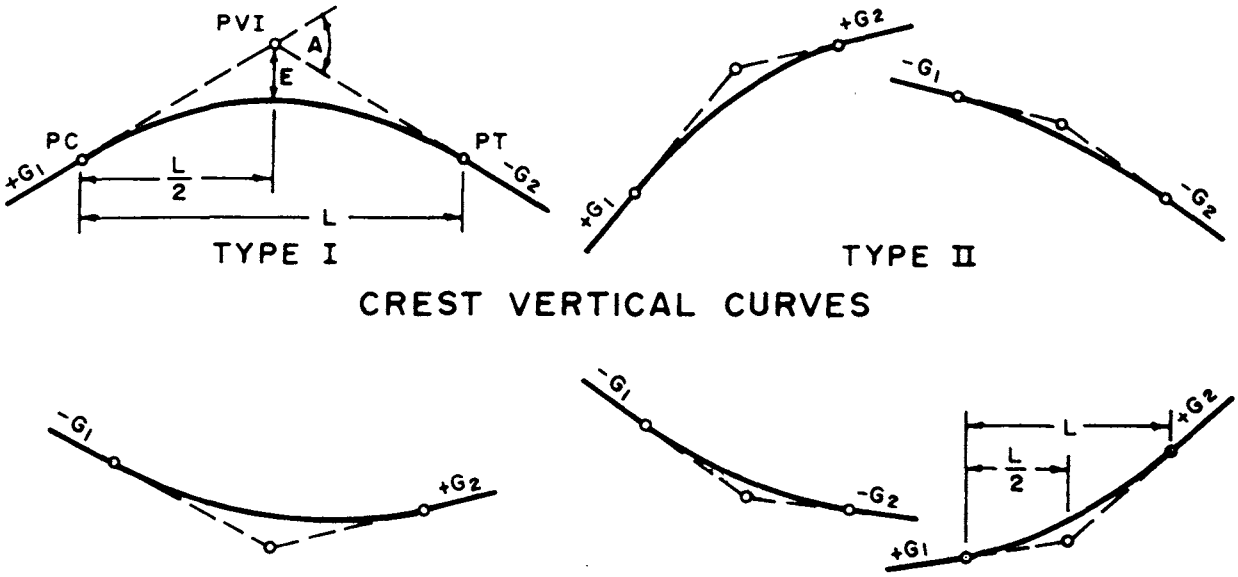




(ESTIMATED FOR A TYPICAL HEAVY TRUCK OPERATING ON VARIOUS GRADES)

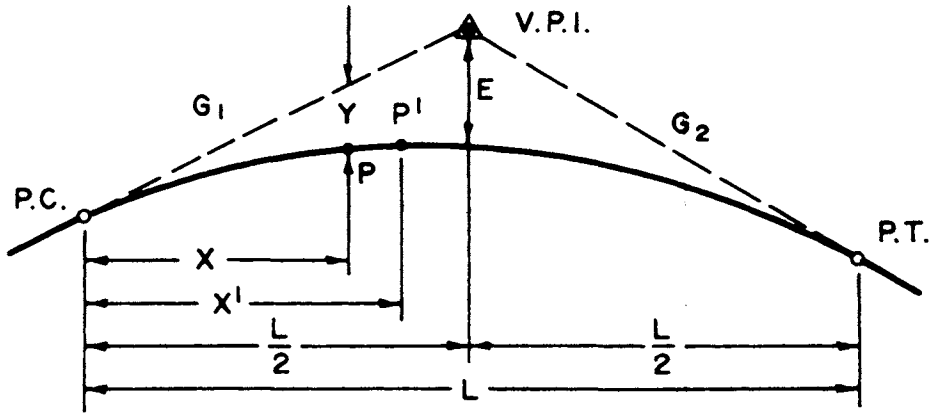
SPEED - DISTANCE RELATION ON GRADES

FIGURE 3-E



TYPES OF VERTICAL CURVES

FIGURE 3-F



L = LENGTH OF VERTICAL CURVE IN METERS

G_1, G_2 = TANGENT GRADES, ALGEBRAICALLY IN DECIMALS

E = ORDINATE FROM V.P.I. TO CURVE IN METERS

P = ANY POINT ON THE CURVE

Y = ORDINATE FROM TANGENT TO "P" IN METERS

X = HORIZONTAL DISTANCE FROM P.C. OR P.T. TO "P" IN METERS

S = SLOPE OF LINE TANGENT TO "P" IN DECIMALS

P' = HIGH OR LOW POINT ON CURVE

X' = HORIZONTAL DISTANCE FROM P.C. TO P' IN METERS

$$\text{ELEV. OF V.P.I} = \text{ELEV. OF P.C.} + G_1 \frac{L}{2}$$

$$\text{ELEV. OF P.T.} = \text{ELEV. OF P.C.} + (G_1 + G_2)\frac{L}{2}$$

$$E = (G_2 - G_1)\frac{L}{8} \qquad Y = \frac{4E(X)^2}{L^2} = \frac{(G_2 - G_1)X^2}{2L}$$

$$S = G_1 - \frac{(G_1 - G_2)X}{L} \qquad X = \frac{LG_1}{G_1 - G_2}$$

$$\text{ELEV. OF P'} = \text{ELEV. OF P.C.} - \frac{L(G_1)^2}{2(G_2 - G_1)}$$

PARABOLIC VERTICAL CURVE FIGURE 3-G

design speed in miles per hour. For example, the minimum length of vertical curves on a highway of design class RE—2 in rolling terrain with a design speed of 60 mph shall be 60 meters.

Table 3—8 gives the K values for crest vertical curves for use in the relation L=KA to determine the length of vertical curve in meters required to provide stopping sight distances for the various design speeds. Values of K are given for both minimum and desirable stopping sight distances. The desirable value should be used whenever feasible. Figure 3—H provides for the graphic solution of the relation L=KA for crest vertical curves.

Drainage problems may arise on long type I vertical curves with K values of 44 or higher in conjuction with curbed pavements because of the flat slopes near the crest which may impede the runoff of surface water along the gutter. Special attention should be given to such cases to insure adequate disposal of the storm water runoff.

The required lengths of crest vertical curves to provide adequate passing sight distance are considerably longer than those for stopping sight distances. The K values for computing the length of vertical curves required to provide the minimum safe passing distances specified in Table 3—1 are as follows:

Design Speed, mph	—	30	40	50	60	70
Rounded K value	—	110	210	300	410	580

It should be noted that the above K values range from 7 to 12 times the K values for stopping sight distance. Thus, it is usually impracticable to provide passing sight distances on crest vertical curves because of the difficulty and cost of fitting to the terrain the very long curves required. Providing such lengths is feasible only in the rare cases where very small algebraic differences in grade occur on low design speed roads.

3. SAG VERTICAL CURVES

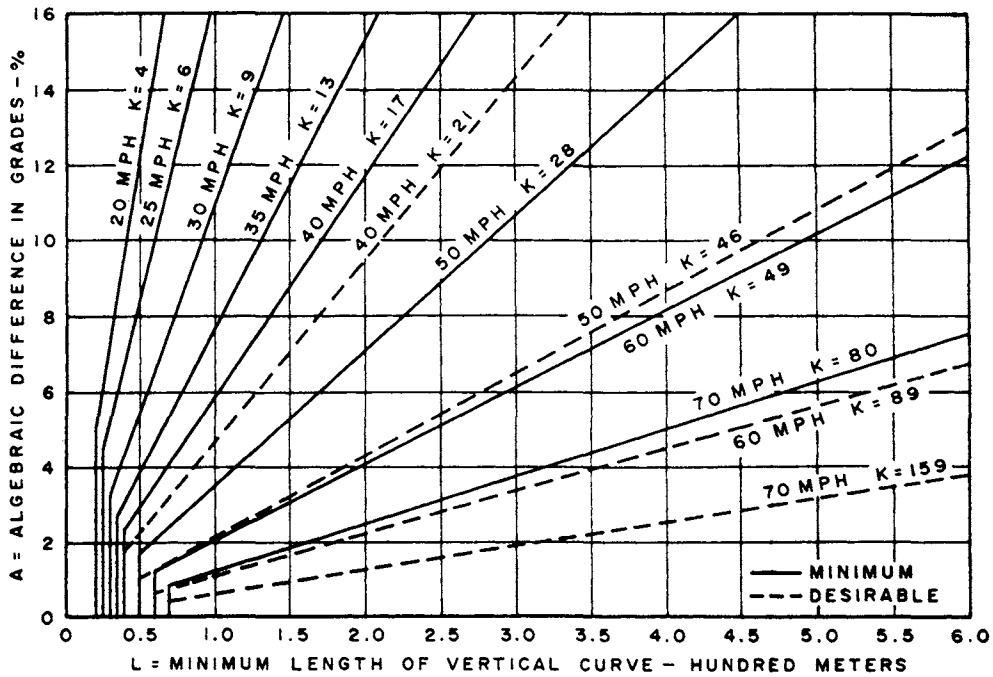
Criteria for establishing the length of sag vertical curves include headlight sight distance, rider comfort, drainage control and general appearance. However, headlight sight distance has been generally accepted for design control but taking into consideration the comfort criteria when the algebraic difference in grades is small.

TABLE 3—8

DESIGN CONTROLS FOR CREST VERTICAL CURVES

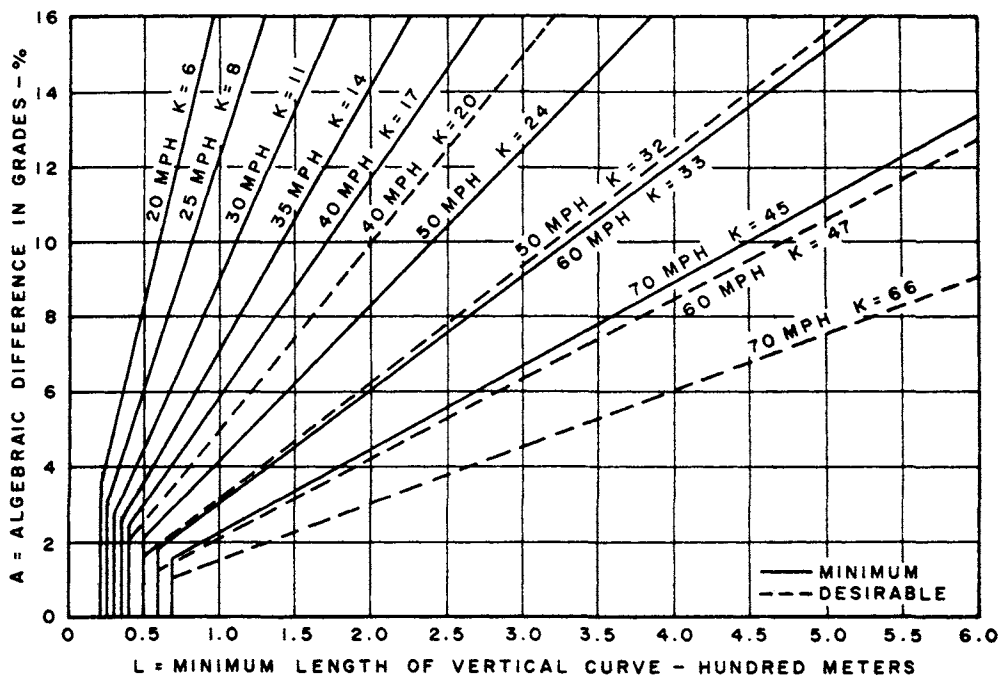
(Based on Stopping Sight Distances)

Design Speed M.P.H.	K = Rate of vertical curvature, length in meters percent of A	
	Minimum	Desirable
20	4	4
25	6	6
30	9	9
35	13	13
40	17	21
50	28	46
60	49	89
70	80	159



DESIGN CONTROLS FOR CREST VERTICAL CURVES

FIGURE 3-H



DESIGN CONTROLS FOR SAG VERTICAL CURVES

FIGURE 3-I

For overall safety, a sag vertical curve should be long enough so that the light beam distance of the vehicle is nearly the same as the stopping sight distance. However, for comfort and appearance the minimum length in meters of a sag vertical curve should be no less than the value of the design speed in miles per hour. Lengths shorter than this minimum may be justified for economic reasons in special cases when an existing major element controls the vertical profile and in some ramps at interchanges with tight space controls.

Table 3—9 gives the K values for sag vertical curves for use in the relation L=KA to determine the length of vertical curve in meters required to provide headlight sight distance for the various design speeds. Values of K are given for both minimum and desirable sight distances. Whenever feasible, the desirable values should be used except on highways with fixed source lighting where the minimum values are ample for comfort and provide sufficient sight distance in case of a lighting failure. Figure 3—I provides for the graphical solution of the relation L=KA for sag vertical curves.

Special attention must be given to long type III vertical curves with K values of 44 or higher and where curbed sections are used because of the flat slopes near the bottom of the sag. The flow of storm waters in the gutter in such cases can be impeded by the flat grades and closer spacing of inlets is required to reduce ponding.

3—04.05 GENERAL CONTROLS FOR VERTICAL ALIGNMENT

In addition to the specific design elements for vertical alignment covered in the previous sections, the following general controls should be considered in design:

1. A smooth grade line with gradual changes, consistent with the terrain and type of highway, should be provided. Numerous breaks and short lengths of tangent should be avoided.

2. To the extent practicable, avoid "hidden-dip" or "roller-coaster" type of profile by using more gradual grades and by introducing some horizontal curvature on relatively straight sections.

3. A broken-back grade line (two vertical curves in the same direction separated by a short section of tangent grade) should be avoided, particularly in sag conditions. This type of grade line may be avoided by joining the vertical curves or replacing them with a single longer curve.

4. On long steep grades it is preferable to have the steepest grades at the bottom and to lighten the grades near the top, particularly on low design speed highways.

5. Where moderate to steep grades approach an intersection at grade, it is preferable to reduce the gradient through the intersection to the extent feasible, even at the expense of somewhat steepening the grade on the aproaches.

3—05 COORDINATION OF HORIZONTAL AND VERTICAL ALIGNMENT

Horizontal and vertical alignment complement each other and should be jointly considered from the initial location stage through the final design phase of a highway. The horizontal alignment and profile are among the most important permanent design elements and warrant a thorough study to insure that in proper combination they provide for the traffic to be served and the design speed selected the most in safety, utility and pleasing appearance at a reasonable cost.

To obtain a proper combination of horizontal and vertical alignment, consideration should be given to the following general controls:

1. Curvature and grades should be in proper balance. Steep grades with flat curvature or flat grade with excessive curvature should be avoided. A logical design is a compromise between these two conditions within the practical limitations of terrain and area traversed.

TABLE 3–9

DESIGN CONTROLS FOR SAG VERTICAL CURVES

(Based on headlight height of 0.61 M. with upward divergence of one degree)

Design Speed M.P.H.	K = Rate of vertical curvature, length in meters percent of A	
	Minimum	Desirable
20	6	6
25	8	8
30	11	11
35	14	15
40	17	20
50	24	32
60	33	47
70	45	66

2. Sharp horizontal curvature should not be introduced at or near the crest of a pronounced vertical curve. This can be avoided if the horizontal curvature leads the vertical curvature and is made somewhat longer than the latter.

3. Sharp horizontal curvature should not be introduced at or near the low point of a pronounced sag vertical curve.

4. Horizontal and vertical alignment should be as flat as feasible on the approaches to and at intersections.

5. On 2—lane highways it is necessary to provide adequate safe passing sections, generally on tangent, as frequently as possible. This requirement often supersedes the desirability for a combination of horizontal and vertical alignment.

6. On divided highways, variation in median width and the use of independent horizontal and vertical alignment for each one-way roadway should be considered where sufficient right-of-way at a reasonable cost is available. When such independent alignment is feasible, a superior design can generally be achieved without additional construction costs.

3–06 OTHER ELEMENTS

There are a number of other elements or features which affect or are affected by geometric design. Most of these, including drainage, structures, safety appurtenances, traffic control devices, pedestrian facilities, utilities, lighting, landscaping and environmental considerations are covered in detail in other chapters of this manual. Some others are discussed below.

3–06.01 TRANSITIONS – TWO LANES TO FOUR LANES

Transitions from two lanes to four lanes are used when sections of a two-lane highway are being upgraded by stages and when 4-lane sections are constructed on 2-lane roads to accomodate larger traffic volumes or to provide safe passing zones. The 4-lane sections may be undivided but are usually divided, particularly in rural areas, as it is the policy of the Department to use medians on multilane highways except on some urban principal and local streets.

The transition from two lanes to four and the reduction from four to two can be dangerous unless properly designed, marked and signed. The transitions should be located where the change in width and the introduction or elimination of a median is in full view of the driver. The minimum length of the transition reducing two one-way lanes to one shall be determined by the formula:

$$L=4V$$

where V is the design speed in mph and L in the length of the transition in meters. However, for rural highways and for all expressways the minimum transition length should be no less than 180 meters.

In urban areas it is sometimes not possible to provide the desired length of transition between four and two lanes. In such cases, the designer should strive to design a safe and adequate connection within the existing restrictive conditions.

3–06.02 DRIVEWAYS

The efficiency and safety of a highway without control of access depend to a great extent on the amount and character of roadside interference most of which originates in vehicle movements to and from adjacent businesses, farms, residences and other development along the highway. Access to Commonwealth highways is subject to control by the Secretary of Transportation and Public Works and any property owner desiring to construct a new access to an existing highway must request a permit from the Secretary. Regulations and standards governing the design and location of accesses have been published.

In the design of improvements or new construction of highways without control of access where access to abutting properties must be provided, the following policies shall be followed:

1. Only such accesses as the Department is legally required to construct will be included in the project.

2. The full width of right-of-way shall be maintained for public highway purposes.

3. The location and design of each access or driveway shall be in accordance with the regulation and standards published by the Secretary of Transportation and Public Works.

4. Adequate width and turning radii for the types of vehicles expected to use the driveway should be provided but large paved areas adjacent to the roadway will be avoided.

5. The portion of the driveway within the right-of-way should normally be paved to protect the roadway section.

6. Driveways should be avoided at locations where sight distance is restricted such as the top of crest vertical curves and on sharp horizontal curves.

7. On main highways in highly developed areas with concentrated business frontage, consideration should be given to reducing the number of individual direct connections to the through traffic lanes by providing a parallel frontage road to which the driveways connect. This will allow the concentration of all access traffic at each end of the frontage road section.

3–06.03 BUS AND "PUBLICO" TURNOUTS

Public transportation is served by buses and "publico" cars in both urban and rural areas. The design requirements for the movement of these vehicles are taken into consideration in the geometric standards and guides specified in this manual.

One problem peculiar to Puerto Rico is the local public transit service provided along many rural roads by "publico" cars and, to some extent, buses. These vehicles will stop to pick-up or

discharge passengers at almost any point where they are flagged by travellers. Such operations impede the smooth flow of traffic and where wide paved shoulders are not available the stops are made on the traveled way, a hazardous operation. In the planning of improvements to main rural highways without control of access, consideration should be given to providing bus and "publico" turnouts for passenger loading at locations where such service is expected. These turnouts should provide paved space outside the normal shoulder width with adequately designed exit from and entrance to the through lanes.

CHAPTER 4

INTERSECTIONS AT GRADE

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CHAPTER 4

INTERSECTIONS AT GRADE

4—01 GENERAL

An intersection is the location where two or more highways join or cross. Intersections are important elements of a highway since much of the efficiency, safety, speed, costs of operation and capacity are dependent upon their design. There are three general types of intersections: intersections at grade, grade separations without ramps, and interchanges.

This chapter covers intersections at grade which are those where the highways join or cross at a common elevation. It includes a discussion of certain intersection design elements, particularly those concerning the accommodation of turning movements, which are also applicable to interchanges.

4—02 TYPES OF INTERSECTIONS AT GRADE

General types of intersections at grade are the three-leg (T or Y), four leg, multi-leg, and rotary. The latter type is not normally used in Puerto Rico. Intersections are further classified as plain (unchannelized), flared, channelized and special designs which include directional channelization and "jug handles".

The primary factors to be considered in the selection of an intersection type for a particular location are the design hour volumes, the character or composition of traffic, and the design speed. The design hour volumes of relative turning and through movements are particularly significant in determining the type of intersection development. The composition of traffic and the design speed affect many of the details of the design after the intersection type has been selected.

A general guide for the selection of rural intersection types is given in Figure 4—A and for urban intersections in Figure 4—B. These are to be used as a guide only. Local conditions and right-of-way costs often influence the type of intersection selected and the design elements. In some instances, the alignment and grade of intersecting roads, the angle of intersection and the accident experience may make it advisable to channelize the intersection regardless of the traffic volumes involved. In urban areas the extent and type of channelization used is normally dependent upon obtaining the desired design capacity and satisfactory operating conditions.

4—03 CAPACITY AT INTERSECTIONS AT GRADE

1. UNSIGNALIZED INTERSECTIONS

For highways with intersections having low volumes of cross and turning traffic, not requiring traffic signal control, it may be assumed that flow is uninterrupted on the through highway and delays are acceptable on the cross roads. On such intersections capacity is affected little and the capacity values of Table 1—4, 1—5, 1—6 and 1—8 of Chapter 1 may be applied on the through highway.

However for higher volume combinations, signal control should be assumed in geometric design, even though signalization may not actually be used, to assure an adequate number of lanes and arrangement at the intersection. Table 4—1 provides a guide to help determine when signal control should be assumed in the design of rural intersections. If the DHV combination at a given intersection is approximately equal or less than that shown in Table 4—1, no intersection capacity analysis is considered necessary and an uninterrupted flow is assumed on the through highway.

HIGHWAY CLASS	RE-1	RE-2	RE-3	RE-4	R-5	R-6	R-7	R-8	R-9	R-10	R-11
RE-1	1	1	1	1	1	1	1	1	2	2	3
RE-2	1	1	1	1	1	1	1	1	2	2	3
RE-3	1	1	1	1 or 4	1 or 4	1 or 4	4	4	4 or 5	5	6
RE-4	1	1	1 or 4	1 or 4	4	4	4	4	4 or 5	5	6
R-5	1	1	1 or 4	4	4	4	4	4	4 or 5	5	5
R-6	1	1	1 or 4	4	4	4	4	4	4 or 5	5	5
R-7	1	1	4	4	4	4	4	4	4 or 5	5	5
R-8	1	1	4	4	4	4	4	4	5	5	5
R-9	2	2	4 or 5	4 or 5	4 or 5	4 or 5	4 or 5	5	5	5	5
R-10	2	2	5	5	5	5	5	5	5	5	5
R-11	3	3	6	6	5	5	5	5	5	5	5

HIGHWAY CLASS

LEGEND:

1 - INTERCHANGE

2 - GRADE SEPARATION

3 - CLOSE OR GRADE SEPARATION

4 - INTERSECTION AT GRADE-CHANNELIZED

5 - INTERSECTION AT GRADE - PLAIN

6 - CLOSE OR PLAIN AT GRADE

GUIDE FOR RURAL INTERSECTION TREATMENT

FIGURE 4-A

HIGHWAY CLASS	UE-1	UE-2	UE-3	UE-4	UE-5	U-6	U-7	U-8	U-9	U-10
UE-1	1	1	1	1	1	1	1	1	2	3
UE-2	1	1	1	1	1	1	1	1	2	3
UE-3	1	1	1	1	1	1	1	1	2	3
UE-4	1	1	1	1	1 or 4	1 or 4	4	4	5	6
UE-5	1	1	1	1 or 4	1 or 4	1 or 4	4	4	5	6
U-6	1	1	1	1 or 4	1 or 4	4	4	4	5	5
U-7	1	1	1	4	4	4	4	4	5	5
U-8	1	1	1	4	4	4	4	4 or 5	5	5
U-9	2	2	2	5	5	5	5	5	5	5
U-10	3	3	3	6	6	5	5	5	5	5

LEGEND:

1 - INTERCHANGE

2 - GRADE SEPARATION

3 - CLOSE OR GRADE SEPARATION

4 - INTERSECTION AT GRADE - CHANNELIZED

5 - INTERSECTION AT GRADE - PLAIN

6 - CLOSE OR PLAIN AT GRADE

GUIDE FOR URBAN INTERSECTION TREATMENT

FIGURE 4-B

However, if the DHV combination is greater than that shown in Table 4—1, the intersection should be designed as if it were under signal control including an intersection capacity analysis. It should be noted that the values in Table 4—1 have no direct relation to warrants for signalization. Warrants for signalization are included in the Manual on Uniform Traffic Control Devices for Streets and Highways. For those intersections that are expected to be signalized during its design life, an overall capacity analysis shall be made as shown on Chart 4—1, and Chart 4—2.

TABLE 4—1

SUGGESTED DESIGN HOUR VOLUME COMBINATIONS FOR WHICH SIGNAL CONTROL SHOULD BE ASSUMED IN GEOMETRIC DESIGN OF RURAL INTERSECTIONS*

	Minimum DHV, two-way on:		
2—lane through highway	400	500	650
Crossroad	250	200	100
4—lane through highway	1000	1500	2000
Crossroad	100	50	25

* These volumes have no relation to warrants for signalization, nor are they indicative of whether or not signalization should be used after the intersection if opened to traffic.

2. SIGNALIZED INTERSECTIONS

Design capacities of signalized intersections are subject to a large number of variables including type of highway, pavement width, short term fluctuations in flow, proportions of trucks and buses, turning movements, type of operation (one-way or two-way), parking conditions, signal timing, etc. To the extent that these variables can be predicted for the design year, design capacities may be estimated by procedures given in Chapter 6 of the Highway Capacity Manual. Peak hours factors (PHF) in the range of 0.80 to 0.90 and a load factor (LF) of 0.3 (level of Service C) should be used in these analysis unless other specific values are provided to the designer with the traffic data.

The charts published in the August 1967 and October 1967 issues of "Public Roads", the FHWA journal, greatly simplify the intersection capacity analysis. These charts were subsequently reprinted in a single issue by the FHWA as a research and development report entitled "Capacity Analysis Techniques for Design of Signalized Intersections".

In design, the capacity of a signalized intersection is determined separately for the approach direction of travel on each intersection leg. Usually the predominant one-way approach movement on one highway and the predominant one-way approach movement on the intersecting highway which occur during the design hour, jointly control the capacity and design of the intersection.

A traffic lane at an intersection under signal control is available for moving vehicles only part of the time and its capacity per hour is less than on the portions of the highway where flow is uninterrupted. Design capacity per lane at signalized intersections is generally in the range of 400 to 700 vph, depending on the amount of green time provided and other conditions. Since

the lane capacity for uninterrupted flow on multilane highways is between 500 and 1200 vph (See Table 1—8), it is apparent that additional lanes at the intersection are required to bring the capacity through the signalized intersection up to that of the highway elsewhere. Additional lanes may be required even when the design traffic volume on the highway is substantially below the uninterrupted flow capacity of that highway.

On 2-lane two-way highways in rural areas the design capacity frequently is less than 600 vph (both directions of travel) and such volumes can very often be handled at signalized intersections without additional lanes. Added lanes may be needed when the distribution of total hourly traffic is more than two-thirds in the predominant direction, where turning movements are above normal, or where a large portion of the signal cycle must be devoted to the movement of traffic on the crossroad. The added lanes should be continued for some distance beyond the intersection to permit traffic to merge into the normal through lanes after clearing the intersection. The design of adequate storage for separate right-and left-turn lanes at signalized intersections shall be made accordingly to Chart 4—3.

4—04 ALIGNMENT AND PROFILES AT INTERSECTIONS

Intersections are points of conflict and potential hazard. The alignment and grade of the intersecting roads should permits drivers to readily make the maneuvers necessary to pass through the intersection with safety and with a minimum of interference between vehicles.

Approach alignment to intersections should be as straight as possible and the angle of crossing as near to 90 degrees as practical. The realignment of one or both of the intersecting roads should be considered whenever the angles of intersection is less than 60 degrees if site conditions permit it. Intersecting angles above 60 degrees produce only a small reduction in visibility and often do not warrant realignment.

Figure 4—C shows several realignment variations. The curves introduced for realignment purposes should permit safe operation at speeds not much below those on the aproaches of the highway, otherwise they may prove to be as great a hazard as the acute angle crossing itself. Samples —3— and —4— of Figure 4—C result in offset intersections and should only be used on low volume intersections because these variations require a crossing vehicle from the minor road to travel some distance along the major road and to execute a left turn either when entering or when leaving the major road.

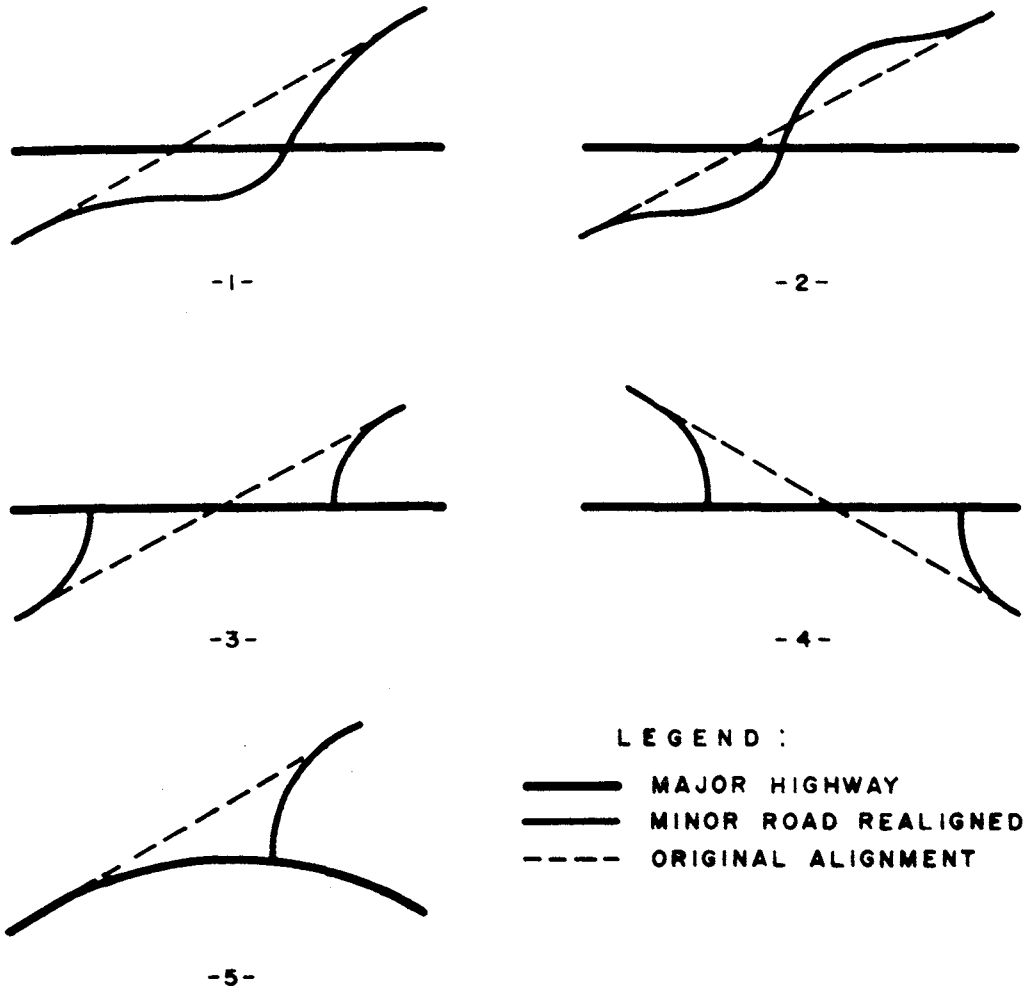
Combinations of grade lines that make vehicle control difficult should be avoided at intersections. Grades on the intersection legs used by stopped vehicles should be as flat as feasible. Approach grades should not exceed 6 percent and desirably should be less than 3 percent. Normally, the grade line of the major highway should be carried through the intersection as a smoth profile and that of the cross road adjusted to it. When the two intersecting highways are of approximately equal importance, the grades should be adjusted for a distance back from the intersection to obtain smooth profiles for each through the intersection, particularly if the crossing is signalized.

4—5 INTERSECTION DESIGN ELEMENTS

Certain intersection design elements, primarily those concerning the accommodation of turning movements, are common to and applicable to both intersections at grade and interchanges. These elements are included in the following sections of this chapter although interchanges are covered in Chapter 5.

4—05.01 DESIGN VEHICLES

The basic dimensions of the six design vehicles considered in Puerto Rico for control of geometric design are given in Table 1—1 of Chapter 1. The minimum turning radius of these design vehicles are given in Table 4—2.



REALIGNMENT VARIATIONS AT INTERSECTIONS

FIGURE 4-C

The minimum turning paths of the design vehicles are illustrated in Figures 4—D throught 4—H. These figures should be used as a guide in determining the turning radii at intersections and the width of turning roadways. The principal dimensions affecting design are the minimum turning radius and those affecting the path of the inner rear tire, tread width and wheel base.

TABLE 4—2

MINIMUM TURNING RADIUS OF DESIGN VEHICLES					
Design Vehicle Type	Symbol	Min. Turing Radius		Min. Inside Radius	
		Feet	Meters	Feet	Meters
Passenger Car	P	24	7.3	15.3	4.66
Single Unit Truck	SU	42	12.8	28.4	8.66
Single Unit Bus	BUS	42	12.8	23.2	7.12
Semitrailer-Intermediate	WB-40	40	12.2	19.9	6.07
Semitrailer-Large	WB-50	45	13.7	19.8	6.04
Semitrailer-Fulltrailer	WB-60	45	13.7	22.5	6.90

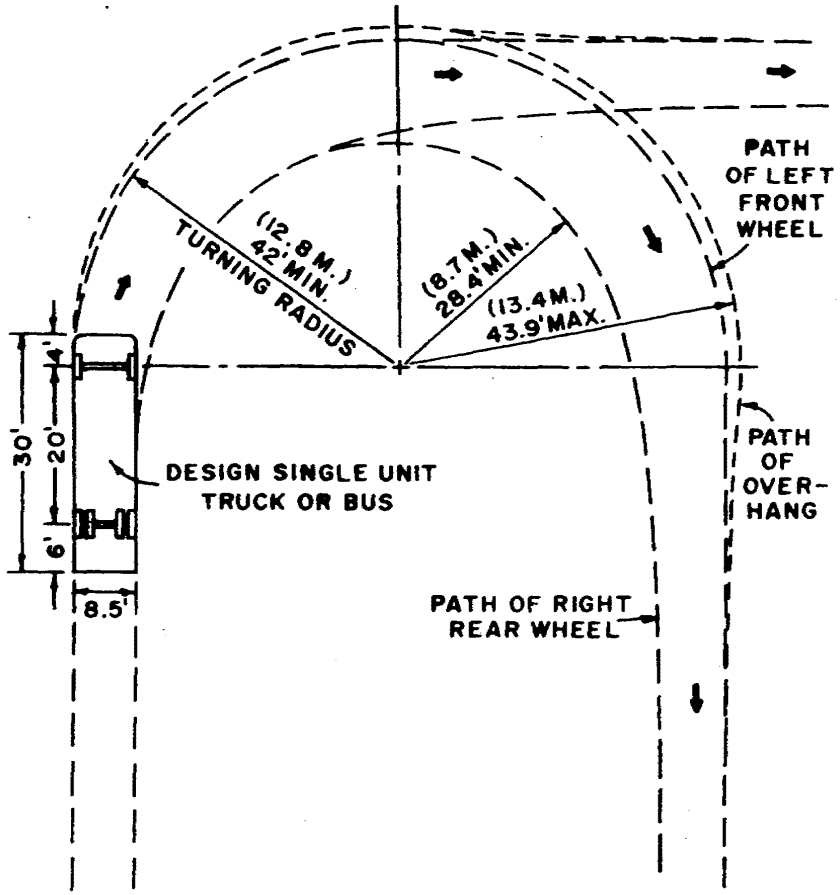
4—05.02 MINIMUM EDGE OF PAVEMENT DESIGN FOR TURNS

Where it is necessary to provide for turning vehicles within minimum space and slow speeds (less than 10 mph), as at unchannelized intersections, the minimum turning paths of the design vehicles apply.

For most simple intersections with angle of turn of 90° or less, a single circular arc joining the tangent edges of pavement provides and adequate design. However, where provision must be made for the larger truck units or when the angle of turn exceeds 90°, a single circular arc would require a much larger radius and a 3-centered compound curve should be used.

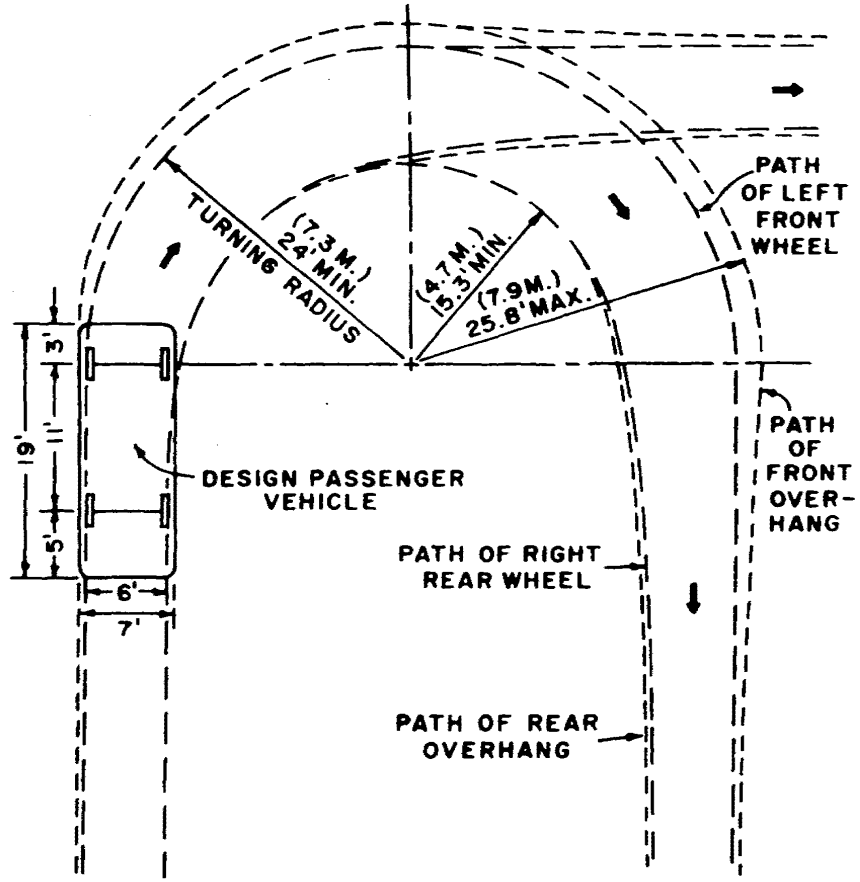
Recommended minimum edge of pavement designs for turns at intersections without corner islands are given in Table 4—3. These are based on the characteristics of the various design vehicles, low turning speeds (less than 10 mph), and no encroachment of adjacent lanes. The application of 3-centered compund curve is illustrated in Figure 4—I.

Table 4—3 covers angles of turn from 30° throught 180° (U-Turn). It should be noted that angles of turn in excess of 120° are considered substandard and are to be avoided whenever possible through realignment of the intersection legs. For 3-centered compound curves, values are given only of the preferred symmetric design. Values for asymmetric design for 3-centered compound curves may be found in the AASHTO rural and urban design policies.



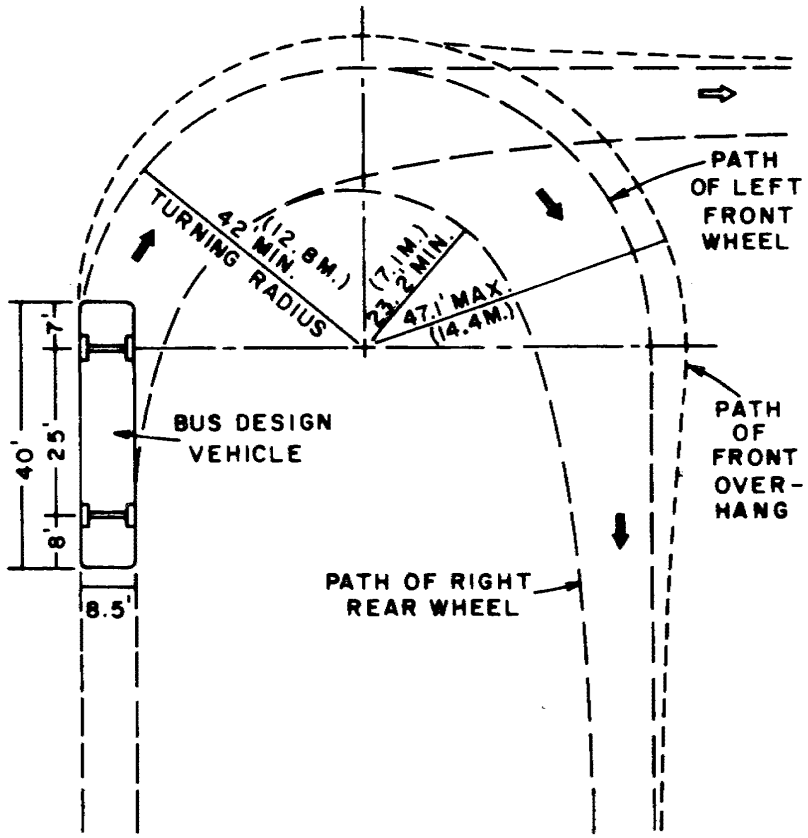
MINIMUM TURNING PATH FOR SU DESIGN VEHICLE

FIGURE 4-E



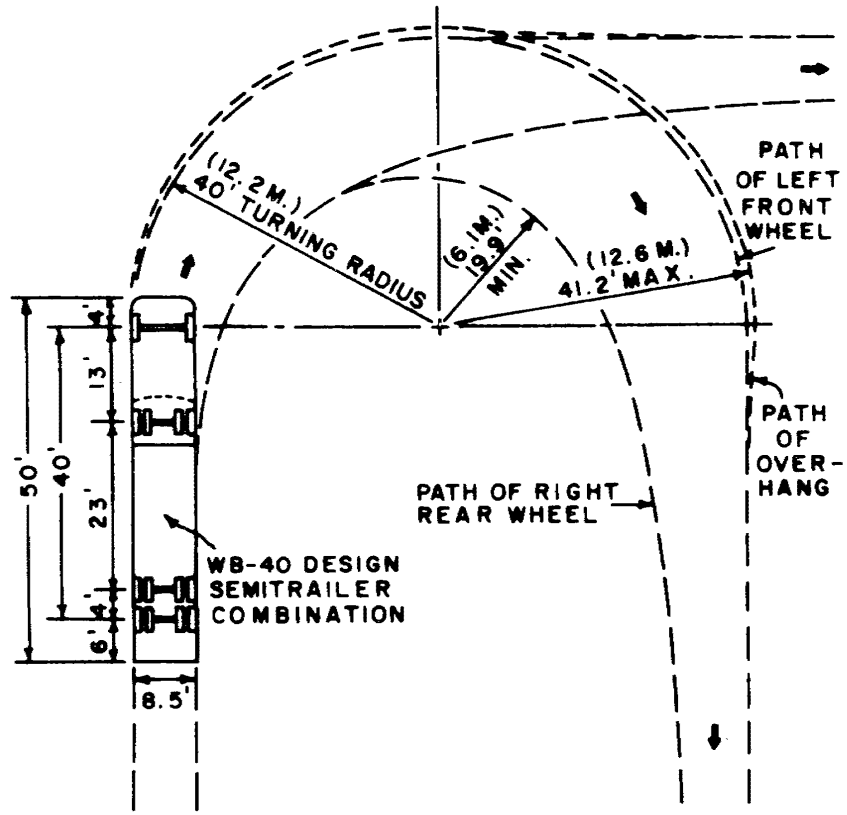
MINIMUM TURNING PATH FOR P DESIGN VEHICLE

FIGURE 4-D



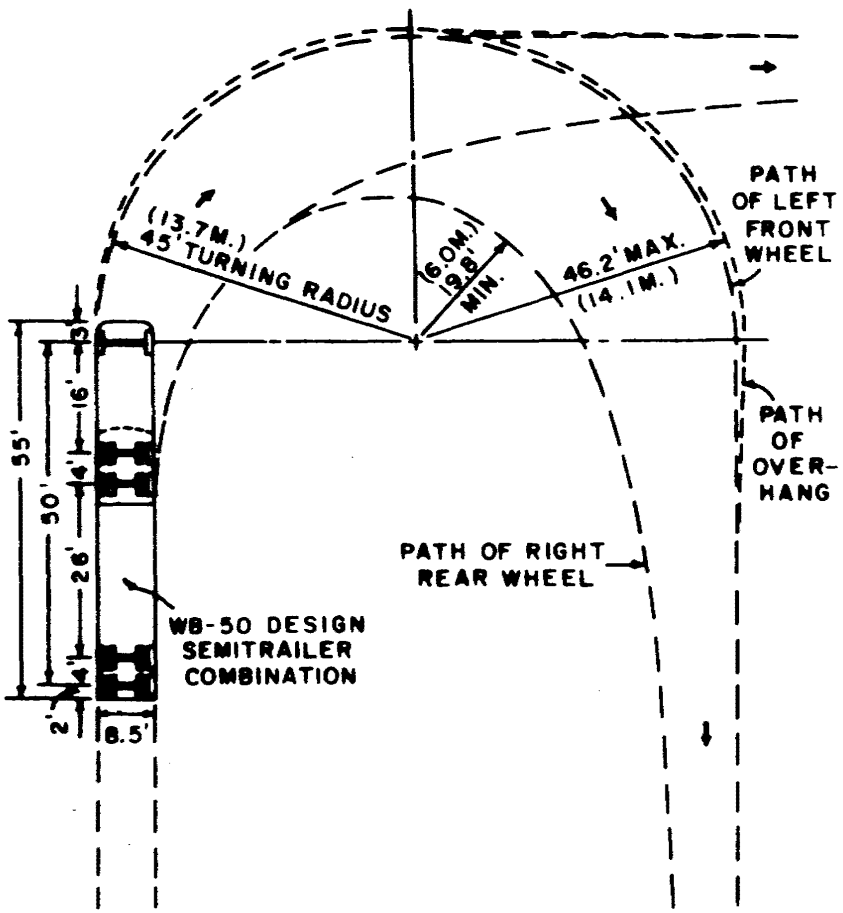
MINIMUM TURNING PATH FOR BUS DESIGN VEHICLE

FIGURE 4-F



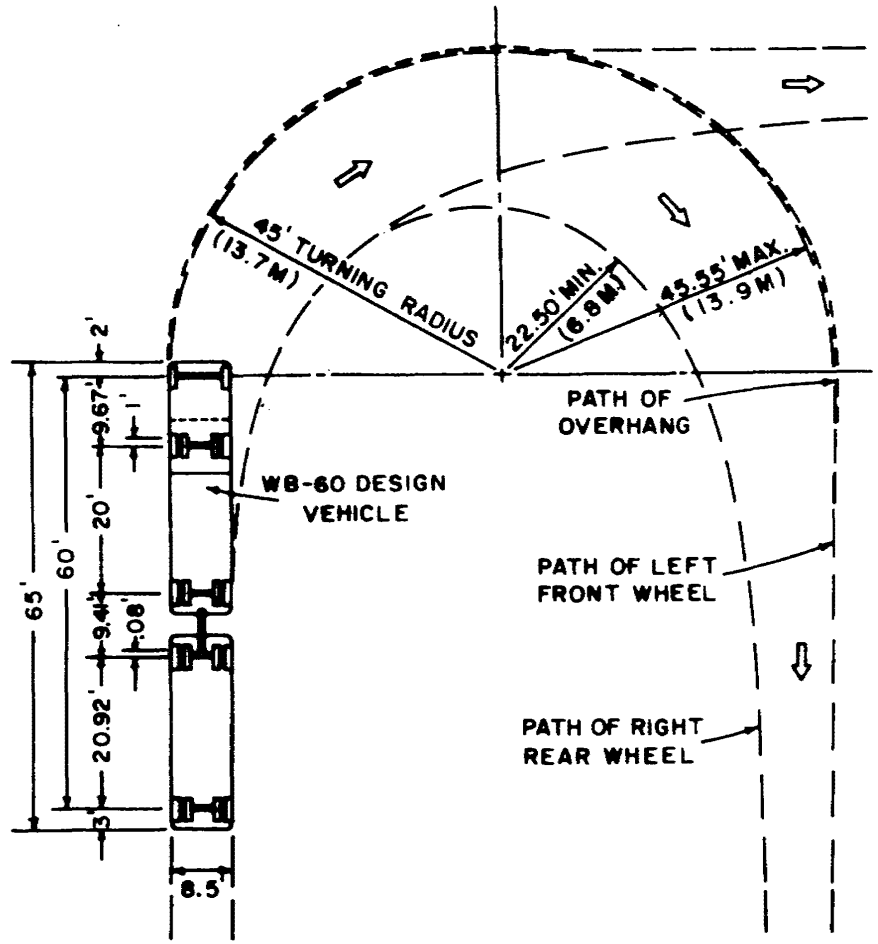
MINIMUM TURNING PATH FOR WB-40 DESIGN VEHICLE

FIGURE 4-G



MINIMUM TURNING PATH FOR WB-50 DESIGN VEHICLE

FIGURE 4 - H



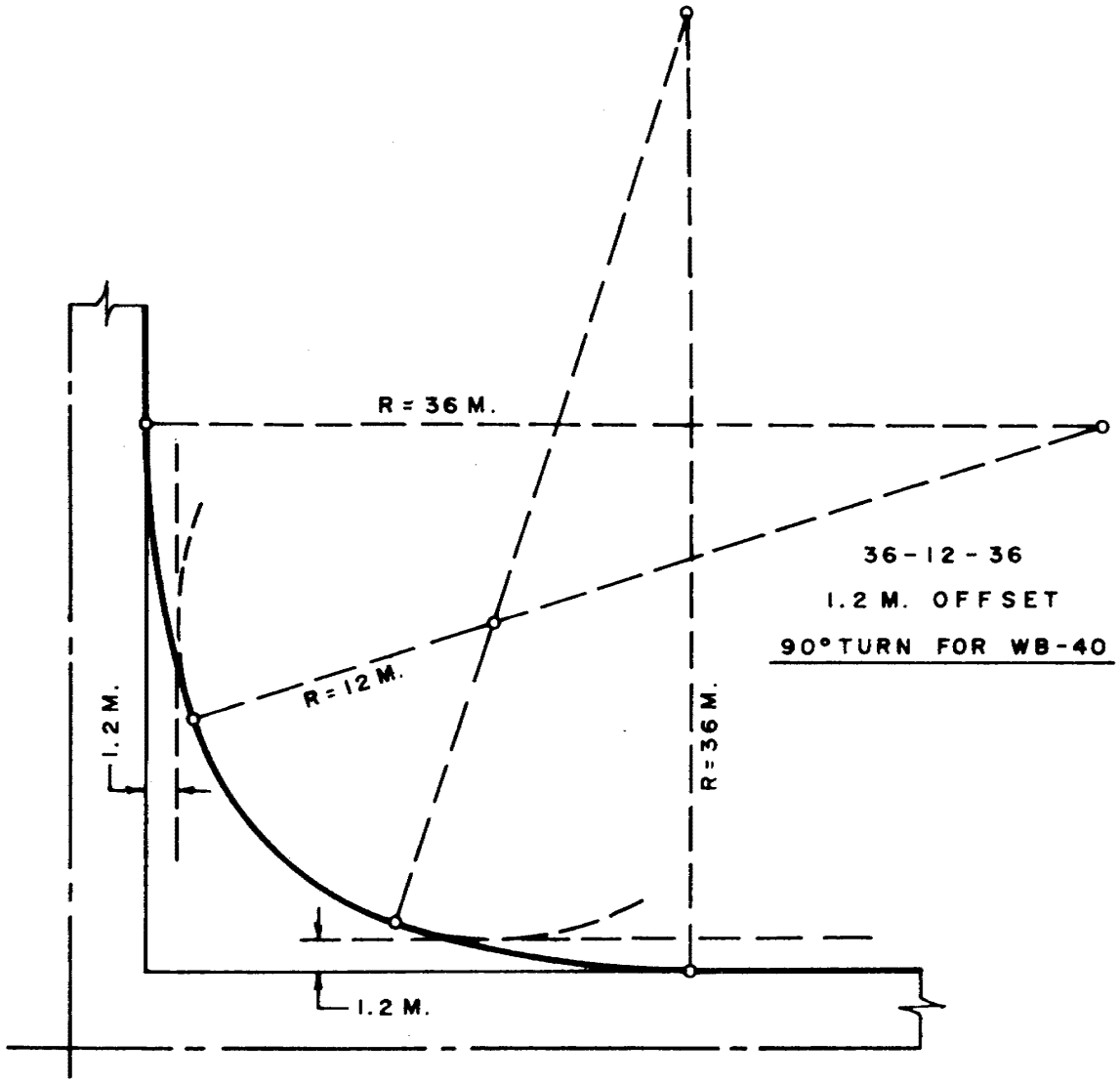
MINIMUM TURNING PATH FOR WB-60 DESIGN VEHICLE

FIGURE 4-H-1

TABLE 4–3

MINIMUM EDGE OF PAVEMENT DESIGNS FOR TURNS AT INTERSECTIONS* (WITHOUT CORNER ISLAND, SPEEDS LESS THAN 10 MPH)							
Design Vehicle	Angle of Turn Degrees	Simple Curve Radius (Meters)	3-Centered Compund Curve		Angle of Turn Degrees	3-Centered Compund Curve	
			Radii (Meters)	Offset (Meters)		Radii (Meters)	Offset (Meters)
P	30	18	—	—	105	30— 6—30	0.8
SU		30	—	—		30—11—30	0.9
BUS		42	—	—		30—11—30	1.2
WB—40		45	—	—		30—11—30	1.5
WB—50		60	—	—		54—14—54	2.4
P	45	15	—	—	120	30— 6—30	0.6
SU		23	—	—		30— 9—30	0.9
BUS		24	—	—		30— 9—30	1.2
WB—40		36	—	—		36— 9—36	1.8
WB—50		52	60—30—60	0.9		54—12—54	2.6
P	60	12	—	—	135**	30— 6—30	0.5
SU		18	—	—		30— 9—30	1.2
BUS		21	—	—		30— 9—30	1.5
WB—40		27	—	—		36— 9—36	2.0
WB—50		—	60—23—60	1.7		48—11—48	2.1
P	75	11	30— 8—30	0.6	150**	23— 5—23	0.6
SU		17	36—14—36	0.6		30— 9—30	1.2
BUS		24	36—14—36	0.9		30— 9—30	1.5
WB—40		26	36—14—36	1.5		30— 9—30	1.8
WB—50		—	45—15—45	1.8		48—11—48	2.1
P	90	9	30— 6—30	0.8	180	15— 5—15	0.2
SU		15	36—12—36	0.6	U-Turn	30— 9—30	0.5
BUS		26	36—12—36	1.2		40— 8—40	2.4
WB—40		—	36—12—36	1.5		30— 6—30	2.9
WB—50		—	54—18—54	1.8		40— 8—40	2.9

* With no encroachment on adjacent lanes.
** Angle of turn substandar.



EXAMPLE OF 3-CENTERED COMPOUND CURVE
FOR MINIMUM EDGE OF PAVEMENT DESIGN FOR TURNS

FIGURE 4-I

Straight tapered wedges may be substituted for the longer radius portions of 3-centered compound curves. The taper should be about 15 to 1.

To design an intersection for the largest vehicle expected to be encountered can sometimes be very uneconomical. Where large truck may be encountered only occasionally, encroachment onto other traffic lanes may be permitted. If the designer determines that the use of a design vehicle less than the maximum is desirable, he should analyze the likely paths and encroachments that will result when a turn is made by vehicles larger than those for which the intersection design is made. This analysis is necessary to determine if the larger trucks can satisfactorily maneuver the turn while remaining on the pavement surface.

1. RURAL

In general, the following minimum edge of pavement designs for turns may be considered in rural areas:

P — for intersections of local roads and at intersections of local roads with minor collector highways.

SU — The minimum for minor arterial and collector highway intersections of low to moderate volumes. However, if percentage of turning trucks is appreciable use in conjunction with speed change lanes.

WB—40 and WB—50 — use at intersections of all major arterial and collector highways handling appreciable numbers of these units.

2. URBAN

Corner radii at intersections on urban streets should satisfy the requirements of the vehicles using them to the extent practical in consideration of right-of-way available, angle of intersection, pedestrians, width and number of lanes on the intersecting streets, and speed reductions. The designer should consider the following general guides:

a. Radii of 12 meters or more, and preferably 3-centered compound curves or simple curves with tapers, should be provided where buses and large truck combinations turn frequently. The Department of Transportation and Public Works requires a minimum radius of 15 meters on arterial and collector highway intersections.

b. Radii of 7.5 meters or more should be provided, where space permits it, at the intersections of arterial and collector streets with minor local streets where little truck or bus turning movements are expected. The DTPW requires a minimum radius of 6 meters at intersections of local streets with collector streets.

c. At intersections of local residential streets with little truck traffic, radii of 4.5 to 7.5 meters which are adequate for passenger vehicles, may be used.

d. Radii dimensions should be coordinated with cross walk distances on special designs to make cross-walks safer for pedestrians.

4—05.03 MINIMUM TURNING ROADWAYS WITH CORNER ISLAND

A turning roadway is a connecting roadway between two intersection legs. They vary from a simple right-turn lane with a small channelizing island at an intersection at grade to ramps at interchanges. The latter are discussed in Chapter 5.

Turning roadways at intersection at grades are used where it is necessary to accommodate large trucks or buses without encroaching on adjacent lanes, to permit passenger vehicles to turn at speeds of 15 mph or more, at skewed intersections, and at important intersections or ramp terminals. Turning roadways facilitate traffic control through separation of the various

movements, shorten travel paths, reduce pavement areas within the intersection, and provide islands which serve as pedestrian refuge areas.

The principal control for the design of turning roadways is the alignment of the inner edge of pavement and the width of the roadway channel to accommodate the design vehicle. Minimum design values for turning roadways with corner islands are given in Table 4—4. To reduce the intersection area, the use of 3-centered compound curves rather than the single circular arc is recommended but simple offset curves with straight tapers may also be used. An example of the use of turning roadway with corner island is shown in Figure 4—J.

TABLE 4—4

MINIMUM EDGE OF PAVEMENT DESIGNS FOR TURNING ROADWAYS WITH CORNER ISLAND

Angle of Turn Degrees	Design Classification (Note 1)	3-Centered Compund Curve (Note 2)		Width of Lane (Meters)	Approx. Size of Island (sq. meters)
		Radii (Meters)	Offset (Meters)		
75	A	45—23—45	1.1	4.3	5.6
	B	45—23—45	1.5	5.5	4.6
	C	54—27—54	1.1	6.1	4.6
90	A	45—15—45	0.9	4.3	4.6
	B	45—15—45	1.5	5.5	7.4
	C	54—20—54	1.8	6.1	11.6
105	A	36—12—36	0.6	4.6	6.5
	B	30—16—30	1.5	6.7	4.6
	C	54—14—54	2.4	9.1	5.6
120	A	30— 9—30	0.8	4.9	11.1
	B	30— 9—30	1.5	7.3	8.4
	C	54—12—54	2.6	10.4	20.4
135	A	30— 9—30	0.8	4.9	42.7
(Note 3)	B	30— 9—30	1.2	7.9	34.4
	C	48—11—48	2.1	10.7	59.5
150	A	30— 9—30	0.8	4.9	130.1
	B	30— 9—30	1.2	9.1	108.7
(Note 3)	C	48—11—48	2.1	11.6	159.8

Note 1 — A — Primarily passenger vehicles; permits occasional single-unit truck to turn with restricted clearances.
B — Adequate for SU; permits occasional Bus and WB—50 to turn with slight encroachment on adjacent lanes.
C — Adequate for all design vehicles.

Note 2 — Asymmetric 3—centered compound curves and straight tapers with simple curves may also be used without significantly altering the pavement width or the corner island size.

Note 3 — Angle of turn substandard.

Table 4—4 shows the approximate size of the corner island that would result for each design case. The smallest size of corner island that should be considered is one with an area of approximately 4.6 square meters but a minimum size of about 7 square meters is preferable. For a triangular island the minimum side dimension should be 2.5 meters and preferably 3.7 meters.

4—05.04 SPEED-CURVATURE RELATIONS ON TURNING ROADWAYS

The minimum design values for intersection turn given in Tables 4—3 and 4—4 provide for low speed turning movements. At major intersections at grade in rural highways and at interchanges, separate roadways and ramps that allow higher turning speeds are normally provided. Table 4—5 shows the minimum pavement edge radii for turning roadways for various design speeds.

TABLE 4—5

MINIMUM RADII FOR PAVEMENT EDGE BASED ON DESIGN SPEED						
Design turning speed, mph	15	20	25	30	35	40
Minimum Radius — Meters	15	27	45	70	100	150
Minimum Superelevation (e)	.02	.03	.04	.06	.06	.06

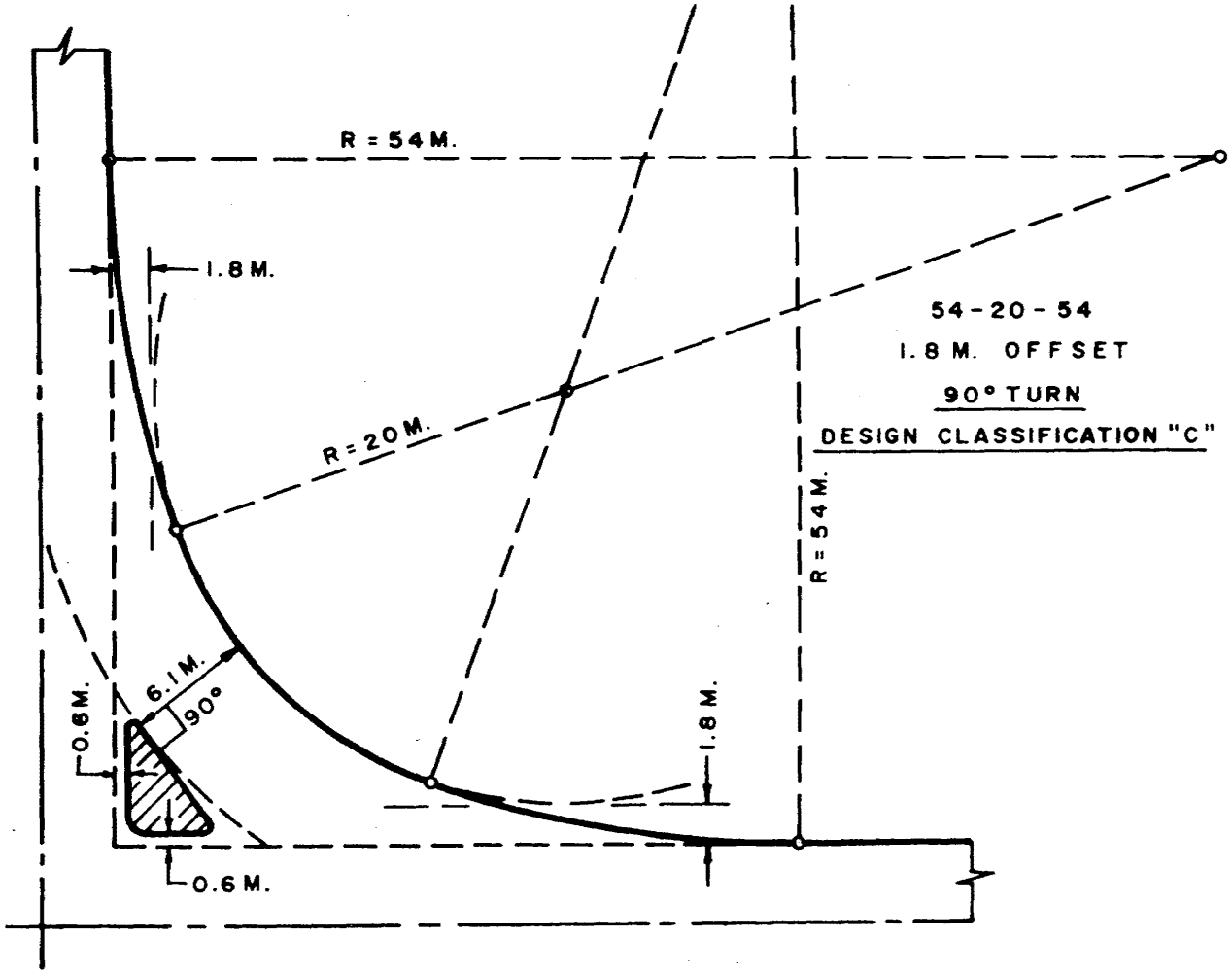
It should be noted that because of the higher side friction factors accepted for turning movements, the minimum allowable design radii in Table 4—5 are somewhat shorter than those specified in Table 3—2 for open highway conditions up to speeds of 25 mph.

Compound circular curves are advantageous in effecting desirable shapes of turning roadways at intersections at grade and of ramps at interchanges, particularly "loop" ramps. The radius of the flatter arc should be no greater than twice the radius of the sharper arc; however, wherever feasible a lesser difference should be used.

In a series of curves of decreasing radii, each curve should be long enough to enable the driver to decelerate at a reasonable rate. Minimum and desirable lengths are shown in Table 4—6.

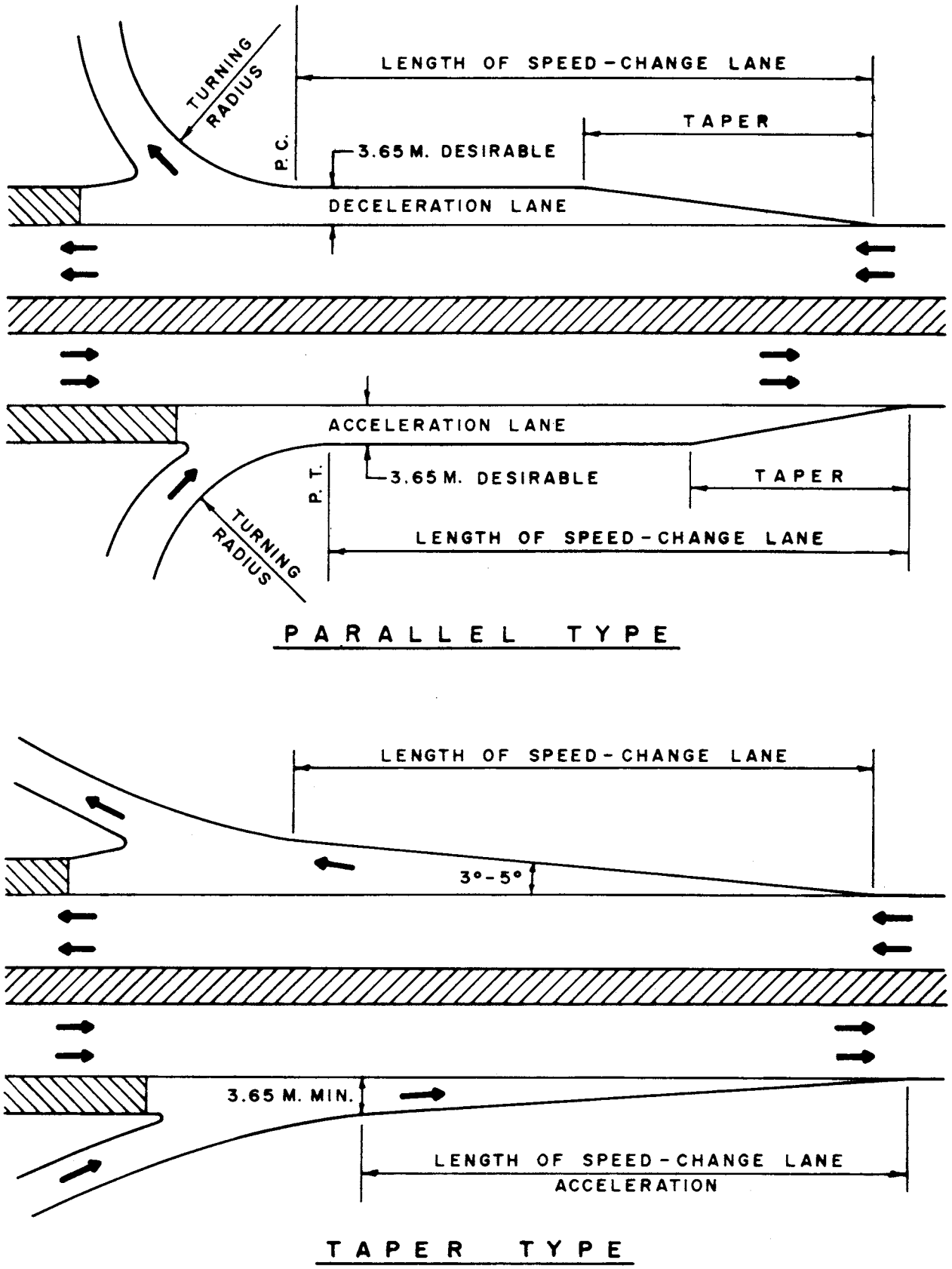
TABLE 4—6

LENGTHS OF CIRCULAR ARC FOR A COMPOUND CURVE ON TURNING ROADWAY WHEN FOLLOWED BY A CURVE OF ONE-HALF RADIUS OR PRECEDED BY A CURVE OF DOUBLE RADIUS							
Radius, meters	30	45	60	75	90	120	150
Length of arc, meters							
Minimum	12	15	18	24	30	36	42
Desirable	18	21	27	36	42	54	60



EXAMPLE OF MINIMUM TURNING ROADWAY WITH CORNER ISLAND

FIGURE 4-J



SPEED - CHANGE LANES

FIGURE 4-K

4—05.05 WIDTH OF TURNING ROADWAYS

Pavement roadway widths for turning roadways that provide for above minimum speeds are governed by the type of operation, curvature, and volume and type of traffic. Pavement width for turning roadways are covered in Section 2—05 and Table 2—2 of Chapter 2.

4—05.06 SPEED-CHANGE LANES

A speed-change lane is an auxiliary lane, including tapered areas, primarily for the acceleration and deceleration of vehicles entering or leaving the through traffic lanes on main highways. The term speed-change lane, acceleration lane, or deceleration lane applies broadly to the added pavement joining the traveled way of the highway with that of the turning roadway, and does not necessarily imply a definite lane of uniform width.

Speed-change lanes are designed in two general forms, the parallel type and the taper type, as illustrated in Figure 4—K.

Acceleration and deceleration lanes should be provided at important intersections on high speed, high volume rural highways. They should also be used at minor intersections on such highways if the absence of speed-change lanes will result in undue forced speed reduction on a significant amount of through traffic.

On urban highways, the use of speed change lanes is normally limited to freeway interchanges and to major intersections at grade on expressways.

When speed and traffic conditions permit, the directional type of speed change lane consisting of a long taper is normally preferred. However, when vehicle storage space is required for high volumes of turning traffic, as at some urban intersections, the parallel type deceleration lane is advantageous. When parallel lanes are used as speed change lanes, they should be at least 3 meters and preferably 3.65 meters in width. The full highway shoulder is not necessary adjacent to speed change lanes.

Ramp terminals, which include speed change lanes, are discussed in Chapter 5 on Interchanges.

1. DECELERATION LANES

Deceleration lanes should be designed to provide a clear indication to the driver of the point of departure from the through lanes.

A tapered deceleration lane, departing from the through lane at a divergence angle between 3 and 5 degrees, provides a direct path to the intersecting ramp or roadway and is the preferred type on freeways and major rural intersections at grade when the turning roadway permits exit speeds of 35 mph or better. However, a parallel lane type with taper is normally needed where:

a. There are exceptionally heavy turning movements.
b. There is a large number of trucks in the turning movement.
c. The design speed of the exit ramp of roadway is such that it requires that additional decelaration length be provided.

Care must be exercised in designing deceleration lanes where the main highway is on a curved section to insure that the driver may clearly differentiate between the through highway and the turning roadway. Prominent signing, lane marking and, if possible, contrasting pavement are essential in such cases.

The recommended minimum design lengths of deceleration lanes on flat grades (2% or less) for various combinations of speeds of main highway and turning roadway are given in Table 4—7. Adjustment factors for steeper grades are given in Table 4—8. The method of measurement is illustrated in Figure 4—K. In Table 4—7 the values in the third column show the lengths

necessary for deceleration to a stop. This condition may occur at any major-minor intersection where the turning traffic is regulated to a stop before entering or crossing a through highway. It may also apply at intersections under traffic signal control and on median left turn lanes.

2. ACCELERATION LANES

It is desirable that vehicles from an acceleration lane enter the through lane at a speed no slower than 5 mph less than the average running speed on the through lane. The recommended minimum design length for acceleration lanes determined on this basis are given in Table 4—7 for relatively flat grades (2% or less) for various combinations of speed of main highway and approach roadway. Adjustment factors for steeper grades are given in Table 4—8. The method of measurement is illustrated in Figure 4—K.

The taper type acceleration lane is the preferable design on freeways provided the geometrics of the approach roadway permit the entering vehicle to attain the merging speed by the time it reaches the point where the right edge of the acceleration lane is 3.65 meters from the right edge of the through lane of the freeway. The design should then provide a uniform taper of about 50:1 (longitudinal to lateral) between the outer edge of the acceleration lane and the edge of the through traffic lane.

TABLE 4-7

DESIGN LENGTHS OF SPEED-CHANGE LANES
Flat Grades — Percent or Less

Design speed of turning roadway curve, mph		Stop condition	15	20	25	30	35	40	45	50
Minimum curve radius, meters			15	27	45	70	100	150	200	250
Design speed of highway, mph	Length of taper, meters	Total length of DECELERATION LANE, including taper, meters: All main highways								
40	60	100	90	85	75	60	—	—	—	—
50	70	130	120	115	105	100	85	—	—	—
60	80	150	150	145	135	130	120	100	90	—
70	90	180	175	170	165	160	150	130	120	105
Design speed of highway, mph	Length of tapers, meters	Total length of ACCELERATION LANE, including taper, meters:								
40	60	—	100	75	70	—	—	—	—	—
50	70	—	210	190	180	150	120	—	—	—
60	80	—	340	330	300	270	240	180	120	—
70	90	—	470	450	420	400	370	300	250	175

TABLE 4-8

RATIO OF LENGTH OF SPEED-CHANGE LANE ON GRADE TO LENGTH ON LEVEL								
DECELERATION LANE			ACCELERATION LANE					
Design Speed of Highway mph	Ratios		Design Speed of Highway mph	Design Speed of Turning Roadway, mph				
All	3-4 % upgrade 0.9	3-4% downgrade 1.2		20	30	40	50	All speeds
All	5-6% upgrade 0.8	5-6% downgrade 1.35		Ratios 3-4% upgrade				Ratios 3-4% down-grade
Ratios in this table multiplied by the values in Table 4-7 give the length of speed-change lane for the respective grade.			40	1.3	1.3	—	—	0.7
			50	1.3	1.4	1.4	—	0.65
			60	1.4	1.5	1.5	1.6	0.6
			70	1.5	1.6	1.7	1.8	0.6
				5-6% upgrade				5-6% down-grade
			40	1.5	1.5	—	—	0.6
			50	1.5	1.7	1.9	—	0.55
			60	1.7	1.9	2.2	2.5	0.5
			70	2.0	2.2	2.6	3.0	0.5

The parallel type acceleration lane is normally used when the speed on the approach roadway or ramp is substantially slower than on the through lane of the main highway and an additional length of full lane width is needed to allow the entering vehicle to attain the desired merging speed.

At intersections of high volume main rural roads, long acceleration lanes are desirable to enable entering vehicles to merge with the through traffic without being required to stop or reduce speeds unduly. The designer should determine if acceleration lane length greater than the minimum should be provided to satisfactorily merge the traffic. The merging length is that portion where the acceleration lane is contiguous to the through traffic lane and, depending on the design, it may be nearly all or only a small part of the length of the acceleration lane. The combined volume on the through lane and a single lane joining ramp (acceleration lane) that merge cannot exceed 1000 to 1200 equivalent passenger cars per hour at stop and go speeds, or about 1500 such vehicles if the design is such that speeds of 35 mph or more can be maintained by the merging vehicles. If merging speeds of 35 to 40 mph are to be maintained, the condition is nearly the same as that of a weaving section and a merging length of 90 to 180 meters is necessary. With a shorter merging length it may be possible to accomplish the merging of comparatively high volumes but the merging speeds will be lower.

Generally, right turn acceleration lanes are not necessary where right turn volumes are low and the roadway being entered has an average running speed under 40 mph. Also, an acceleration lane should not be used in conjunction with traffic signal or STOP sign control at the intersection.

Acceleration lanes are seldom used on urban arterials other than freeways. However, at intersections with no signal control, it may be desirable to provide acceleration lanes where

separate channelized roadways are provided for vehicles turning right into an arterial from a cross street.

4—05.07 SIGHT DISTANCE-TURNING ROADWAYS

Sight distance along a turning roadway or ramp should be at least equal to the minimum safe stopping distance. Sight distance for passing is not required. The minimum stopping sight distance that must be provided by both the vertical and horizontal alignment are the same as those required for open highway conditions which are given in Table 3—1 for design speeds of 20 mph and higher. For a design speed of 15 mph the required minimum stopping sight distance is 25 meters.

The minimum length of vertical curves for turning roadways are the same as those given in Section 3—04.04 of Chapter 3 for open highway conditions. The "K" values for crest and sag vertical curves given in Tables 3—7 and 3—8 for design speeds of 20 mph and higher should be used to compute the required length of vertical curves. For a design speed of 15 mph, a "K" value of 2 should be used for crest vertical curves. In all cases the minimum length of vertical curve in meters should be no less than the value of the design speed in miles per hour.

The sight line along the inner part of horizontal curves should be checked on a plan layout to insure that lateral obstructions (cut slopes, walls, piers, other structures, etc.) do not restrict the sight distance to below the required minimum.

4—05.08 SIGHT DISTANCE – STOP CONDITION

As a minimum, adequate stopping sight distance must be provided on each aproach to an intersection at grade.

In practically all cases where a minor road intersects a major highway at grade, either STOP or signal control is provided. At such intersections it is necessary that the vehicle driver on the minor road have sufficient sight distance along the major highway to allow crossing from a stopped position before a vehicle on the major highway, coming into view after he has started, reaches the intersection. The required sight triangle is illustrated in Figure 4—L.

The length of the major road open to view must be greater than the product of its design speed and the time necessary for the stopped vehicle to start and cross the road. The required sight distance along the major highway can be computed by the following equation:

$$d = 0.45V\ (J + ta)$$

when d = minimum sight distance along the major highway in meters.
V = design speed of major highway (mph).
J = driver reaction time, use 2 seconds.
ta = time in seconds required to accelerate and traverse the distance S to clear the major highway pavement.

The travel distance S = D + W + L, as shown in Figure 4—L, where:

D = distance in meters from front of stopped vehicle to nearest edge of through pavement (use 3 meters).
W = Width of pavement in meters along path of crossing vehicle.
L = Overall length of design vehicle in meters (P = 5.8, SU = 9.1, BUS = 12.2, WB—40 = 15.2, WB—50 = 16.8)

Once S is computed the acceleration and crossing time "ta" is obtained from Figure 4—M.

The grade of crossing of the minor road materially affects the crossing time. The rations to be applied to the "ta" to correct for grade are given in Table 4—9.

TABLE 4–9

EFFECT OF GRADE ON CROSSING TIME					
Design Vehicle	RATIO BASED ON CROSSROAD GRADE RATE*				
	-4%	-2%	0%	+2%	+4%
P	0.7	0.9	1	1.1	1.3
SU	0.8	0.9	1	1.1	1.3
WB–50	0.8	0.9	1	1.2	1.7

* Apply to "ta" in formula $d = 0.45\ V\ (J + ta)$

The required sight distance "d" determined as previously indicated should be checked against the proposed major roadway vertical and horizontal alignment. The following checks should be made:

1. The sight distance should be tested against the vertical alignment using a height of eye of 1.14 meters (3.75 ft.) to a top of object of 1.37 meters (4.5 ft.) above the pavement. The crossing driver's eyes are assumed to be 5.2 meters back from the edge of the major road pavement.

2. Any object within the minimum sight triangle high enough above the elevation of the adjacent roadways to constitute a sight obstruction should be removed or lowered.

3. At skewed intersections the "W" value used should be increased to reflect the additional distance caused by the skew angle.

4. Horizontal curvature on the major road may alter the design of the intersection. A check will be necessary to determine if any obstructions block the line of sight.

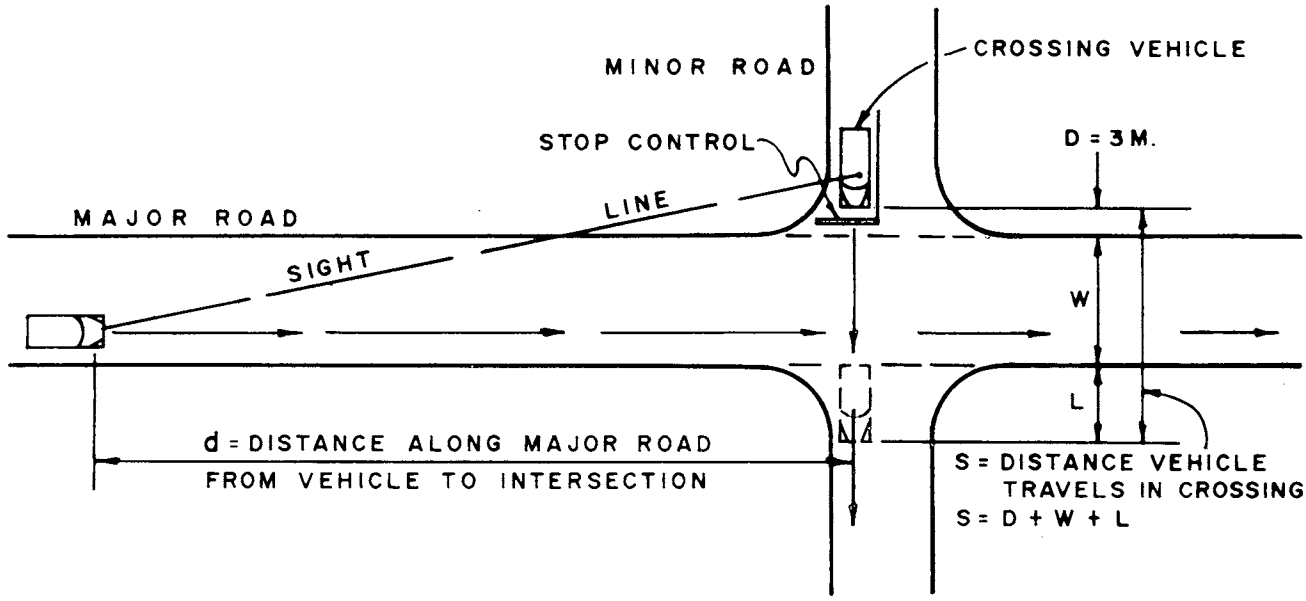
The criteria and values discussed above are applicable to intersections at grade on major urban arterial streets.

4–05.09 LEFT TURN CONTROL RADII

The normal intersection at grade does not have an edge of pavement delineating the path for left turning vehicles. Instead, the driver has a guide at the beginning and at the end of the left turn operation provided by channelizing island (or median) noses or by pavement markings and lane lines. Provision must be made to insure that the design vehicle can adequately negotiate the left turning movement and simple radii are used as a control measure. Minimum left turn control radii for various design vehicle conditions are given in Table 4–10. These radii are substantially larger than the minimum vehicle turning radius but are needed to provide for vehicle maneuverability and proper placement of channelizing island or median noses.

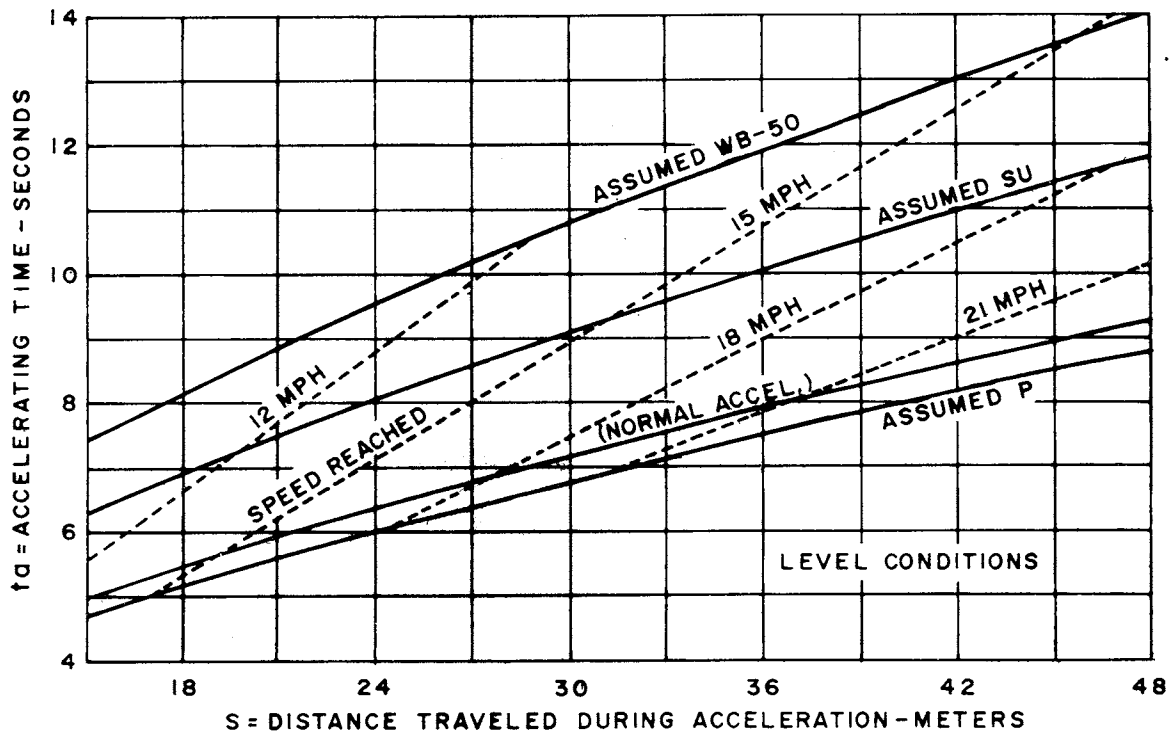
4–06 CHANNELIZATION

Channelization is the separation or regulation of conflicting traffic movements into definite paths of travel by means of islands or pavement markings to facilitate the safe and



MINIMUM SIGHT TRIANGLE AT INTERSECTION
WITH STOP CONTROL ON MINOR ROAD

FIGURE 4-L



SIGHT DISTANCE AT INTERSECTIONS
DATA ON ACCELERATION FROM STOP

FIGURE 4-M

TABLE 4-10

MINIMUM LEFT TURN CONTROL RADII	
DESIGN VEHICLE CONDITION	RADIUS-METERS
P and SU	12
SU, BUS and WB-40 (occasional WB-50)	15
WB-50	23

orderly movement of both vehicles and pedestrians. Channelization may serve one or more of the following purposes:

1. Increase the traffic capacity of the intersection.
2. Provide separation of conflicts.
3. Reduce excessive pavement areas.
4. Control de angle at which vehicles cross, merge or diverge.
5. Provide clearer indication as to the proper manner in which movements are to be made.
6. Give preference to predominant turning movements.
7. Provide areas for pedestrian protection.
8. Provide storage lanes or areas for turning vehicles clear of the through lanes.
9. Discourage or prevent prohibited turns.
10. Provide space for locating traffic control devices and lighting standards.
11. Control vehicular speeds through the intersection area.

Properly designed channelization is advantageous when through and turning movements are heavy. However, in rural areas the use of channelized intersections is normally limited to multilane highways and the more important intersections on 2—lane highways. In urban areas, where traffic volumes are generally higher, channelization is primarily used at the intersections of arterial and major collector highways.

4—06.01 ISLANDS

An island is a defined area between traffic lanes for control of vehicle movements or for pedestrian refuge. Within an intersection a median or outer separation is considered an island.

Islands generally are either triangular or elongated in shape, the dimensions depending upon the particular intersection layout. Triangular corner islands are normally used to separate right turning traffic from through traffic (See Section 4—05.03). Elongated or divisional islands are often introduced at intersections on undivided highways to separate opposing traffic and to regulate traffic at the intersection, particularly to provide storage for, and control of, left turning vehicles.

The minimum size of islands should be 4.6 square meters and preferably 7.0 square meters. Triangular islands should measure not less than 2.5 meters, and preferably not less than 3.7 meters, on the side after roundings of corners. Elongated islands or divisional islands should be not less than 1.2 meters wide and 4 to 6 meters long. However, divisional islands introduced at intersections on high speed rural highways should be not less than 60 meters long and preceded by appropriate pavement markings and signing.

Islands should be highly visible at all times and from a position sufficiently in advance so that the motorist will not be surprised by their presence. They may be designated by curbs, raised bars, raised buttons, paint, pavement edge, guide posts or other suitable devices.

Small islands are normally outlined either by pavement markings (flush island) or curbs (raised islands). Where curbs are used they should be mountable, particularly in rural areas. Barrier curbs should be used only where pedestrian protection is a primary consideration. On urban streets in congested areas where vehicular speeds are low, the use of barrier curbs is appropriate for protection of pedestrians, traffic control devices and lighting standards. Raised islands are sometimes difficult to see at night and, where used, the intersection should have fixed source lighting.

Curbs should not be used on large islands in rural areas. Satisfactory delineation can be obtained by pavement edge margings. Grassing and planting in the island should provide the necessary contrast.

The central area of an island has, in most cases, a turf or other vegetative cover. However, small triangular islands and narrow elongated islands (less than 2.5 meters wide) are normally paved because of the difficulty in growing and maintaining a vegetative cover.

Advance warning to approaching drivers should be provided in front of the approach noses to islands through the use of pavement markings, contrasting pavement or jiggle bars, etc., in accordance with the Manual on Uniform Traffic Control Devices.

1. TRIANGULAR ISLANDS

Where the roadway approaches are without shoulders or auxiliary lanes, as is the case in most urban highways and streets other than freeways, the triangular corner islands should be offset a minimum of 0.6 M. from the edge of through traffic lanes. The approach nose should be offset at least 1.2 M. from the through traffic lanes in the case of intermediate and large islands, and at least 0.6 M. from the edge of the turning roadway in all cases. Figure 4—N illustrates the recommended design for curbed triangular islands under conditions of no shoulders on the approach roadways.

On highways with auxiliary lanes or shoulders, the corner islands should be offset the full auxiliary lane or shoulder width on both the main highway and the crossroad but otherwise the island design is similar to that shown in Figure 4—N. When the shoulders on the approach roadways are unpaved, they should be paved through the intersection area.

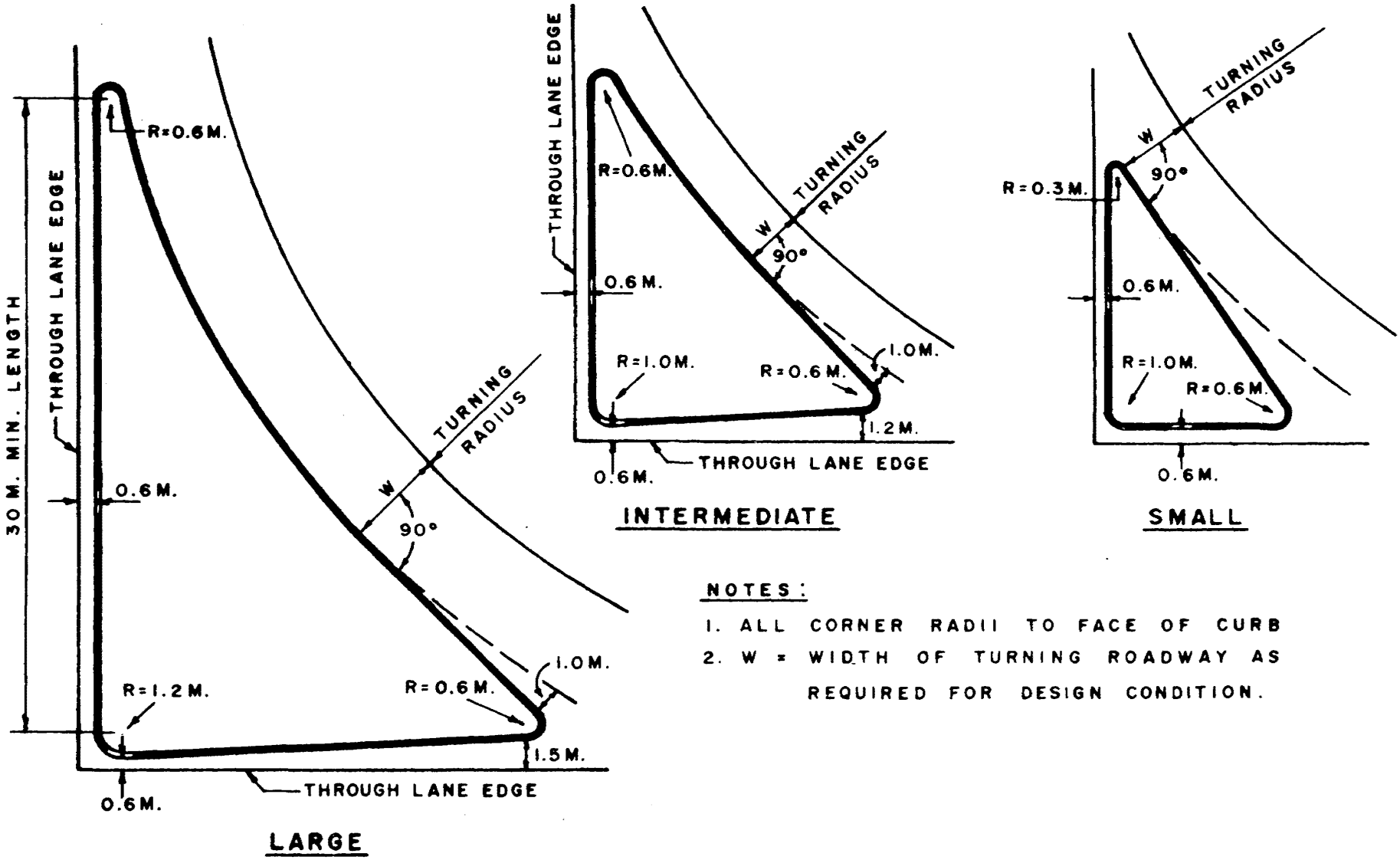
2. DIVISIONAL ISLANDS

The most common type of elongated divisional island is the median island for which a design guide is provided in Figure 4—0.

Divisional median islands may be introduced at major intersections on 2—lane highways or on undivided highways with four or more lanes. When a divisional island is introduced on a 2—lane highway the transition principles given in Section 3—06.01 apply and the total transition length in meters should, to the extent practicable, be equal to at least four times the design speed in miles per hour.

The flush section of the divisional island illustrated in Figure 4—0 may be delineated by pavement markings, jiggle bars, contrasting pavement or other suitable device which will warn the approaching driver but that may be safely crossed at high speed by errant drivers if necessary.

The nose at the cross road end of the divisional island should be designed in accordance with the requirements of the left turning movements, including a left turn median lane if

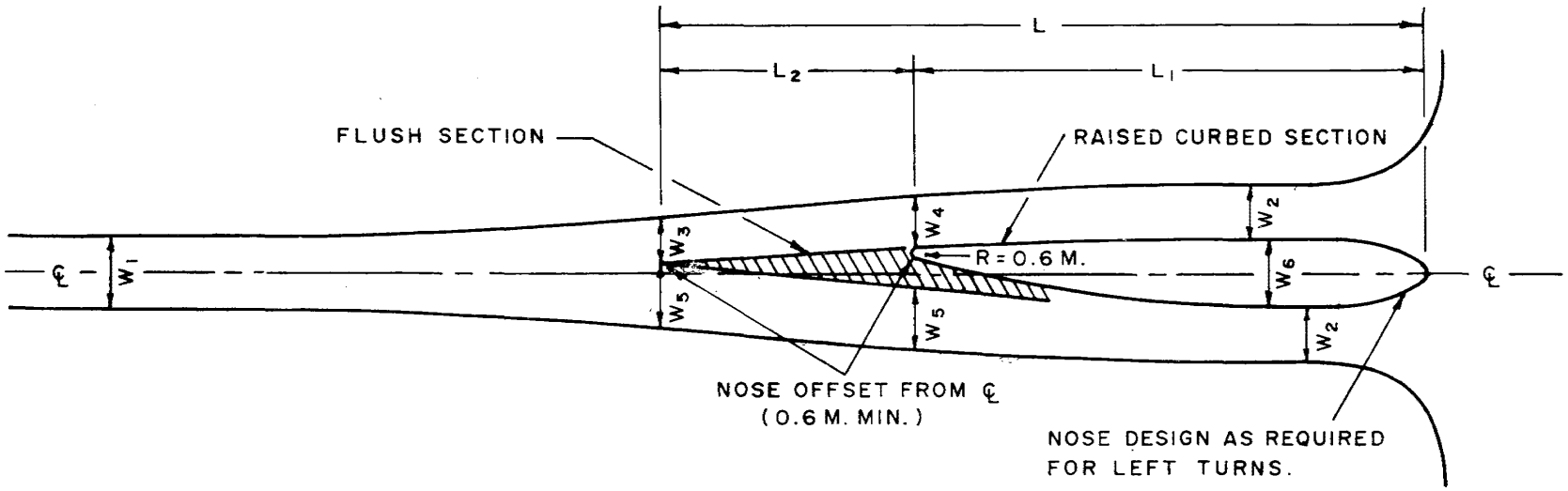


NOTES:

1. ALL CORNER RADII TO FACE OF CURB
2. W = WIDTH OF TURNING ROADWAY AS REQUIRED FOR DESIGN CONDITION.

TRIANGULAR ISLAND DESIGN - CURBED, NO SHOULDER

FIGURE 4-N



W_1 = UNDIVIDED APPROACH WIDTH

W_2 = DIVIDED ONE-WAY WIDTH

W_3 = $1/2\,(W_1)$ BUT NO LESS THAN 4.3 M.

W_4 = APPROX. $1/2\,(W_2 + W_3)$

W_5 = W_2 + 0.3 M.

W_6 = AS REQUIRED BY LEFT TURN CONTROL RADII OR ADDED LEFT TURN LANE.

L = TOTAL ISLAND LENGTH

L_1 = APPROX. $2/3$ L

L_2 = APPROX. $1/3$ L

SUGGESTED MIN. L VALUES *

DESIGN SPEED (MPH)	30	40	50	60
L IN METERS	60	80	100	120

* EXCLUSIVE OF ANY ADDITIONAL LEFT TURN STORAGE LANE LENGTH.

DIVISIONAL ISLAND DESIGN GUIDE

FIGURE 4-0

required. The criteria on median openings and median lanes discussed in Sections 4—07 and 4—08 of this chapter apply to this nose design.

4—07 MEDIAN OPENINGS

A simple median opening of minimum design is normally sufficient at minor intersections on divided highways on which operating speeds are low (less than 40 mph), traffic volumes are moderate, and left turn movements minor (less than 30 v.p.h.). The bullet nose design shown in the upper portion of Figure 4—P is used in such cases. For a minimum design, the control radii given in Table 4—10 are used for R^1 in the nose design. However, when through traffic volumes and speeds are high, higher values of R^1 should be used as indicated in Figure 4—P to facilitate and accelerate the left turning maneuver. For median widths of less than 2.4 M. a circular nose rather than a bullet nose is used with the design control radii determining the location of the nose.

The length (L) of the median opening should equal the full cross road roadway (pavement plus shoulders, plus median if divided) but in no case less than 12 meters, nor less than the crossroad traveled way (plus median, if any) plus 2.4 M. when the cross road has no shoulders.

When the cross road intersects the main highway at a skew angle, the use of a symmetrical bullet nose design may result in an excessive median opening. For such cases an assymetrical bullet nose design should be developed to avoid undesirably long median opening.

4—08 MEDIAN LANES

A median lane is provided at an intersection as a deceleration and storage lane for vehicles turning left to leave the highway. Median lanes may be operated with traffic signal control, with STOP signs, or without either, as traffic conditions warrant.

Left turn lanes should be provided on low speed divided highways (urban or rural) with moderate traffic volumes at intersections where the left turn movement exceeds 30 vehicles per hour and where the median width is 4.2 meters or wider. They should also be provided on all high speed (40 MPH or higher) divided highways with median widths of 4.2 meters or wider regardless of the number of left turn volumes for greater safety.

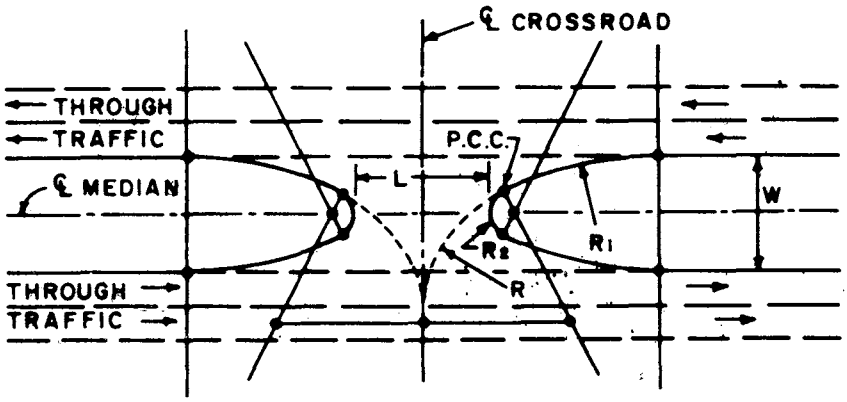
The design of typical median lanes is illustrated in Figure 4—Q. The following comments apply to the various elements of median lane design:

1. Widths—A minimum median width of 4.2 M. is required to provide a minimum median lane width of 3.0 M. and a narrowed median end width of 1.2 meters. On most new designs wider medians are provided and the preferable median lane width of 3.65 M. should be used. Under very restricted urban conditions a median lane of 3.0 M. width may be designed on a 3.65 M. median but in such cases a flush type median outlined by pavement markings would be used.

2. Taper—The symmetrical reverse curve taper is shown in Figure 4—Q but an assymetrical reverse curve or a partial tangent taper may be used. Where speeds are low, as on most urban arterials, a taper length of 30 to 45 meters is adequate. However, on high speed highways the taper should be designed as a speed change lane in accordance with the criteria covered in Section 4—05.06.

3. Nose Design—The design of the nose at the end of the narrowed median normally follows the bullet nose design shown in Figure 4—P. However, variations as illustrated in the AASHTO rural and urban geometric design policies may be used.

4. Storage Length—The storage length should be sufficient to accommodate the number of vehicles likely to accumulate during a critical period. Suggested storage length for various volumes of turning vehicles are given in Figure 4—Q. These generally apply at unsignalized



W - MEDIAN WIDTH, MIN. 24 M.

R - CONTROL RADIUS (SEE TABLE 4-10)

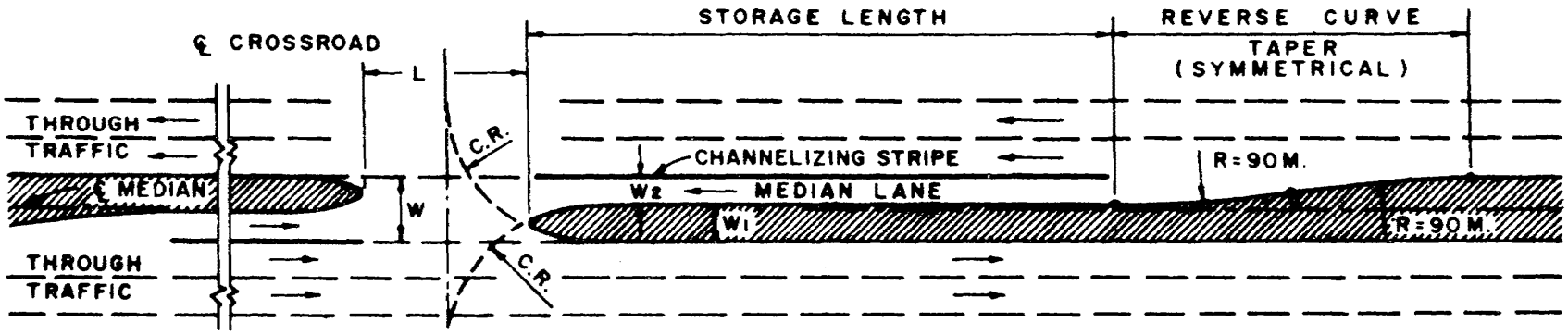
R_1 VARIABLE RADIUS, 30 TO 70 METERS (FOR MINIMUM DESIGN $R_1 = R$)

R_2 - $\frac{1}{5}$ W BUT NOT LESS THAN 0.6 M.

L - MEDIAN OPENING, MIN. 12 M. (SEE SECTION 4-07)

BULLET NOSE

TYPICAL MEDIAN OPENING FIGURE 4-P



NOTES:

1. MINIMUM MEDIAN WIDTH (W) – 4.2M. BUT 5.5M. PREFERABLE
2. MINIMUM NARROWED END (W_1) – 1.2M. BUT 1.8M. PREFERABLE
3. MINIMUM MEDIAN LANE WIDTH (W_2) – 3.0M. BUT 3.65M. PREFERABLE
4. MINIMUM TAPER LENGTH – 30M.
5. FOR BULLET NOSE DESIGN SEE FIGURE 4-P
   BUT WHERE W_1 < 2.4M. USE ROUND NOSE
6. FOR CONTROL RADII (C.R.) SEE TABLE 4-10
7. SUGGESTED MINIMUM STORAGE LENGTH:

DHV TURNING VEHICLES	30	60	100	200	300
STORAGE LENGTH – METERS	10	15	30	60	90

TYPICAL MEDIAN LANE DESIGN

FIGURE 4-Q

intersections. At signalized intersections a more detailed analysis is required since the required storage length will depend on the signal cycle length, the phasing distribution, and the rates of arrivals and departures of left-turning vehicles.

4—09 ACCESS CONTROL

Accesses to adjacent properties in the intersection area should be controlled on non-controlled access highways. The regulations of the Department of Transportation and Public Works require the following general minimum distances in meters from the beginning or end of the turning radius returns to the nearest access:

Highway Type	Commercial	Residential
URBAN ARTERIAL	18	6
URBAN COLLECTOR OR LOCAL	12	6
RURAL — ALL	18	12

(Special requirements aply to major traffic generators)

The above values are for simple intersections. At intersections where speed-change lanes are provided these should be protected from access to adjoining properties for their full length.

4—10 GENERAL DESIGN CONSIDERATIONS – CHANNELIZED INTERSECTIONS

1. The design of channelized intersections usually involves consideration of the following significant controls:

a. Type of design vehicle.
b. Cross section of main highway.
c. Cross section of intersecting roads or streets.
d. Traffic volumes, composition and turning movements, and their relation to capacity.
e. Pedestrian needs.
f. Vehicle speeds.
g. Type of traffic control.
h. Location of traffic control devices.
i. Physical controls — right-of-way, terrain, etc.
j. Location of bus or publico stops, if any.

2. The geometry of the intersection is determined by utilizing:

a. Radiuos returns required for right turning vehicles.
b. Control radii for left turns.
c. Radii of island noses.
d. Types of directional islands to be provided.
e. Angle of intersection.
f. Widths of approaches.
g. Width and length of auxiliary lanes.

3. The following principles should be followed in the design of the intersection:

a. Motorists should not be confronted with more than one decision at a time.
b. Unnatural paths, such as reverse curvature, or left-turn maneuver requiring an initial turn to the right, should be considered only for special cases.
c. Area of vehicle conflict should be reduced as much as possible.
d. Merging and weaving areas should be as long as conditions permit.
e. Traffic streams that cross without merging or weaving should intersect at or near right angles.

f. Angle of intersection between merging traffic streams should be small.
g. Points of crossing or conflict should be well separated from other such points.
h. Refuge areas for turning vehicles should be provided clear of through lanes.
i. Prohibited turns should be blocked wherever possible.
j. Location of essential traffic control devices and lighting standards, if any, should be established as part of the design.
k. If multiphase signals are to be used, it is desirable to separate the various traffic movements.

4. Any one basic intersection type can vary widely in scope, shape and degree of channelization. Once the basic type to be used at a particular location is established, the design involves the application of the controls and criteria covered in Chapter 3 and in this chapter to arrive at a suitable geometric plan. Types and examples of intersections at grade are covered in detail in the AASHTO rural and urban design policies. These publications should be referred to for guidance in the design of specific intersections.

TABLE C - RATIO OF POSSIBLE CAPACITY (LEVEL E) TO DESIGN CAPACITY (LEVEL C)

STREET TYPE	PARKING CONDITIONS	Factor f, when W_A (in feet) is -								
		10	15	20	25	30	35	40	50	60
TWO WAY	No Parking	1.20	1.20	1.20	1.20	1.21	1.23	1.25	1.27	1.30
	With Parking	-	-	1.10	1.14	1.18	1.21	1.25	1.31	1.34
ONE WAY	No Parking	-	-	1.15	1.13	1.12	1.12	1.13	1.15	1.17
	Parking One Side	-	-	1.10	1.13	1.16	1.18	1.20	1.25	1.30
	Parking Both Sides	-	-	-	1.25	1.25	1.25	1.27	1.32	1.37

EXAMPLE

Given

MP = 2,000,000, C.B.D.

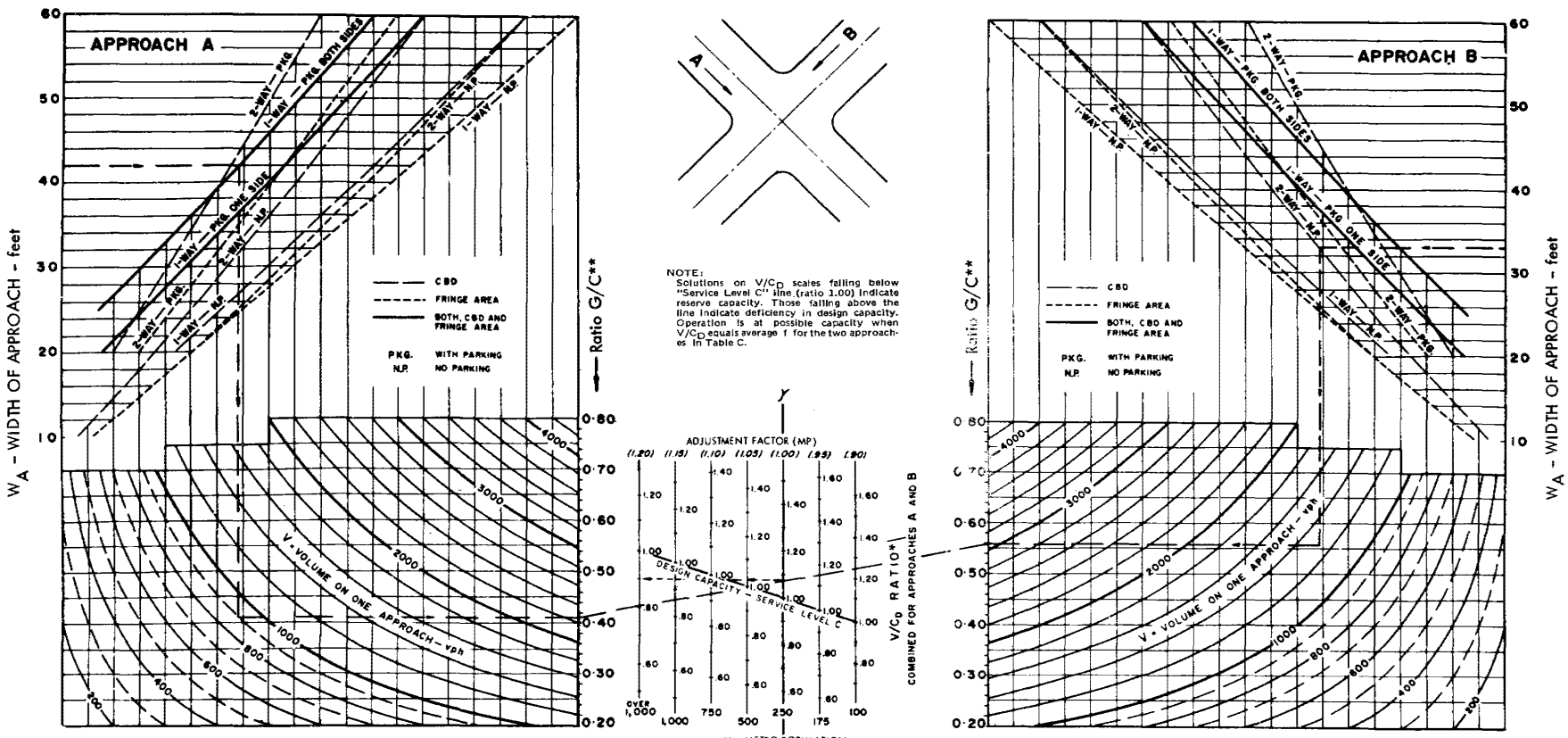
APPROACH A:
- One-way street
- Parking both sides
- W_A = 42'
- DHV = 900 vph

APPROACH B:
- Two-way street
- No Parking
- W_A = 33'
- DHV = 1280 vph

Solution

V/C_D = 0.90

Operation superior to service level C; i.e. demand volume below design capacity.



NOTE:
Solutions on V/C_D scales falling below "Service Level C" line (ratio 1.00) indicate reserve capacity. Those falling above the line indicate deficiency in design capacity. Operation is at possible capacity when V/C_D equals average f for the two approaches in Table C.

**Proportion of green time required on one approach for operation at design capacity for MP = 250,000; for other metro sizes, divide by corresponding adjustment factor, 0.90 to 1.20.

AVERAGE CONDITIONS - EACH APPROACH

Trucks & Buses	5%	No Bus Stops
Right Turns	10%	Amber, 10% of Cycle
Left Turns	10%	

DESIGN CAPACITY OF SIGNALIZED INTERSECTIONS

OVER-ALL INTERSECTION CAPACITY — AVERAGE URBAN CONDITIONS

C.B.D. AND FRINGE AREA

CHART 4 - I

TABLE C - RATIO OF POSSIBLE CAPACITY (LEVEL E) TO DESIGN CAPACITY (LEVEL C)

STREET TYPE	PARKING CONDITIONS	Factor f, when W_A (in feet) is-								
		10	15	20	25	30	35	40	50	60
TWO WAY	No Parking	1.20	1.20	1.20	1.20	1.21	1.23	1.25	1.27	1.30
	With Parking	-	-	1.10	1.14	1.18	1.21	1.25	1.31	1.34
ONE WAY	No Parking	-	-	1.15	1.13	1.12	1.12	1.13	1.15	1.17
	Parking One Side	-	-	1.10	1.13	1.16	1.18	1.20	1.25	1.30
	Parking Both Sides	-	-	-	1.25	1.25	1.25	1.27	1.32	1.37

EXAMPLE

Given

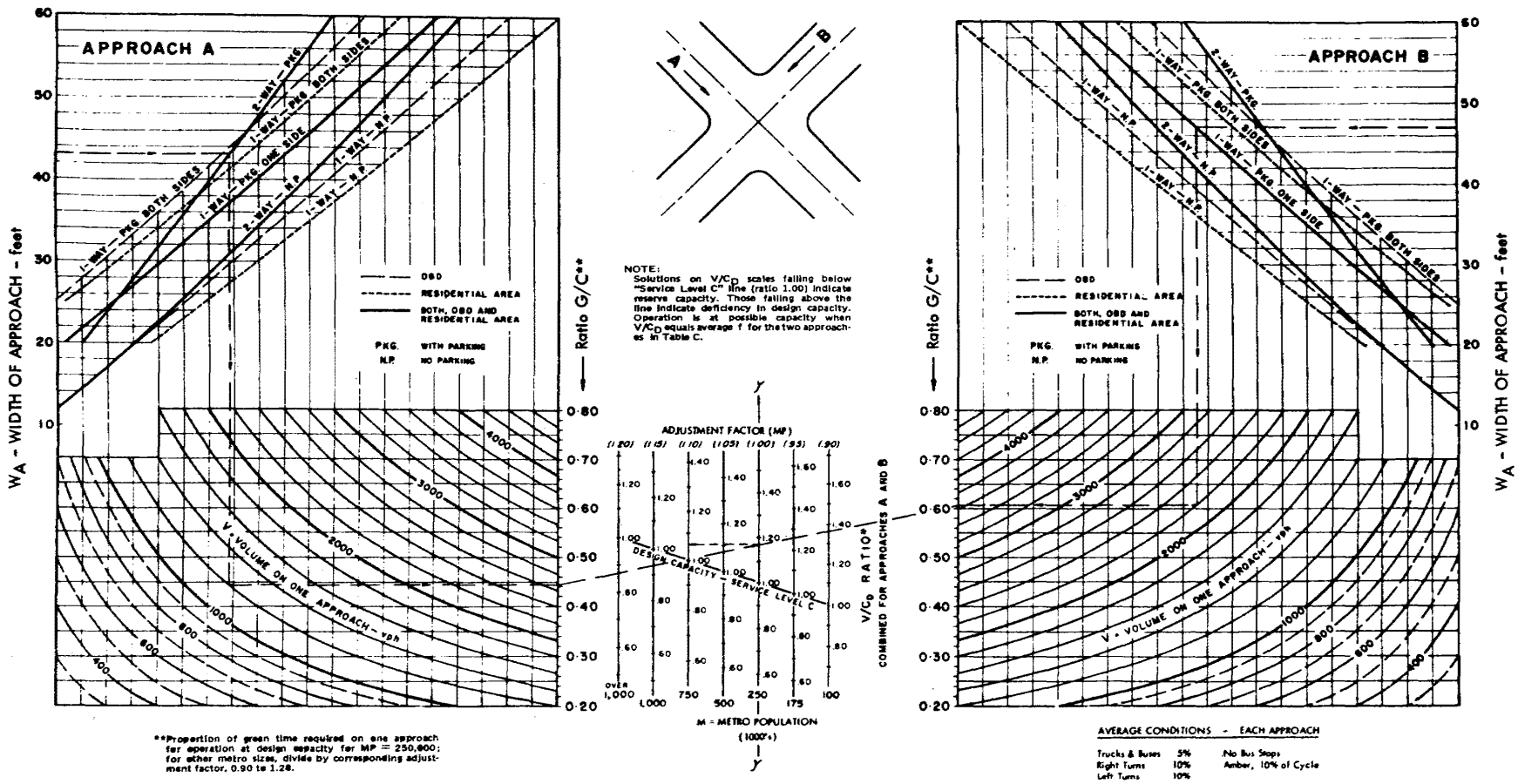
MP = 750,000 C.B.D.

APPROACH A:
Two-way
With parking
W_A = 43'
DHV = 1200 vph

APPROACH B:
One-way
Parking one side
W_A = 47'
DHV = 2200 vph

Solution

V/C_D = 1.06
Operation inferior to service level C; i.e., demand volume exceeds design capacity, but well within possible capacity for which the ratio would be 1.25 (average f for the two approaches in Table C).



NOTE:
Solutions on V/C_D scales falling below "Service Level C" line (ratio 1.00) indicate reserve capacity. Those falling above the line indicate deficiency in design capacity. Operation is at possible capacity when V/C_D equals average f for the two approaches in Table C.

**Proportion of green time required on one approach for operation at design capacity for MP = 250,000; for other metro sizes, divide by corresponding adjustment factor, 0.90 to 1.28.

AVERAGE CONDITIONS - EACH APPROACH

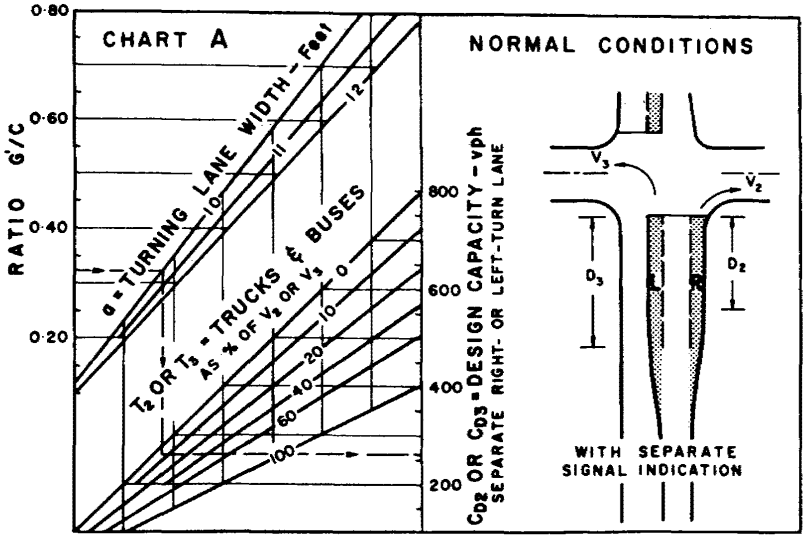
Trucks & Buses	5%	No Bus Stops
Right Turns	10%	Amber, 10% of Cycle
Left Turns	10%	

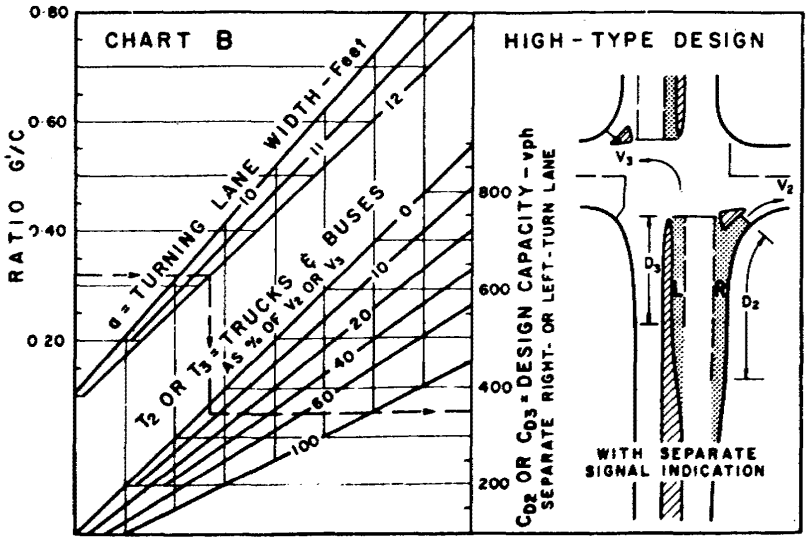
DESIGN CAPACITY OF SIGNALIZED INTERSECTIONS

OVER-ALL INTERSECTION CAPACITY — AVERAGE URBAN CONDITIONS

C.B.D. AND RESIDENTIAL AREA

CHART 4-II





NOTE:

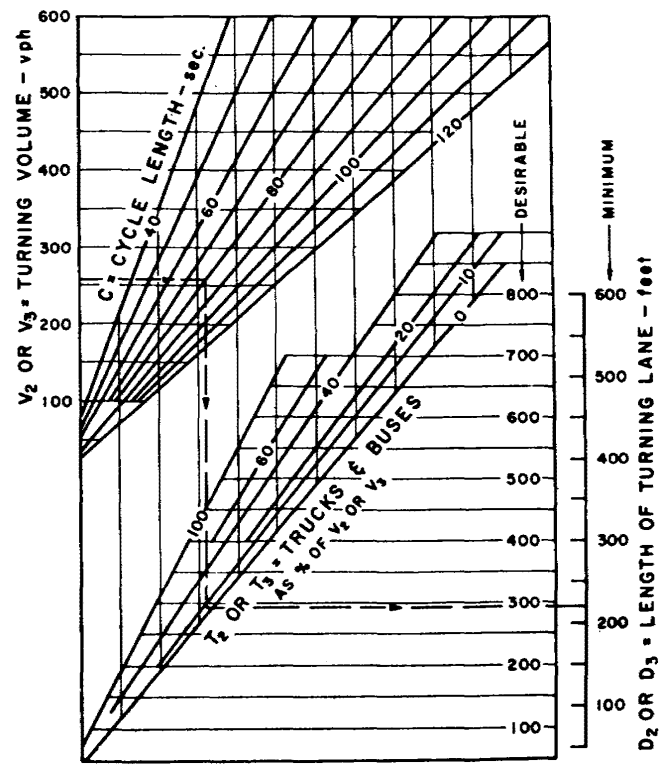
a. Charts A and B apply to both two-way and one-way streets.

b. Chart B generally does not apply to CBD.

c. Design Capacity equals Service Volume at Level of Service C. Use Table A to adjust to other Levels of Service.

TABLE A - ADJUSTMENT FACTORS FOR LEVEL OF SERVICE - SEPARATE TURN LANES

LEVEL OF SERVICE	ADJUSTMENT FACTOR
A	0.90
B	0.90
C	1.00
D	1.20
E and E'	1.30



LENGTH OF RIGHT- OR LEFT-TURN LANE

CHART C

SEPARATE RIGHT- AND LEFT-TURN LANES

WITH SEPARATE SIGNAL INDICATION FOR TURNING MOVEMENTS

CHART 4-III

CHAPTER 5

INTERCHANGES

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CHAPTER 5

INTERCHANGES

5—01 GENERAL

The capacity of arterial highways, particularly in urban areas, to handle high volumes of traffic safely and efficiently depends to a considerable extent upon their ability to accommodate cross and turning movements at intersecting highways. The greatest efficiency, safety and capacity is attained when the intersecting through traffic lanes are grade separated.

A grade separation is a crossing of two highways (or a highway and a railroad) at different levels. An "Overpass" is a grade separation when the subject highway passes over an intersecting highway. An "Underpass" is when the subject highway passes under an intersecting highway. Grade separation structures are covered in Chapter 6.

An interchange is a system of interconnecting roadways in conjunction with one or more grade separations, providing for the movement of traffic between two or more roadways at different levels. This chapter covers the various types of interchanges and their basic design elements.

5—02 WARRANTS FOR INTERCHANGES

1. FREEWAYS

Interchanges are provided on freeways at all intersections where access is to be permitted. Other intersecting roads or streets are either grade separated, terminated or rerouted. Figures 4—A and 4—B (Chapter 4) provide a general guide on what to provide at the intersections of rural and urban freeways with other classes of Commonwealth highways. However, the determination as to how to handle each intersecting facility is made during the planning and location studies on the basis of the traffic to be served and other factors having a bearing on the design.

2. OTHER HIGHWAYS

On highways with only partial control or no control of access definite warrants can not be specified as they may differ at each location. The following factors should be considered in analyzing a particular situation:

a. Elimination of Congestion—Insufficient capacity at the intersection of heavily travelled highways resulting in intolerable delays and congestion in one or all approaches. The inability to provide the essential capacity with an intersection at grade provides the warrant for an interchange.

b. Elimination of Hazard—Some intersections at grade have a high accident rate even though serving light traffic volumes. Other more heavily travelled intersections have a history of serious accidents. If the hazards at such intersections can not be eliminated by more inexpensive methods, providing an interchange facility may be warranted.

c. Site Topography—At some sites the topographic conditions may be such that the provision of an interchange facility may entail no more cost than an intersection at grade.

d. Traffic Volume—For a new intersection under design, an interchange would be warranted where a capacity analysis indicates that an at-grade design can not be provided to satisfactorily serve, without undue delay and congestion, the traffic volumes and turning movements expected.

5—03 TYPES OF INTERCHANGES

The basic interchange types used by the P.R.H.A. include the diamond, the trumpet, the full cloverleaf, the partial cloverleaf and the directional. Examples of these various types are illustrated in Figures 5—A through 5—E. These basic types and variations within each type can normally be adapted to the traffic service needs, terrain, available right-of-way, and other design requirements at most locations. However, in some instances unusual conditions may require the development of a special configuration. In any case, whether basic or special design, the various design elements and principles discussed in this chapter must be properly employed to insure adequate operation of the interchange.

5—04 INTERCHANGE DESIGN ELEMENTS

Design elements applicable to all types of intersections are covered in Chapter 4. In addition to those, the following design elements are applicable to interchanges.

5—04.01 ALIGNMENT, PROFILE AND CROSS SECTION

Traffic passing through an interchange should be provided the same degree of utility and safety as on the approaching highways. The standards for design speed, alignment, profile and cross section for the main lanes through the interchange area should be as high as on the approach legs. Desirably the alignment and profile of the through highways at an interchange should be relatively flat with high visibility. The full roadway cross section should be continued through the interchange area and adequate clearances, as discussed in Chapter 6, provided at structures. Two-lane highways having high speeds or high traffic volumes, or both, generally warrant a divided section through the interchange area. Similarly, 4—lane undivided highways should be divided through the interchange area.

5—04.02 SIGHT DISTANCE

Sight distance along the through highways and all ramps should be at least equal to the minimum safe stopping sight distance for the applicable design speed as per Table 3—1. However, the sight distance on freeways preceding the approach nose of an exit ramp should at least equal the desirable values indicated in Table 3—1. A check should be made of both horizontal and vertical alignment for any obstructions to sight distance such as abutments, piers and railings, particularly where the highways are on curves (see Section 3—03.05).

5—04.03 RAMPS

The term ramp denotes a turning roadway at an interchange for travel between intersection legs. The components of a ramp are a terminal at each end and a connecting road usually with some curvature and on a grade. Ramps are normally one-way roadways but two-way ramps are sometimes used.

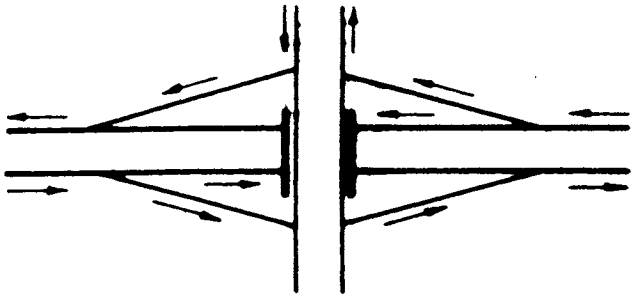
1. RAMP TYPES

Ramps are of a variety of shapes but can be classified into four basic categories as follows:

a. Right-turning roadway—referred to as diagonal ramp, parallel ramp, or outer connection depending on its shape or type of interchange.

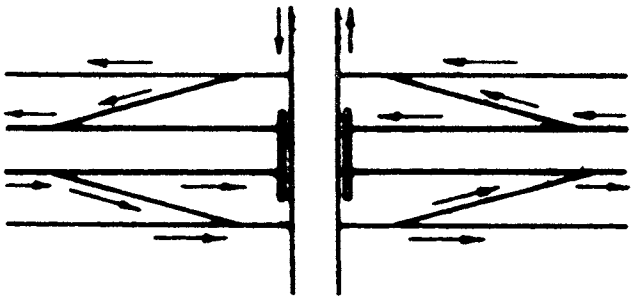
b. Loop—a ramp for a left turn accomplished by a right exit and a turn to the right through about 270 degrees.

c. Semidirect connection—a ramp for left turns accomplished with a partial deviation from the intended path.



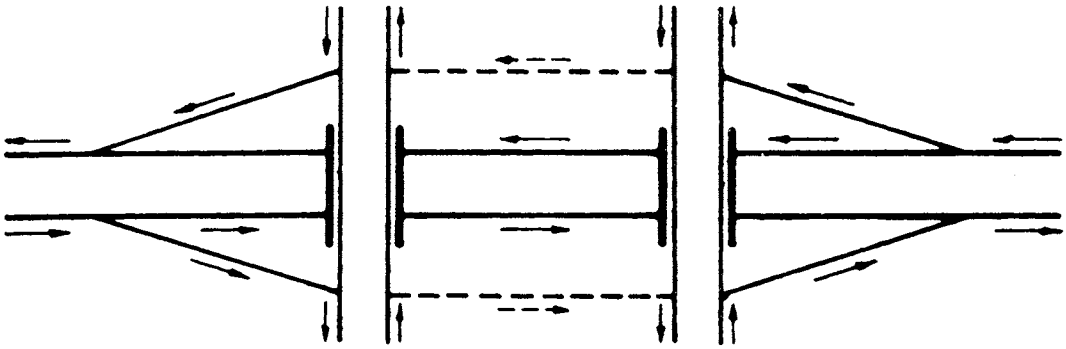
CONVENTIONAL DIAMOND

-1-



WITH ONE-WAY FRONTAGE ROADS

-2-

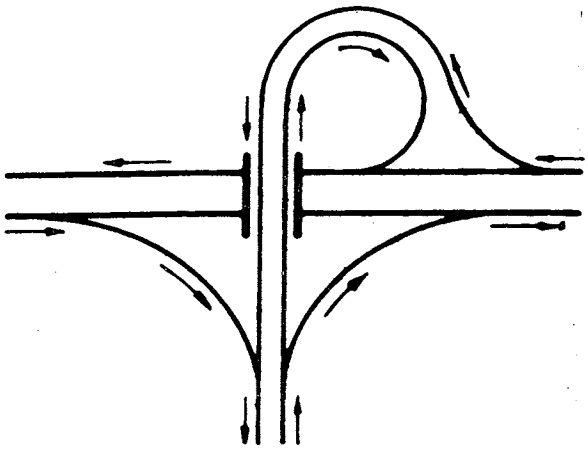


SPLIT DIAMOND

-3-

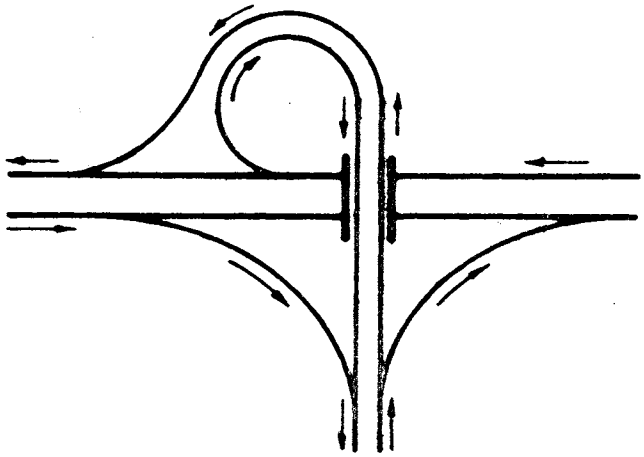
DIAMOND INTERCHANGES

FIGURE 5-A



TRUMPET-A

-1-

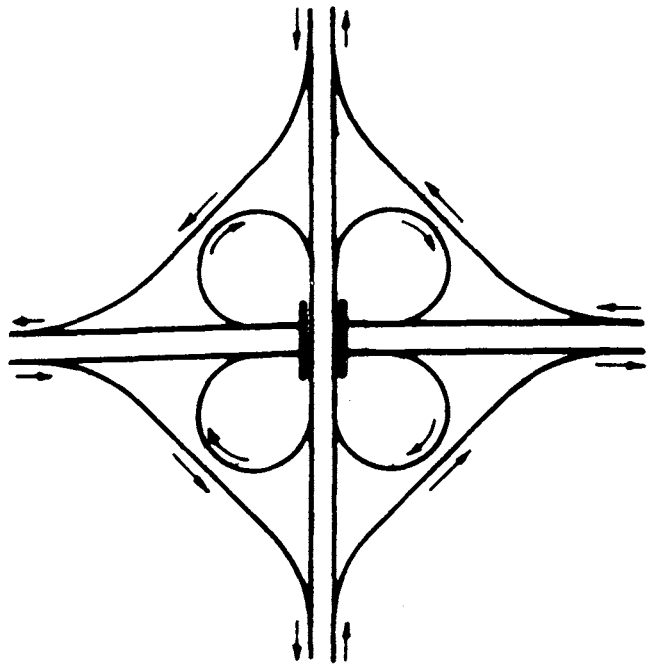


TRUMPET-B

-2-

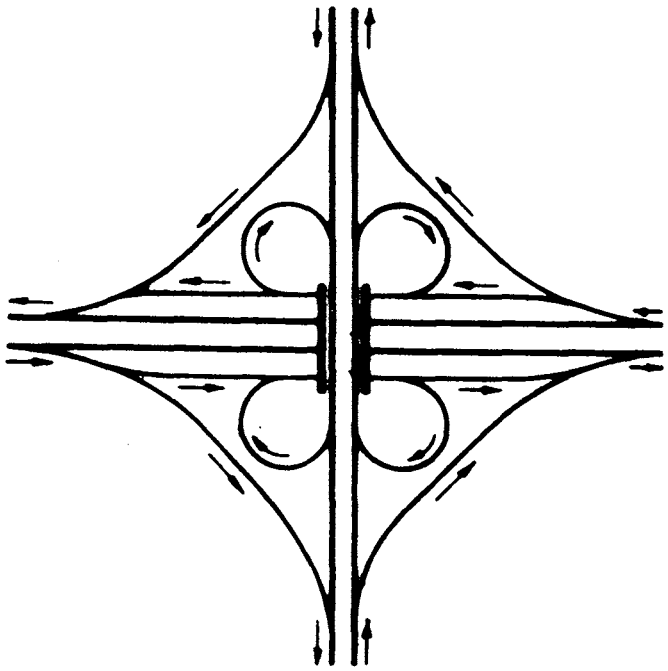
TRUMPET INTERCHANGES

FIGURE 5-B



CONVENTIONAL

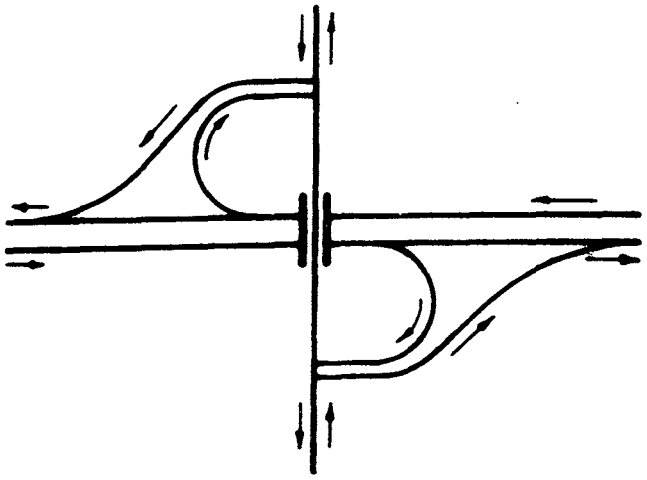
-1-



WITH C-D ROADS

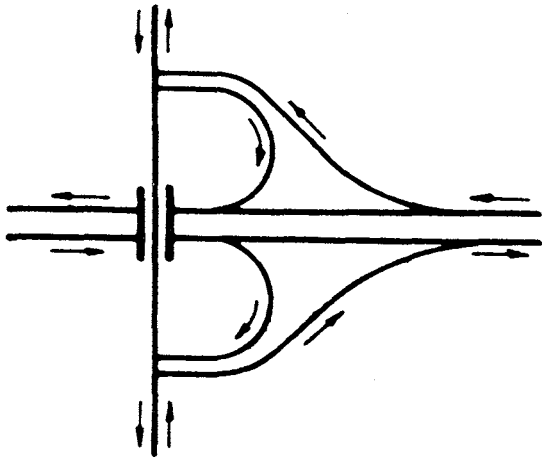
-2-

FULL CLOVERLEAF INTERCHANGES FIGURE 5-C



RAMPS IN OPPOSITE QUADRANTS

-1-



RAMPS IN ADJACENT QUADRANTS

-2-

PARTIAL CLOVERLEAF INTERCHANGES FIGURE 5-D

d. Direct connection—a ramp for left turns accomplished by a left directional maneuver wherein traffic leaves and enters the connecting highways on the left.

Figure 5—F illustrates several types of ramps and their characteristic shapes. Combinations of these ramp types form the various interchange patterns previously discussed in Section 5—03.

Diagonal ramps, which provide direct connection for right turn movements, are the most common type and are used at most interchanges. Diamond interchanges (Figure 5—A) normally have four diagonal ramps.

A combination of a loop and a diagonal or outer connection in one quadrant is the basic pattern of the cloverleaf (Figure 5—C) and the partial cloverleaf (Figure 5—D).

The semidirect connections, frequently called "jug handle", is a basic component of the trumpet interchange (Figure 5—B). Travel distance and/or travel time on a semidirect connection are normally less than on a loop but more than on a direct connection. The use of semidirect connections on 3-leg T type interchanges is illustrated in Figures 5—E—3 and 5—E—4, and on a cloverleaf interchange in Figure 5—E—6.

Directional left turn ramps minimize adverse travel for left turns; however, they are seldom used unless turning volumes are very large because they require additional space and structures. Direct connections are more often used at Y interchanges on freeways such as illustrated in Figures 5—E—1 and 5—E—2.

2. DESIGN SPEED

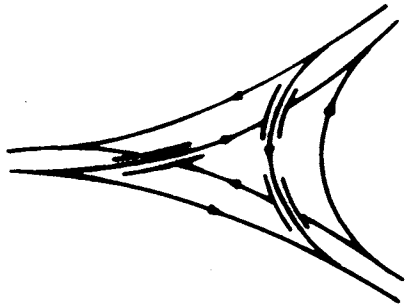
It is not practical to provide design speeds on ramps comparable to those on the through lanes except on some major fully directional interchanges such as at a Y—type directional interchange. However, the design speed on the ramps should be related to the design speed of the intersecting highways to minimize the adverse effects of the deceleration and acceleration operations. Guide values for ramp design speed as related to highway design speed are given in Table 5—1.

TABLE 5—1

GUIDE VALUES FOR RAMP DESIGN SPEED AS RELATED TO HIGHWAY DESIGN SPEED

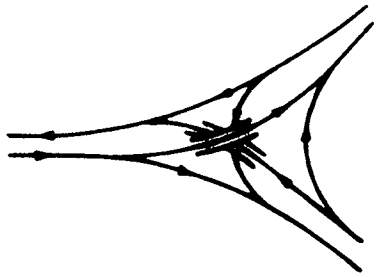
Highway Design Speed, mph	30	40	50	60	65	70
Ramp Design Speed, mph						
Desirable	25	35	45	50	55	60
Minimum	15	20	25	30	30	30
Min. Ramp Radius, meters*						
Desirable	45	100	200	250	315	385
Minimum	15	27	45	70	70	70

* Based on a maximum superelevation rate of 0.06



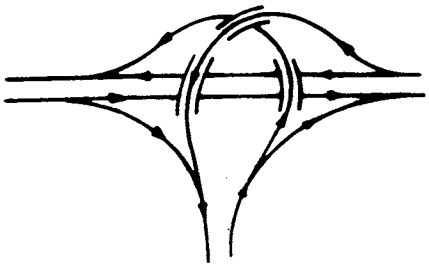
Y - 3 STRUCTURES

-1-



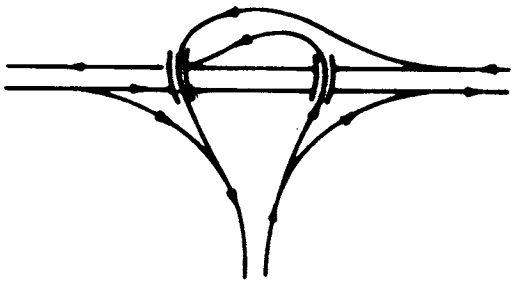
Y- 3-LEVEL STRUCTURE

-2-



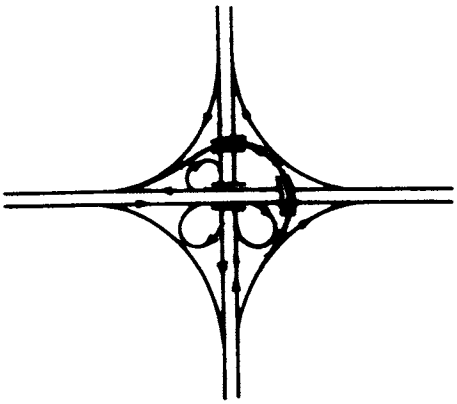
T - 3 STRUCTURES

-3-



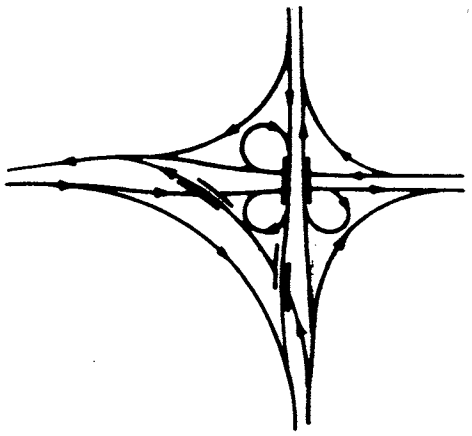
T - 2 STRUCTURES

-4-



PARTIAL CLOVERLEAF WITH SEMIDIRECT CONNECTION

-5-

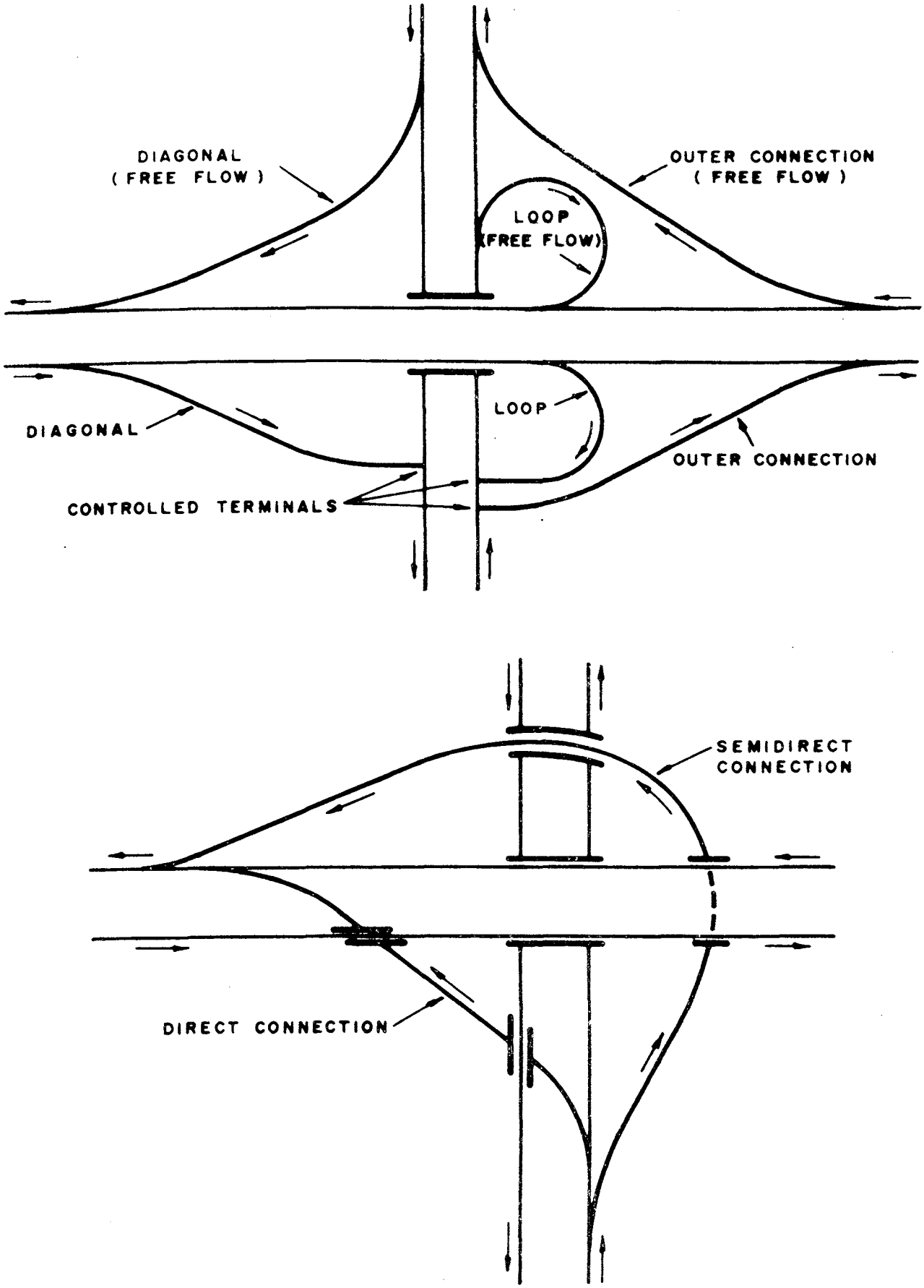


PARTIAL CLOVERLEAF WITH DIRECT CONNECTION

-6-

DIRECTIONAL INTERCHANGES

FIGURE 5-E



RAMP TYPES

FIGURE 5-F

In aplying the values in Table 5—1 to specific interchange designs the following principles should be followed:

a. The values in the table apply to the sharpest or controlling curve on the ramp. These speeds do not pertain to the free flow ramp terminals which should be properly transitioned and provided with speed change lanes adequate for the highway speed involved.

b. For right turn ramps—values above the minimums are usually attainable and should be used.

c. For loops design speeds above 30 mph require large areas which are not normally economically justified and in urban areas rarely available. In addition, the longer loops are costly and require considerable extra travel distance. Minimum values usually control loop design.

d. For semidirect connections—design speeds above the minimum are practicable. A design speed of less than 30 mph should not normally be used.

e. For direct connections—desirable design speeds should be used and in no case less than 35 mph.

f. The higher highway design speed should be the control in selecting the ramp design speed. However, the ramp design speed may vary with the lowest speed assigned to the portion of the ramp closer to the lower-speed highway. This is particularly applicable where the ramp is on an up-grade from the higher speed highway to the lower speed highway.

3. HORIZONTAL ALIGNMENT

Horizontal alignment of ramps should be closely tied to the geometrics of the main line in order to avoid sharp slopes in the gore area.

Special consideration should be given to the first horizontal curve on an exit ramp. Main line speed, deceleration lengh a available, grades, and curvature should be interrelated so as to avoid excessive overdriving in this area.

The minimum turning radii corresponding to each value of desirable and minimum ramp design speed are given in Table 5—1. These radii are based on a maximum superelevation rate of 0.06 and on somewhat higher side frictions factors than for open highway conditions for speeds up to 25 mph.

The principles on turning roadways covered in Chapter 4 and Table 4—6 are also applicable to ramps.

4. VERTICAL ALIGNMENT

Ramp vertical alignment generally consists of a section of tangent grade with vertical curves at each end connecting to the profiles of the intersection legs. The controlling tangent grade should be as flat as feasible for the site conditions but may be steeper than on the through highways. Recommended maximum grade values for ramps, as given in Table 1—11, are 6% when the main highway has a design speed of 70 mph and 7% in other cases. However, the following guidelines should be followed in designing ramp profiles:

a. Ramp gradients should be desirably be limited to 6% on up grades and 7% on down grades.

b. When the ramp is to be used by many heavy trucks, up grades should be limited to 4%.

c. In exceptional cases, minor low-volume ramps may be as steep as 10%.

d. A steep grade on a ramp is not objectionable if the gradient helps in acceleration or deceleration to meet intersecting highway speed conditions.

e. Ramps with high design speeds or those joining high-speed highways should normally have flatter grades than ramps with low design speed or minor low-volume traffic.

f. Ramps with sharp curvature on down grades should not be steeper than those on up grades as the high rate of superelevation in conjunction with a down grade makes steering more difficult.

Ramp profiles usually have and "S" shape but intermediate vertical curves may be necessary on some ramps. The minimum length of vertical curves on ramps is normally controlled by stopping sight distance and crest conditions. The "K" values given in Table 3—7 and Figure 3—H may be used for both crest and sag conditions on ramps. For a design speed of 15 mph a "K" value of 2 should be used. When a crest or sag vertical curve extends onto a ramp terminal, the length of curve may be determined by using a "K" value for a design speed intermediate between those on the ramp and the highway. The minimum lenght in meters of vertical curve should be no less than the selected design speed in miles per hour.

It is desirable that freeway ramp terminal profiles be designed with a "platform" on the ramp side of the aproach nose or merging end. This platform should be a length of about 200 feet or more on which the profile does not greatly differ from that of the adjacent through traffic lane.

Care must be exercised in designing the ramp profile that the initial crest vertical curve of a descending ramp provides the driver with a clear view of the initial horizontal ramp curve. Similarly, the final crest vertical curve of an ascending ramp should provide the driver a clear view of the through highway and the merging area.

5. CROSS SECTION

Typical ramp sections are illustrated in Figure 2—0 of Chapter 2. Pavement widths for ramps are governed by the type of operation, curvature, and design vehicle. These are discussed in Chapter 2 and guide values given in Table 2—2. Most ramps will be designed for Case II operation (one-lane, one-way with provision for passing a stalled vehicle) and Traffic Condition B or C depending on whether a significant number of the large combination units will be present in the ramp traffic.

The use of two-lane, one-way ramps will normally be limited to semidirect or direct ramps when the traffic volume will exceed the capacity of a one-lane ramp and both terminals can be designed for adequate two—lane entrance and exit. Two—lane widths may also be provided on a portion of a ramp with a controlled terminal at the minor highway when both right and left turns are to be permitted, such as at diamond interchanges, to provide vehicles storage space. However, the ramp exit terminal from the main highway in such cases will be designed for one—lane operation.

Two—lane, two-way ramps are very seldom used and when used will be designed as abutting ramps with physical separation as illustrated in Figure 2—0.

6. SUPERELEVATION

The general factors which control superelevation for open highway conditions, discussed in Chapter 3 are also applicable to ramps. However, on interchange ramps the superelevation rate is not as critical as on through pavements since drivers anticipate the sharper curvature and accept operation with higher side friction than on open highway curves. Even so, it is desirable to provide as much superelevation as practicable on ramps, particularly when the curve is sharp and on a down grade.

The maximum superelevation rate used by the Highway Authority is 0.06 but in special cases on down ramps a rate of 0.08 may be authorized. However, the development of a desirable superelevation without an abrupt change in cross slope at the ramp terminals is often prevented by the sharp curvature and short length of turning roadway. This is compensated by accepting higher side friction factors. Table 5—2 gives a range of allowable superelevation rates for different ramp design speeds and radii.

The cross slope on tangent ramp sections are normally sloped in one direction only at a minimum rate of 0.02.

7. SUPERELEVATION RUNOFF

The principles of superelevation runoff discussed in Chapter 3 generally apply to ramp curves. The rate of cross slope change on ramp curves, as on open highways should vary with the design speed; however, higher values of cross slope change are acceptable on low speed turning ramps. Cross slope change rates as high as 0.08 per 30-meter length may be used on sharply curved, low-speed ramps without undue distortion in appearance or hazard in operation. Guide design rates for rates of cross slope change on ramp curves are given in Table 5—3.

TABLE 5—2

SUPERELEVATION RATES FOR RAMP CURVES
RANGE IN DESIGN VALUES

Radius, Meters	Superelevation Rates, for Ramps with Design Speeds of: (MPH)					
	15	20	25	30	35	40
15	.02 — .08	—	—	—	—	—
27	.02 — .07	.03 — .08	—	—	—	—
45	.02 — .05	.02 — .08	.04 — .08	—	—	—
70	.02 — .04	.02 — .06	.03 — .08	.06 — .08		
100	.02 — .03	.02 — .04	.03 — .06	.05 — .08	.06 — .08	
150	.02 — .03	.02 — .03	.03 — .05	.04 — .07	.06 — .08	.06 — .08
200	.02	.02 — .03	.02 — .04	.03 — .05	.05 — .07	.06 — .08
300	.02	.02 — .03	.02 — .03	.03 — .04	.04 — .05	.05
450	.02	.02	.02	.02 — .03	.03 — .04	.04

NOTES:

1. Rates above 0.06 to be used only when authorized by the Highway Authority.
2. Use highest rate practicable, preferably in upper third of range.
3. For design speeds above 40 mph use values for open highway curves as per Table 3—3.
4. Radius refers to the inner edge of the curved pavement.

TABLE 5–3

DESIGN RATES OF CROSS SLOPE CHANGE FOR RAMPS				
Change in Superelevation (meter per meter)	Design Speed, mph			
	15-20	25	30	35 or more
Per 30-meter length	.08	.07	.06	.05
Per 10-meter length	.027	.023	.02	.017

At terminals where the ramp joins the main pavement through a speed-change lane (Figure 4—K), the superelevation development is started or ended along the auxiliary pavement. However, care must be exercised to avoid excessive difference between the cross slope on the through pavement and that on the auxiliary lane. Normally, it is not possible to develop the desired superelevation on the turning roadway until some point beyond the approach nose where the main line and ramp pavements are fully separated.

The maximum acceptable algebraic differences in cross slope rates at the crossover crown line between the through pavement and the auxiliary pavement are given in Table 5—4. When both pavements slopes down and away from the crossover crown line, the algebraic difference is the sum of the two cross slope rates; when the slope is in the same direction, it is the difference in their cross slope rates. The desirable maximum algebraic difference at the crown line is 0.05 but it may be as high as 0.08 at low speed exits where there are few trucks.

TABLE 5–4

MAXIMUM ALGEBRAIC DIFFERENCE IN PAVEMENT CROSS SLOPES AT RAMP TERMINALS	
Design Speed of Exit or Entrance Curve (mph)	Maximum Algebraic Difference in Cross Slope at Crossover Crown Line
15 and 20	.05 — .08
25 and 30	.05 — .06
35 and over	.04 — .05

The development of the superelevation over the auxiliary pavement and over the whole of the turning roadway should not be abrupt. It is desirable to plot and study profile lines for both edges to determine that all profiles match the control points and that no unsightly bumps and dips are inadvertently introduced.

Four shcemes for the development of superelevation at turning roadway or ramp terminals are illustrated by the sketches in Figure 5—G. Example 5—G—1 shows the variation in cross slope when the ramp exits from a through highway which is on a tangent and the auxiliary pavement is a taper type. The normal cross slope of the through pavement is usually maintained along the auxiliary lane until point "d" when a full lane width (3.65 M.) has been attained. Beyond point "d" the superelevation of the turning roadway is developed by warping the pavement until the desired rate is attained which is generally beyond the approach nose and into the ramp curve proper by point "f". Where the taper length is short it may be necessary to begin developing the superelevation before point "d" is reached, say about point "c".

Figure 5—G—2 shows the development of superelevation when there is present a parallel type speed change lane. The normal cross slope of the main pavement is maintained through the taper and along the full lane portion until, for example, point "c" when the development of the superelevation is started. Usually more than half of the desired superelevation can be attained by point "d" and the remainder not far beyond the nose as at point "f".

Figure 5—G—3 is similar to 5—G—1 for the condition where the through pavement and the ramp curve in the same direction. Under this condition, the desired superelevation on the exit pavement can be attained in a relatively short distance since the through lanes will already be superelevated and a lesser "rollover" is required. The superelevation rate of the through pavement can usually be maintained until about point "d" with the desired ramp superelevation reached by "e" or "f".

A more difficult condition is encountered when the through pavement and the ramp curve in opposite directions as in Figure 5—G—4. Due to the superelevation of the through lanes it may be impracticable to slope the auxiliary pavement in an opposite direction for reasons of safety, riding quality and appearance. The sketch shows a case with moderate superelevation on the through lanes which is extended onto the auxiliary pavement as at "c" where rotation about the crossover line is initiated. By "d" the auxiliary pavement is almost horizontal and by "e", near the nose, some of the desired ramp superelevation is attained. However, most of the superelevation usually must be gained beyond the nose.

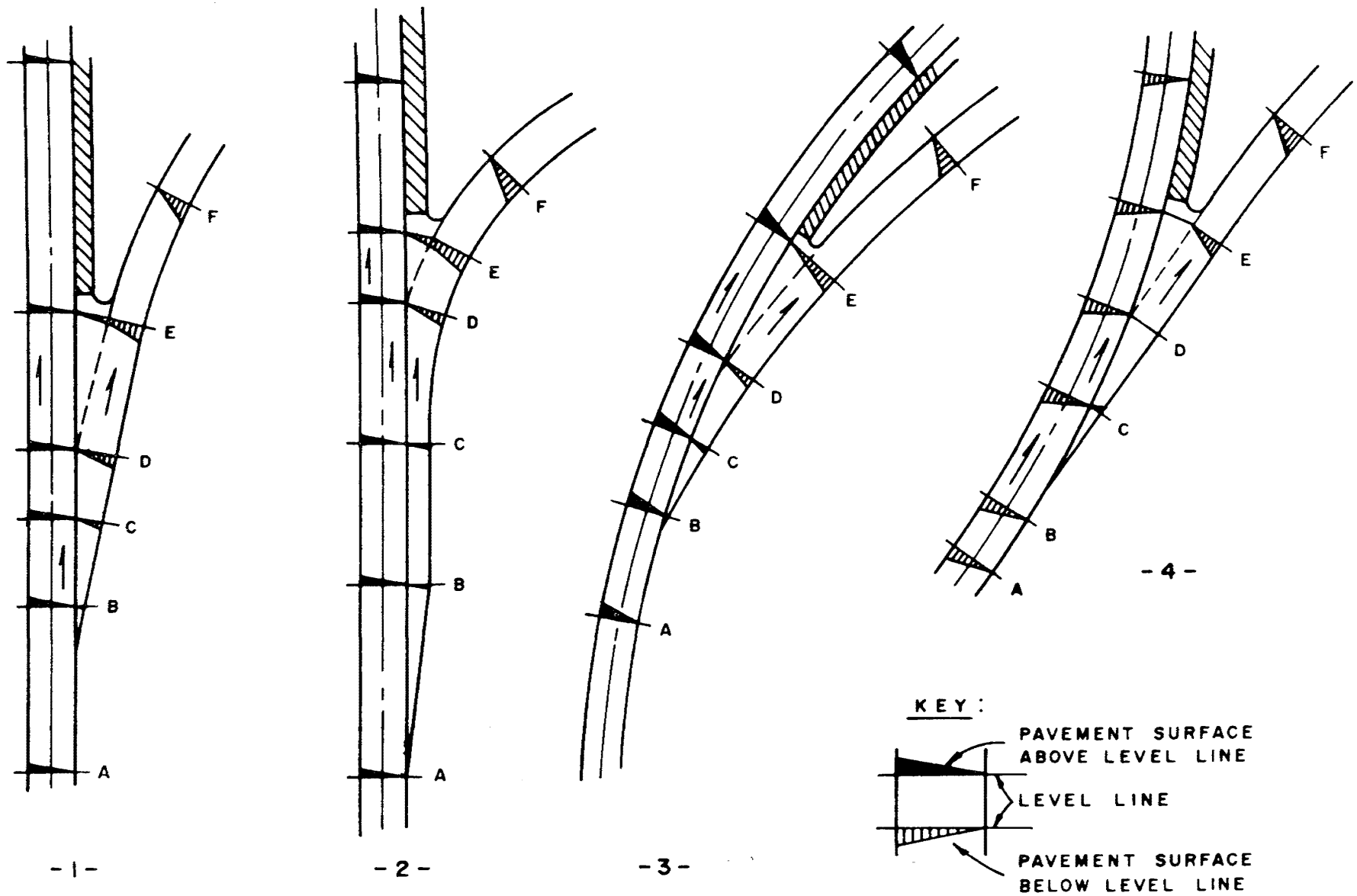
The above examples cover exit conditions. The same principles are aplicable to the design of entrance terminals.

Mathematical vertical curves are not always practicable at ramp terminals. The profile curves can be readily developed with spline or irregular curve templates. The final profile may not precisely produce the selected cross slopes at the control points but this difference is not serious as long as the cross slope change is progressive and smooth, and within the design control limits.

5—04.04 MAJOR TURNING ROADWAYS

Interchanges involving two freeways nearly always call for directional layouts. In such cases, turning movements in one or more quadrants are often comparable in volume to through movements and need to be provided with semidirectional or directional connections. In addition, these turning movements will normally exceed the capacity of a one-lane ramp and must be served by a major turning roadway of two or more lanes in cross section.

Major turning roadways should have the same design speed and other geometric design requirements as on the through highways. The terminals become major divergence and convergence points within the interchange area and must be designed accordingly.



DEVELOPMENT OF SUPERELEVATION AT RAMP TERMINALS

FIGURE 5-G

5—04.05 RAMP TERMINALS

1. RAMP TERMINAL TYPES

The ramp terminal is the portion of the ramp adjacent to the through travel lanes and includes the speed-change lane, tapers, noses, merging ends and islands, if any. Ramp terminals may be of the free-flow type or the controlled type as illustrated in Figure 5—F. On the free-flow type the ramp traffic merges or diverges from the high speed through traffic at flat angles on speed-change lanes. On the controlled type, also called at-grade type, the ramp intersects the crossroad at nearly right angle, traffic is controlled by STOP sign or traffic signal, and both left and right turns are allowed unless the crossroad is a one-way facility.

Free-flow types are used at the ramp terminals on high speed facilities such as freeways and expressways. They are a standard terminal on all directional and semidirectional ramps, and on loops and outer connections of full cloverleaf and trumpet type interchanges. Free flow terminals are also used at the entrance and exit terminals on the major road of the diagonal ramps of diamond interchanges.

Controlled type terminals are used at the ramp terminals on the minor crossroad or street of diamond and partial cloverleaf interchanges. The design of these controlled type terminals follows the principles of intersections at grade covered in Chapter 4. These terminals are normally designed for near minimum turning speed conditions.

2. FREE-FLOW EXIT TERMINALS

The frèe-flow exit ramp terminal includes a speed-change lane to allow the driver to safely decelerate from the highway operating speed to the ramp speed with a minimum of interference with the through traffic. The elements of speed-change lanes are discussed in Chapter 4.

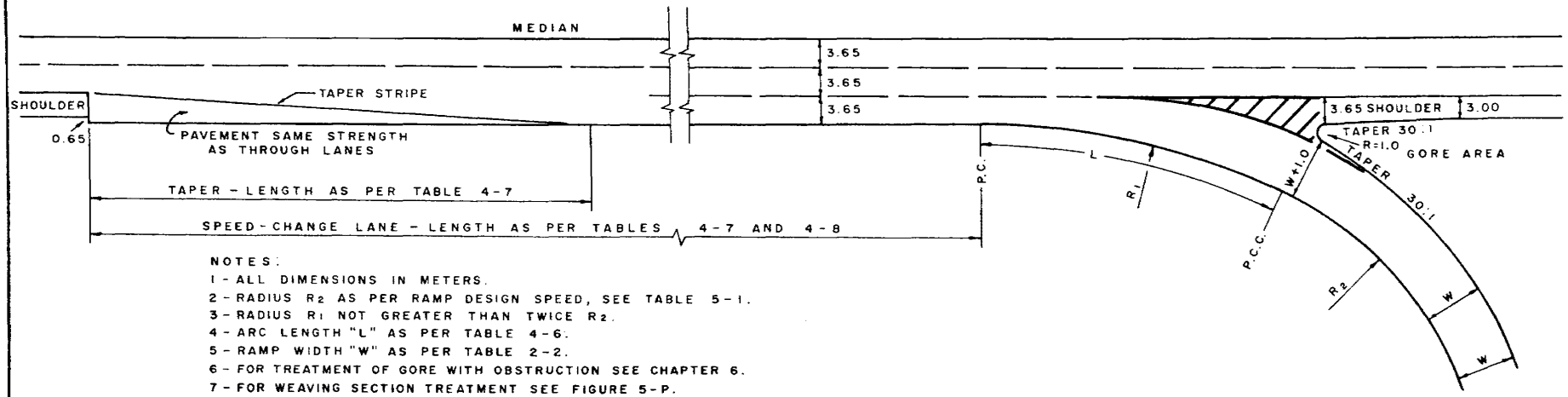
Typical exit terminals covering the two most frequent conditions are illustrated in Figure 5—H. The upper sketch shows the exit terminal to a low-speed loop ramp. To minimize interference with through traffic a parallel type speed-change lane is normally used because of the long deceleration length required due to the substantial speed differential between the through lanes and the ramp. The lower sketch shows the exit terminal to a diagonal ramp. Since diagonal ramps can normally be designed for a higher exit speed than loop ramps, the deceleration length required adjacent to the through lanes is shorter than for loops and a taper type speed-change lane is generally used.

The nose should be offset the full width of the auxiliary lane, normally 3.65 meters, from the edge of the through pavement. Since the Puerto Rico standards call for 3.0 — meter surfaced shoulders, the additional offset required is normally 0.65 meter. The nose taper on the through lane side should be 30:1 but may be reduced to 15:1 in special cases. The nose should also be offset on the ramp side a minimum distance of 0.6 meter but preferably 1.0 meter with a taper of about 30:1 as shown in Figure 5—H.

The examples illustrated in Figure 5—H are used where the number of through lanes remain unchanged through the interchange area. When a lane drop at the exit is made, the recovery area beyond the nose needs to be made much longer and should be designed as an acceleration lane with an appropriate length selected from Tables 4—7 and 4—8. The use of a design speed differential of 30—40 mph is recommended.

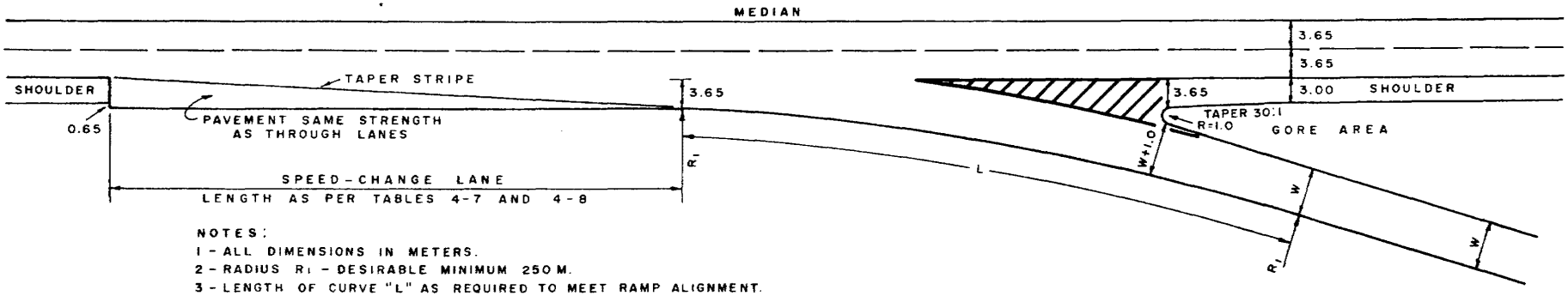
3. FREE-FLOW ENTRANCE TERMINALS

The free-flow entrance ramp terminal includes a speed-change lane to allow the driver to accelerate from the ramp speed to near the highway operating speed and to safely merge with the through traffic. Acceleration lanes are covered in Chapter 4.



NOTES:
1 - ALL DIMENSIONS IN METERS.
2 - RADIUS R_2 AS PER RAMP DESIGN SPEED, SEE TABLE 5-1.
3 - RADIUS R_1 NOT GREATER THAN TWICE R_2.
4 - ARC LENGTH "L" AS PER TABLE 4-6.
5 - RAMP WIDTH "W" AS PER TABLE 2-2.
6 - FOR TREATMENT OF GORE WITH OBSTRUCTION SEE CHAPTER 6.
7 - FOR WEAVING SECTION TREATMENT SEE FIGURE 5-P.

LOOP RAMP WITH PARALLEL TYPE DECELERATION LANE



NOTES:
1 - ALL DIMENSIONS IN METERS.
2 - RADIUS R_1 - DESIRABLE MINIMUM 250 M.
3 - LENGTH OF CURVE "L" AS REQUIRED TO MEET RAMP ALIGNMENT.
4 - RAMP WIDTH "W" AS PER TABLE 2-2.
5 - FOR TREATMENT OF GORE WITH OBSTRUCTION SEE CHAPTER 6.
6 - FOR WEAVING SECTION TREATMENT SEE FIGURE 5-P.

DIAGONAL RAMP WITH TAPER TYPE DECELERATION LANE

TYPICAL EXIT RAMP TERMINALS

FIGURE 5-H

Typical entrance terminals are illustrated in Figure 5—I. The upper sketch shows the entrance terminal from a loop ramp and the lower from a diagonal type ramp. Where the ramp speeds are substantially lower than the highway speeds, as in the case of cloverleaf loops, a parallel type acceleration lane is normally provided as shown in the upper sketch. However, where the ramp geometrics allow the entering vehicles to attain an adequate merging speed (about 5 mph under the highway operating speed) by the time they reach the exit nose, a taper type speed change lane as shown in the lower sketch is preferred.

The merging nose of the island at the terminal of the entrance ramp should be as narrow as practicable, usually 0.6 meter in width or diameter. The ramp pavement is narrowed to a 4.25 meter width at the island nose by tapering the left edge. The minimum taper shall be 10:1 but longer tapers of about 20:1 should be used whenever practicable. The entrance is further narrowed through pavement markings to a normal lane width (3.65 M.) beyond the island nose.

When capacity considerations require the addition of another lane to the highway beyond the ramp entrance the terminal design is as illustrated in Figure 5—I but the speed-change lane is replaced by a full highway lane.

4. MULTILANE FREE-FLOW TERMINALS

Multilane free-flow ramp terminals are infrequently used in Puerto Rico. However, a two-lane entrance or exit may be required at a freeway interchange when the turning traffic requires a two-lane ramp. The design of the exit and entrance terminals are similar to those illustrated in Figures 5—H and 5—I except that another lane width is added on the right of the ramp and mainline pavements shown. However, the principles of lane balancing and lane drops discussed subsequently in this chapter apply to these cases and must be considered in the overall interchange design.

5. GORES

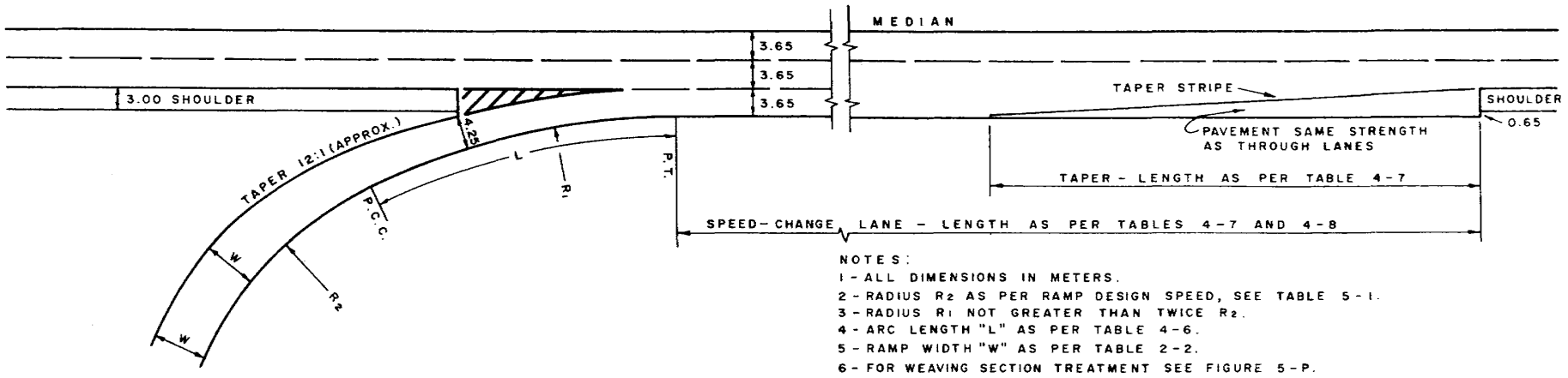
The "gore" at an intersection is the area immediately beyond the divergence of two roadways, bounded by the edges of those roadways. In common usage the term gore includes the paved triangular island area ahead of the approach or ramp nose of the island and the graded area beyond the approach nose. The paved triangular area is provided with pavement markings to guide the vehicles along the intended path but it also serves as an emergency maneuver area that can be safely traversed by vehicles that deviate from their proper path.

The unpaved area beyond the nose should be graded as nearly level with the roadways as practicable so that drivers of errant vehicles be afforded an opportunity for recovery of control and not be abruptly stopped or upset by steep slopes. In addition, this gore area shall be kept free of hazardous objects such as structure supports, heavy sign supports and light poles. If placement of a highway sign within the gore area is essential, such as a standard EXIT (SALIDA) sign, it shall be set well back of the nose and mounted on a yielding or breakaway sign support on a flush base.

Whenever possible curbing should be avoided on ramps, specially on the outside of curves, since they may provoke overturning accidents.

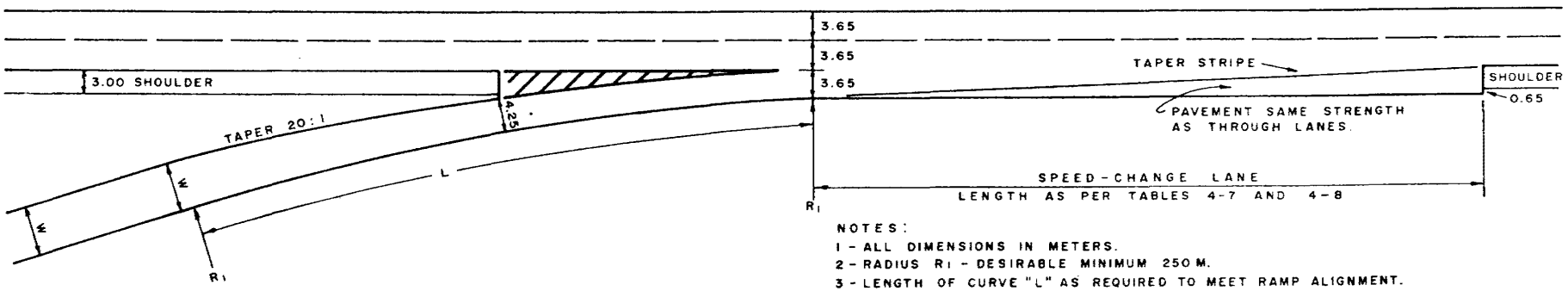
The use of curbs on the approach nose shall be avoided. If curbs are found to be necessary in the roadway design they shall be sloped and easily mountable, and the area beyond the nose and within the curbs paved for a distance of a least 3.0 meters. Barrier type curbs shall not be used on approach noses.

There are locations when the placement of a hazardous obstruction in a gore area is unavoidable. The two most common situations are where the gore is located on an elevated structure and when a bridge pier within a gore can not be avoided. In such case an area must be provided for the installation of an impact attenuation device. This reserve area is detailed in Chapter 6 and impact attenuators are covered in Chapter 8.



NOTES:
1 - ALL DIMENSIONS IN METERS.
2 - RADIUS R_2 AS PER RAMP DESIGN SPEED, SEE TABLE 5-1.
3 - RADIUS R_1 NOT GREATER THAN TWICE R_2.
4 - ARC LENGTH "L" AS PER TABLE 4-6.
5 - RAMP WIDTH "W" AS PER TABLE 2-2.
6 - FOR WEAVING SECTION TREATMENT SEE FIGURE 5-P.

LOOP RAMP WITH PARALLEL TYPE ACCELERATION LANE



NOTES:
1 - ALL DIMENSIONS IN METERS.
2 - RADIUS R_1 - DESIRABLE MINIMUM 250 M.
3 - LENGTH OF CURVE "L" AS REQUIRED TO MEET RAMP ALIGNMENT.
4 - RAMP WIDTH "W" AS PER TABLE 2-2.
5 - FOR WEAVING SECTION TREATMENT SEE FIGURE 5-P.

DIAGONAL RAMP WITH TAPER TYPE ACCELERATION LANE

TYPICAL ENTRANCE RAMP TERMINALS

FIGURE 5-I

6. CONTROLLED TYPE TERMINALS

Controlled or at-grade type ramps terminals are designed following the principles of intersections at-grade with operation and capacity being the determining factors. However, certain elements require special consideration in their location and design as follows:

a. Discouraging wrong-way entry—In spite of signing and pavement markings, there is always the danger of a driver from the crossroad making a wrong-way entry into a one-way exit ramp and proceeding along the freeway or main highway in the wrong direction. This problem is particularly evident at diamond and partial cloverleaf ramp terminals on the crossroad. This problem can be practically eliminated if the following points are considered in the design:

1. Provide a median on the crossroad within the interchange area even though the crossroad may be basically a two-lane highway, and channelize the ramp terminal at the crossroad.

2. Design the median openings, median noses, islands and curb returns so as to make difficult and effectively discourage wrong-way entry into the ramps. The sketches in Figure 5—J illustrate how this may be done.

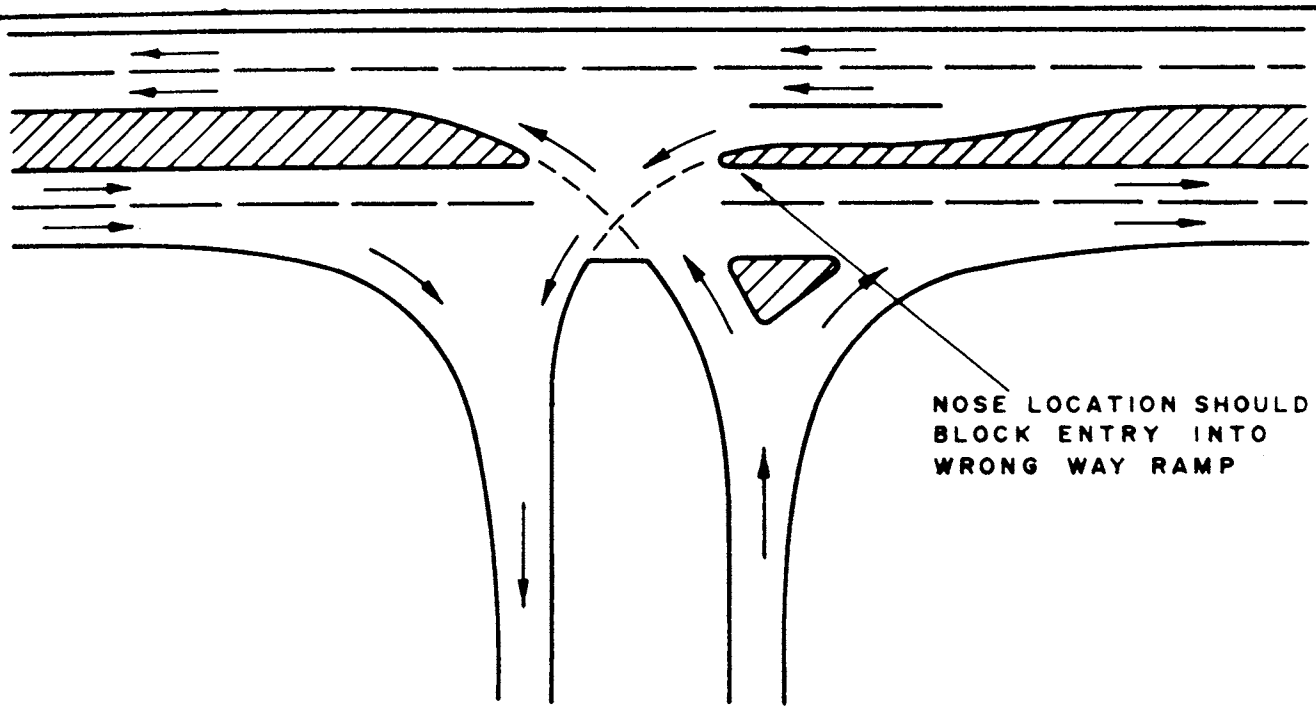
b. Providing adequate sight distance—at ramp terminals with STOP control it is necessary that the driver of a stoped vehicle see enough of the highway to be able to safely complete his turning maneuver before a vehicle on the highway coming into view after he has started, reaches the ramp terminal. This is similar to the sight distance requirement for intersections at grade discussed in Section 4—05.08 except that normally a left turn movement and not a crossing maneuver is involved, and there is invariably a structure in the immediate vicinity of the ramp terminal which may restrict the sight distance. These conditions area commonly found on diamond interchanges at the ramp terminals on the minor crossroad and, where signals are not used, may control the location of the ramp terminal with respect to the structure.

When the grade of the minor crossroad is carried over the major highway, the sight distance at the ramp terminal may be restricted by the crest vertical curve or the structure railing as illustrated in Figure 5—K. When the grade of the minor crossroad is carried under the major highway, the sight distance may be restricted by the structure piers or abutments.

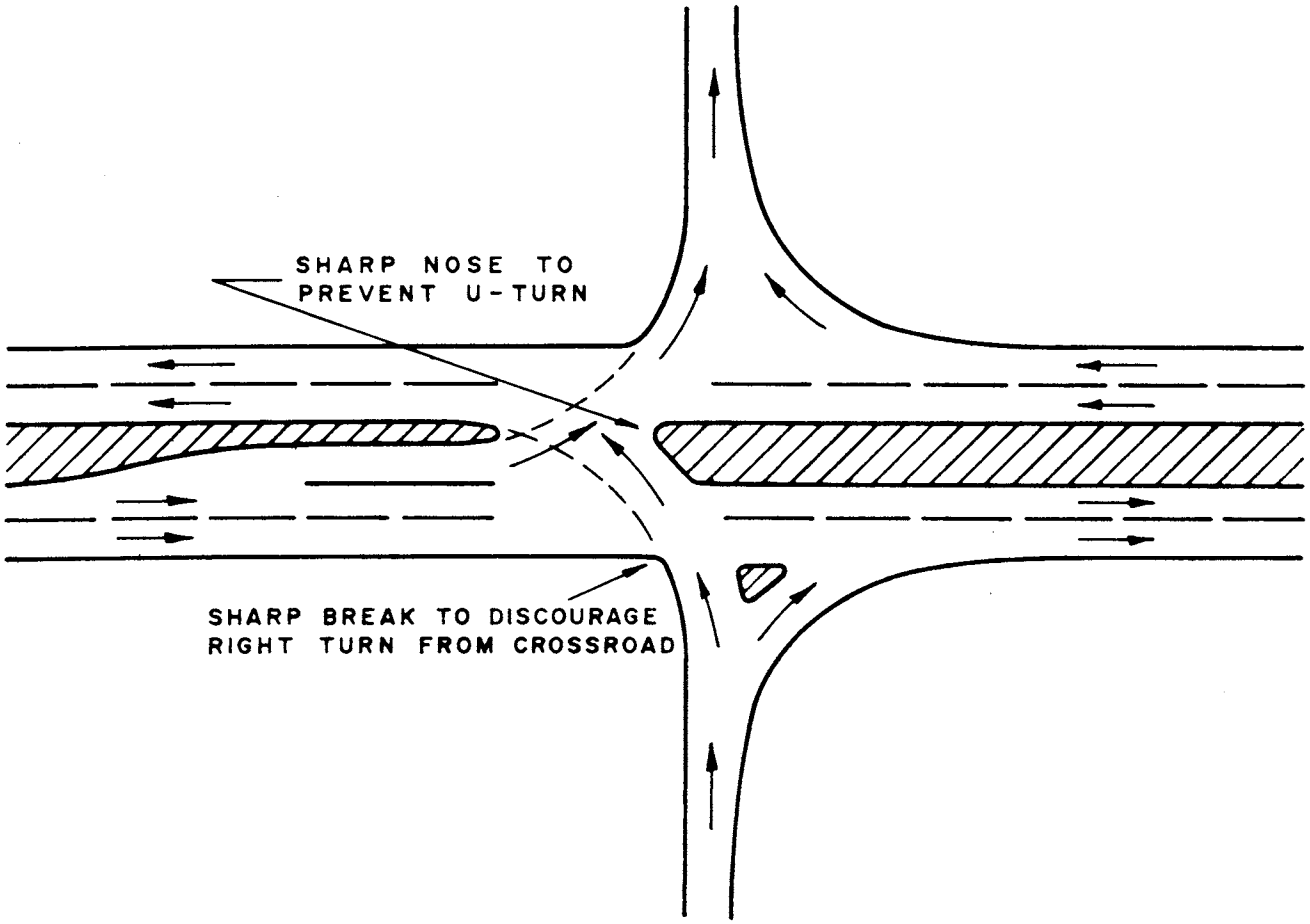
The only difference between the ramp terminal and the ordinary intersection at-grade is the time and distance traveled by the vehicle turning left rather than crossing the highway. The travel distance "S" is measured as shown in the upper portion of Figure 5—K and the formulas, tables and graphs discussed in Section 4—05.08 are used to determine the sight distance required.

Both the horizontal sight triangle and the vertical curvature should be checked graphically as illustrated in Figure 5—K to insure that the required sight distance is available. The designer should locate the ramp terminal so as to provide the required sight distance. If upon testing the design, the sight distance provided is unsufficient one or more of the following solutions may be considered:

(1) Relocate the ramp terminal farther from the structure.
(2) Increase the vertical curve length on the structure.
(3) Increase the lateral clearance at the structure.
(4) Provide traffic signals at the ramp intersection.



PARTIAL CLOVERLEAF RAMPS



DIAMOND RAMPS

RAMP INTERSECTIONS AT CROSSROAD

FIGURE 5-J

5—04.06 SUCCESSIVE RAMP TERMINALS

At interchanges and on urban freeways there are frequently two or more ramp terminals in close succession along the through lanes. In some interchange designs, ramps split into two separate ramps or combine into one ramp such as when collector-distributor roads are provided. To provide sufficient maneuvering length and adequate space for signing, a reasonable distance is required between terminals.

Minimum and desirable distances between successive ramp terminals are illustrated in Figure 5—L for various combinations of terminals. The designer should strive for the desirable or longer distance with the minimun to be used only in critical situations. It should be noted, as shown on Figure 5—L that in many cases the length required to provide the necessary speed-change lane or weaving distance will govern over the values given in the table.

When the distance between the end of a taper on an entrance terminal and the beginning of the taper on an exit terminal (Figure 5—L—4) is less than 500 meters (or greater when weaving volumes indicate a need) the speed-change lanes should be connected to provide a continous lane with a recovery lane added beyond the exit.

5—04.07 RAMP CAPACITY

The capacity of a ramp may be controlled by that of the ramp proper, the entrance terminal or the exit terminal. It may also be governed by sections where ramp traffic is required to weave with other traffic.

The Highway Capacity Manual (HCM) provides detail procedures and nomographs for the determination of service volumes and capacities of merging and diverging conditions at ramp termini. The FHWA publication "Capacity Analysis Techniques for Design and Operation of Freeway Facilities" (FHWA—RD—74—24) presents procedures for the graphic solution of the capacity of freeway facilities, including ramp elements, which simplify the work required by the computational procedures in the HCM.

The ramp capacity values presented in the following sections provide working data and policy guidance for application to most design analyses.

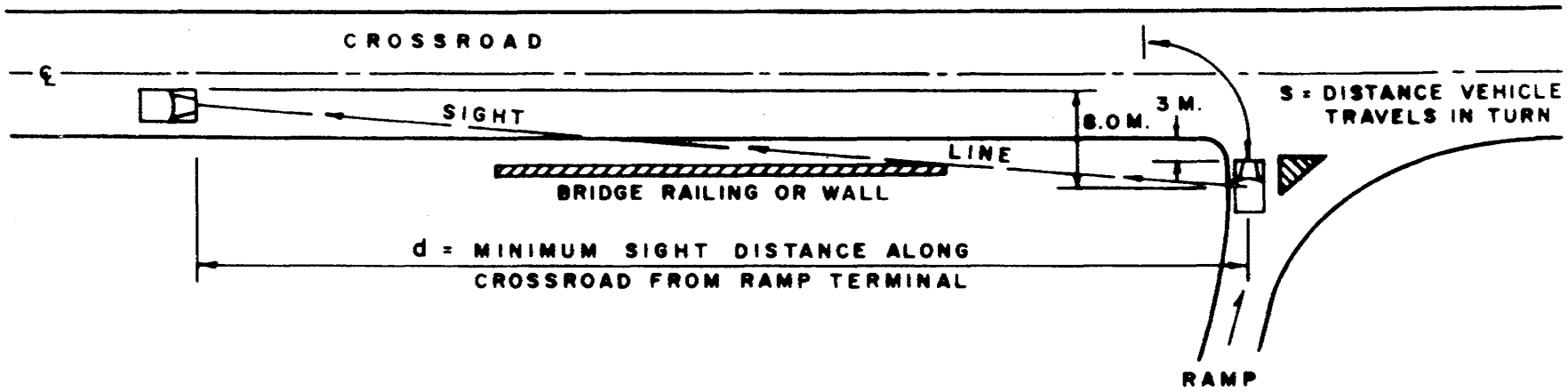
1. RAMP PROPER

The capacity of a ramp is generally controlled by one of its terminals. However, occasionally the ramp proper way determine the capacity when speeds are significantly affected by curvature, grades and truck operations. Table 5—5 gives values for design capacity of the ramp proper under various conditions of curvature (design speed), grades and percentage of trucks in the traffic flow. The values shown are on the basis that the ramp width is adequate for off tracking and lateral clearances.

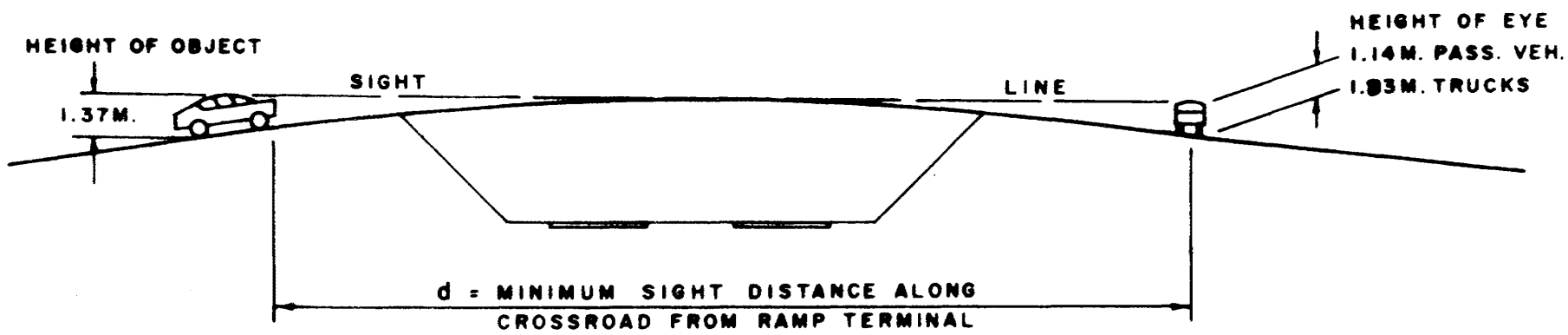
The Service Level "B" values should normally be used for rural freeways and the "C" values for urban and suburban freeways.

2. ENTRANCE TERMINAL (Free-flow)

For ramps entering free flowing roadways, about 1,500 passenger cars per hour can merge in one lane without reducing the speed of traffic on the highway to less than about 35 mph provided that an adequate acceleration lane and good sight distance are provided. This value may be used for design capacity of urban and suburban facilities while 1,200 passenger cars per hour should be used for rural conditions. These values include both the vehicles entering from the ramp and those on the outer lane of the through roadway. To determine the number of entering vehicles per hour that can merge with traffic on the highway it is necessary to deduct from this hourly capacity value the through vehicles per hour occupying the lane adjacent to the



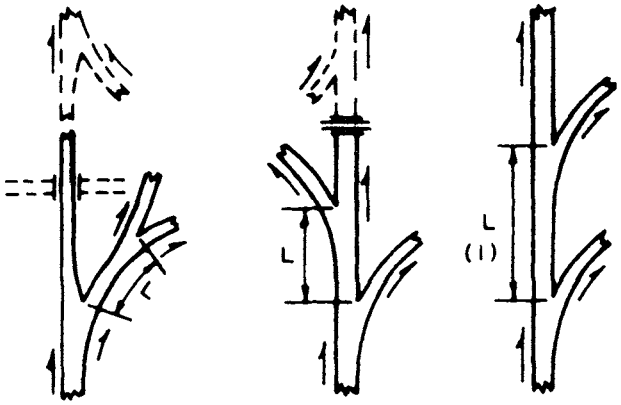
HORIZONTAL CONTROL



VERTICAL CONTROL

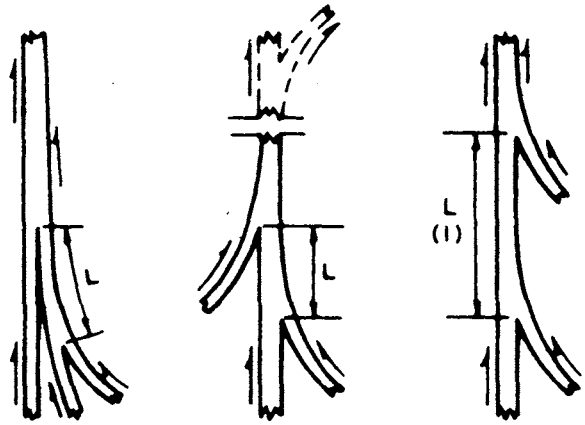
SIGHT DISTANCE AT RAMP TERMINALS WITH STOP CONTROL

FIGURE 5-K



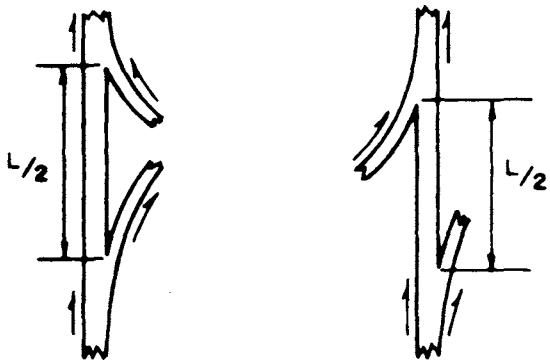
SUCCESSIVE EXIT TERMINALS

-1-



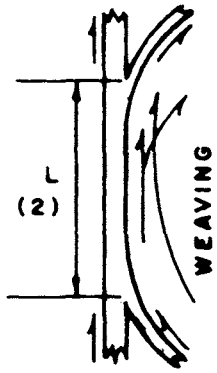
SUCCESSIVE ENTRANCE TERMINALS

-2-



EXIT TERMINAL FOLLOWED BY ENTRANCE TERMINAL

-3-



ENTRANCE TERMINAL FOLLOWED BY EXIT TERMINAL

-4-

(1) L AS IN TABLE BUT NOT LESS THAN LENGTH REQUIRED FOR SPEED-CHANGE LANE AS PER TABLES 4-7 AND 4-8

(2) L AS IN TABLE BUT NOT LESS THAN LENGTH REQUIRED FOR WEAVING MANEUVER. SEE SECTION 5-04.08

DISTANCE BETWEEN SUCCESSIVE RAMP TERMINALS

DESIGN SPEED (MPH)	30 OR LESS	40 TO 50	60 OR 70
AVG. RUNNING SPEED (MPH)	23 TO 28	36 TO 44	52 TO 58
DISTANCE L (METERS)			
MINIMUM	65	125	155
DESIRABLE	125	215	275

SUCCESSIVE RAMP TERMINALS

FIGURE 5-L

ramp and to adjust for the proportions of trucks involved. The method of computation is shown in Table 5—6.

As indicated in Table 5—6, the HCM provides equations and nomograph charts for estimating the volume (V^1) of through traffic in the lane adjacent to the ramp which is dependent on a number of variable roadway and traffic conditions. However, the previously mentioned FHWA publication RD—74—24 provides simplified techniques and graphic solutions that facilitate these computations.

3. EXIT TERMINAL (Free-flow)

The design capacity of combined through and exiting traffic at a single-lane exit terminal is about 1,300 passenger cars per hour for rural conditions and 1,600 for urban and suburban areas. The computation for the design capacity of the ramp exit is shown in Table 5—7. As in the case of entrance terminals, the volume V^1 is obtained from equations and nomograph charts in the HCM but FHWA publication RD—74—24 provides simplified techniques and graphic solutions.

4. CONTROLLED TYPE TERMINALS

Ramp terminals of the controlled type are in effect an intersection at-grade and their capacity is evaluated on the same basis. See Chapter 4.

5—04.08 WEAVING SECTIONS

Weaving is the crossing of traffic streams moving in the same general direction accomplished by merging and diverging. A weaving section is a length of one-way roadway at one end of which two one-way roadways merge and at the other end of which they separate.

Basic types of weaving sections are illustrated in Figure 5—M. They may be simple as in Figure 5—M(1), an entrance ramp followed by an exit ramp, or they may be multiple as in Figure 5—M(2), an entrance ramp followed by two or more successive exit ramps. Simple and multiple weaving sections may be further subdivided into those in which weaving takes place on only one side of the roadway, as in Figure 5—M(3), and those that require weaving across the through traffic flow and entail maneuvers on both sides, as in Figure 5—M(4).

Weaving sections often result in simple layouts and economies in interchange design. However, large volumes of weaving movements result in considerable friction and reduction in speed of traffic. There is a definite limit to the amount of traffic that can be handled by a given wearing section without congestion.

Weaving sections should be designed, checked and adjusted so that the design capacity is at least as great as the design hourly volume. The design capacity of a wearing section is dependent on its length, number of lanes, the acceptable degree of congestion, and the relative volumes of individual movements.

The level of service and capacity of a weaving section are a function of the number of lanes and the length of the weaving section. Both length and number of lanes requirements must be met in the design of a weaving section. The two are interrelated and linked by the weaving intensity factor K.

The needed number of lanes, N, is determined by the use of the equation shown in Figure 5—N. Both the length of the weaving section and the weaving traffic are known from the initial design data. From these two variables the weaving influence factor K is obtained using the chart in Figure 5—0. It should be noted that in using this chart the total weaving traffic must be expressed in terms of equivalent passenger cars per hour.

TABLE 5-5

DESIGN CAPACITY OF RAMP PROPER													
Design Condition	T % Truck During Peak Hour	Ramp Service Volume (vph) — Single-Lane Operation											
		Design Speed 20 mph or less			Design Speed 25 mph			Design Speed 30-40 mph			Design Speed 50 mph or more		
		Rate of Upgrade—%			Rate of Upgrade—%			Rate of Upgrade—%			Rate of Upgrade—%		
		0-2	3-4	5-5+	0-2	3-4	5-5+	0-2	3-4	5-5+	0-2	3-4	5-5+
Service Level B	0	800	800	800	1000	1000	1000	1100	1100	1100	1200	1200	1200
	10	720	670	610	910	830	770	1000	920	850	1090	1000	920
	20	670	570	500	830	720	620	920	780	690	1000	860	750
	30	610	500	420	770	620	530	850	690	580	920	750	630
Service Level C	0	1000	1000	1000	1250	1250	1250	1400	1400	1400	1500	1500	1500
	10	910	830	770	1140	1040	960	1270	1170	1080	1360	1250	1150
	20	830	720	620	1040	890	780	1170	1000	870	1250	1070	940
	30	770	620	530	960	780	660	1080	880	740	1150	940	790

Adapted from FHWA Report on "Capacity Analysis Techniques For Design and Operation of Freeway Facilities"— 1974

NOTES:

1—For loops having design speeds under 40 mph reduce ramp capacity by 20%.
2—For downgrades use same values as for 0—2% upgrade.
3—For 2—lane ramps multiply tabular values as follows: 1.7 for 20 mph or less, 1.8 for 25 mph, 1.9 for 30—40 mph; and 2.0 for 50 mph or more.
4—To approximate possible capacity (Service Level E) multiply values for Service Level C by 1.25.

TABLE 5-6

CAPACITY OF RAMP ENTRANCE TO HIGHWAY (Merging)
A. SINGLE-LANE — with acceleration lane (Figure 5-I) Rural: $C = \frac{1200 - V_1 (1 + t_1)}{1 + t}$ Urban: $C = \frac{1500 - V_1 (1 + t_1)}{1 + t}$ Where C = design capacity, vph from the ramp V_1 = volume of through traffic in lane adjacent to ramp, vph t_1 = truck as a percentage of total through volume t = trucks as a percentage of entering volume See Highway Capacity Manual for procedure to estimate V_1 for various roadway and traffic conditions.
B. SINGLE-LANE ENTRANCE — with right lane from ramp continued onto highway beyond ramp as an added lane on highway. Capacity is that of single lane on ramp proper.
C. TWO-LANE ENTRANCE — major fork design with right lane from ramp continued onto highway beyond ramp as an added lane on highway, and ramp of adequate width to discharge two lanes of vehicles. C = sum of capacities of the two lanes — Right lane, use single-lane capacity on ramp proper. Left lane, use expression A above.

NOTE: Capacity of ramp entrance may also be governed by the capacity of the highway beyond the ramp; i. e., the v combines volume of entering and through traffic should not exceed the capacity of the highway section used ahead. This type of check should always be made.

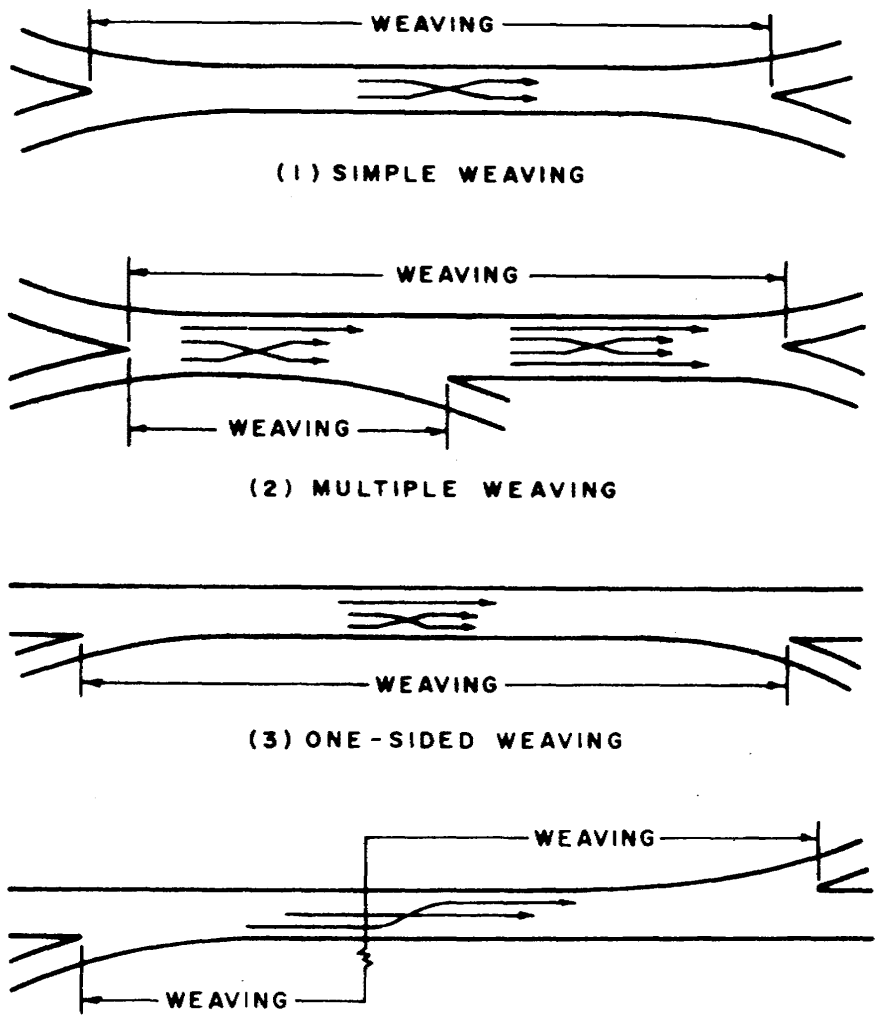
TABLE 5-7

CAPACITY OF A RAMP EXIT FROM HIGHWAY (Diverging)
A. SINGLE-LANE EXIT — with deceleration lane (Figure 5-H) Rural: $C = \frac{1300 - V_1 (1 + {}^{t}1)}{1 + t}$ Urban: $C = \frac{1600 - V_1 (1 + {}^{t}1)}{1 + t}$ Where C = design capacity, vph to the ramp V_1 = Volume of through traffic in lane adjacent to ramp, vph ${}^{t}1$ = trucks as a percentage of through volume t ≡ trucks as a percentage of ramp volume See Highway Capacity Manual for procedure to estimate V_1 for various roadway and traffic conditions.
B. SINGLE-LANE EXIT — with outer lane of highway continued onto ramp and number of lanes on highway reduced beyond ramp. Capacity is that of single lane on ramp proper.
C. TWO-LANE EXIT — major fork design with outer lane of highway continued onto ramp and the ramp of adequate width to receive two lanes of vehicles. Capacity of right lane as in B above. Capacity of left lane as in A above.

The curves in Figure 5—0 are numbered (roman numerals) to indicate the quality of flow which can be correlated to the level of service. Table 5—8 indicates the relationship between quality of flow curves and level of service for various types of highway facilities.

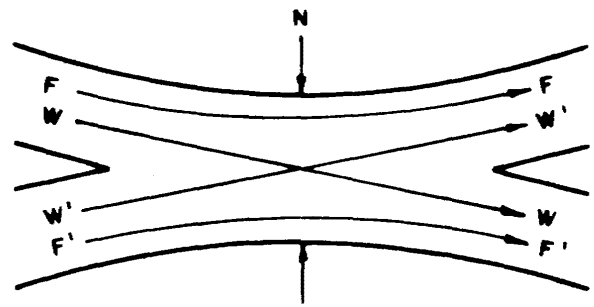
The value of C, capacity per lane in vehicles per hour on approach and exit roadways, for use in the equation for computing number of lanes can be obtained from the capacity tables included in Chapter 1 for the corresponding facility. For C—D roads a capacity of 1,200 to 1,500 equivalent passenger cars per hour may be used.

As an example on the use of the chart in Figure 5—0 assume a proposed simple weaving section on a freeway having a length of 640 meters and a total weaving volume (W+W') of 1,600 equivalent passenger cars per hour. The value of K is determined from the chart by entering a vertical line from an L=640 meters to intersect a horizontal line of W+W' = 1,600 and reading 2.7, interpolating between the 2.6 and 2.8 curves. This K value is then used in the equation to determine N. To check the minimum lentgh L of weaving section required, the horizontal line at a W+W' value of 1,600 is extended to where it crosses Curve III and an L value of 300 meters is read. This would be the minimum length of weaving section required in this example to maintain a service level of C.



BASIC TYPES OF WEAVING SECTIONS

FIGURE 5-M



$$N = \frac{W + KW' + F + F'}{C}$$

$$\text{or} \quad N = \frac{V + (K-1)W'}{C}$$

N – NUMBER OF LANES NEEDED

W – LARGER WEAVING VOLUME, VPH

W' – SMALLER WEAVING VOLUME, VPH

F, F' – OUTER FLOWS, VPH

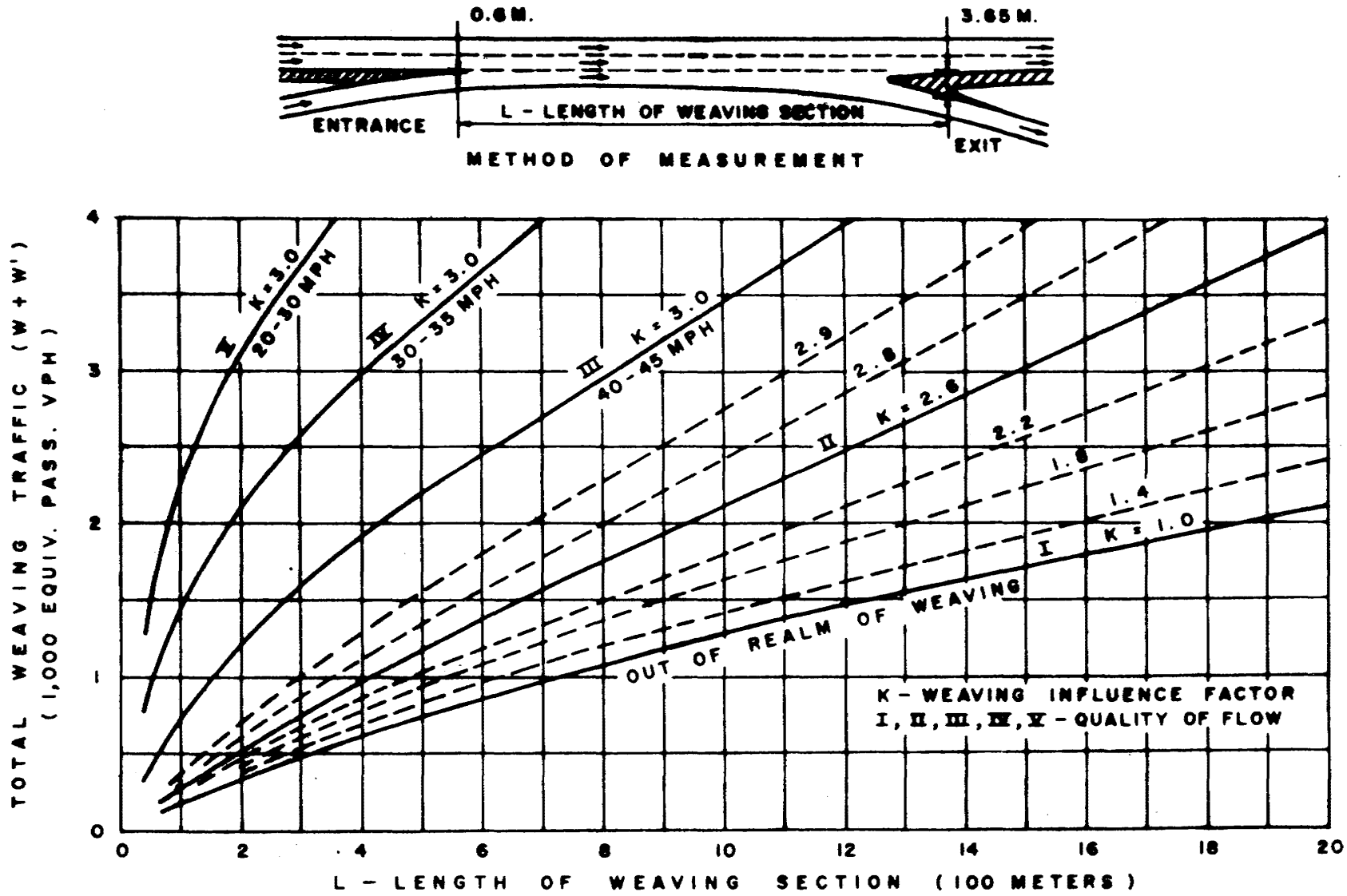
V – TOTAL VOLUME (F + F' + W + W')

C – CAPACITY PER LANE ON APPROACH AND EXIT ROADWAYS

K – WEAVING INFLUENCE FACTOR

WEAVING SECTIONS
DETERMINATION OF NUMBER OF LANES

FIGURE 5-N



WEAVING SECTIONS - OPERATING CHARACTERISTICS

FIGURE 5-0

Analysis of multiple weaving sections involves a more complex operation. These are discussed in the Highway Capacity Manual and in the FHWA Report RD—74—24.

The location of the terminal points for measuring the length of weaving section L is illustrated in Figure 5—0. Details of a typical weaving section at a cloverleaf interchange are illustrated in Figure 5—P.

TABLE 5-8

WEAVING SECTIONS
RELATIONSHIP BETWEEN LEVEL OF SERVICE AND QUALITY OF FLOW

Level of Service	Quality of Flow (1)			
	Freeways and Multilane Rural Highways		Two-lane Rural Highways	Urban, Suburban Arterials
	Highway Proper	C-D Roads and Interchanges		
A	I - II	II - III	II	III - IV
B	II	III	II - III	III - IV
C	II - III	III - IV	III	IV
D	III - IV (3)	IV (3)	IV	IV
E (2)	IV - V (3)	V (3)	V (3)	V (3)

NOTE: (1) See Figure 5-0. When two entries are shown, that on left is desirable, that on right is minimum. For two-sided weaving use left entry.
(2) Capacity operation.
(3) Not normally considered for design.

5—04.09 COLLECTOR-DISTRIBUTOR ROADS

A collector-distributor road is an auxiliary roadway parallel to and separated from the main highway which serves to collect and distribute traffic from several points of ingress and egress. The C—D road eliminated weaving and reduces turbulence on the through roadway thereby increasing its capacity, safety and operating speed. C—D roads may be provided within a single interchange, as illustrated in Figure 5—Q, through two adjacent interchanges or in urban areas continous through several interchanges. They do not allow access to abutting properties as in the case of frontage roads.

The C—D road exit and entrance terminals at the freeway are designed similar to ramp terminals. The C—D road itself is designed similar to a ramp with the pavement width depending on capacity and weaving requirements. They normally have a design speed of 20 mph less than the through lanes.

5—05 LANE BALANCE

For efficient and safe traffic operation through and beyond an interchange, there should be a balance in the number of traffic lanes on the highway and ramps. The basic number of lanes should be established for a substantial length of the freeway on the basis of design traffic volumes and a capacity analysis. This basic number of lanes should have continuity and not be changed between successive pairs of interchanges because there are substantial volumes of traffic entering and leaving. These variations in traffic demand should normally be handled through the use of auxiliary lanes as needed.

Once the number of basic lanes for each roadway has been determined the balance in the number of lanes should be checked applying the following principles:

1. The number of lanes beyond the merging of two traffic streams should not be less than the sum of all traffic lanes minus one.

2. Where an entrance brings two lanes of traffic into a highway, the highway beyond the ramp entrance should be at least one lane wider than before the entrance.

3. Where an exit require two lanes, the number of lanes on the highway should be reduced by one lane downstream from the ramp exit. However, this reduction should be accomplished through the use of an adequate auxiliary lane to effect the transition. Abrupt ending of a through lane at an exit must be avoided. The exception is here a major fork is designed such as at a freeway-to-freeway interchange.

4. The highway traveled way should be reduced by no more than one traffic lane at a time except at a major fork.

In applying the above principles of lane balancing care must be exercised to avoid conflict with the concept of continuity of the basic number of lanes. By building upon the basic number of lanes through the use of auxiliary lanes as exits and entrances, the balance between traffic load and capacity is provided and needed operational flexibility attained.

5—06 ACCESS CONTROL

There should be control of access along the full lenght of all ramps, including speed-change lanes at the crossroad ramp terminals, to insure safety and free flow of traffic. It is also desirable to obtain control of access on the crossroad for a distance of at least 30 meters and preferably a 100 meters from the beginning or end of a speed-change lane. When the ramp terminal at the crossroad is of the controlled type, the minimum requirements on access control for intersections at grades covered in Section 4—09 shall apply. However, if economically feasible the access control should be extended a distance of 30 to 60 meters from the beginning or end of the turning radius returns.

Special care must excercised in the location of accesses to major traffic generators existing or proposed in the vicinity of an interchange such as large industrial plants and shopping centers. The location of these accesses should be based on traffic studies and design analyses to prevent interference with the interchange operation.

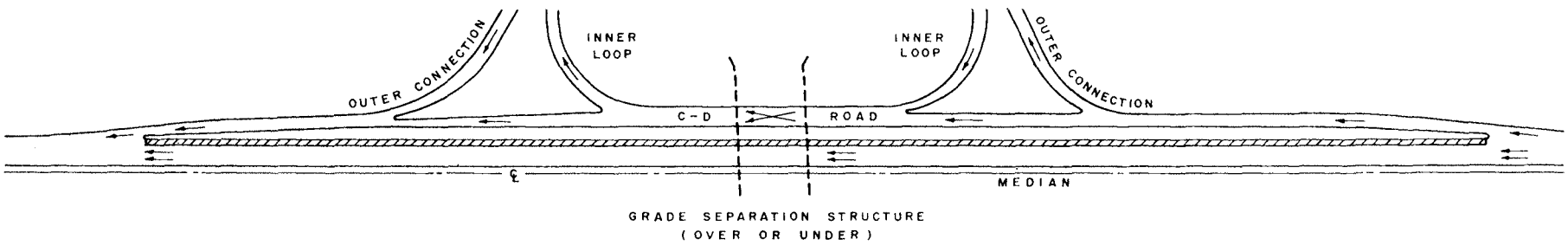
5—07 GRADING PLAN

A grading plan shall be prepared for each interchange area to correlate all elements of the design. The plan shall show the control lines, pavement edges, curbs, structures, drainage inlets, ditches, etc. in sufficient detail to make clear the design. In addition it shall show existing and proposed contour lines at a contour interval of 0.5 meters or less, and finished pavement elevations spaced at no more than 6-meter intervals and adequately tied to stations on the control lines. See Chapter 19.

5—08 APPLICABILITY OF INTERCHANGE TYPES

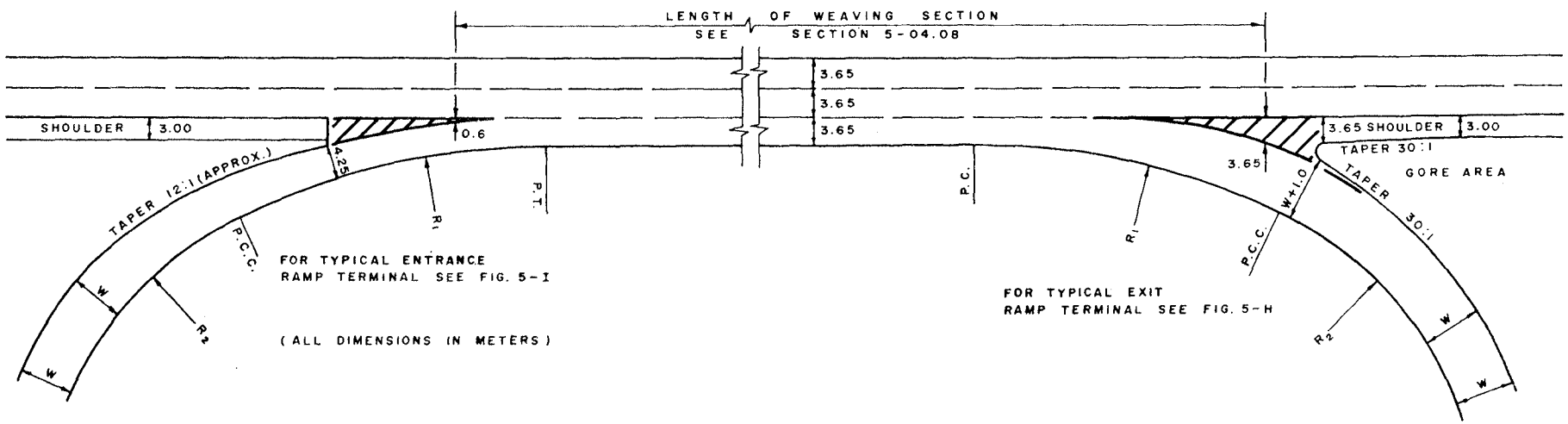
1. DIAMOND

The diamond interchange, Figure 5—A, has a wider range of application than any other type for four-leg designs. It may be used with crossroads carrying low to intermediate traffic volumes. However, with increasing volumes it can have serious operational problems because of the at-grade intersections and left turns at the crossroad terminals. Capacity can be increased by the addition of storage lanes on the ramps and appropriate channelization at the crossroad terminals.



COLLECTOR - DISTRIBUTOR ROAD AT CLOVERLEAF INTERCHANGE

FIGURE 5-Q



TYPICAL WEAVING SECTION AT CLOVERLEAF INTERCHANGE

FIGURE 5-P

For urban areas it is the simplest and most common type of interchange as the controlled ramp terminals are compatible with interrupted street flow and can be designed with slip ramps connecting to frontage roads parallel to and close to the main facility. It can be developed within a relatively narrow right-of-way and is normally the least expensive of the interchange types.

2. FULL CLOVERLEAF

The full cloverleaf interchange, Figure 5—C, is applicable at the intersection of an expressway or freeway with another expressway or major multilane facility carrying large volumes of free-flow traffic. They are not desirable for freeway to freeway interchanges because of the comparatively low design speeds of the loops. They are not warranted at 2-lane cross-roads because left turns can ordinarily be made at intersections at grade. They also are not apropiate at the intersection with a major multilane urban street which has signal control for at-grade intersections within a short distance of the ramp terminals.

The cloverleaf has the disadvantage of the weaving operations involved between the entrance and exit loop ramp terminals. However, their operating efficiency and capacity can be substantially increased by the addition of C—D roads. Another disadvantage of the cloverleaf is that it requires considerably more right-of-way than a diamond and some directional types.

3. PARTIAL CLOVERLEAF

Partial cloverleaf interchanges of the two-quadrant type, Figure 5—D, are applicable for the same range of traffic volumes and types of facilities as the diamond interchange. They are used at locations where cultural or natural features restrict the development of a diamond type.

A partial cloverleaf interchange with two free-flow loops in opposite quadrants and diagonal ramps in all four quadrants may be used to attain higher capacity than a diamond by providing high-speed entrance and exits from the freeway, and eliminating left-turn movements at the crossroad. However, substantially more right-of-way is required.

4. TRUMPET

The trumpet interchange, Figure 5—B, is used at three-leg intersections but it is generally limited to low an intermediate traffic volumes because the low-speed loop ramp should normally be designed for one-lane operation. Trumpet interchanges are used at the intersections of non-controlled-access roads or streets with an expressway or freeway. When the intersecting highway is of major importance and serves large volumes, a directional type interchange should be used.

5. DIRECTIONAL

Directional interchanges with semidirect or direct connections accommodating the heaviest turning movements are normally used at freeway intersections with other freeways or with major multilane highways with high traffic volumes and turning movements. The direct and semidirect connections, as compared with loops, have shorter travel distance, higher operating speeds, higher capacity, and often eliminate weaving operations. Direct connections should be avoided because they involve left-hand exits and entrances unless major fork criteria applies to the terminal design.

Right-of-way requirements for directional interchanges are generally similar to or smaller than for cloverleaf. However, construction costs are normally substantially higher than for any other type of interchange because of the multiple long span or multi-level structures required.

5—09 DESIGN PROCEDURE

The AASHTO Policy on Geometric Design of Rural Highways includes a detailed intersection design procedure, including example problems, which should be used as a guide in developing an interchange design. The procedure assures complete coverage of all aspects but avoids needless refinements in the preliminary study stages. The procedure is summarized into twelve basic steps as follows:

A. Basic data for design

1. Obtain and analyze traffic data to determine design hour volumes for all through and turning movements.
2. Obtain physical data for the site including topographic maps showing all existing and proposed development.
3. Determine the location, type and general design features of all highways in the area, both existing and planned, which may have a bearing on the design.

B. Preliminary design

4. Prepare study sketches for several layouts that are suitable for the traffic needs and practical for the site and design controls.
5. Analyze alternative schemes and select two or more for further study.
6. Prepare preliminary plans and profiles for the alternatives selected.
7. Prepare preliminary signing layout and location plans for each alternate to insure that it can be properly signed.

C. Selection of preferred plan

8. Evaluate each alternate with respect to the highway design and the environmental effects. Consider capacity vs. volume, operational characteristics, adequate signing, overall adaptability, maintenance of traffic during construction, suitability to stage construction, right-of-way requirements, persons and businesses to be relocated, jobs eliminated, effect on local transportation network, and other pertinent factors.
9. Make preliminary estimates of cost for each alternate.
10. Calculate annual road user costs and road user benefit ratios for each alternate.
11. Analyze steps 8, 9 and 10 jointly to arrive at a recommended plan.

D. Final Design

12. Prepare construction plans after all the steps required by the Action Plan concerning environmental evaluation, public hearings and preliminary design approval have been completed and the final design authorized.

5—10 GENERAL DESIGN CONSIDERATIONS

In the design of an interchange the following general principles should be taken into consideration in addition to the specific design requirements on the various interchange elements previously discussed.

1. A uniform pattern of interchange geometric layouts should be maintained, to the maximum extent possible, throughout a freeway or expressway route to avoid driver confusion.

2. Design for a minimum of weaving since weaving sections reduce speed, capacity and safety. Whenever possible remove weaving to C—D roads and frontage roads.

3. Try to have no more than one exit in each direction of travel on a freeway at the interchange to reduce the driver decisions required on the high speed facility. Again, C—D roads can help by transferring the second decision to the lower speed C—D roadway.

4. Avoid left hand exists and entrances. This does not apply to a major fork design.

5. Try to have exits precede entrances to avoid main line weaving and reduce congestion.

6. Try to design all entrances for one lane operation. When traffic volumes exceed the capacity of a one-lane entrance, consider providing two one-lane entrances rather than a two-lane entrance provided they can be maintained at least 300 meters apart.

7. Avoid designing ramps for minimum speeds and use desirable values whenever possible to reduce the magnitude of the speed changes at the ramp terminals on the freeway or expressway.

8. Full pavement structures should be provided on accel/deceleration lanes and auxiliary lanes.

CHAPTER 6

BRIDGES

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CHAPTER 6

BRIDGES

6—01 GENERAL

This chapter covers design policies and criteria for bridge structures including bridges over waterways and grade separation structures (overpasses and underpasses) but excluding pedestrian bridges which are covered in Chapter 15. By AASHTO definition a bridge is a structure having an opening measured along the center of the roadway of more than 6.1 meters (20'). Culverts, which are structures with clear openings of 6.1 meters or less, are discussed in Chapter 11.

6—02 DESIGN CRITERIA

The current edition of the AASHTO "Standard Specifications for Highway Bridges", as suplemented by this Manual and the directives and guides issued by the Design Area and its Structural Design Office covers the basic criteria and allowable factors governing bridge designs for the Department.

The general bridge design standards for the various highway design classes are included in Tables 6—1 (Rural) and 6—2 (Urban). These general bridge standards complement the general highway design standards given in Tables 1—11 through 1—15 of Chapter 1.

6—02.01 CONCRETE DESIGN

1. CONCRETE (Non-Prestressed)—Design on the basis of an ultimate cylinder compressive strength at 28 days of 4,000 psi. (Class A 4) for bridge deck slabs and 3,000 psi. (Class A) for all other members. Design prestressed concrete members as per 6—02.02.

2. REINFORCING STEEL—Design on the basis of Grade 60 with a yield strength of 60,000 psi.

3. LOAD FACTOR DESIGN—Do not use except with the prior approval of the Structural Design Office.

6—02.02 PRESTRESSED CONCRETE

1. BEAM SHAPES—Use standard AASHTO sections unless another type of section can be justified and specific prior approval is obtained from the Structural Design Office.

2. CONCRETE—Design for a compressive strength of 5,000 psi at 28 days. Design for compressive strength at time of stress transfer of 4,000 psi except for beam types V and VI for which 4,500 psi should be used.

NOTES – TABLES 6—1 AND 6—2

(1) For ramp widths see Chapter 2 and Table 2—2.

(2) Medians 9.0 M. or less in width shall normally be covered unless special conditions require separate structures. Dual structures will be used where the median width exceeds 9.0 meters. See Figure 6—A.

(3) These are highway over highway clearances. Use a minimum clearance above highway of 5.25 M. for overhead signs and pedestrian overpasses, see Chapters 9 and 15 respectively. Above private industrial railroads, provide minimum vertical clearances as agreed upon with owners. See Section 6—02.08.

TABLE 6-1

GENERAL BRIDGE DESIGN STANDARDS – RURAL HIGHWAYS

DESIGN CLASS		EXPRESSWAYS					OTHER ARTERIALS AND COLLECTORS				LOCAL ROADS		
		RE-1	RE-2	RE-3	RE-4	RAMPS	R-5	R-6	R-7	R-8	R-9	R-10	R-11
TRAVELED WAY WIDTH		2 AT 10.95	2 AT 7.30	2 AT 7.30	7.30	VAR.(1)	2 AT 7.30	7.30	6.70	6.10	6.10	6.10	6.10
MIN. MEDIAN WIDTH(2)		9.0	9.0	6.0	—	—	6.0	—	—	—	—	—	—
SHOULDER WIDTH	RIGHT	3.0	3.0	3.0	3.0	VAR.(1)	3.0	3.0	2.4	1.8	1.8	1.8	1.8
	LEFT	1.8	1.2	1.2		VAR.(1)	1.2						
RAIL OFFSET FROM OUTSIDE EDGE OF SHOULDER	RIGHT	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
	LEFT	0.6 IF DUAL STRUCTURES(2)				0.6	0.6(2)						
MIN. BRIDGE WIDTH F.-F. OF RAILINGS	SINGLE	38.10	30.80	27.80	14.5	VAR.(5)	27.80(4)	14.50	12.70	10.90	10.90	10.90	10.90
	DUAL(2)	16.95 EA.	12.70 EA.	12.70 EA.			12.70 EA.						
MIN. VERTICAL CLEARANCE		4.95(3)								4.40(3)			
HORIZONTAL CLEARANCES AT UNDERPASSES		SEE FIGURES 6-D AND E			FIG. 6-F	FIG. 6-G	FIGS. 6-D & E	FIG. 6-F			FIG. 6-G		
DESIGN LIVE LOAD		HS 20-44									HS 20-44		
MIN. DESIGN FLOOD FREQ.(7)		100 YR.(6)									100 YR.(8)		
MIN. CLEAR. ABOVE DESIGN H.W.		0.60 FOR 100 YR., 0.30 FOR GREATER FLOODS(9)									0.60(10)		

ALL DIMENSIONS IN METERS. FOR NUMBERED NOTES REFER TO PAGE 6-4.

TABLE 6-2

GENERAL BRIDGE DESIGN STANDARDS - URBAN HIGHWAYS

DESIGN CLASS		EXPRESSWAYS						AVE-NUES	PRINCIPAL STREETS		LOCAL STS.	
											COMM.	RES.
		UE-1	UE-2	UE-3	UE-4	UE-5	RAMPS	U-6	U-7	U-8	U-9	U-10
PAVEMENT WIDTH		2 AT 14.60	2 AT 10.95	2 AT 7.30	2 AT 10.95	2 AT 7.30	VAR.(1)	2 AT 11.00	2 AT 7.30	14.60	8.0-12.0	8-11.0
MIN. MEDIAN WIDTH(2)		6.6	5.4	4.2	6.0(11)	6.0(11)	—	6.0(12)	4.25(12)	—	—	—
SHOULDER WIDTH	RIGHT	3.0	3.0	3.0	3.0	3.0	VAR.(1)	—	3.0 PARK. LANE(13)	3.0 PARK. LANE(13)	—	—
	LEFT	3.0	2.4	1.8	—	—	VAR.(1)					
SIDEWALK WIDTH(14)		—	—	—	—	—	—	4.0	3.0	2.5	2.5	2.5
RAIL OFFSET FROM OUTSIDE EDGE OF SHOULDER	RIGHT	0.6	0.6	0.6	0.6	0.6	0.6	SIDEWALK WIDTH				
	LEFT	0.6 IF DUAL STRUCTURES(2)			COVERED MEDIAN		0.6	COVERED MEDIAN		—	—	—
MIN. BRIDGE WIDTH F.-F. OF RAILINGS	SINGLE	43.0(4)	34.5(4)	26.0(4)	35.1(4)	27.8(4)	VAR.(5)	36.0(15)	30.85(15)	25.60(15)	13.5-17.0(15)	13.0-16.0(15)
	DUAL(2)	21.8 EA.	17.55 EA.	13.3 EA.								
MIN. VERTICAL CLEARANCE		4.95(3)									4.40(3)	
HORIZONTAL CLEARANCES AT UNDERPASSES		SEE FIGURES 6-D AND E					FIG. 6-G	FIGURE 6-H				
DESIGN LIVE LOAD		HS 20-44										HS 20-44
MIN. DESIGN FLOOD FREQ.(7)		100 YR.(6)										
MIN. CLEAR. ABOVE DESIGN H.W.		0.60 FOR 100 YR., 0.30 FOR GREATER FLOODS(9)										

ALL DIMENSIONS IN METERS. FOR NUMBERED NOTES REFER TO PAGE 6-4.

(4) These widths are based on a covered median of standard minimum width. However, the bridge median width shall match that on aproach roadway and the required bridge width shall be determined accordingly.
(5) Required ramp width plus a minimum clearance of 0.6 M. to bridge railing on each side. See Figure 6—B.
(6) Greater historial floods may be considered if economically feasible and whenever a similar flood would cause extensive damage to adjoining property or the loss of a costly structure.
(7) For definition and application see Section 6—02.05.
(8) On low volume R—10 and R—11 design class roads encroaching on flood plains, lower design flood frequencies may be warranted by economic considerations provided that the 100-year flood can be conveyed over the highway and structures without causing significant damage to the structures and to existing or reasonably anticipated future development upstream or downstream.
(9) The designer should excercise his judgment and assume both buoyancy forces and current pressure at the deck, specially whenever a clearance under 0.60 meters is provided.
(10) May be reduced to 0.30 M. in special cases covered under Note (8) above and for greater floods.
(11) Raised median normally used with curb offset from through lanes. See Figure 2—G.
(12) Raised median, see Figure 6—C.
(13) If provided on approach roadways, see Figure 2—H. May be omitted on long bridges even if provided on approaches.
(14) Sidewalk widths may be reduced in special cases but to not less than 1.5 meters.
(15) These width are based on normal cross sections. However, when a reduction in sidewalk width and/or elimination of parking lane is authorized, the bridge width will vary accordingly. See Figure 6—C.

6—02.03 EARTHQUAKE STRESSES

Design for Seismic Zone 3 requirements using the latest AASHTO criteria.

6—02.04 EARTH PRESSURE

Structural elements which retain fills, such as abutments and wingwalls, shall be designed for earth pressures as recommended by soils study but in no case less than an equivalent fluid pressure of 35 pounds per cubic foot.

6—02.05 DESIGN FLOOD FREQUENCIES

The term "design flood" means the peak discharge, volume (if appropriate), and stage or wave crest elevation of the flood associate with the frequency interval selected for the design. It is necessary to make an evaluation, using the 100-year flood or the maximum flood or record, whichever is greater, of the flood hazard to other property, stream stability, and the stream and flood plain environment.

In any case, the overall design must permit the conveyance of the 100-year or greater floods without increasing flood heights or velocities to an extent which would cause significant damage to upstream or downstream existing or reasonably anticipated future development.

6-02.06 BRIDGE CROSS SECTIONS

Bridge cross sections for the various design classes of highway are illustrated in Figures 6—A, B and C. The basic criteria is to provide a bridge section that matches the approach highway traveled way and shoulder widths plus a clearance of 0.6 meter to the bridge railings or parapets on structures without sidewalks.

On urban highways with sidewalks, the full sidewalk width plus planting strip width, if any, will normally be carries on the bridge section. However, in the case of undivided principal (U-8) and local (U-9, 10) streets with light pedestrian traffic, the bridge sidewalk width may be reduced by eliminating the planting strip width but in no case to less than 1.5 meters.

On some urban bridges serving large pedestrian volumes adjacent to highspeed roadways it is desirable to physically separate the pedestrian from the vehicular traffic by providing a parapet between the roadway and the sidewalk. These special cases are discussed in Chapter 8.

When an auxiliary lane with a partial shoulder is carried across the structure, the bridge rail may be placed at the outside edge of the partial shoulder without the additional offset of 0.6 M. provided that the bridge section is consistent with that on the approaches to provide roadway continuity.

6-02.07 HORIZONTAL CLEARANCES AT UNDERPASSES

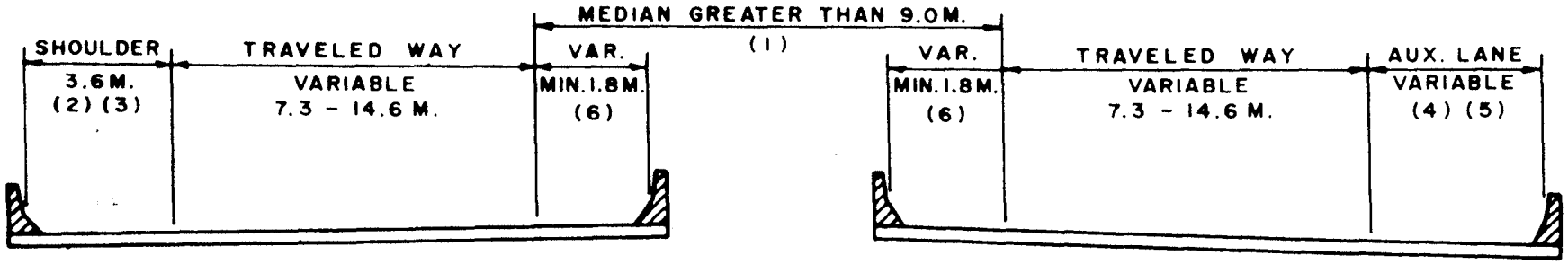
The basic principle in designing structures over highways is to normally provide for the entire roadway section of the underpassing highway including the traveled way, median, shoulders and clear recovery area. The normal minimum underpass clearances for the various highway design classes are illustrated in Figures 6—D through 6—H.

Underpasses for expressways and other highways with design speeds of 50 mph or greater, shall normally provide a horizontal clearance between the right edge of through pavement and adjacent pier or abutment of at least 9.0 meters. Exception to this policy may be made when the approach roadway is restricted and does not itself provide a 9.0 M. clear recovery area due to right-of-way or other physical considerations. In such cases there shall be continuity between the lateral clearances on the approaches and those at the underpass with a minimum of 4.2 M. normally provided to accommodate the full shoulder and guardrail or concrete barrier protection. Exception may also be made for extreme skew crossings where the 9.0 M. right side clearance would result in very long spans or in very high unit cost structures but in no case shall the clearance be less than 4.2 meters.

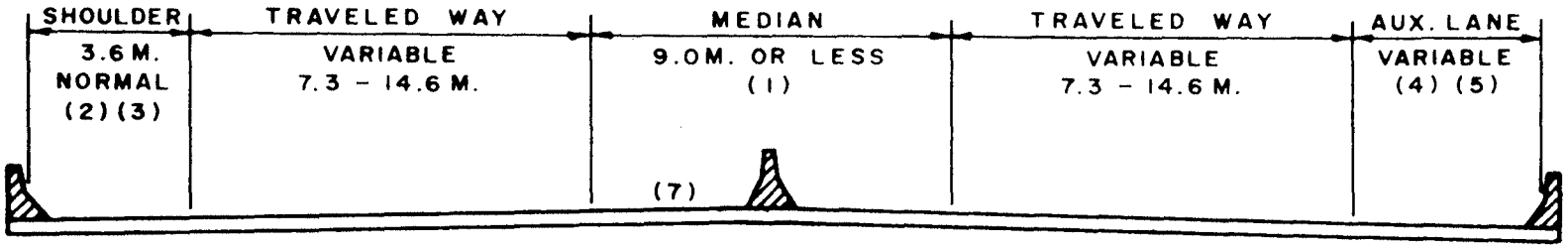
Figure 6—I illustrates typical treatment of the side slopes at underpasses. By careful slope transitioning and design of drainage facilities it is possible to provide a clear recovery area with traversable side slopes at underpasses on high speed highways without unduly lengthening the spans. It is desirable that whenever possible the back slope to the side pier or abutment not exceed 3:1.

Auxiliary lanes may be accommodated within the 9.0 M. right side clear space except for high-speed (50 mph or greater) auxiliary lanes which should be provided with 9.0 M. clearance from the right edge of the lane to pier or abutment. In no case shall this clearance be less than the width of the shoulder adjacent to the auxiliary lane plus 1.2 meters.

On divided highways with median widths of 6.0 M. or wider it is normally necessary to accommodate a pier in the median. In such cases the pier should be located at the center and preferable parallel to the underpassing roadway. The clearance from the left edge of the travel way to the pier should be no less than 2.4 meters and barrier protection provided. For structures over highways with narrow medians consideration should be given to a design without a median pier but maintaining the required minimum right side clearances.



DUAL STRUCTURES - OPEN MEDIAN



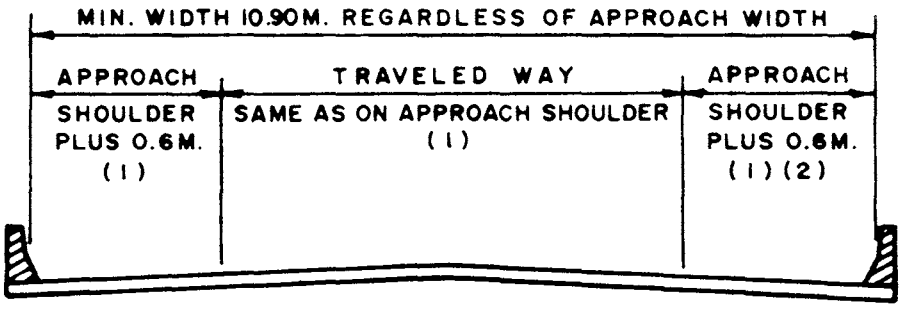
SINGLE STRUCTURE - CLOSED MEDIAN

NOTES:

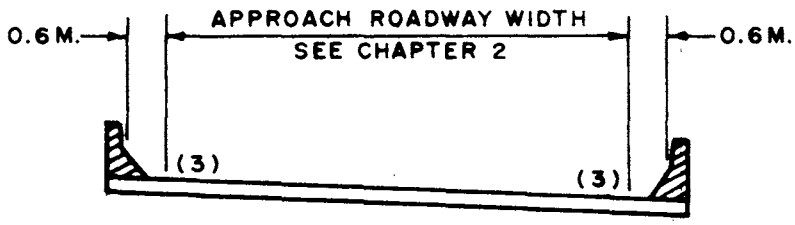
(1) MEDIAN WIDTH SAME AS ON APPROACH ROADWAY.
(2) APPROACH SHOULDER WIDTH PLUS 0.6 M. CLEARANCE TO UPPER FACE OF RAILING.
(3) IF AUXILIARY LANE PRESENT, TREAT AS IN (4).
(4) AUXILIARY LANE WIDTH PLUS APPROACH SHOULDER, IF ANY, BUT AT LEAST AUXILIARY LANE WIDTH PLUS 0.6M.
(5) IF NO AUX. LANE PRESENT, TREAT AS IN (2).
(6) SAME WIDTH AS INSIDE SHOULDER ON APPROACH ROADWAY PLUS 0.6M. CLEARANCE TO UPPER FACE OF RAILING.
(7) MEDIAN FLUSH WITH TRAVELED WAY SURFACE EXCEPT ON DESIGN CLASSES UE-4 AND 5. SEE CHAPTER 2.
* ALSO APPLICABLE TO OTHER DIVIDED MULTILANE RURAL HIGHWAYS.

BRIDGE CROSS SECTIONS - EXPRESSWAYS *

FIGURE 6-A



RURAL TWO-LANE ROADS



RAMP STRUCTURE

NOTES:

(1) SEE CHAPTERS 1 AND 2 FOR TRAVELED WAY AND SHOULDER WIDTHS FOR THE VARIOUS HIGHWAY DESIGN CLASSES.

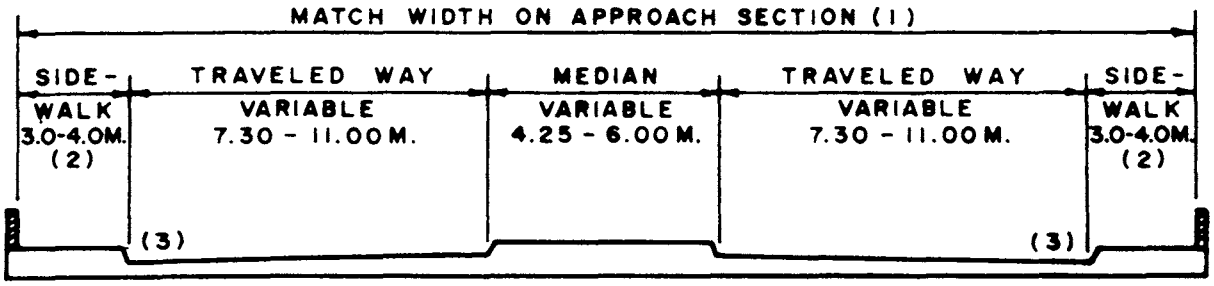
(2) IF AUXILIARY LANE PRESENT, USE AUXILIARY LANE WIDTH PLUS APPROACH SHOULDER WIDTH PLUS 0.6M. TO RAILING.

(3) IF APPROACH ROADWAY IS CURBED, ALIGN APPROACH CURB WITH BASE OF RAILING.

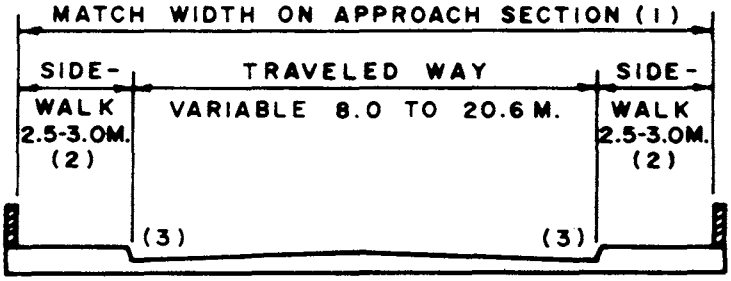
BRIDGE CROSS SECTIONS

RURAL TWO-LANE ROADS AND RAMPS

FIGURE 6-B



AVENUES AND DIVIDED PRINCIPAL STREETS



UNDIVIDED PRINCIPAL AND LOCAL STREETS

NOTES:

(1) SEE CHAPTERS 1 AND 2 FOR CROSS SECTION WIDTHS FOR THE VARIOUS HIGHWAY DESIGN CLASSES.

(2) SIDEWALK WIDTH MAY BE REDUCED IN SPECIAL CASES WHEN AUTHORIZED BY CENTRAL OFFICE BUT IN NO CASE TO LESS THAN 1.5 M.

(3) BARRIER CURB AS ON APPROACH ROADWAY.

BRIDGE CROSS SECTIONS
AVENUES, PRINCIPAL AND LOCAL STREETS

FIGURE 6-C

Figures 6—J and 6—K illustrate typical barrier installation where restricted right side or left side clearances require their use to shield piers or abutments. Details on barrier types, lengths, approach transitions, end treatments, etc. are discussed in Chapter 8.

6—02.08 VERTICAL CLEARANCE

The required vertical clearance for all new structures spanning the various highway design classes are given in Tables 6—1 and 6—2 and illustrated in Figures 6—D through 6—H.

The standard vertical clearance for new highway over highway structures is 4.95 meters except for design classes R—8, 9, 10, 11 and U-9, 10 for which a 4.40 M. clearance is normally provided. However, on some urban expressways and avenues a minimum clearance of 4.40 meters may be considered when there are alternate routes available for an occasional high body vehicle. Under urban conditions, the 0.55 M. difference between a 4.40 M. and a 4.95 M. clearance may represent a substantial reduction in cost.

6—03 GENERAL AND SPECIAL DETAILS

6—03.01 BEARINGS

Elastomeric bearing pads shall be used unless another type of bearing is justified or required and approval is obtained from the Structural Design Office. All superstructures shall be securely anchored to the substructure at both fixed and expansion ends unless otherwise herewith indicated. Except at stream crossings, anchorage may be omitted over continous supports if not required to resist uplift or to secure against horizontal crawling.

6—03.02 ATTACHMENT OF UTILITIES

Attachment of utilities to structures on controlled access highways is not permitted except in very special cases and on other highways should be avoided since such attachment can materially affect the structure, its apearance and its maintenance. When utility attachments to a structure is permitted, the installation must comply with the requirements of the DTPW "Policy on the Accommodation of Utilities on Highway Rights-of-Way" as supplemented by Chapter 13 of this Manual.

6—03.03 RAILINGS

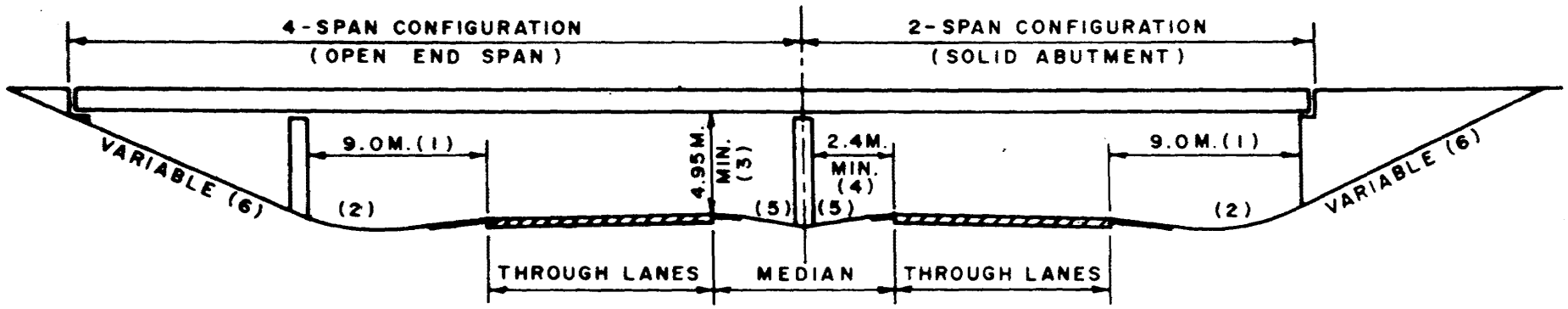
The typical railing types used by the Department are illustrated in Figure 6—L. On structures without sidewalks the standard railing is a sloped concrete parapet which follows the New Jersey barrier contour.

On bridges with sidewalks, a combination traffic-pedestrian railing is used. Two of the most commonly used types are illustrated in Figure 6—L, and all concrete type and another that combines a concrete parapet with single aluminum rail on top.

6—03.04 GUARD RAIL TIE TO BRIDGE PARAPET

The transition from an approach guard rail to a bridge parapet is a key safety element. A typical design of such transition is illustrated in Figure 6—M. In the design of these transitions the following items must be considered:

1. STRENGTH OF CONNECTION—At the connection point the attachment must have the strength of at least the strength of the weaker of the two barriers, usually the guard rail on the approach. In the case of the W-beam type commonly used in Puerto Rico, the connection should at least equal the tensile strength of the beam.



NOTES:

(1) A RESTRICTED MINIMUM CLEARANCE OF 4.2M. WITH GUARD RAIL PROTECTION MAY BE AUTHORIZED WHERE SPECIAL APPROACH OR SITE CONDITIONS MAKE A 9.0M. IMPRACTICAL. SEE FIG. 6-J.

(2) FOR TYPICAL SIDE SLOPE TREATMENTS SEE FIG. 6-I.

* (3) MINIMUM VERTICAL CLEARANCE TO BE PROVIDED OVER ENTIRE ROADWAY SURFACED WIDTH.

(4) FOR MEDIANS WIDER THAN 19.2M. USE 9.0M. MINIMUM CLEARANCE.
FOR MEDIANS UNDER 19.2M. PLACE PIER IN CENTER OF MEDIAN.
WHERE CONTINUOUS MEDIAN BARRIER IS PRESENT ON HIGHWAY, MIN. CLEARANCE MAY BE THE SAME AS ON HIGHWAY. SEE FIG. 6-K.

(5) USE GUARD RAIL OR BARRIER PROTECTION WHERE CLEARANCE IS UNDER 9.0M. SEE FIG. 6-K.

(6) VARIABLE SLOPE AS PER HIGHWAY SECTION, SEE CHAPTER 2. NORMAL MAXIMUM 2:1.

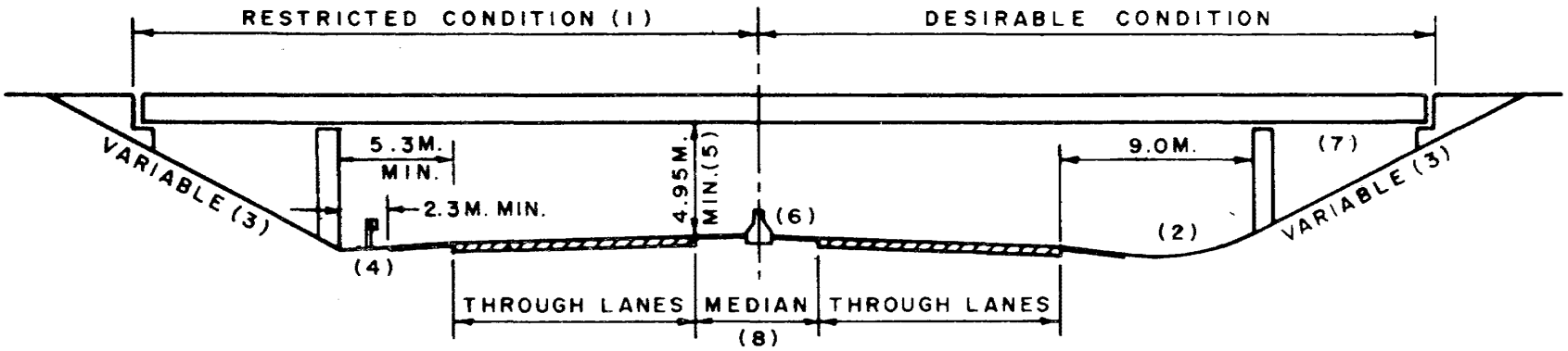
* TO BE PREDICATED ON FUTURE PAVEMENT WIDENINGS IN THE CASE OF EXPANSIBLE MEDIANS.

UNDERPASS CLEARANCES

DIVIDED HIGHWAYS WITH PIER IN MEDIAN

EXPRESSWAYS AND OTHER HIGH-SPEED HIGHWAYS

FIGURE 6-D



NOTES:

(1) TO BE USED ONLY WHERE TERRAIN OR SPACE LIMITATIONS, SKEW CONDITIONS, OR STRUCTURE COSTS MAKE A 9.0M. CLEARANCE IMPRACTICAL.

(2) FOR TYPICAL SIDE SLOPE TREATMENTS SEE FIG. 6-I.

(3) VARIABLE SLOPE AS PER HIGHWAY SECTION. SEE CHAPTER 2. NORMAL MAXIMUM 2:1.

(4) GUARDRAIL OR BARRIER PROTECTION REQUIRED. SEE FIG. 6-J.

* (5) MINIMUM VERTICAL CLEARANCE TO BE PROVIDED OVER ENTIRE ROADWAY SURFACED WIDTH.

(6) MEDIAN BARRIER WHEN REQUIRED. SEE CHAPTERS 2 AND 8.

(7) OPEN SPAN OR SOLID ABUTMENT.

(8) NORMALLY UNDER 6.0M. WIDE BUT NOT LESS THAN ON APPROACH ROADWAY.

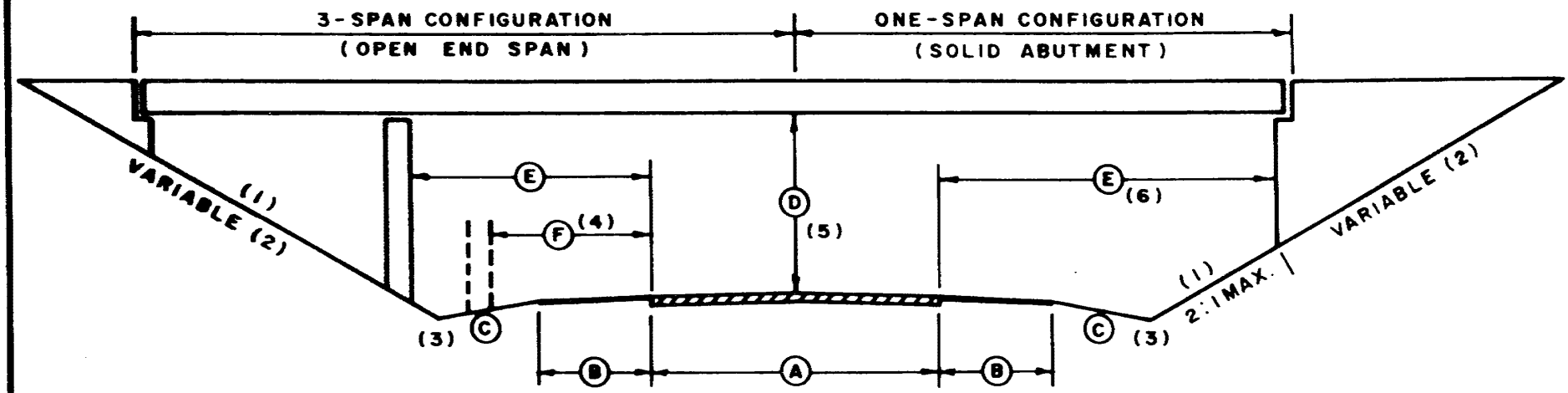
* TO BE PREDICATED ON FUTURE PAVEMENT WIDENINGS IN THE CASE OF EXPANSIBLE MEDIANS.

UNDERPASS CLEARANCES

DIVIDED HIGHWAYS WITH NO PIER IN MEDIAN

EXPRESSWAYS AND OTHER HIGH-SPEED HIGHWAYS

FIGURE 6-E



NORMAL DIMENSIONS (METERS)

	DESIGN CLASS:	RE-4	R-6	R-7	R-8
A	PAVEMENT WIDTH	7.30	7.30	6.70	6.10
B	SHOULDER WIDTH	3.00	3.00	2.40	1.80
C	MAX. INSLOPE	6:1	6:1	4:1	4:1
D	MIN. VERT. CLEAR.	4.95	4.95	4.95	4.40
E	NORMAL LATERAL CLEAR.	9.00	9.00	6.00	6.00
F	MIN. LATERAL CLEAR.	5.30	5.30	5.60*	5.90*

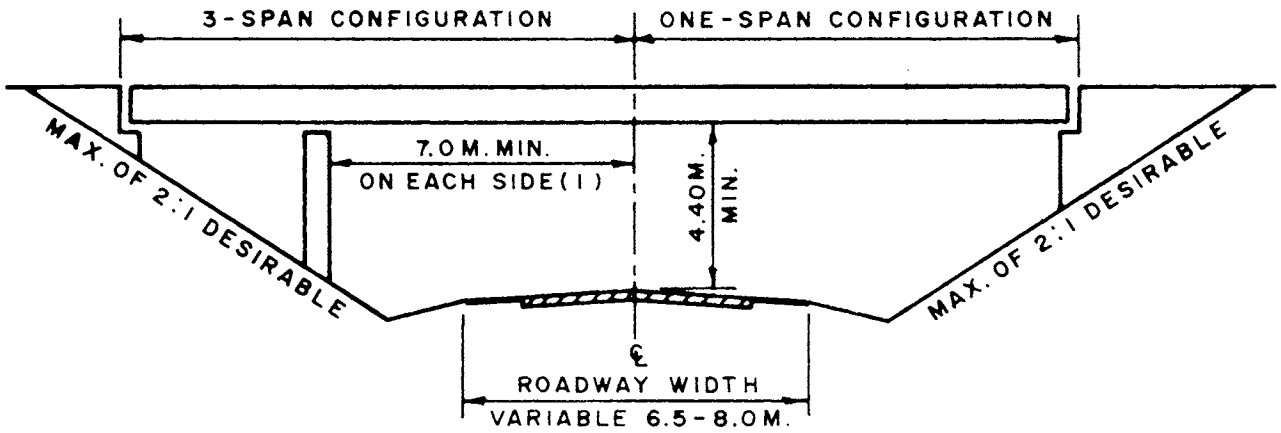
* TO ALLOW FOR POSSIBLE WIDENING TO R-6 SECTION

NOTES:

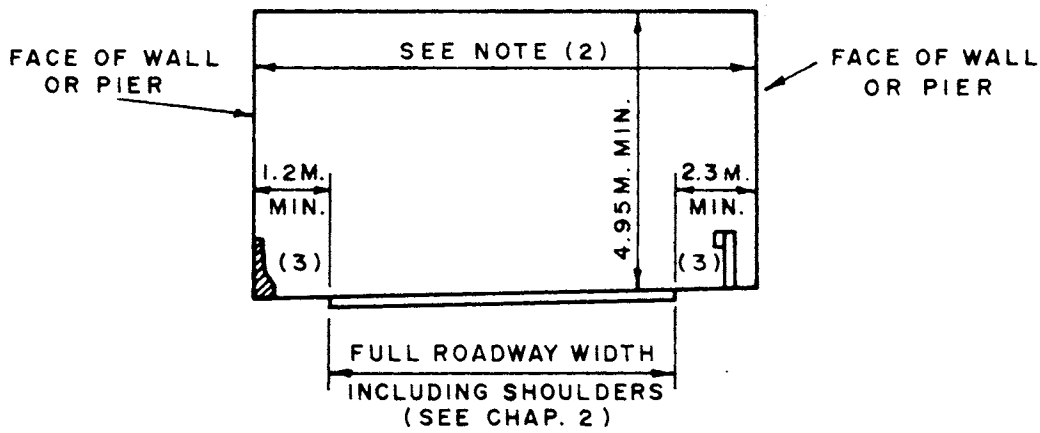
(1) PROVIDE SLOPE PAVING.
(2) VARIABLE SLOPE AS PER HIGHWAY SECTION. SEE CHAPTER 2. NORMAL MAXIMUM 2:1.
(3) ROUNDED DITCH SECTION. SEE CHAPTER 2 AND FIG. 6-I.
(4) RESTRICTED MINIMUM CLEARANCE TO BE USED ONLY WHERE CONDITIONS MAKE THE NORMAL CLEARANCE IMPRACTICAL. GUARDRAIL PROTECTION REQUIRED, SEE FIG. 6-J.
(5) MINIMUM VERTICAL CLEARANCE TO BE PROVIDED OVER ENTIRE ROADWAY WIDTH.
(6) AUXILIARY LANES MAY BE INCLUDED WITHIN "E".

UNDERPASS CLEARANCES
TWO-LANE RURAL ARTERIALS AND COLLECTORS

FIGURE 6-F



LOCAL RURAL ROADS, DESIGN CLASSES R-9, 10, 11



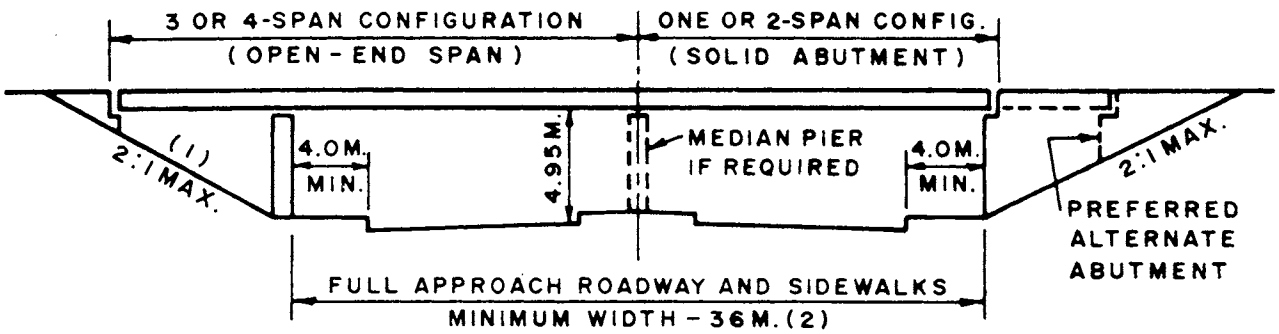
INTERCHANGE RAMPS

NOTES:

(1) TO ALLOW FOR POSSIBLE FUTURE WIDENING OF ROAD.
(2) ON MAJOR TURNING ROADWAYS APPLY SAME CLEARANCES AS ON CONNECTING MAIN LINES.
(3) BARRIER OR GUARD RAIL AS REQUIRED. SEE FIGS. 6-J AND 6-K.

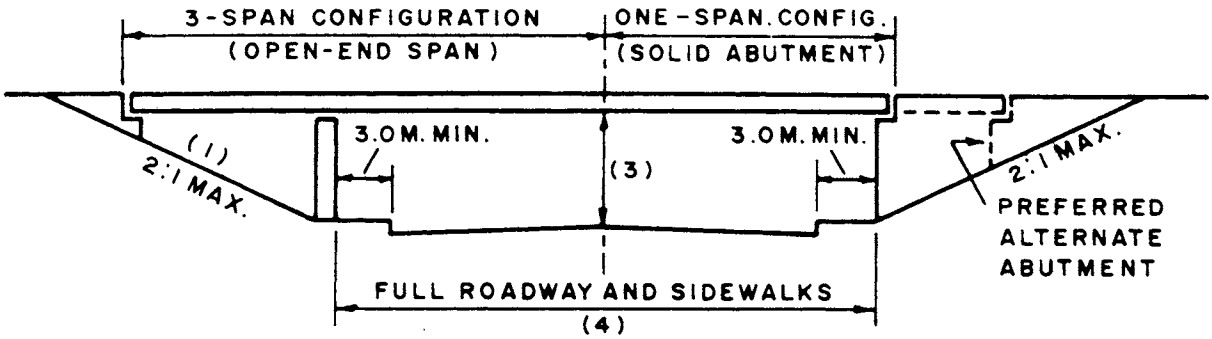
UNDERPASS CLEARANCES
LOCAL RURAL ROADS AND RAMPS

FIGURE 6-G



AVENUES

(DESIGN CLASS U-6)



PRINCIPAL AND LOCAL STREETS

(DESIGN CLASSES U-7, 8, 9, 10)

NOTES:

(1) PROVIDE SLOPE PAVING.

(2) INCREASE AS REQUIRED FOR ANY AUXILIARY LANES.

(3) MINIMUM VERTICAL CLEARANCE:

4.95M. FOR PRINCIPAL STREETS (U-7, 8).

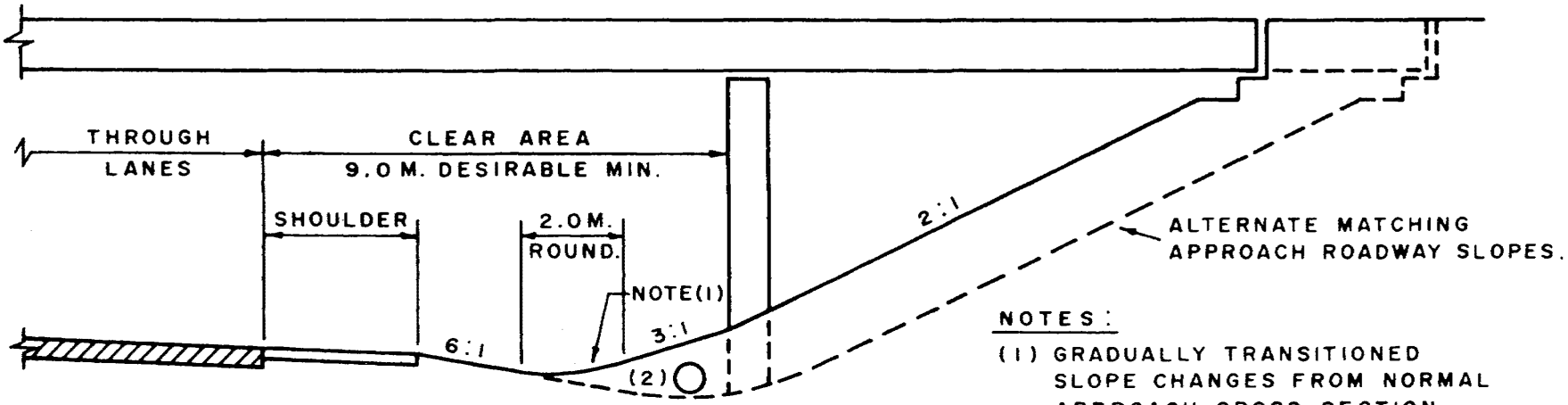
4.40M. FOR LOCAL STREETS (U-9, 10)

(4) WHERE FUTURE WIDENING OF STREET IS POSSIBLE, PROVIDE AT LEAST THE MIN. WIDTH NECESSARY FOR FINAL TYPICAL SECTION.

UNDERPASS CLEARANCES

OTHER URBAN HIGHWAYS AND STREETS

FIGURE 6-H

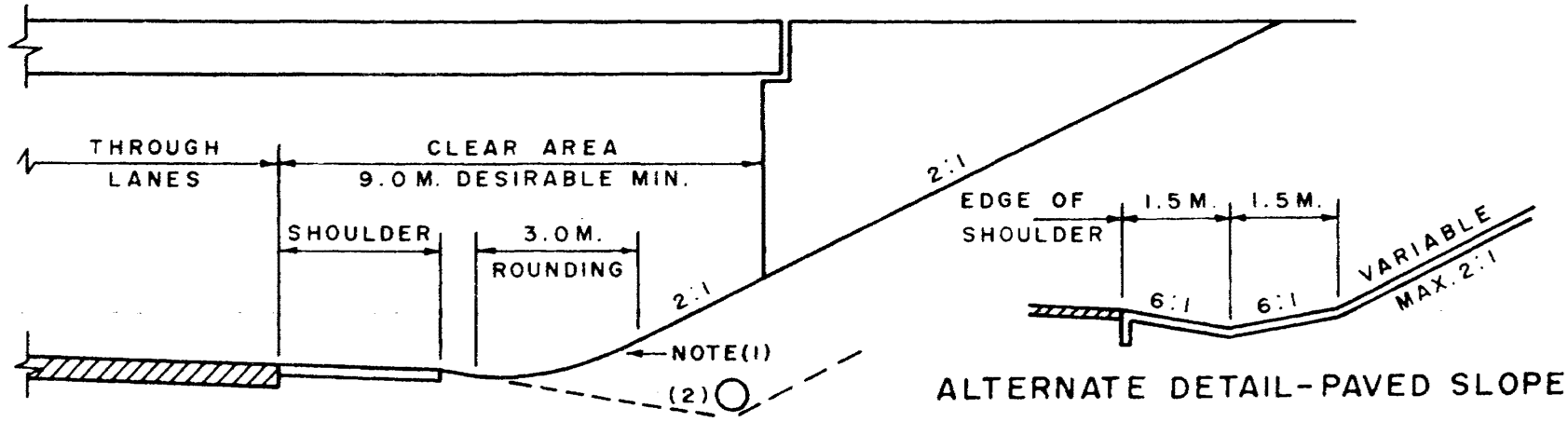


OPEN END SPAN

NOTES:

(1) GRADUALLY TRANSITIONED SLOPE CHANGES FROM NORMAL APPROACH CROSS SECTION.

(2) CULVERT IF REQUIRED FOR DRAINAGE CONTINUITY BUT AVOID IF POSSIBLE.

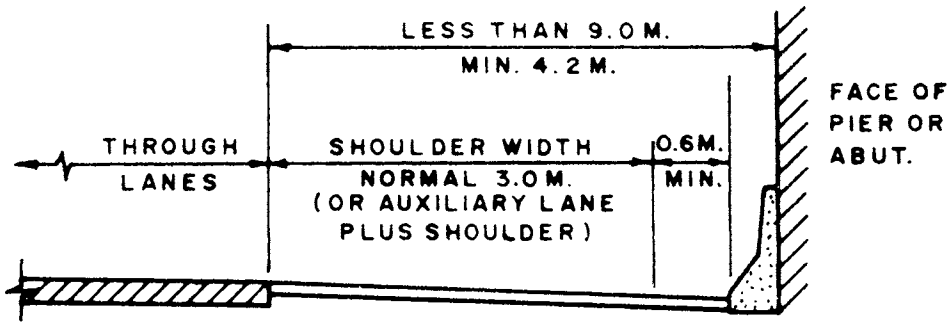


ALTERNATE DETAIL-PAVED SLOPE

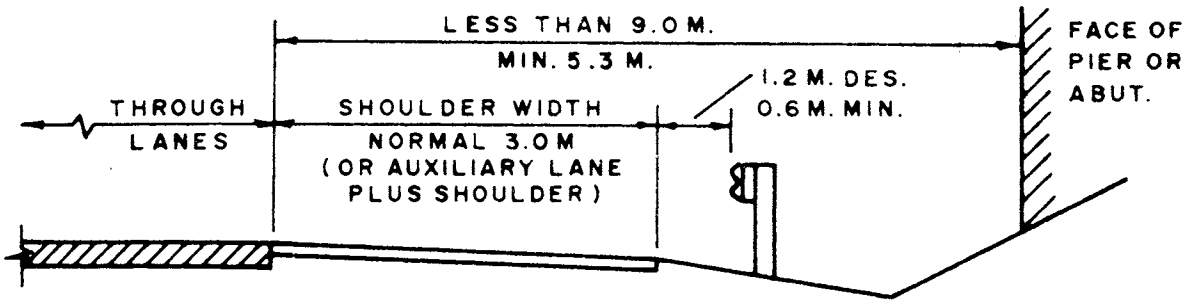
SOLID ABUTMENT

TYPICAL TREATMENT OF SIDE SLOPES AT UNDERPASSES

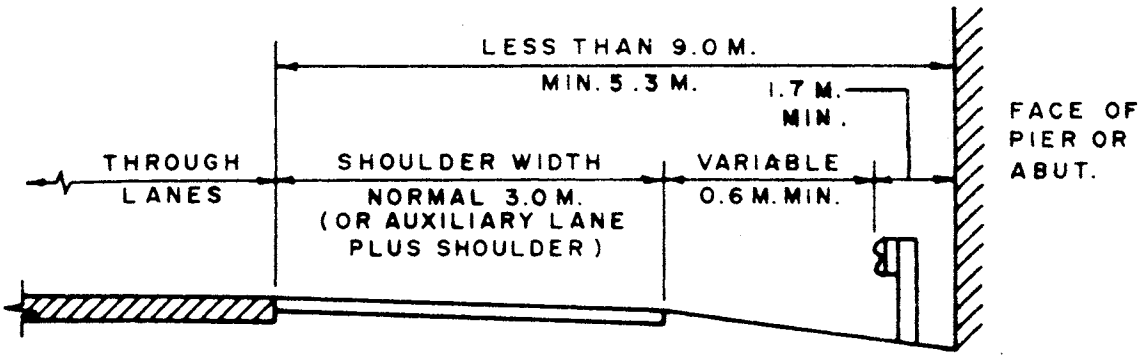
FIGURE 6-I



INTRODUCED CONCRETE BARRIER



GUARD RAIL ON BROKEN SIDE SLOPE

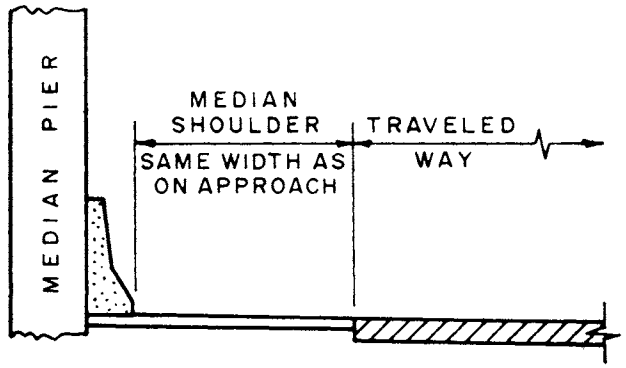


GUARD RAIL ON UNIFORM SIDE SLOPE

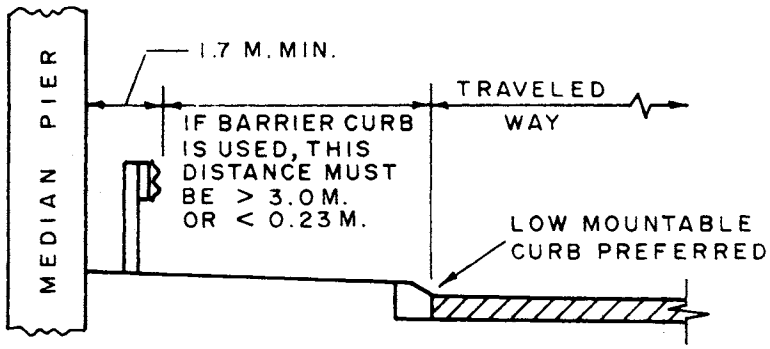
NOTE: REFER TO CHAPTER 8 FOR APPROACH TRANSITION AND END TREATMENT DETAILS OF BARRIERS.

TYPICAL BARRIER INSTALLATIONS AT UNDERPASSES WITH RESTRICTED RIGHT SIDE CLEARANCE

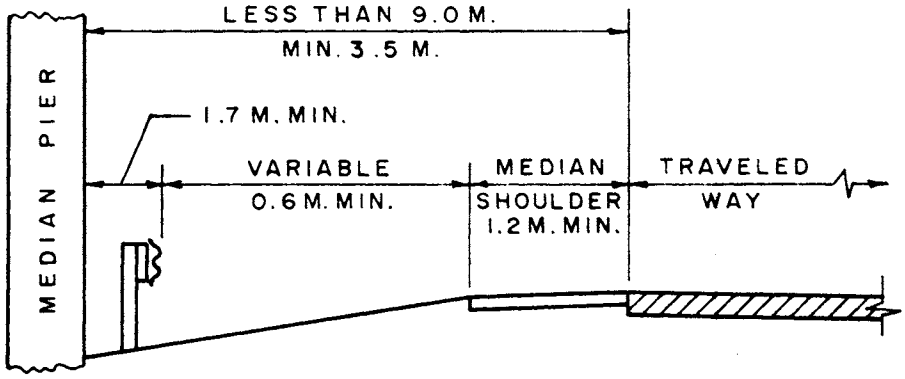
FIGURE 6-J



NARROW MEDIAN WITH CONTINUOUS MEDIAN BARRIER



CURVED MEDIAN WITH INTRODUCED GUARD RAIL



INTERMEDIATE MEDIAN WIDTHS
WITH INTRODUCED GUARD RAIL

NOTE: REFER TO CHAPTER 8 FOR APPROACH TRANSITION AND END TREATMENT DETAILS OF BARRIERS.

TYPICAL BARRIER INSTALLATIONS AT UNDERPASSES WITH PIERS IN MEDIAN

FIGURE 6-K

2. ALIGNMENT OF BARRIER FACES—The alignment and transition of the two barriers should be such as to allow an impacting vehicle to slide smoothly along from one barrier to the other without snagging on projecting parts.

3. CHANGE IN FLEXIBILITY—The approach guard rail is purposely designed as a flexible barrier which will deflect 0.60 M. or more depending on the type. Since it is to be connected to a rigid bridge parapet, a transition must be made to develop a gradual stiffening that will prevent pocketing of an impacting vehicle. This gradual stiffening may be accomplished by decreasing the post spacing or strengthening the posts as the guard rail approaches the bridge parapet.

6—03.05 SIDEWALKS IN RURAL AREAS

No sidewalks are provided on expressways and none are normally provided on other rural highway and local roads. However, there may be instances along some non-controlled access rural highways where existing development, such as a school or factory, may generate sufficient pedestrian traffic to justify providing a sidewalk on one or both sides of the structure and its corresponding accesses. Such sidewalk shall be placed beyond the normal approach shoulder width so that the full approach roadway is carried on the structure. The determination of need for such sidewalks is made during the planning stage.

6—03.06 LIGHTING SUPPORTS

When the highway lighting design calls for locating lighting units on a bridge superstructure, the poles shall be installed on special supports back of the bridge railing. The installation of lighting poles on top of railings or at breaks in the railing will be avoided.

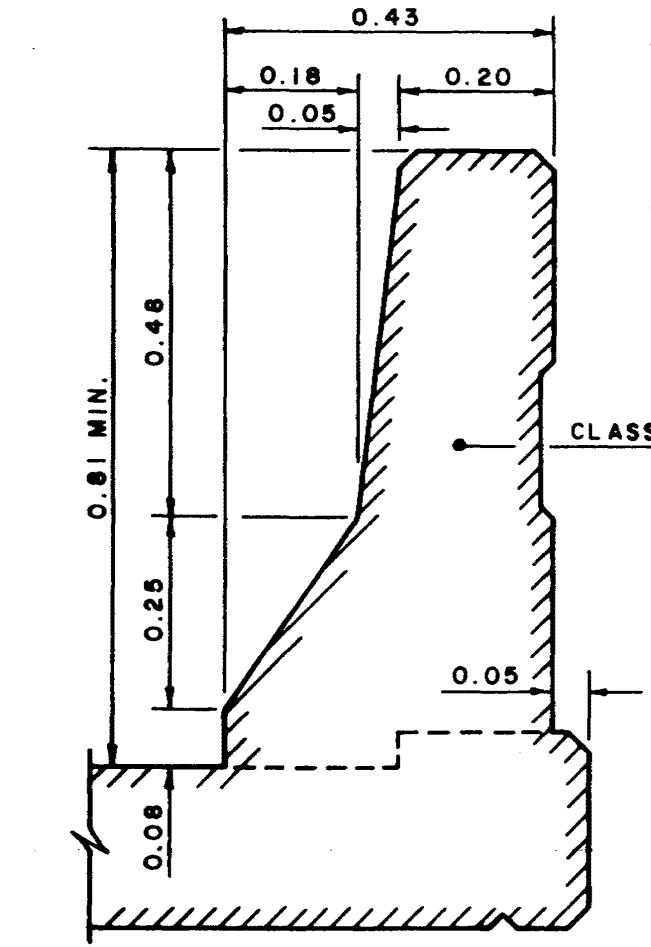
6—03.07 IMPACT ATTENUATOR RESERVE AREAS

When fixed obstructions must be placed in a gore area, such as the bridge railings at the exit ramp terminals on an elevated structure or when a bridge pier in a gore cannot be avoided, a reserved area for the installation of an impact attenuator (energy dissipating device) must be provided. The details for these impact attenuator reserve areas are illustrated in Figure 6—N. The various energy dissipation devices are covered in Chapter 8.

In selecting the dimensions to be applied to new designs from the tabulation shown in Figure 6—N, the minimum values for unrestricted conditions should be used. The restricted conditions minimum values should not be used except when there are extremely tight geometric conditions and the use of the greater values would result in unreasonably higher costs. The preferred values may be applied when their use would only result in minor increases in project costs.

6—04 PRELIMINARY DESIGN PROCEDURES

The general design requirements for bridges on a particular route are established during the route location studies which include the investigation of alternate routes and their evaluation on the basis of service, socio-economic, environmental and cost factors. During this planning phase consideration is given to the location and costs of structures required with particular emphasis on waterway crossings because of their possible effects on drainage areas, flood plains, navigation, fish and wildlife, and water pollution. The planning phase and the subsequent preliminary and final design involve the consultation and coordination with, and in some cases approvals by, a number of agencies as appropriate. For waterway crossings these may include the Department of Natural Resources, the Planning Board, the Flood Control Area of the DTPW, the U.S. Corps of Engineers, the U.S. Geological Survey and the U.S. Coast Guard.



TRAFFIC - NO SIDEWALK

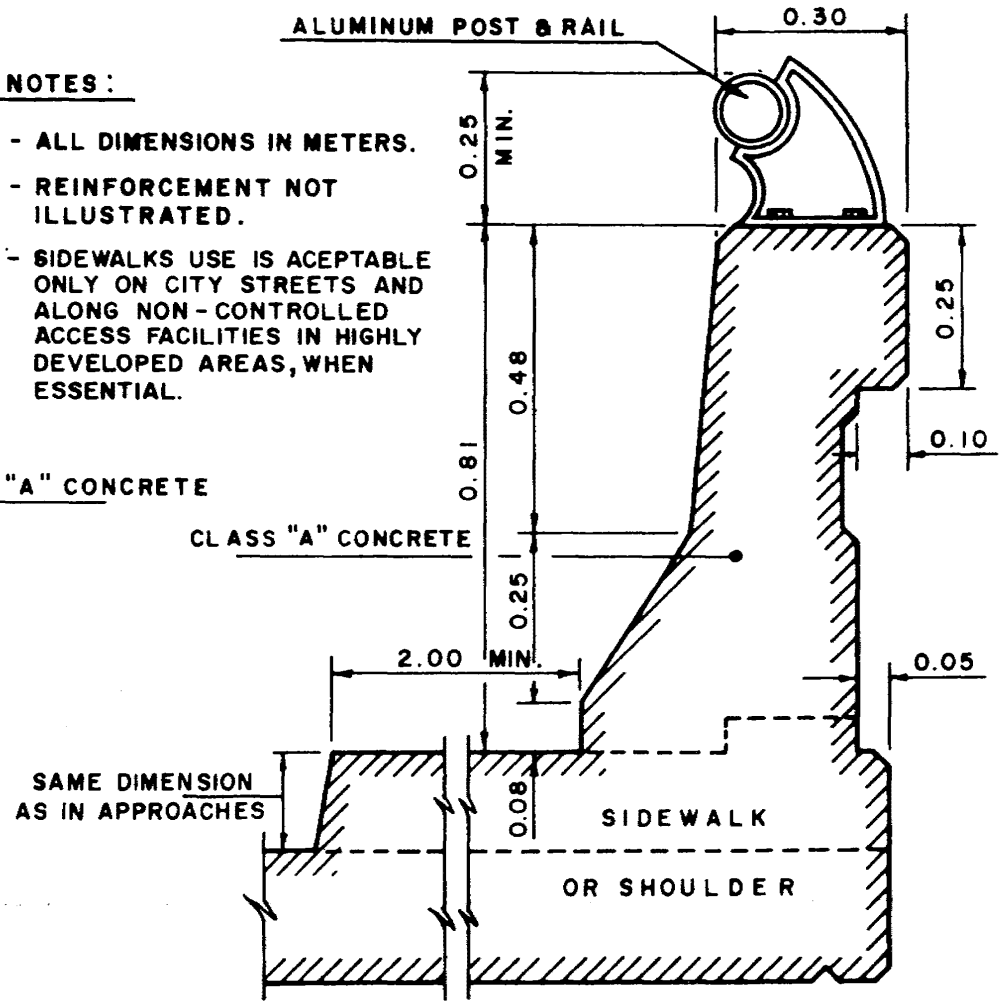
NOTES:

1 - ALL DIMENSIONS IN METERS.

2 - REINFORCEMENT NOT ILLUSTRATED.

3 - SIDEWALKS USE IS ACEPTABLE ONLY ON CITY STREETS AND ALONG NON-CONTROLLED ACCESS FACILITIES IN HIGHLY DEVELOPED AREAS, WHEN ESSENTIAL.

CLASS "A" CONCRETE

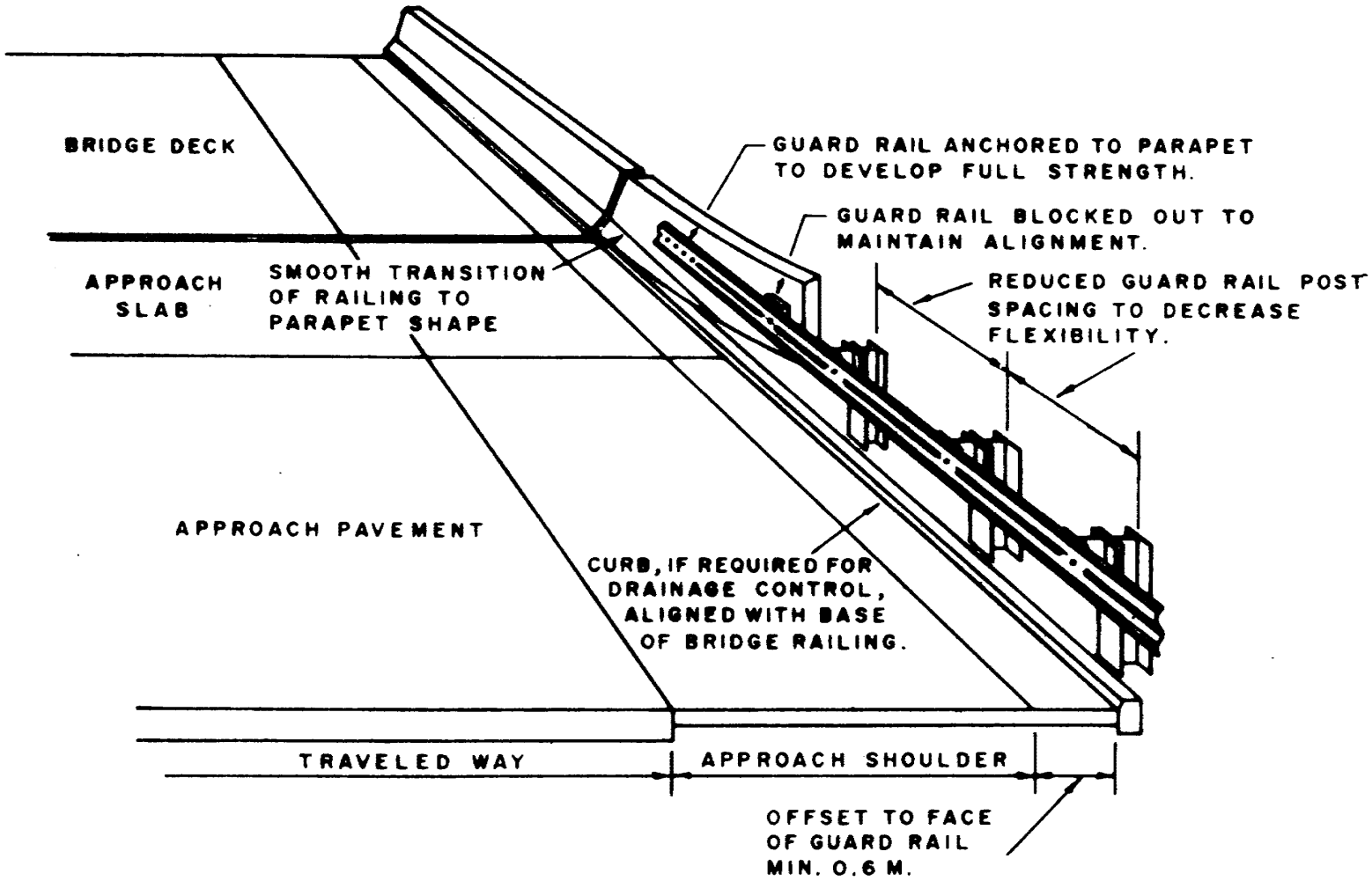


COMBINATION TRAFFIC AND PEDESTRIAN *

TYPICAL RAILINGS

FIGURE 6-L

* SEE NOTE #3 AND SECTION 6-03-05



TYPICAL TRANSITION OF APPROACH GUARD RAIL TO BRIDGE RAILING

FIGURE 6-M

After the route location has been approved, the preliminary design of the highway and bridge structures is initiated including further evaluation and expansion of the design requirements previously established during the initial planning stages. The activities described below are undertaken during the preliminary design phase.

6—04.01 SITE DATA

Complete site data is necessary for the proper selection and development of plans to provide a structure that best fits the location. Initial site data is available from the route location studies which normally include topographic maps obtained by aerial survey and photogrammetric methods. Additional data is provided by field surveys made by the Surveying Division, see Chapter 16.

The site data for grade separation structures is presented in large scale topographic maps (1:200 to 1:500, depending on site) showing the existing topography, base lines, stationing, control points, existing roads and structures, bench marks, existing utilities, and other pertinent information that will have a bearing on the design of the proposed structure. In addition, data is provided on the approach highways including all elements of the highway sections, horizontal alignment and proposed profiles.

Bridges over waterways require all of the above site data plus additional information necessary for the hydraulic analysis as indicated in the next section.

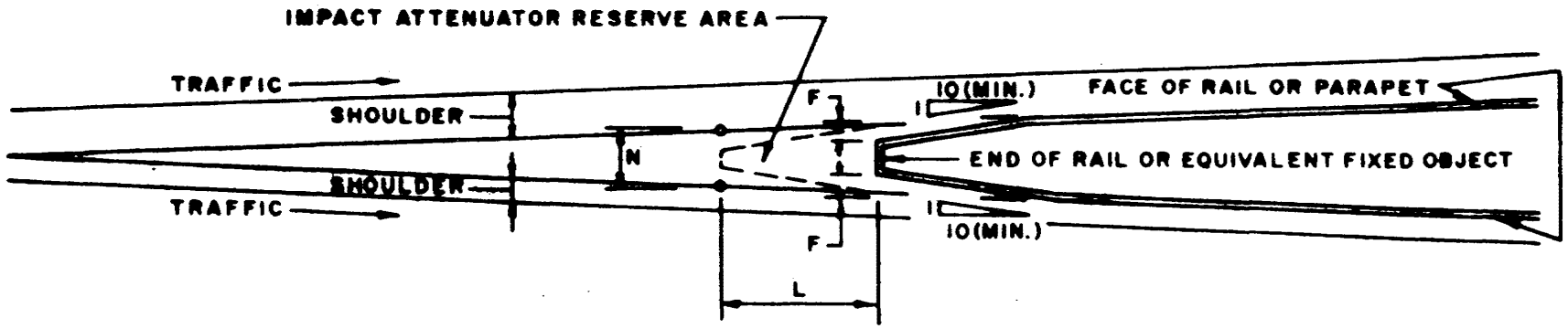
6—04.02 HYDROLOGIC AND HYDRAULIC ANALYSIS

The determination of adequate waterway opening for stream crossings is essential to the design of safe and economical bridges. In addition, whenever a highway encroaches on a flood plain an evaluation of the flood hazard is required as indicated in Section 6—02.05. Thus, hydraulic studies of bridge sites for stream crossings are a necessary part of the preliminary design phase.

An outline guide for hydraulic studies and reports is shown in Table 6—3. The extent of the study should be commensurate with the importance and magnitude of the project, the complexity of the problems encountered, and the risk to life and property. Less comprehensive studies are appropriate for minor stream crossings and at locations where the risk of property damage or loss of the highway is small. In all cases a written report shall be prepared including the hydrologic and hydraulic data, the design computations, the analysis of the effect on the stream stability, and the favorable or adverse effects on the stream environment.

6—04.03 SITE INSPECTIONS

It is expected that the designer and the design reviewer in the case of consultant's design shall visit and become familiar with the site during the preliminary design phase and prior to the selection of the possible bridge types. These field visits provide the opportunity to review field reports previously submitted by others, determine what additional site data may be necessary, consider possible shifts in alignment and profile, ascertain foundation data requirements, and inspect any special topographic or other features which may have an important influence on the design or construction requirements.



DESIGN SPEED ON MAINLINE (M.P.H.)	DIMENSIONS FOR IMPACT ATTENUATOR RESERVE AREA ON NEW DESIGNS (METERS)								
	MINIMUM						PREFERRED		
	RESTRICTED CONDITIONS			UNRESTRICTED CONDITIONS					
	N	L	F	N	L	F	N	L	F
30	1.8	2.4	0.6	2.4	3.3	0.9	3.6	5.2	1.2
50	1.8	5.2	0.6	2.4	7.6	0.9	3.6	10.0	1.2
70	1.8	8.5	0.6	2.4	13.7	0.9	3.6	16.8	1.2

NOTE - SEE TEXT FOR GUIDANCE ON APPLICATION

IMPACT ATTENUATOR RESERVE AREA

FIGURE 6-N

TABLE 6–3

GUIDE FOR HYDRAULIC STUDIES AND REPORTS

A. SITE DATA

1. Vicinity map — use a USGS quadrangle, an aerial photo, or map of similar detail to show proposed highway alignment and reach of river, bends and stream meanders, and general flow directions.

2. Site map — specially prepared map showing contours (0.5 or 1.0 M. interval), vegetation and manmade improvements. In some cases, cross sections normal to flood-flow are acceptable in lieu of a map. At least 3 cross sections are desirable — upstream, at crossing and downstream.

3. Existing structures, including relief or overflow structure —

   a. Locate on map existing structures upstream and downstream from proposed crossing.

   b. Describe each structure fully, giving —

      (1) Type, number of spans and length of each, pier design and orientation. For culverts give size and number of cells.

      (2) Foundation type (spread footing, piling) and depth.

      (3) Scour history at abutments and piers or culvert outlets; stream aggradation or degradation.

      (4) Cross sections beneath structure, noting clearance to superstructure and skew with direction of current during extreme floods.

      (5) Flood history, high water marks (elevations) with dates of occurrence, nature of floding including overtopping, damages and sources of information.

      (6) Damage from abrasion, corrosion, wingwall failure, culvert end failure.

4. Locate and determine elevations of high water marks along stream, giving dates of occurrence. Describe or list critical flood elevations of interest in evaluating possible damage and indicate datum used. Refer to any available flood hazard studies for the area.

5. Comment on drift, nature of stream bed, bank stability, bends, meanders, vegetative cover and land use.

6. Include photographs of existing structures, past floods, main channel and flood plain to help in evaluating a location and documenting conditions existing prior to construction.

7. List factors affecting water stages —

   a. High water from other streams.
   b. Reservoirs — existing or proposed and date of construction.
   c. Flood control projects — give status.
   d. Tides.
   e. Other controls.

B. HYDROLOGICAL ANALYSIS

1. List available flood records.
2. Determine drainage area above proposed construction.
3. Evaluate potential for changes in watershed characteristics which would change magnitude of flood peaks such as urbanization, channelization, etc.
4. Plot flood — frequency curve for site.
5. Plot stage — discharge — frequency curve for site.
6. Determine distribution of flow and velocities for several discharges or stages in natural channel for existing conditions.

C. HYDRAULIC ANALYSIS

1. Determine permissible upstream water surface elevations.
2. Compute backwater for various trial bridge lengths and discharges.
3. Select design flood and waterway design.
4. Provide for conveyance of 100-year flood or maximum flood of record, whichever is greater.
5. Estimate scour depth at piers and abutments.
6. Design riprap for bank protection and scour attenuation devices, if required.
7. Investigate need for spur dikes.
8. Show final layout in plan and profile —

   a. Show design discharge, elevations and frequency.
   b. Show discharge and elevations for 100-year flood (or max. flood or record).

9. Comment on —

   a. Selection of design flood.
   b. Conveyance of 100-year flood (or max. flood of record).
   c. Channel change, if provided.
   d. Effects of construction.
   e. Need for stream controls to protect the highway.

NOTE — See Section 6—06 for suggested references.

6—04.04 COORDINATION WITH OTHER AGENCIES

Approval and/or permits from various agencies are required in the case of most stream crossings and in the case of some grade separation structures. Initial coordination with and identification of their specific requirements will have been made during the planning and route location studies. Follow up and required permit applications should be completed during the preliminary design phase.

1. AIRWAY—HIGHWAY CLEARANCES

Highway projects in the vicinity of airports must be designed to provide minimum clearances between the highway and the navigable airspace. This may have an influence in the design of the project structures, particularly grade separation structures. The coordination and requirements for airway-highway clearances should be available to the bridge designer in the location report as discussed in Chapter 18.

2. FLOOD CONTROL AREA, DTPW

The flood Control Area of the Department of Transportation and Public Works is responsible for the design, construction and maintenance of flood control works. Coordination with them on highways encroaching on flood plains is initiated during the route location study

phase. They are to be consulted during the preliminary design stages on the hydrologic and hydraulic aspects of the stream crossings and agreement with them reached on the hydraulic design features of the bridges.

3. NAVIGABLE WATERS

Bridges over navigable waters require a permit from the U.S. Coast Guard and also from the U.S. Corps of Engineers for all work affecting the navigable waterway (other than the bridge itself) such as channel relocations. Although there are very few rivers and streams in Puerto Rico that are navigable in fact, the Coast Guard has not as yet identified all of those which they consider navigable for which a permit is required. The questions of identifying crossings over waterways which are considered navigable should be completed during the route location study and the navigation requirements established in coordination with the Coast Guard and the Corps of Engineers. The formal applications for permits for the construction of such bridges should be submitted to the Coast Guard and the Corps of Engineers during the preliminary design phase. Detailed design should not be initiated until the required permits have been obtained.

4. WATER POLLUTION

The Corps of Engineers has been given control over the discharge of dredge material and placement of fill material over practically all lakes, streams, rivers, coastal water and contiguous wetlands under the Federal Water Pollution Control Act. Therefore, any bridge project involving the discharge of dredged material or placement of fill material over practically any body of water will require an application for a permit by the Corps of Engineers. The regulations of the Corps provide for the implementation of these permit requirements by phases. Coordination with the Corps of Engineers and identification of water bodies subject to Corps' control should be completed during the route location study phase. The bridge designer should become familiar with the permit conditions and detailed design should not be initiated until the permit has been obtained.

6–04.05 PRELIMINARY DESIGN REPORT

On the basis of the site data, site inspection, hydraulic report highway requirements and design criteria, and other agencies' requirements (if applicable), the designer will select alternate structure types for consideration. Dimensioned sketches will be prepared showing plan, elevations and typical sections. Approximate detailed cost estimates will be made based on estimated quantities of principal construction items and current unit price data.

At least two alternate types or layouts should be worked for each site. In the case of major structures several alternates may need to be considered to help arrive at the most appropriate solution.

A report shall be prepared and submitted to the Director of the Structural Design Office. The report shall include the sketches and estimates of the various alternate considered, a discussion of major elements considered and recommendations as to which alternate should be selected and why. In evaluating the various alternates under review the designer should consider estimated construction costs, aesthetics, time and ease of construction, availability of materials, future maintenance requirements and costs, and special conditions such as maintenance of traffic during construction. In addition, the report should include a section on specific additional site data required for the design including soil information and borings for the foundations design.

Because of any number of conditions peculiar to each site it is not practical to furnish blanket recommendations on structure types. In general concrete construction is favored in Puerto Rico and in particular prestressed concrete beams. However, it should be remembered that cost trends, new materials, and new design and construction procedures influence the

economy, aesthetics and maintenance of structure types and that basic materials are subject to constant cost fluctuations.

6–04.06 SOILS STUDY

After agreement has been reached on the alternate design proposed for the site, the designer will prepare a memorandum to the Soils and Materials Office requesting the subsurface explorations and soils reports needed for the foundation design. A standard format for this memorandum is available in the Structural Design Office. The request will include a layout of the structure showing the location of each pier and abutment tied to the survey line stationing and the suggested boring locations. As a minimum, at least one boring should be requested at each pier and abutment. In addition borings are required on the approaches unless already available from the roadway soil survey. However, although suggested boring locations are indicated, the soils engineer may alter the number and locations of borings in line with his judgement of the site conditions. The soils report will provide specific data and recommendations for the design of the foundations. Soils investigations and reports are discussed in Chapter 12.

6–04.07 ADVANCE PLANS

After approval of the preliminary design report, the preparation of advance plans at full scale will be initiated. These advance plans will eventually develop into the final detailed construction plans. However, miscellaneous details such as access slab, reinforced steel tables etc., may be omitted at this stage.

The advance plans should include all geometric data such as vertical and horizontal clearances, profiles, superstructure depth, cross sections, waterway information, and typical piers which will enable the necessary agencies to make a proper review of the plans. It is essential that the designer maintain coordination with the roadway designer during the development of the advance plans to insure continuity of design and avoid discrepancies in the overall final project plans. The designer should also be congnizant of any special requirements affecting the structure which may have evolved from the environmental evaluation, the public hearings, and the review and approval by other agencies.

Consultants doing design work for the Department shall submit the advance plans for each bridge for review and approval by the Structural Design Office. The consultant should refrain from further development of the final construction plans until he has received comments and recommendations from the Department and agreement has been reached.

Advance plans shall be submitted to the FHWA Division Administrator for review and approval for all bridges financed under the Federal-aid program. Further work in the development of these final bridge plans should normally be withheld until agreement has been reahced with the FHWA.

6–05 FINAL DESIGN AND PLANS

An explanation of the procedures for detailed design of the structural elements of bridges is beyond the scope of this Manual. The bridge designer must combine education, experience and judgement in order to develop designs that provide durable and economical structures that best meet the requirements of the individual sites.

It is the bridge designer's responsibility to correlate all available data and develop a design that will provide the most efficient construction procedures and staging. He must include in the final plans all necessary notes, instructions, details and construction controls that will insure that the structure when built will be consistent with the design.

A copy of all the design computations, after checking, shall be filed in the permanent project file. After the detailed plans have been developed they are made into reproducible plans. Basic final construction plans requirements and what should be included in the plan set for each bridge are covered in Chapter 19 on "Contract Plans, Specifications and Estimates".

In the case of design by consultants, a copy of the design computations and prints of the detailed plans shall be submitted for review through the Design Area following approval of the preliminary plans for the structure. The Highway Design Office makes a general review to insure that the structure is properly coordinated into the total project. The Structural Design Office makes a more thorough examination for structural adequacy, material economy, completeness of information and compliance with the Department design criteria. However, althought the Structural Design Office spot checks dimensions and elevations, makes a cursory review of quantities, and reviews other features of the design, the consultant remains responsible for the completeness and accuracy of the design and final plans. The consultant shall submit a reproducible copy in mylar or approved equal of all the final plan sheets after approval.

6—06 REFERENCE AND GUIDES

Chapter I on "General Design Criteria" includes a listing of selected references that highway designers should have access to and be familiar with. Several of these are repeated herein in addition to other references and guides of particular interest to bridge designers.

1. AASHTO Publications:
   - a. A Policy on Geometric Design of Rural Highways — 1965
   - b. A Policy on Design of Urban Highways and Arterial Streets — 1973
   - c. Standard Specifications for Highway Bridges—1973 and subsequent amendments
   - d. Standard Specifications for Welding of Structural Steel Highway Bridges — 1977
   - e. Highway Drainage Guidelines, Volumes I, II and III, 1973
   - f. Standard Specifications for Transportation Materials, Part I, 1974
2. FEDERAL HIGHWAY ADMINISTRATION
   - a. Hydraulic Design Series

     No. 1 — Hydraulics of Bridge Waterways, 1970
     No. 3 — Design Charts for Open-Channel Flow, 1961
     No. 4 — Design of Roadside Drainage Channels, 1965
   - b. Standard Plans for Highway Bridges

     Vol. 1 Concrete Superstructures — 1976
     Vol. 2 Structural Steel Superstructures — 1968
     Vol. 4 Typical Continuous Bridges — 1975
   - c. Handbook of Highway Safety Design and Operating Practices — 1973
3. Transportation Research Board—
   - a. NCHRP Report No. 149 — Bridge Rail Design—Factors, Trends and Guidelines
   - b. NCHRP Synthesis No. 5 — Scour at Bridge Waterways
4. Reinforcing Steel Welding Code, AWS D12.1-75

4A. Structural Welding Code AWS D1.1-75

5. P.R. Planning Board — Planning Regulation No. 13, Regulation on the Control of Buildings and Land Development in Areas Suceptible to Flooding, 1971.

6. U.S. Water Resources Council — Flood Hazard Evaluation Guidelines for Federal Executive Agencies, 1972

7. U.S. Department of Commerce, National Weather Service — Technical Paper No. 42 on Generalized Estimates of Probable Maximum Precipitation and Rainfall—Frequency Data for Puerto Rico and Virgin Islands, 1961

8. U.S. Geological Survey — Hydrologic Investigation Atlases and Map Series for various river basins in Puerto Rico.

9. U.S. Corps of Engineers — Flood Plain Information Reports for various rivers in Puerto Rico.

10. Bureau of Structural Design, DTPW

    a. Procedural Memorandums
    b. Design Policy Memorandums
    c. Guide Detail Sheets covering such items as parapets and railings, embankment cones at grade separation structures, deck drainage, wingwalls, rip-rap protection, AASHTO beams, deck slabs, diaphragms, spur dikes, etc.

11. Other References

    a. "Standard Specifications for Structural Support for Highway Signs, Luminaries and Traffic Signals" — 1975
    b. "Highway Design and Operational Practices Related to Highway Safety" (Yellow Book) — 1974
    c. "Guide for Selecting, Locating and Designing Traffic Barriers" — AASHTO — 1977

CHAPTER 7

PAVEMENTS

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CHAPTER 7

PAVEMENTS

7—01 GENERAL

This chapter provides general guidance on the policies and procedures followed by the Department in the design of pavement structures, the provision of skid resistant pavement surfaces, and the selection of pavement types.

7—02 PAVEMENT TYPES

The two basic types of pavement structure are the rigid and the flexible. A rigid pavement structure consists of a portland cement concrete slab placed on a subbase course of granular material, normally crushed stone or gravel. The subbase course is often identified in the typical sections as a "base course" in line with the nomenclature used in the Puerto Rico standard specifications for crushed stone or gravel pavement courses. The subbase course may also consist of material stabilized by a suitable admixture such as lime or cement. When the roadbed soils are of subbase quality, the subbase may be omitted.

A flexible pavement structure consists of a surface course made of a mixture of mineral aggregates and bituminous materials placed on a base course and, if necessary, a subbase course. The base course immediately below the surface course consists of aggregates (crushed stone, gravel or crushed gravel) with or without admixtures. The subbase course, when used, normally consists of compacted layer of untreated gravel or material such as crushed stone, crushed gravel or gravel. When the required pavement structure is relatively thin the subbase course in often omitted.

Because of the advances achieved by the highway construction industry, practically all the surface courses for flexible pavement now being, used in Puerto Rico are made of hot bituminous mixes (asphalt concrete) produced under controlled plant conditions. Also, when a flexible pavement is selected for a high-volume major highway serving heavy truck traffic and requiring a relatively thick pavement structure, a bituminous hot plant mix is normally specified for the base course. Such a base course is commonly called "black base".

7—03 DESIGN OF PAVEMENT STRUCTURES

Guides for the structural design of both rigid and flexible pavement were developed some years back both by the Department of Public Works and the Highway Authority. These guides need to be reviewed and updated and until this work is completed, the 1972 AASHTO "Interim Guide for Design of Pavement Structures" is to be used as the Department's guide for the design of both rigid and flexible pavements, supplemented by the previous Highway Authority guides and the instructions included in this chapter.

7—03.01 GENERAL FACTORS

The following factors are related to the structural design of both rigid and flexible pavements.

1. TRAFFIC DATA—The traffic data needed for the pavement design is furnished by the Transportation Planning Area of the Department. It should include the current ADT, the ADT for the design year (design period is normally 20 years), the directional distribution factor "D", and the truck factor "T" (This factor should be the 24 hour truck factor and not the one normally associated with DHV used for geometric design purposes). In addition, the Transportation Planning Area provides the W-2 and W-4 tables from the most recent truck weights

survey. The W-2 tables show the classification of trucks by types at the weighing stations. The W-4 table includes the 18 — kip axle equivalency factors for both rigid and flexible pavements for the various truck types. These tables may be used to calculate the daily equivalent 18-kip single axle load applications for use with the design charts following the procedures detailed in the Highway Authority's structural design guides for flexible pavements (1970) and for concrete pavements (1968) (In the development of the 18K single axle equivalents for pavements designs, the ADT expected to use the facility upon opening it to traffic and the traffic projected 20 years hence, should be averaged). In these calculations, a 100% lane distribution factor should be used to determine the average number of 18-kip single axle load applications in the design lane when designing 2-lane highways and 80% when designing highways with two or more lanes in each direction.

2. SERVICEABILITY INDEX (Pt)—Design charts for two values of serviceability index, 2.0 and 2.5, are provided in the guide. A serviceability index of 2.5 should be used for all major highways, design classes RE—1 through R—6 and UE—1 through U—8. An index of 2.0 may be used for other roads and streets.

3. ROADBED SOILS—The performance of the pavement structure is directly related to the physical properties of the roadbed soils. The structural design guides are based on the premise that the roadbed soils will provide adequate support to obtain an economical pavement structure. The soils study should identify locations where special treatment or replacement of problem soils are expected such as those that are excessively expansive, resilient, or highly organic.

7—03.03 RIGID PAVEMENTS

The following conditions apply to the structural design of portland cement concrete (rigid) pavements.

1. MODULUS OF SUBGRADE REACTION (K)—The design chart for rigid pavements in the AASHTO guide requires the Westergaard's modulus of subgrade reaction (k) as a key factor in the use of the chart. The values of "k" for a specific highway section are to be furnished by the Soils and Materials Testing and Research Office of the Department. The values of "k" may be obtained by correlation with standard AASHTO test such as T—222 (ASTM D—1196), T—190 (ASTM D—2844) or T—193.

2. WORKING STRESS IN CONCRETE (ft)—The AASHTO design chart calls for the working stress in concrete (ft) as one of the controlling factors. The values shown on the chart are based on the flexural stress of concrete as obtained by AASHTO test T—97 (ASTM C—78), simple beam with thirs point loading. The current standard specifications of the Department for P.C. concrete pavement call for the concrete to have a splitting tensile strength of at least 480 psi at 28 days as determined by AASHTO T—198 (ASTM C—496). This is aproximately equivalent to a flexural strength of 700 psi. A working stress value of 525 psi (.75 x 700) should be used for the pavement design.

3. SUBBASE—A minimum subbase 15 cm thick of dense graded granular material shall be used under all PC concrete pavements except where subgrade soils are determined to be of subbase quality. When variations in the roadbed soils result in non-uniform support characteristics, variations may be required in the thickness of the subbase.

4. PAVEMENT THICKNESS—The minimum PC concrete pavement thickness to be used on major highways, design classes RE—1 through R—6 and UE—1 through U—8, shall be 20 cm even when a lower value is obtained from the design chart. The maximum thickness for the concrete pavement shall be 25 cm. Where the thickness obtained from the design chart exceeds

25 cm, the use of continuously reinforced concrete pavement may be considered and a new design analysis made on the basis of the alternate procedure given in Appendix D of the AASHTO guide.

5. IMPROVEMENT POLICIES—Pumping (Ejection of water and subgrade material through joints and cracks or at the pavement edge, caused by the deflection of the slab after free water has accumulated under the slab), excessive cracking, and faulting (failure of joints representing a nuisance to the driving public in that they may set up a resonance in the vehicle, which leads to rider discomfort) affect rigid pavements in Puerto Rico.

In order to improve in this areas the following policies are established:

a) Subgrades shall be stabilized wherever silt-clay materials of fair to poor rating as subgrade materials, are found.

b) Dowels for load transfer must be used if the joint spacing is greater than about 15 to 20 feet, to prevent faulting.

c) Transverse and longitudinal joints shall be sawed to a depth of T/3 by means of approved concrete saws.

The longitudinal joint shall be sawed before the end of the curing period but not latter than three (3) days after the pavement has been placed.

All joints shall be sawed before equipment or vehicles are allowed on the pavement.

The sawed area shall be thoroughly cleaned and, if required, the joint shall immediately be filled with sealer.

d) Underdrains—It is desirable to make certain that all surface infiltration is minimized.

Benefits derived from proper drainage cannot be overemphasized.

If the base is a drainable material, use of subdrains is to be recommended.

7—03.03 FLEXIBLE PAVEMENTS

The following conditions apply to the design of flexible pavements.

1. SOIL SUPPORT VALUE (S)—The design charts for flexible pavements in the AASHTO guide require a determination of the soil support value of the roadbed soil. This soil support value has no direct relationship to any procedure for testing soils. The soil support value for a specific highway section is to be furnished by the Soils and Materials Testing and Research Office of the Department. Approximate correlations values with Resistance R—values obtained by AASTO T—190 and with CBR values established by AASHTO T—193 are given in the Highway Authority's and DPW design guides respectively.

2. REGIONAL FACTOR (R)—The regional factor is used in the design chart to adjust the pavement structural number (SN) for various climatic conditions. The main variable in climatic conditions considered for this purpose in Puerto Rico has been the mean annual rainfall. The values developed for the Highway Authority's design guides are being currently used. These are as follows:

Average Annual Precipitation	Regional Factor
40" or less	1.0
41 to 60"	1.5
61 to 70"	2.0

71 to 85"	2.5
86 to 100"	3.0
over 100"	3.5

The above values are not to be considered absolute. Other environmental conditions and local factors may require consideration and the application of engineering judgement in the design of specific road sections such as susceptibility to flooding, groundwater table, steep grades and subsurface drainage.

TABLE 7–1

MINIMUM THICKNESS OF FLEXIBLE PAVEMENT COURSES

(Centimeters)

HIGHWAY DESIGN CLASS:	RE-1, 2, 3, 4, R-5 UE-1, 2, 3, 4, 5	RE-4, R-6 U-6, 7, 8, 9	R-7, 8, 9	R-10, 11 U-10
SURFACE COURSE				
Asph. Concrete	(1) 5.0	(1) 5.0	2.5	2.5
BASE COURSE				
Asph. Concrete	15.0	10.0	5.0	5.0
Cr. Stone or Cr. Gravel	(2)	(2)	10.0	10.0
SUBBASE (3)				
Cr. Stone or Cr. Gravel	15.0	15.0	15.0	10.0
Gravel	15.0	15.0	15.0	15.0

Notes:

(1) Normally placed in two layers with the top layer (wearing course) designed for skid resistance. See Section 7–04.

(2) Not recommended for these highway design classes.

(3) May be omitted in full depth asphalt concrete pavements or when roadbed soils are of subbase quality.

3. STRUCTURAL NUMBER (SN)—The structural number obtained from the design chart is an abstract number expressing the structural strength of the flexible pavement required for a particular combination of soil support value, equivalent 18-kip axle loads, terminal serviceability index, and regional factors. It is converted to actual thickness of surfacing, base and subbase courses by means of layer coefficients representing the relative strength of the material to be used in each pavement course.

4. LAYER COEFFICIENT—The layer coefficient expresses the relationship between the structural number (SN) and thickness, and is a measure of the relative ability of a material to function as a structural component of the pavement. Layer coefficients for various types of pavement materials, based on the AASHTO guides, are includes in the Highway Authority's design guide. The suggested values are to be applied to the depth of each pavement course expressed in centimeters.

5. COURSE THICKNESSES—Once the structural pavement number for the total pavement structure has been determined from the chart, alternate pavement structures are designed, using appropriate materials and layer coefficients for the surface, base and subbase courses, and

following the procedures included in the AASHTO design guide. The alternate designs are compared on the basis of economics, availability of materials, and other pertinent considerations to arrive at an optimum design.

A flexible pavement consists of a two-course or three-course structure. The composition of the pavement structure must be such that the strength characteristics of the surface course material are higher than those of the base or subbase, and the strength of the base course material is higher than that of the subbase. This must be kept in mind in selecting the materials to be used in each pavement course.

Minimum thickness requirements for the various materials commonly used for surface, base and subbase courses have been established to avoid the development of impractical designs. The minimum thicknesses recommended for use are shown in Table 7—1. These are minimum values only are and not to be interpreted as typical designs. The thickness of each course is to be based on the structural design analysis for the specific highway.

7—04 SKID RESISTANCE

Increased emphasis is being placed in providing skid resistant surfaces on new and old pavements as a major measure for reducing accidents and improving highway safety. The required level of pavement skid resistance depends primarily on the traffic volume and speed, with additional consideration given to special locations such as steep grades, curves, intersecting an other site requiring extreme vehicle maneuvering.

Adequate pavement surface drainage is an essential element in decreasing the skidding potential. Special attention should be given to providing adequate surface drainage at sag vertical curves, horizontal curve areas and transition locations where water buildup and ponding may occur. The requirement for adequate skid resistance surfaces becomes more critical with increased wet pavement time and increased traffic volume.

The current practices of the Department to obtain skid resistance surfaces are described in this section. However, the designer should be cognizant that research and experimentation is still going on in this field and he should be alert to new developments reported in AASHTO, TRB and FHWA publications. The Department's Materials and Soil Testing and Research Office is also working with the Construction Area and with the local asphalt concrete industry in developing improved skid resistant asphalt surfaces.

7—04.01 P.C. CONCRETE PAVEMENTS

The current standard specification for PC concrete pavement (Spc. 501) calls for a final broom finish. This specification is in the process of being revised and updated. Until such time as the revised specification is issued, all projects calling for PC concrete pavement on high speed highways (design of speeds of 50 mph or higher) will include a special provision modifying Spec. 501 to provide a final finish using a steel tined comb or other approved device that will produce tranverse corrugations in the surface 2 to 4 mm in depth, 2 to 3 mm in width, and randomly spaced at not less than 12 nor more than 25 mm.

The optimum time for grooving depends on many variables including concrete materials and proportions, consistency, temperature, humidity and wind velocity. The correct timing is to be determined on the job as the paving progresses. If done too early, the striations may become partially filled with mortar. If done too late, the desired depth may not be obtainable.

7—04.02 ASPHALT CONCRETE PAVEMENTS

To obtain a durable high skid resistance surface an open graded surface or wearing course mix made with highly polish-resistant aggregates is recommended. The materials and Soils

Testing and Research Office has developed variations of the standard Mix II-c (Spec. 401) which have already been used with satisfactory results. These new mixes are to be used on all new high-speed highway designs for which an asphalt concrete pavement has been selected.

The depth of the open graded mix should be twice the maximum size aggregate. Additional thickness is not necessary. If trueing and leveling is necessary, it should be accomplished by a fine mix prior to the placement of the open graded mix. A desirable practice is to specify it as the top or wearing layer of a 5 cm surface course.

7—05 SHOULDER PAVEMENTS

Shoulder pavements are not required to have the same structural strength as the pavement of the travel lanes. However, they should be capable of supporting intermittent heavy loads.

When a subbase is used it shall extend the full width of the roadbed which includes the shoulders.

Shoulders adjacent to PC concrete pavement can be either P.C. concrete or asphaltic concrete.

An asphalt concrete surface course should be at least 5 cm in depth, and its use instead of a P.C. concrete one is a matter of economics. The top or wearing layer should be an open graded surface mix with good skid resistance characteristics and sufficiently coarse in appearance and quality to discourage its use as a travel lane. The base course may be a dense graded untreated aggregate such as crushed stone or crushed gravel.

When the travel lanes are provided with an asphalt concrete pavement, the same surface course thickness is provided on the paved shoulders. However, a coarser mix should be specified to provide some degree of contrast. The shoulder base course may be a dense graded untreated aggregate such as crushed stone or crushed gravel.

Specific features of P.C. concrete shoulders are:

a) Reduction of pavement deflection.

b) Reduction of subsequent distress. Concrete shoulders may be thinner than the pavement and they must be tied to the pavement slab.

7—06 PAVEMENT TYPE SELECTION

The Department has not developed a specific analysis procedure to follow in the selection between a rigid or a flexible pavement type for a specific highway section. However, a report documenting the justification for the pavement type selected is required for all major highway sections. The factors included in the section of "Paving type Determination and Documentation" in the AASHTO booklet "An Informational Guide on Project Procedure" (1960) are to be followed as a guide. Of the 15 items listed in the AASHTO guide, all those appropriate to the specific highway under study are to be considered.

The following factors shall also be considered in conjunction with the AASHTO guide.

1. The cost of the pavement shall be a prime consideration in the selection of the type to be used.

2. In the absence of reliable cost accounting data, the annual maintenance cost should be considered equal for both the rigid and flexible types.

3. The salvage value of the two types of pavement at the end of the design period are considered to be equal.

4. It is expected that the flexible pavement will require at least one resurfacing layer (estimate 2.5 cm) during the normal design period of 20 years.

5. The levels of service provided by the two types of pavements are considered to be equivalent at all times.

6. In areas where the soils studies indicate that the subsoil conditions are such that subsidence requiring resurfacing should be expected during the design period, the consideration of rigid pavements may be omitted. For example, at all locations where the use of sand drains and/or surcharge are recommended to stabilize the existing soils, only flexible pavement will be considered.

7. A single type of pavement should be maintained on a highway section between major termini provided soil conditions permit it and there are no radical variations in cost.

8. Flexible type pavements are normally used for highways of design classes R—7 through R—11 and U—9, 10. No pavement type selection justification is required for these except in specific cases where a rigid type is recommended.

7—07 GOVERNING FACTORS IN PAVEMENT TYPE DETERMINATION

1. Traffic
2. Soils characteristics
3. Weather
4. Performance of similar pavements in the area
5. Economics or cost comparison
6. Adjacent existing pavements
7. Stage construction
8. Depressed, surface, or elevated design
9. Highway system
10. Conservation of aggregates
11. Stimulation of competition
12. Construction considerations
13. Municipal preference and recognition of local industry
14. Traffic Safety
15. Availability of and adaptations of local materials or of local commercially produced paving mixes

PRINCIPLE FACTORS

I. Traffic

The volume of passenger cars generally affects only the geometric or lane requirement. The percentage of commercial traffic and frequency of heavy load application generally has the major direct effect on the structural design of the pavement. Existing heavy-duty highways constitute sufficient evidence that both flexible and rigid pavement designs can meet requirements under given conditions.

If a cost comparison between competitive paving types is to be of value, it is imperative that the structural designs compared have equal capacity to carry loads. Since the matter is one of basic economics, the cost comparison must also include not only the cost of original construction, but that of needed periodic repairs and routine maintenance over the service life of the pavement, and an estimate as to what its probable useable salvage value will be at the end of that time.

It must be conceded that in these important areas, some assumption still must be made pending the results of current and further research developments not already available in guide form. When such assumptions are made, they must be made by the best qualified personnel available.

Present legal load limits are, to all intents and purposes, frozen by the Federal-Aid Highway Act of 1956, and will remain until certain studies are presented to the Congress for its consideration and further action.

Even accepting this restriction, it is reasonable and proper to make allowances in the structural designs of pavements for possible future modest legal load increases as well as the occassional overloads, whether moving by special permit or illegally, that are likely to use the pavement.

Currently, the AASHO Transport Committee is preparing new proposed vehicle weights and size regulations for consideration of the various States from data received fr m the AASHO Road Test and other appropriate sources. The Transport Committee assignment is to develop recommended size and weights to give an optimum balance between the best highway use and maximum highway life, for roads and bridges that can be furnished with the funds available for highway purposes.

In the projection of the density and weight of future traffic that will likely use the pavement during its lifetime, it is essential that not only normal increases be enticipated, but that consideration be given to the possibility of additional traffic being generated by potential industrial development or changes in land use for the area served.

The construction of a modern highway may also divert large amounts of heavy traffic, from other routes in the same broad traffic corridor, that should be considered by the designer.

II. Soils Characteristics

Of paramount importance is the ability of a native soil, which forms the subgrade for the pavement structure in cuts and on areas the inherent qualities of such native soils are far from uniform, and they are further subjected to variations by the influence of weather.

The characteristics of native soil not only directly affect the pavement structure design, but may, in certain cases, dictate the type of pavement economically justified for a given location.

The evaluation of the characteristics of soils is, axiomatically, a requirement for each individual pavement structure design.

III. Weather

Weather affects subgrade as well as pavement wearing course. The amount of rainfall, will seasonally influence the bearing capacity of subgrade materials. Moisture, will affect pavement wearing surfaces as to maintenance costs, etc.

In drawing upon performance record of pavements elsewhere, it is most important to take into consideration the conditions pertaining in the particular climatic belt.

IV. Performance of Similar pavements in the Area

To a large degree, the experience and judgment of the highway engineer is based on the performance of pavements in the immediate area of his jurisdiction. Past performance is a valuable guide, provided there is good correlation between conditions and service requirements between the reference pavements and the designs under study. This factor should not be

allowed to develop into blind prejudice. Caution must be urged against reliance on short-term performance records, and on those long-term records of pavements which may have been subjected to much lighter loadings for a large portion of their present life. The need for periodic reanalysis is apparant.

V. Cost Comparison

In any cost comparison of paving types, the matter of availability of local or commercially produced materials, and the existence and proximity of manufacturing or processing plants will be of significant importance.

Unavoidably, there will be instances where the financial circumstances are such as to make first cost the dominant factor in paving type selection even though greater maintenance costs may be involved later. Where circumstances permit, a better and more realistic measure would be the cost on the basis of service life or service rendered by a pavement structure. Such cost computation should reflect original investment, anticipated life, maintenance expenditures, and salvage value.

Original cost can be fairly accurately estimated. Doubt as to validity arises in the case where on type of pavement has been given monopoly status by the long-term exclusion of a competitive type.

The highly desirable determination of cost on a service life basis is presently adversely affected by some incomplete areas in needed factual information. One such area is the life expectancy of different paving types, a second, the matter of maintenance costs, and a third, the salvage value of pavements.

With our present state of limited knowledge as to the effect of frequency of heavy load applications, it is difficult to conceive of anything but an empirical approach to the determination of life expectancy of a pavement. The Bureau of Public Roads report "Lives of Highway Surfaces-Half Century Trends" shows a difference in the probable life for rigid and flexible pavements. It is not known if these trends hold for the pavements currently being constructed for the modern heavier traffic loadings, such as will be involved for the National System of Interstate and Defense Highways. The experience of the individual states as to assignment of probable life expectancy of different paving types, under the pertaining conditions, must for the present be accepted.

Assigned maintenance costs will seriously affect the cost comparison. If these costs are to be considered wholly valid, they must be based-on accurately kept, long-term maintenance records reflecting an established maintenance standard adhered to in practice. Since traffic and structural standards in the past have been such variables, it is difficult to accurately evaluate maintenance costs. This has not been a derelication of the highway official.

It is urged that the individual states take the necessary steps to develop factual information from Interstate System of highways, which will be valuable in the years ahead. These highways are built to modern standards. Establishment of, and adherence to, a maintenance standard, supplemented by accurate cost recording, will produce for the future more reliable data on maintenance cost and life expectancy.

Salvage value to be ascribed to pavements is somewhat open to conjecture. As it were, a large proportion of highway reconstruction involves changes in alignment or gradient which negate the salvage value. Each project actually must be considered individually.

SECONDARY FACTORS

I. Adjacent Existing Pavements

Provided there is no radical change in conditions, the choice of paving type on a highway may be influenced by existing sections thereof which have given adequate service. This will result in a desirable continuity of pavement and consequent simplification of maintenance operations.

II. Stage Construction

Where financial circumstances dictate stage construction of the type of pavement, where a thinner wearing course is later brought up to design requirements by an additional course or courses of wearing course material, flexible design becomes mandatory.

III. Depressed, Surface, or Elevated Design

Depressed and surface design may involve a high water table which will influence the choice of paving type. Elevated design, as in the case of approaches to long bridges or viaducts with concrete decks, may influence the decision in favor of rigid pavement to preserve a desirable continuity of pavement surface. A depressed design, presenting some periodic possible drainage problems, may also indicate the use of one type of pavement over another.

IV. Highway System

It is not considered good practice to let a system designation influence the choice of paving type. Merits of the individual case and economics should prevail.

V. Conservation of Aggregates

This consideration may well have influence in choosing a paving type which will involve, in the total pavement structure, less of the scarce critical material than might be required by another type.

VI. Stimulation of Competiton

It is desirable that monoply situations be avoided, and that improvement in products and methods be encouraged through continued and healthy competition among industries involved in the production of paving materials.

VII. Construction Consideration

Such considerations as speed of construction, reduction of traffic maintenance during construction, ease of replacement, anticipated future widening, need for minimum of surface maintenance in highly congested locations, seasons of the year when construction must be accomplished, and perhaps others may have a strong influence on paving type selections in specific cases.

VIII. Municipal Preference, Participating Local Government Preference and Recognition of Local Industry

While these considerations seem outside of the realm of the highway engineer, they cannot always be ignored by the highway administrator, especially if all other factors involved are indecisive as to the pavement type to select.

IX. Traffic Safety

The particular characteristics of a wearing course surface, the need for delineation through pavement and shoulder contrast, reflectivity under highway lighting, and the maintenance of a non-skid surface as affected by the available materials may each influence the paving type selection in specific locations.

X. Availability of and Adaptation of Local Materials or of Local Commercially Produced Paving Mixes

The prevalence of adaptability of local materials may influence, or the availability of commercial produced mixes particularly on small projects, may influence the selection of pavement type.

Conclusion . . .

In the foregoing, there have been listed and discussed those factors and considerations which influence, to various degree, the determination of paving types. This has brought to the fore the need, in certain areas, for the development of basic information that is not available at present. It has also served to point out that, in general, conditions are so variable, and influences sufficiently different from locality to locality, to necessitate a study of individual projects in most instances.

The public, although a critical judge, cannot be expected to be aware of the variety of considerations which influence the decisions of a highway administrator.

Consequently, whatever factors control the selection of the pavement type should be made part of the project file and should carry the identity of the person or persons involved in the entire process of making recommendations and in making the final decisions. It is very important that the reasons for reaching the decision be fully documented in the project file.

The judgment of the decision may be disputed at some subsequent time, but if the reasons are fully outlined and documented, the matter becomes only a difference of opinion and the reasons or the person of persons, who are responsibile for the decision, are a matter of record for any future review or investigation.

CHAPTER 8

TRAFFIC BARRIERS AND FENCING

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CHAPTER 8

TRAFFIC BARRIERS AND FENCING

8—01 GENERAL

Numerous studies has been made in recent years in an effort to improve highway safety. National Cooperative Highway Research Program (NCHRP) Report 118, published in 1971, updated and superseded previous NCHRP reports and extended scope of coverage to all types of traffic barriers.

In this year. the American Association of State Highway and Transportation Officials (AASHTO), issued the publication, "Guide for Selecting, Locating and Designing. Traffic Barriers", AASHTO 1977. When "AASHTO Barrier Guide" title appears in Figures and on Tables of this Chapter, it refers to this publication.

The Department has adopted the recommendations included in the Guide as the design criteria for selecting, locating and designing traffic barriers in Puerto Rico.

In this chapter free use will be made of the publication in discussing traffic barriers. We recommend that the Guide be consulted at all times since the Department's standards and design criteria are all based in its recommendations.

This chapter is assembled so that it could be used by construction and maintenance personnel to up-grade existing highway safety environment. The design philosophies included herein should be carried thru construction and maintenance operation. Deviation of the recommendations included should only be permitted whenever accident records for and specific site indicate a high frequency of severe accidents. In that instance sound engineering judgement will be used in the determination of the safety measures to be applied.

8—02 PURPOSE

The purpose of this document is to summarize the current state of knowledge and to present specific design guidelines for highway traffic barriers. The guidelines establish the conditions which warrant barrier protection, the type of barriers available, their strength, safety and maintenance characteristics, selection procedures, and how the barriers should be installed dimensionally or geometrically.

Also presented is a cost-effective selection procedure. This procedure is presented as an alternate to the more conventional selection procedure. In the conventional procedures, barrier need is usually based on an evaluation of the relative hazard of the barriers versus the hazard of the unprotected obstacle. The barrier is warranted if the obstacle is more hazardous to the motorist than the barrier itself. In the cost-effective procedure, need is based on an evaluation of the costs associated with the barrier versus the costs associated with the unprotected obstacle. Initial costs, maintenance costs, and accident costs are included in the evaluation.

For the purpose of this chapter all traffic barriers are classified as one of two basic type, namely, longitudinal barriers and crash cushions. Longitudinal barriers function primarily by redirecting errant vehicles. Crash cushions function primarily by decelerating errant vehicles to a stop. Roadside barriers (guardrails), median barriers, and bridge rails are the three types of longitudinal barriers.

The procedure in this chapter will have applications to both new and existing roadways. Consideration should be given to the application of the principles and criteria presented for reconstruction projects. A survey of existing facilities should be made and substandard conditions should be identified. Unnecessary barriers should be removed, substandard barriers should be upgraded or replaced with acceptable systems, unproperly located barriers should be relocated, and, if warranted, barriers should be installed to shield hazardous conditions which cannot be removed.

When an existing substandard guardrail is hit and damaged by a vehicle it shall be replaced with an operational system.

8—03 EVALUATION CRITERIA

Various factors may affect the determination of barriers need and, if warranted, the barrier best suited for the given conditions. Safety requirements, economic constraints, environmental constraints, and in some cases traffic control constraints are all factors the designer must usually confront. This chapter addresses primarily the safety requirements and the economic constraints.

8—03.01 WARRANTS

All of the warrants are based on the premise that a traffic barrier should be installed only if it reduces the severity of potential accident. Every effort should be made in the design stage to eliminate the need for traffic barriers, since a traffic barrier is in itself a hazard. If it is judged that a guardrail installation is not necessary at a particular embankment (that is, the guardrail is a greater hazard than the embankment); such a decision remains valid whether one or one thousand vehicles run off the road at that point.

8—03.02 STANDARD AND SAFETY CHARACTERISTICS

A traffic barrier serves dual and often conflicting roles. It must be capable of redirecting and/or containing an errant vehicle without imposing untolerable conditions on the vehicle occupants.

Generally, the structural adequacy of a longitudinal barrier is determined by impacting it with an 4,500 lbs. automobile at a 25 degree angle. The impact severity and vehicle trajectory hazard of a longitudinal barrier is determined by impacting it with a 2250 lbs. automobile at a 15 degree angle.

The barrier system chosen for inclusion in this chapter are operational. An operational system is one that has performed satisfactorily in full scale crash tests and has demonstrated satisfactory in-service performance.

8—03.03 MAINTENANCE CHARACTERISTICS

Maintenance is an important factor to consider when selecting a traffic barrier. Repair requirements in terms of manpower, material and equipment for typical collisions, the future availability of parts and the normal maintenance requirements are items to consider. Another important consideration is the time maintenance crews must be exposed to dangerous traffic conditions to repair the barrier. Repairs can also disrupt the traffic flow which increases the potential for accidents.

8—04 ROADSIDE BARRIERS

A roadside barrier is a longitudinal system used to shield vehicles from hazards in the roadside. It may also be used to shield hazards other than opposing traffic in extensive areas between divided highways. It may occasionally be used to protect pedestrians and "bystanders" from vehicular traffic.

It is the purpose of this section to delineate criteria pertinent to the various elements of design, including warrants, structural and safety characteristics of operational systems, maintenance characteristics of operational systems, a selection procedure, placement recommendations, and guidelines for upgrading substandard installations.

8—04.01 WARRANTS

Highway hazards that may warrant shielding by a roadside barrier can be placed in one of two basic categories: embankment and roadside obstacles. Pedestrians or "bystanders" may also warrant protection from vehicular traffic.

Roadside barriers warrants have applied to highways designed for vehicle speeds of approximately 50 mph or greater. However, conditions on lower volume highways will also be considered.

8—04.02 EMBANKMENT

Height and slope of the embankment are the basic factors in determining barrier need for a fill section. Warranting criteria for fill sections are shown in Figure 8—A. Embankment with slope and height combinations below the curve do not warrant protection. Obstacles on the slope may, however, warrant protection. The criteria in section 8—04.03 should be used in such cases. Embankments with slope and height combinations above the curve warrant protection.

Rounding of the shoulder, to reduce its hazard potential, should be accomplished to reduce the chances of an errant vehicle becoming airborne. Figure 8—B ilustrates shoulder rounding parameters and it contains the equations for determining the rounded profile. A limited number of studies have shown that aproximately 80 percent of errant vehicles leaving the roadway on high speed facilities do so at an encroachment angle of approximately 15 degrees or less. An encroachment angle of 15 degrees or less should be used for design purposes in applying equations III—A—1, III—A—2, and III—A—3, in Figure 8—B. In Figure 8—C values of the distance are given as a function of operating speed and (e—b/a). All of the curves are based on an encroachment angle of 15 degrees.

8—04.03 ROADSIDE OBSTACLES

Roadside obstacles are classified as nontraversable hazards and fixed objects. These highway hazards account for over thirty percent of all highway fatalities each year and their removal should be the first alternative considered. If it is not feasible or possible to remove or relocate a hazard, then a barrier may be necessary. However, a barrier should be installed only if it is clear that the barrier offers the least hazard potential.

Barrier warrants for roadside obstacles are a function of the nature of the obstacle and its distance from the edge of the traveled way. Figure 8—D shows criteria for determining the clear zone on fill and cut sections for three different vehicle operating speeds. The clear zone widths obtained by this Figure are considered appropiate for high traffic volume highways. (Average daily traffic volume of over 6,000 vehicles). Section 8—08.04 provides a method for adjusting clear zone widths for lower volume and different vehicle operating speeds highways. Clear zone is defined as the roadside border area, starting at the edge of the traveled way (edge of pavement), available for safe use by errant vehicles. Nontraversable hazards or fixed objects should be removed, relocated, or shielded by a barrier if they are within the indicated minimum clear one widths.

The procedure for use of Figure 8—D is as follows:

1) Locate on the appropiate curve based on given operating speed the point whose ordinate (vertical axis) coincides with the slope of the embankment.
2) Locate in the abcissa (horizontal axis) the minimum clear zone width from the traveled way.
3) If the obstacle or hazard is located within this clear zone width, it must be removed or relocated. Otherwise a barrier is warranted.

The clear zone width should be increased on the outside of curves by the amount DCZc in which:

$$DCZc = R(1\text{-}\cos\frac{L_R D^o}{100})$$

D^o = degree of curve, 100 ft. are definition
R= radius of curve, ft.
L_R = runout path length, from Table 8—17, ft.

The distance DCZc given by this equation is for slopes of 10:1 or flatter. For steeper slopes this distance should be increased by the ratio of clear zone width on steeper side slope divided by clear zone width on zero side slope.

The additional clear zone width DCZc should be applied at a distance L_R into the curve. The increase should be tapered on the curve at the entrance end and on the tangent at the exit end of the curve. (See Figure 8—D).

The clear zone criteria represents the present state of knowledge and it underlines the fact that flat, unobstructed roadsides are highly desirable. This clear zone width should be provided whenever posible.

Typical nontraversable hazards and appropiate barriers warrants are shown in Table 8—1. Any nontraversable hazard that warrants shielding by a barrier should be removed. If this is not practical, a barrier should be provided.

Another common hazard on non-freeway facilities is a driveway or roadway which crosses a main roadway. The slope of the driveway or crossing roadway should be 10:1 or flatter. Also sloping inlet and outlet culvert grates should be used. (See model 4—Z of the Puerto Rico Highway Authority).

It the embankment of the main roadway leading up to a driveway or crossing roadways must be shielded, a layout similar to that shown in Figure 8—E should be used. Additional fill should be provided adjacent to the driveway in order that the barrier terminal be flared away from the main roadway as far as posible. The need for crashworthy end treatments on the north and south side would depend on their distance from adjacent and opposing traffic lanes. Reference should be made to Section 8—07.04 for guidelines.

Typical fixed objects and the warranting criteria are given in Table 8—2. Fixed objects within a clear zone that warrant barriers protection by this Table should be removed. If removal or relocation is not practical or feasible, the object should be shielded by a barrier.

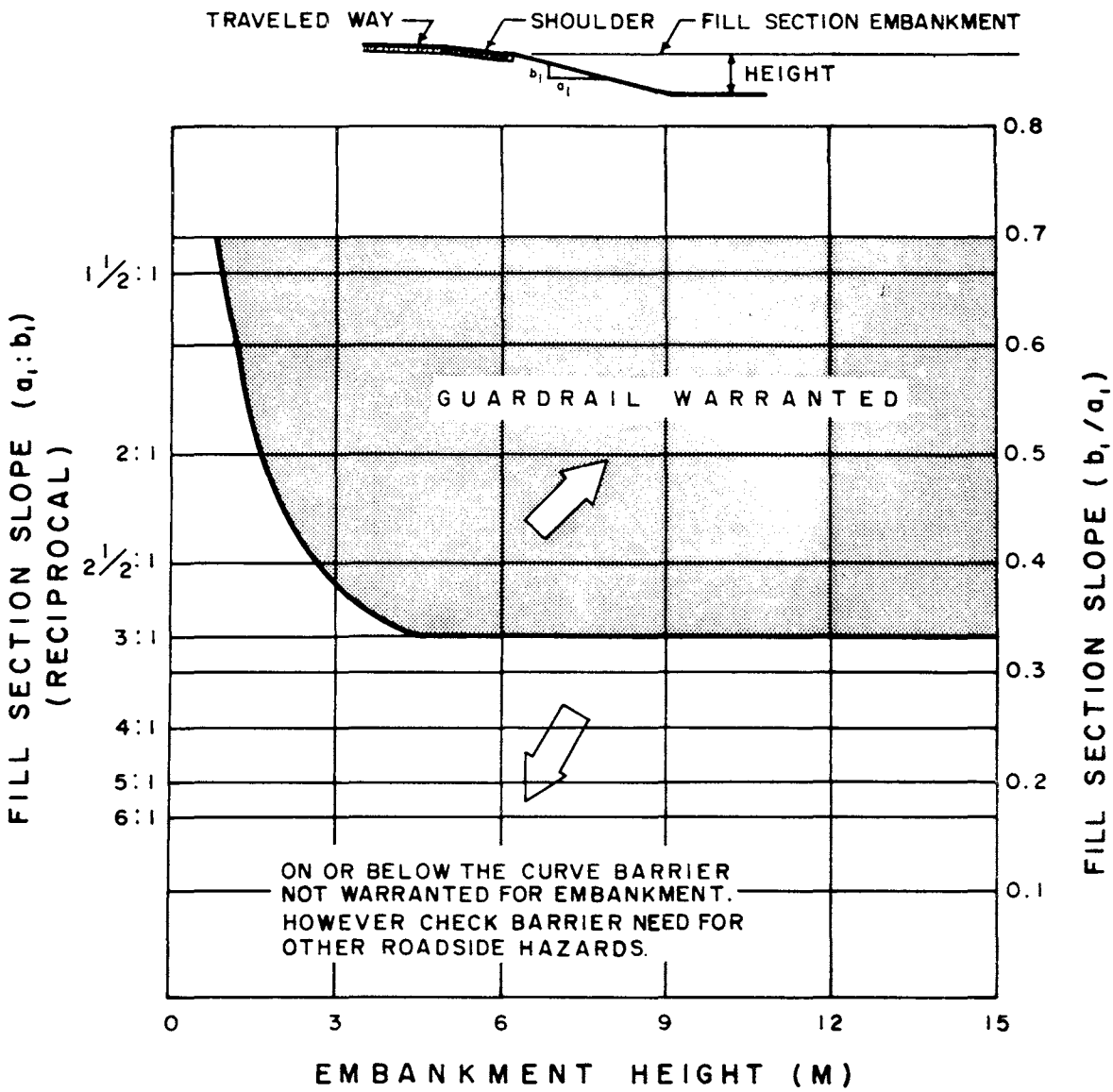
Figure 8—F outlines the procedure to follow to determine roadside barriers needs for fill and cut sections and roadside obstacles. The procedure should be followed for each roadside hazard until barrier need is established.

8—04.04 BRIDGE RAIL ENDS, TRANSITIONS, AND END TREATMENTS

Most bridge rail approach barrier systems are some type of roadside barrier. Figure 8—G summarized the warrants for an approach barrier to a bridge. These criteria are again based on the clear zone requirements for fixed hazards (Figure 8—D) since the unprotected end of a bridge rail is considered a fixed object hazard.

If an approach barrier is warranted based on Figure 8—G adequate transition section between the approach barrier and the bridge rail is warranted. If the end of the approach barrier terminates within the clear end zone, a crashworthy end treatment is also warranted.

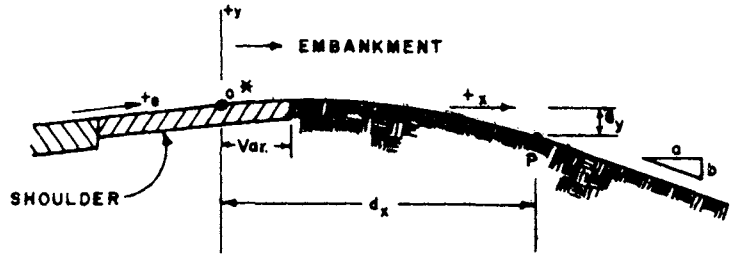
A transition section is warranted when there is a significant change in the lateral strength or lateral stiffness of a roadside barrier.



WARRANTS FOR FILL SECTION EMBANKMENTS.

FIGURE 8-A

* NOTE: BEGINING OF ROUNDING WAY BE WITHIN SHOULDER WIDTH, IF DESIRED, PROVIDED SLOPE OF SHOULDER DOES NOT BECOME EXCESSIVE.



ROADSIDE ELEVATION

EQUATIONS

	Metric	
$y = x\left[e - \frac{6.9x}{V^2\sin^2\phi}\right]$	$y = x\left[e - \frac{2.1x}{V^2\sin^2\phi}\right]$	(III-A-1)
$0 \le x \le d_x$	$0 \le x \le d_x$	
$d_x = \frac{V^2\sin^2\phi}{13.8}\left[e - \frac{b}{a}\right]$	$d_x = \frac{V^2\sin^2\phi}{4.2}\left[e - \frac{b}{a}\right]$	(III-A-2)
$d_y = d_x\left[e - \frac{6.9d_x}{V^2\sin^2\phi}\right]$	$d_y = d_x\left[e - \frac{2.1d_x}{V^2\sin^2\phi}\right]$	(III-A-3)
y, x, d_x, and d_y in feet.	y, x, d_x, and d_y in meters.	

where, e = shoulder slope (ft/ft) [m/m], positive if sloping upward;

$\frac{b}{a}$ = embankment slope (ft/ft) [m/m], negative if sloping downward;

V = vehicle velocity (ft/sec) [m/s]; and

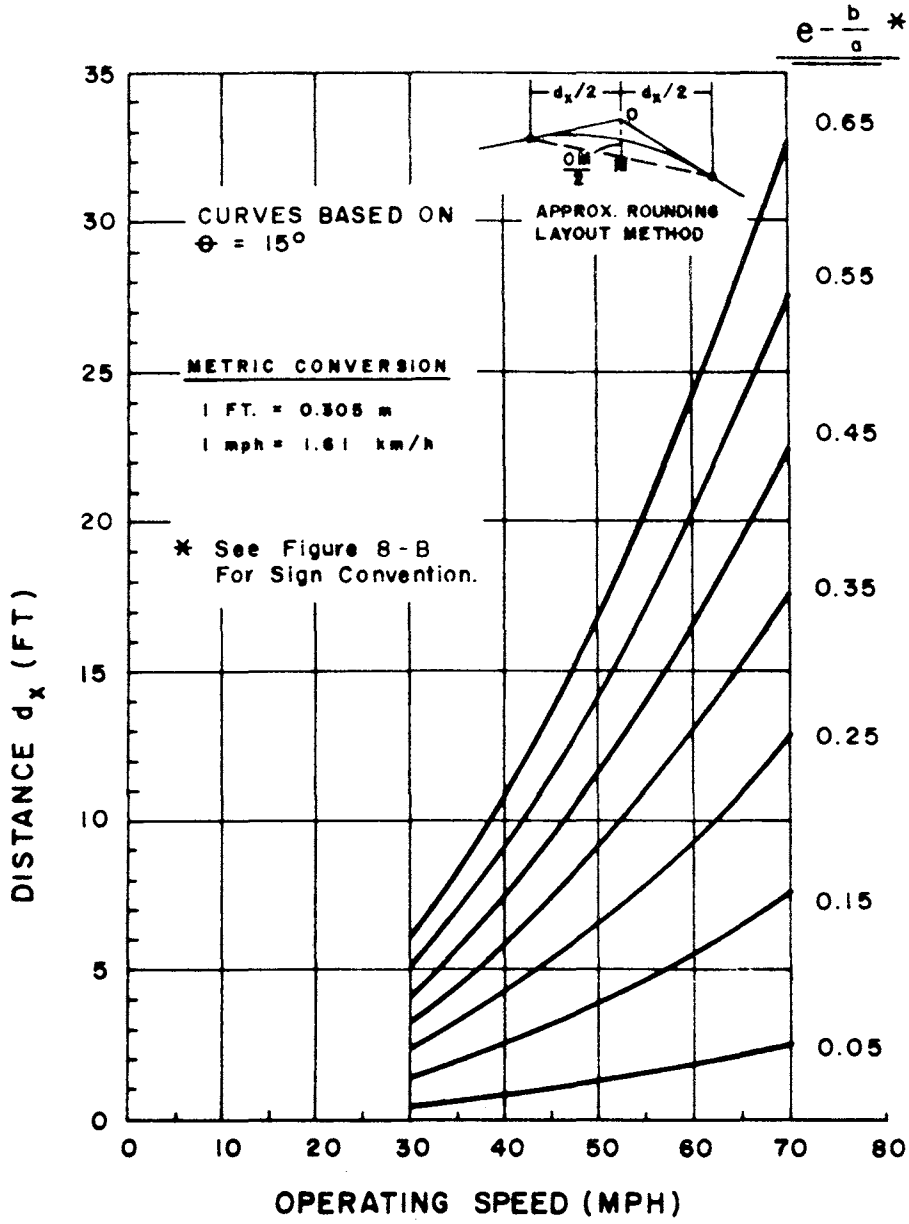
ϕ = vehicle encroachment angle (deg), or the angle between vehicle heading and tangent to roadway.

"O" = shoulder slope tangent point, and origin of x-y axis.

"P" = side slope tangent point.

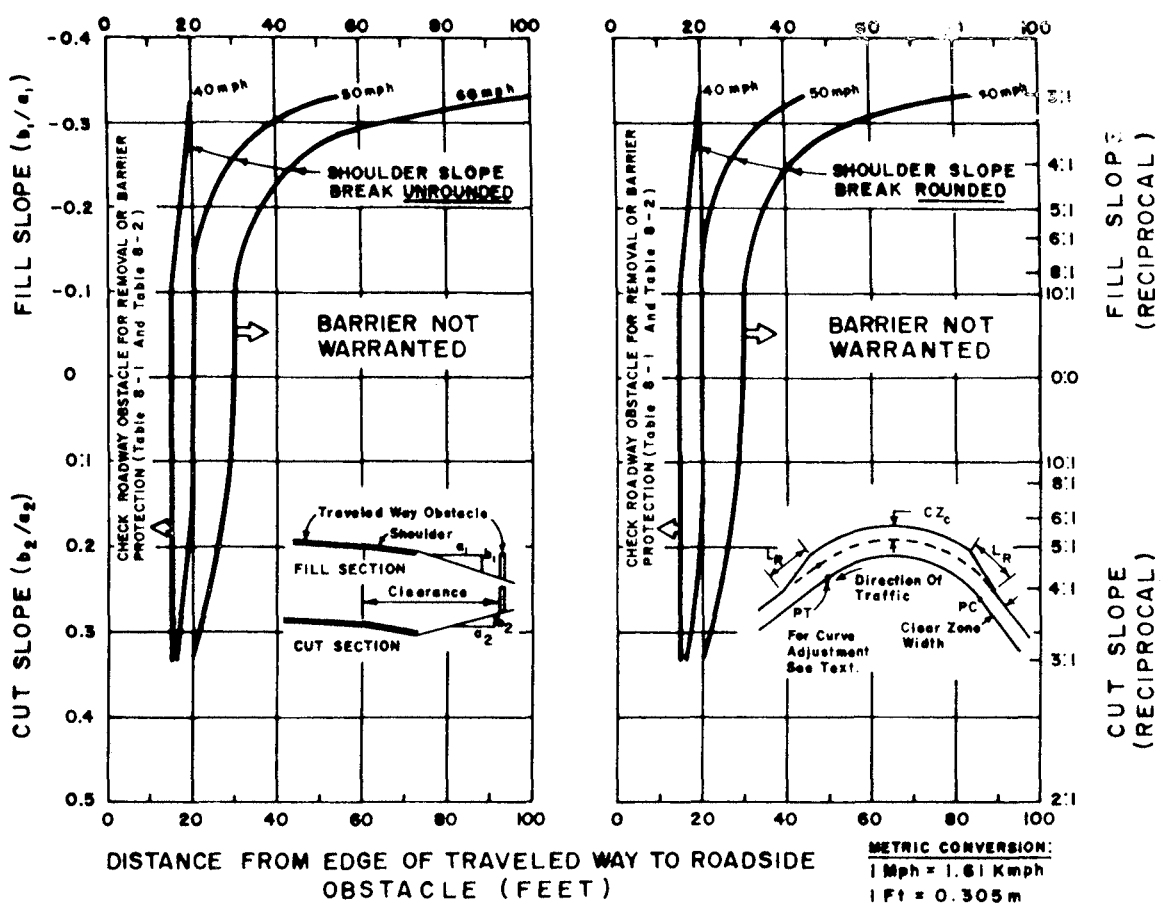
ROUNDING PARAMETERS AND EQUATIONS.

FIGURE 8-B



LATERAL ROUNDING DISTANCE, d_x, VERSUS OPERATING SPEED.

FIGURE 8 - C



$CZ_c = R(1 - \cos \frac{L_R D}{100})$

(Side Slope-Or Flatter)

D = Degree Of Curve

R = Radius Of Curve

L_R = Runout Length

METRIC CONVERSION:
1 Mph = 1.61 Kmph
1 Ft = 0.305 m

CLEAR ZONE WIDTH, SPEED AND SLOPE CRITERIA.

FIGURE 8-D

Nontraversable Hazard Within Clear Zone As Determined By Figure 8-D	Traffic Barrier Required	
	Yes[1]	No
Rough Rock Cuts	X	
Large Boulders	X	
Streams Or Permanent Bodies Of Water Less Than 2 Ft. In Depth		X
Streams Or Permanent Bodies Of Water More Than 2 Ft. In Depth	X	
Shoulder Drop-Off With Slope Steeper Than 1:1 And		
a) Height Greater Than 2 Ft.	X	
b) Height Less Than 2 Ft.		X

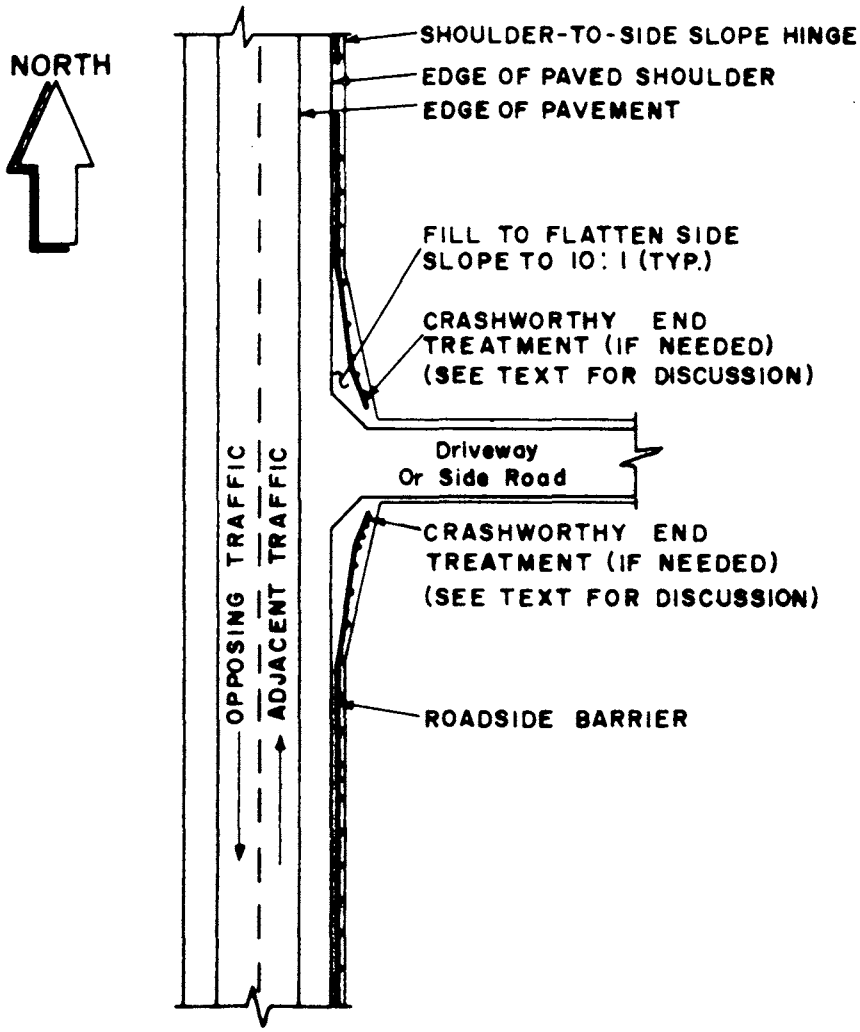
[1]All Roadside Obstacles Within The Clear Zone Should Be Removed If Possible, Otherwise Provide Barrier Protection.

Metric Conversions

1 Ft. = 0.3048 m

WARRANTS FOR NONTRAVERSABLE HAZARDS.

TABLE 8-1



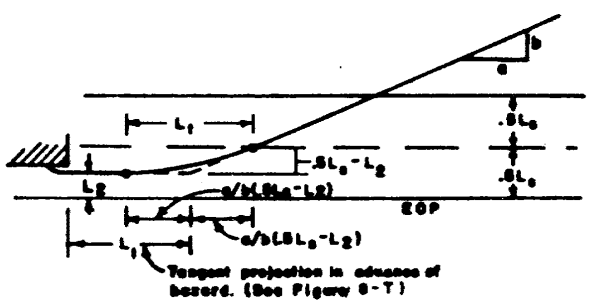
POSSIBLE LAYOUT FOR INTERRUPTING ROADSIDE BARRIER AT DRIVEWAY.

FIGURE 8-E

Operating Speed (mph)	Design Traffic Volume (ADT) Over 6000 Runout Length L_R (ft)	2000-6000 Runout Length L_R (ft)	800-2000 Runout Length L_R (ft)	800-250 Runout Length L_R (ft)	Under 250 Runout Length L_R (ft)	Sky Line Offset - L_s (ft.)	Flare Rate (a:b)*
70	480	440	400	360	330	10.0	15 **
60	400	360	330	300	270	8.0	13 **
50	320	290	260	240	210	6.5	11 **
40	240	220	200	180	160	5.0	9 **

*When $L_2 < .5L_s$, L_1 shall have a minimum length = $\frac{2a}{b}(.5L_s - L_2)$

Where $\frac{a}{b}$ = flare rate from this table



**Values are for yielding barrier (2' > dynamic deflection)

for rigid barriers increase numerator by $.1\left[\frac{V}{10}\right]^2$

V = operating speed (mph)

**Adjustment factor for rigid barriers is $V^2(3.86 \times 10^{-4})$, When V is in Km/hr.

Metric Conversions

1 ft. = 0.305 m
1 mph = 1.61 Km/h

DESIGN PARAMETERS FOR ROADSIDE BARRIER LAYOUT.

TABLE 8-17

8—04.05 BYSTANDERS, PEDESTRIANS, AND CYCLISTS

Conventional criteria presented in the previous sections cannot be used to establish barrier needs concerning the "bystander" problem. Even when the boundaries of a school, business and/or residences are beyond the clear zone, a barrier may be needed. If there is any reasonable probability of an errant vehicle encroaching any of these, a barrier would be warranted. In these cases the barrier must be placed near the boundary of the structure to minimize the hazard to the motorist.

Pedestrians and Cyclists must be separated from vehicular traffic by physical means whenever possible. On low speed highways, a barrier curb will be sufficient. At speeds in excess of 30 to 40 mph a roadside barrier should be installed. Proper consideration must be given to the deflection characteristics in the selection and lateral placement of the barrier.

8—04.06 DITCH CROSS SECTIONS

Ditches within the clear zone area must be so designed that it can be easily tranversed by an errant vehicle.

Figures 8—H, 8—J and 8—K present front slopes and back slopes for various ditch configurations. Ditch sections for high speed facilities should fall within the shaded region of each of the figures. Ditch sections which fall outside the shaded region should be flattened and rounded or internal drainage systems must be added.

8—04.07 EXAMPLE PROBLEMS

This section presents illustrative problems for determining barrier needs for the roadside hazards ilustrated in Figures 8—L and 8—M. Figure 8—F is used for each situation in conjunction with other appropiate figures and tables in previous sections. An operating speed of 60 mph and shoulder width of 12' were used at each section.

Section A—A:

East Side of Roadway:

1) Fill section.
2) Slope not steeper than 3:1.
3) Clear zone criteria: For roadside hazards not located on the slope, a "weighted" average approach may be used to determine the average slope of the section from the edge of the shoulder to the roadside obstacle. For sections flatter than or equal to 10:1 a slope of 10:1, should be used. Average slope of the clear zone.

$$(b_1/a_1)\ \text{AVE} = \frac{(50\ \text{ft.})\ (0.333) + (20\ \text{ft.})\ (0.1)}{70\ \text{ft.}}$$

$$= 0.27$$

Enter Figure 8—D (60 mph unrounded) with $(b_1/a_1) = 0.27$ and clearance=82 ft. (25.0 m)

4) Barrier not warranted.

West Side of Roadway:

1) Cut section traversable.
2) Enter Figure 8—D (60 mph unrounded) with (b_2/a_2)=0.5 and clearance=37 ft. (11.3 m)
3) Barrier not warranted.

Section B—B:

East Side of Roadway:

1) Fill section.
2) Slope is steeper than 3:1.

TABLE 8–2 WARRANTS FOR FIXED OBJECTS

Fixed Objects Within Clear Zones as Determined by Figure 8–D	Traffic Barrier Required	
	Yes	No
Sign, traffic signal, and luminaire supports[2]		
a) Breakaway or yielding design with linear impulse:[3]		
1) less than 1,100 lb-sec		X
2) greater than 1,100 lb-sec	X[4]	
b) Concrete base extending 6 in. or more above ground	X	
Fixed sign bridge supports	X	
Bridge piers and abutments at underpasses	X	
Retaining walls and culverts	X	
Trees with diameter greater than 6 in.	X[4]	
Wood poles or posts with area greater than 50 in.[2]	X[4]	

[1]Fixed object should be removed or relocated so that a barrier is unnecessary if practical.

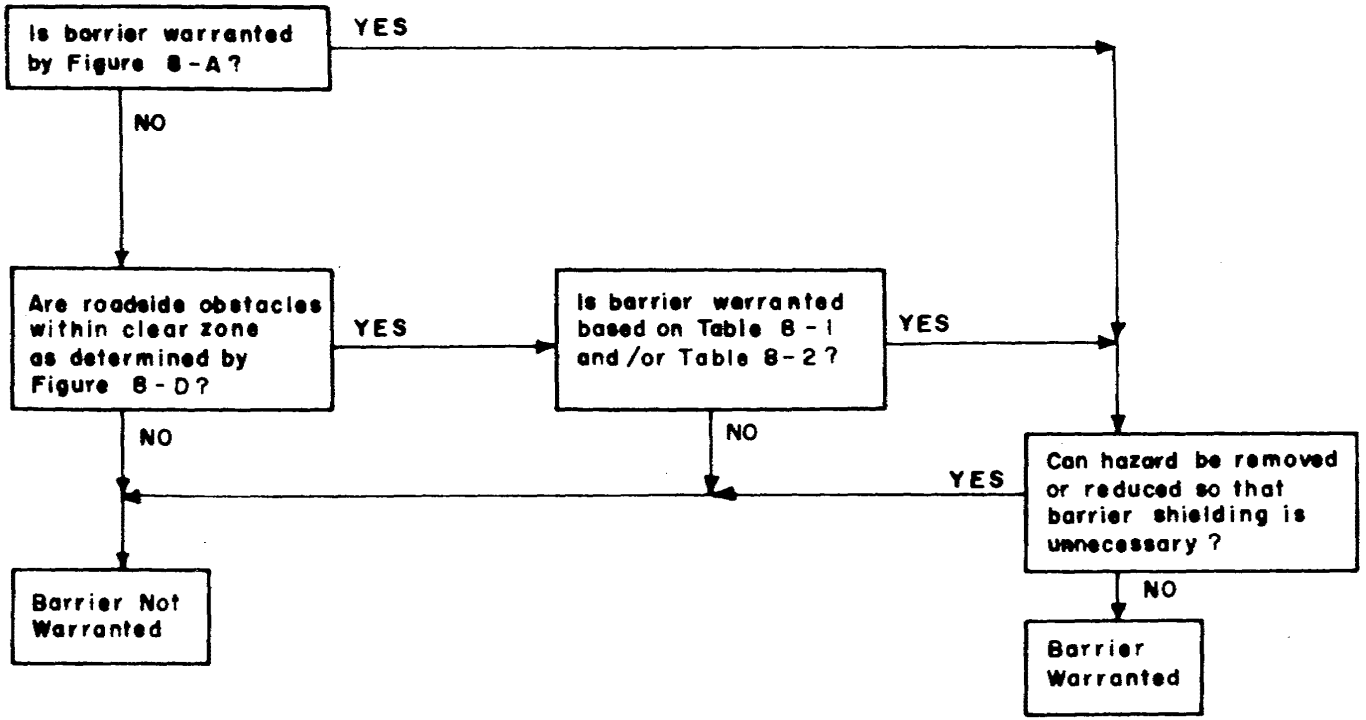
[2]Breakaway or yielding design is desirable regardless of distance from traveled way.

[3]See discussion in text.

[4]A judgment decision (see discussion in text).

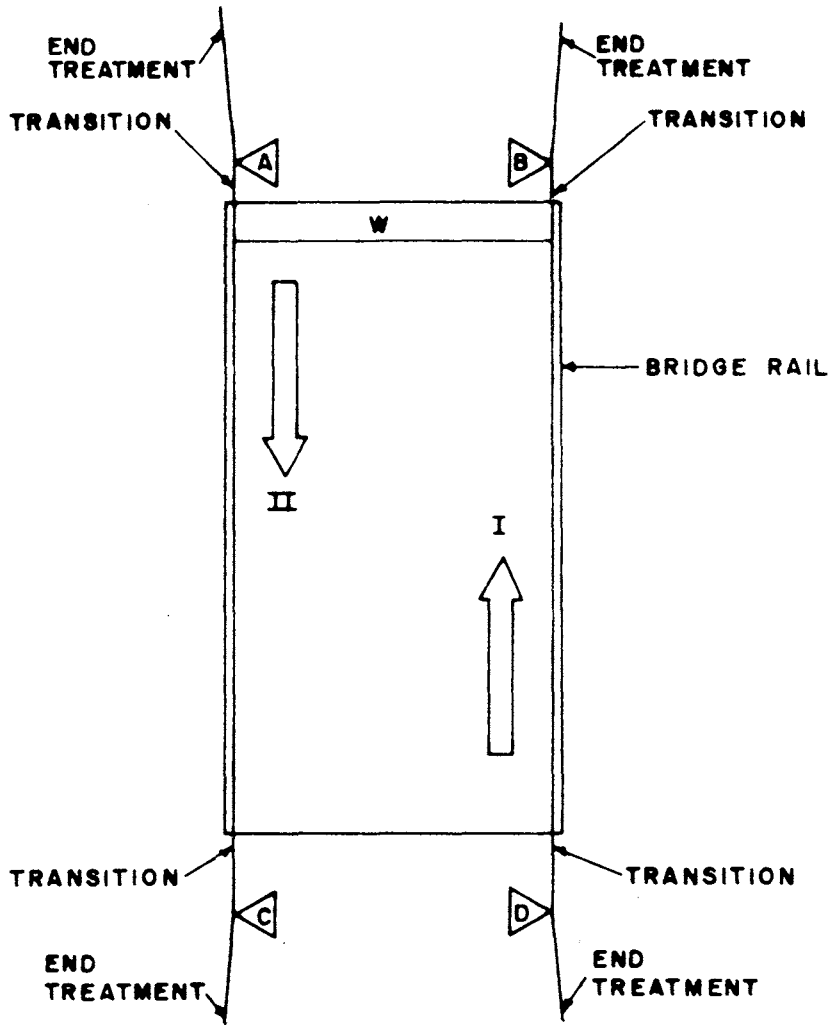
Metric Conversions:

1 lb-sec = 4.45 N-sec
1 in = 0.0254 m



SUMMARY OF ROADSIDE BARRIER WARRANTS.

FIGURE 8-F

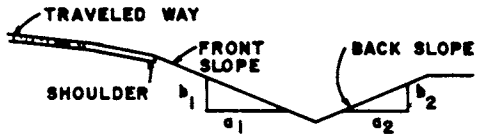


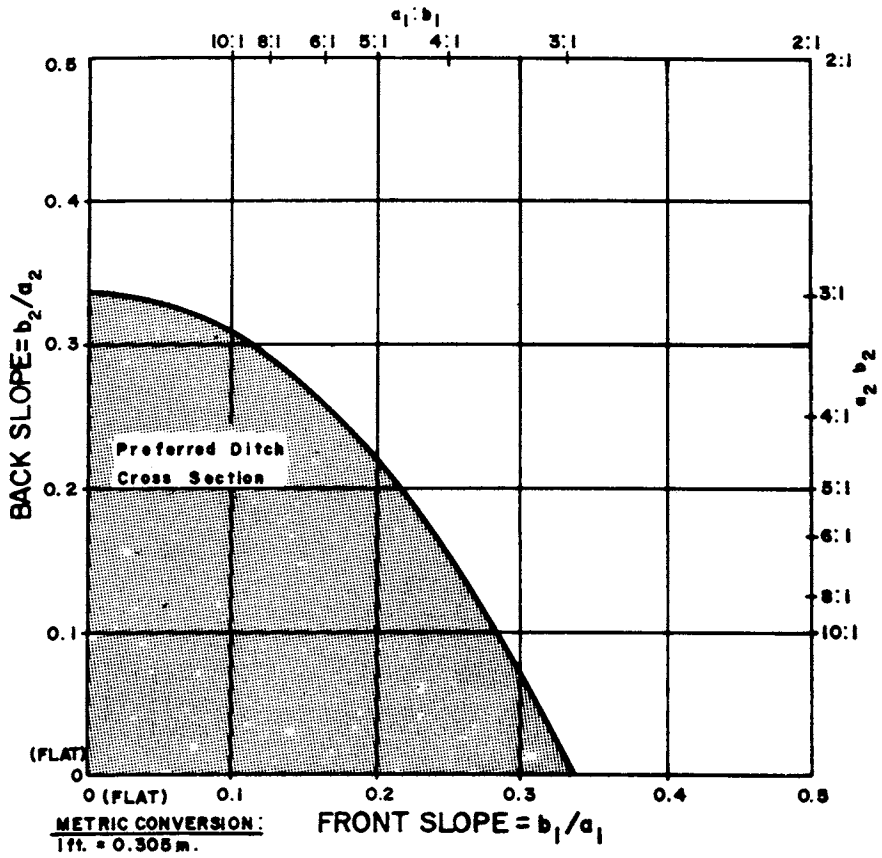
TRAFFIC DIRECTION	DISTANCE BETWEEN BRIDGE RAILS-W(ft.)	APPROACH BARRIER REQUIRED AT *
I AND II	≤ 2 X Clear zone width (see Fig. 8-D)	A,B,C,D
I AND II	> 2 X Clear zone width (see Fig. 8-D)	A,D
II ONLY	ALL WIDTHS	A,B
I ONLY	ALL WIDTHS	C,D

Check roadside for other warranting features.

BRIDGE APPROACH BARRIER CRITERIA.

FIGURE 8-G

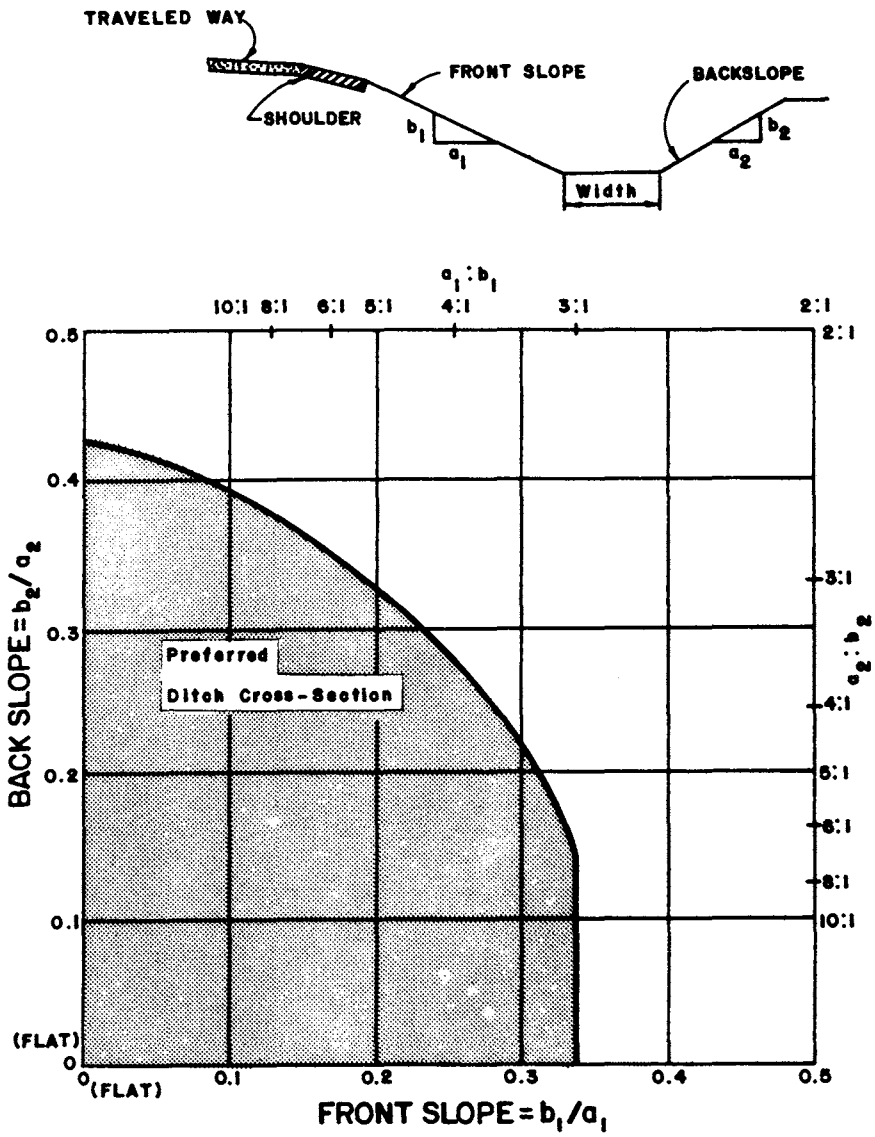




PREFERRED DITCH SECTIONS, A FOR:

(a) Vee Ditch.; or
(b) Round Ditch, Bottom Width < 8ft.; or
(c) Trapezoidal Ditch, Bottom Width < 4ft.; or
(d) Rounded Trapezoidal Ditch, Bottom Width < 4ft.

FIGURE 8-H

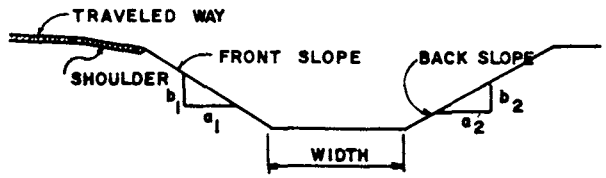


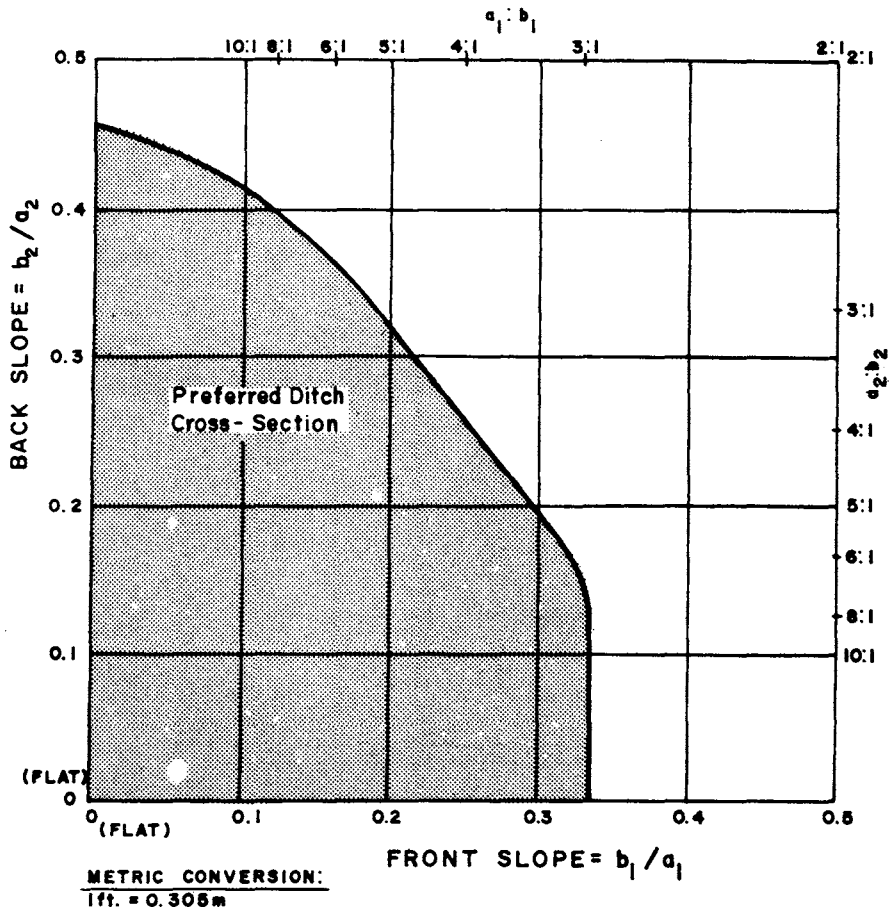
METRIC CONVERSION:
1ft. = 0.305m.

PREFERRED DITCH SECTIONS, B FOR:

(a) Trapezoidal Ditch, Bottom Width = 4ft. To 8ft., Or
(b) Round Ditch, Bottom Width = 8ft. To 12ft.

FIGURE 8-J





METRIC CONVERSION:
1 ft. = 0.305 m

PREFERRED DITCH SECTIONS, C FOR:

(a) Trapezoidal Ditch, Width > 8 ft.; or
(b) Round Ditch, Width > 12 ft.; or
(c) Rounded Trapezoidal Ditch, Width > 4 ft.

FIGURE 8-K

3) Enter Figure 8—A with fill height=10 ft. (3.05 m) and $(b_1/a_1)=0.667$, Barrier is warranted.

Solution: Flatten slope and remove or cover boulders. If this is not feasible provide barrier.

West Side of Roadway:

1) Cut section.
2) 1:1 backslope off scale on Figure 8—H.
3) Improvement in cross section through widening the cut, rounding, flattening of the back slope or a combination of these measures should be considered.

(Note: The task force that steered the development of the Guide recognized the potential hazard of ditches and cut back slopes. However, in the absence of data on the relative hazards of roadside barriers and ditches and backslopes, the task force was reluctant to recommend shielding such hazards with roadside barriers. The decision maker faced with a question of wether to shield a ditch or back slope is referred to Chapter VII of the Guide and is reminded that a roadside barrier has a hazard potential, has initial and maintenance costs and will encroach on otherwise available recovery space).

Section C—C:

East Side of Roadway:

1) Fill Section.
2) Slope is not steeper than 3:1.
3) Enter Figure 8—D (60 mph unrounded) with $(b_1/a_1)=0.167$ and clearance= 32 ft. (9.15 m). Further check of obstacle is needed.
4) Check Table 8—1 for permanent body of water with 6 ft. depth Barrier is warranted.

Solution: This problem calls for the exercise of additional judgement. The 6:1 slope is relatively gentle and continues into the water hazard, which begins very close to the outer limit of the clear zone indicated in Fig. 8D. In the absence of accident experience a barrier probably should not be installed.

West Side of Roadway:

1) Fill section.
2) Slope is not steeper than 3:1.
3) Enter Figure 8—D (60 mph unrounded) with $(b_1/a_1)=0.2$ and clearence = 62 ft. (18.9m). Intersection of two points falls in region bordering further roadside obstacle check and barrier unwarranted.

Solution: Barrier not warranted unless frequency of accidents is high.

Section D—D:

East Side of Roadway:

1) Fill or flat section.
2) Slope is not steeper than 3:1.
3) Enter Figure 8—D (60 mph unrounded) with $(b_1/a_1)=0.1$ and clearance 22 ft. (6.7 m) Further check of obstacle needed.
4) Check Table 8—2 for sign supports.
5) Assume supports are of breakway design. Barrier not warranted.

(Note: In almost all cases, a roadside sign can either be relocated, made breakway, or removed. Hence, the need to shield a roadside sign with a barrier should be nil).

West Side of Roadway:

1) Cut Section, (Figures 8—H, J and K should be checked to see if improvement in cross sections should be considered. See note for section B—B West Side.)
2) No roadside obstacles to be checked.
3) Barrier not warranted.

Section E—E:

East Side of Roadway:

1) Fill Section.
2) Average slope.

$$(b_1/a_1)\ AVE = \frac{(15\ ft.)\ (0.25) + (20\ ft.)\ (0.333)}{65\ ft.} + \frac{(30\ ft.)\ (0.1)}{65\ ft.} = 0.21$$

Enter Figure 8D (60 mph unrounded) with (b_1/a_1)=0.21 and clearance=77 ft. (23.5 m). No further check on rough rock cut needed.

3) Barrier not warranted.

West Side of Roadway:

Cut section not traversable. However, barrier would probably not be warranted if back slope surface is smooth and does not cause vehicle to pocket and/or overturn.

Section F—F:

East Side of Roadway:

1) Flat Section.
2) Slope not steeper than 3:1.
3) Enter Figure 8—D (60 mph) with (b_1/a_1)=0.1 clearance=33 ft. (10.1 m).
4) Barrier not warranted by standard criteria, however a playground near a high speed facility may need to be shielded. Need must be based on judgement. The driveway presents special problems. Reference should be made to the discussion in Section 8—04.03.

West Side of Roadway:

1) Fill section.
2) Slope not steeper than 3:1.
3) Enter Figure 8—D (60 mph unrounded) with (b_1/a_1)=0.25 and clearance=42 ft. (12.8 m). Further check of obstacle needed.
4) Check Table 8—I for drop-off of 3 ft. (0.91 m) at bottom of slope. Barrier warranted.

Solution: Fill in and round drop-off to a 3:1 or flatter slope.

Section G—G:

East Side of Roadway:

1) By bridge approach barrier criteria in Figure 8—G an approach barrier system is warranted. An appropiate transition section and end treatment should also be provided with the approach rail. (See Section 8—08.04 for discussion.)

West Side of Roadway:

1) Again by bridge approach barrier criteria in Figure 8—G an approach barrier system is warranted. An appropiate transition section and end treatment should also be provided with the approach rail system. Note that at Station 8, bridge approach barrier with

appropiate transition section and end treatment would also be warranted on the east and west side of the roadway, although this is not considered in this example. (See Section 8—08.04 for discussion.)

Section H—H:

East Side of Roadway:

1) Fill section.
2) Slope is steeper than 3:1.
3) Enter Figure 8—D with (b1/a1)=0.5 and fill height=3 ft. (0.91 m) Height and slope of fill section does not warrant protection.
4) No roadside obstacle on or near fill section.
5) Barrier protection not warranted. (It would be desirable to flatten the side slope.)

West Side of Roadway:

1) Fill section.
2) Slope is steeper than 3:1.
3) Slope is 2:1 and height is approximately 40 ft. (12.2 m). By Figure 8—D barrier is warranted. It should be noted, however that the slope has been rounded (see discussion in Section 8—04.02 and Figure 8—B). Under some circumstances, such as low volume roadways or roadways with operating speeds below 60 mph (96.6 km/h) or low frequency of accidents, the highway engineer may choose not to provide a barrier for such a cross-section.

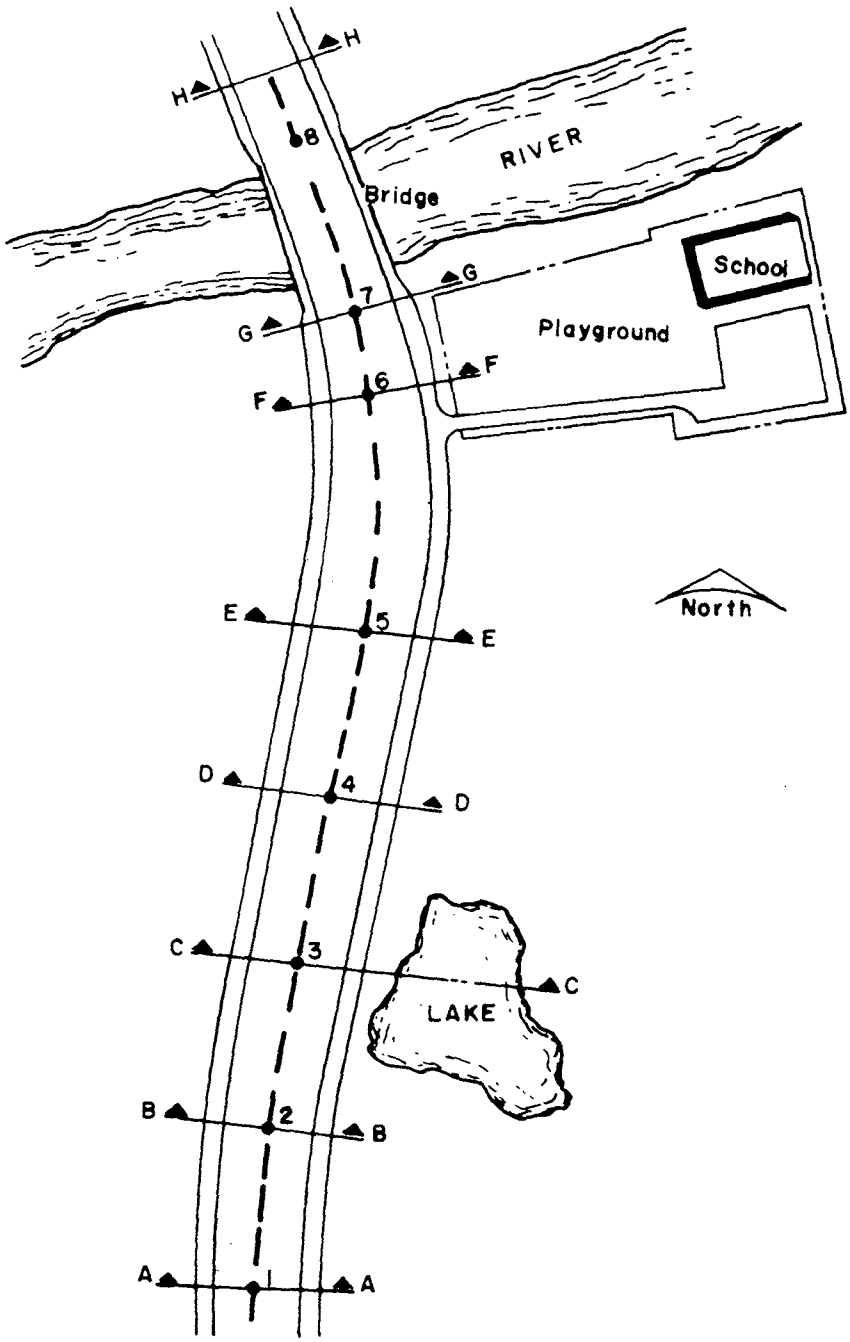
8—05 STRUCTURAL AND SAFETY CHARACTERISTICS

It is the purpose of this section to present operational roadside barrier systems in current use in Puerto Rico and to point out desirable structural and safety characteristics. The section is subdivided according to standard sections of roadside barriers, transitions, and end treatments for roadside barriers. Figure 8—N is an example to ilustrate these three roadside barrier elements.

It has been shown that small variations in designs or in construction details can have adverse effects on the impact performance of barriers. Thus, the design details should correspond to the as-tested details, as shown on the following sections. In many cases, the barriers were subjected to series of crash tests. Appendix C of the Guide contains a summary of all crash tests performed on each of the systems.

8—05.01 STANDARD SECTIONS OF ROADSIDE BARRIERS

Tables 8—3 thru 8—6 present a summary of the structural and safety characteristics of current operational roadside barriers. The G—2 ("W" Beam, Steel Weak Post) and G—4 (1S) (Blocked-Out "W" Beam, Steel Strong Post) systems are the most commonly used in Puerto



ILLUSTRATIVE EXAMPLE FOR ROADSIDE BARRIER WARRANTS, A.

FIGURE 8-L

Rico. They correspond to standard models No. 1 and No. 1—A, of the Puerto Rico Highway Authority, respectively.

The roadside barriers are usually denoted as either flexible (weak-post) a semi-rigid (strong post systems). Flexible systems undergo considerable dynamic deflection upon impact and are generally more forgiving than the semi-rigid systems since they impose lower impact forces on the vehicle.

In selecting a roadside barrier, as discussed in Section 8—07, close attention must be given to its deflection characteristics. If the barrier can be placed a considerable distance from the hazard, a flexible barrier can be used. Conversely, semi-rigid barriers are necessary if the barrier-to-hazard distance is small. However, short intermittent sections of any roadside barrier are undesirable. Gaps of less than 60 meters between barriers installations should be avoided.

The rail heights in Tables 8—3 thru 8—6 range from 27 inches to 32 inches with 27 inches as the most common height. A minimum height of 27 inches is a necessary condition to insure proper barrier impact performance.

Post spacing for strong post systems is 6.25 feet. Tests have shown that this spacing is needed to minimize vehicle snagging or pocketing, post spacings may also allow a rail to twist into a ramp and thus cause vaulting. All the systems in Table 8—7 are considered to be structurally adequate, although some deflect more than others.

It is important to note that the performance of a roadside barrier is sensitive to a variety of conditions. Difference in the response are attributed to three important parameters: The type of soil, the length of installation, and the end treatment. Barriers installed in soft or yielding soil may require deeper embedment of the post and/or closer post spacing.

An effort has been made to standardized hardware for widely used traffic barriers. Roadside barriers which have been stadardized are so noted in the last colum of Table 8—7. This table also contains a summary of the impact performance data on each of the operational systems.

8—05.02 TRANSITIONS

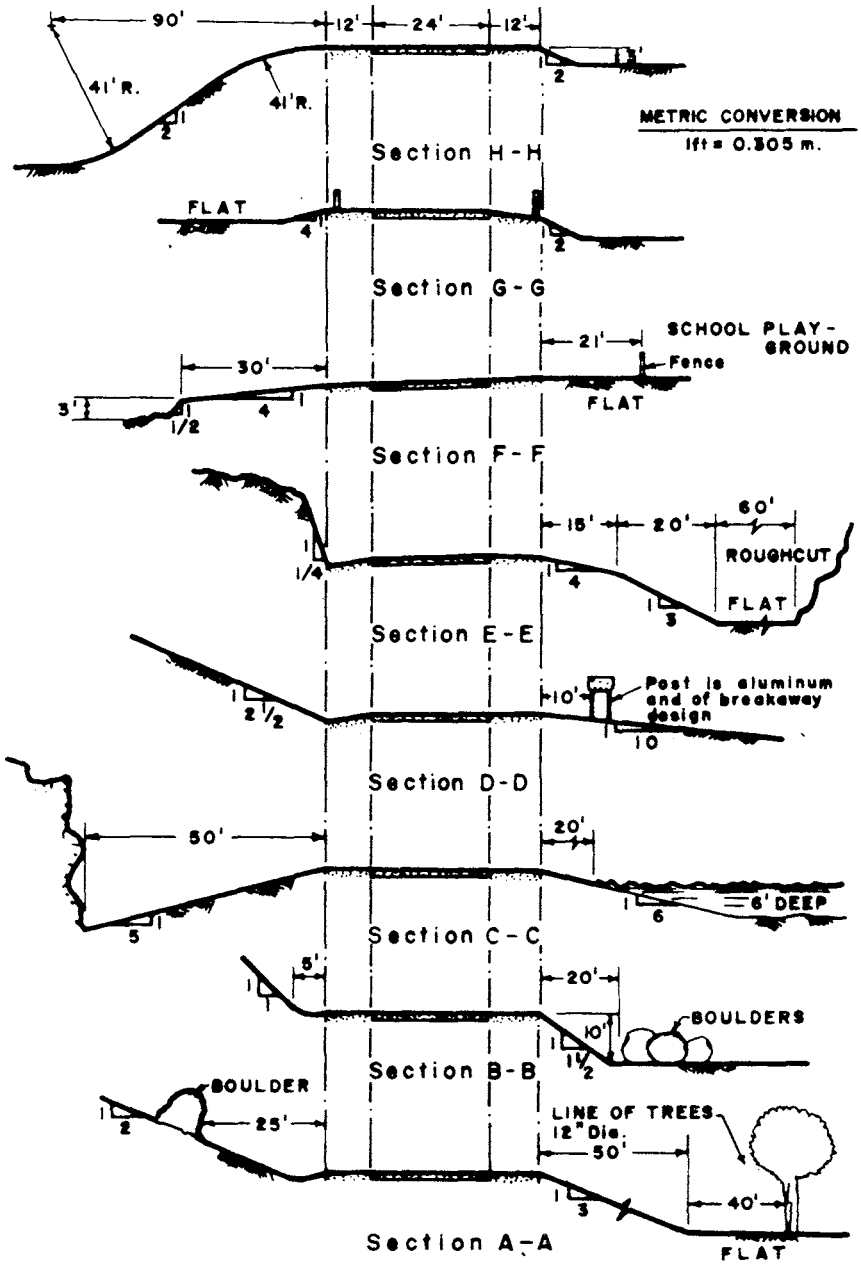
Transition sections are necessary to provide continuity of protection when two different roadside barriers join, when a roadside barrier joins another barrier system (weak-post to strong-post), or when a roadside barrier is attached to a rigid object (such as concrete barrier or bridge parapet).

Shown in Tables 8—8 thru 8—11 are transition sections that are considered operational. Standard models No. 1—A and No. 1—A—1, of the Puerto Rico Highway Authority, show the most common use of transition, the one that occurs between approach roadside barrier and bridge parapets. In these models the rail-to-parapet connection is effectively archieved by providing a recessed area in the bridge parapet wall to receive the rail, similar to Figure 8—P.

Strong post systems must be used on transition to bridge parapets. Such systems must be blocked-out to prevent vehicle snagging on the posts.

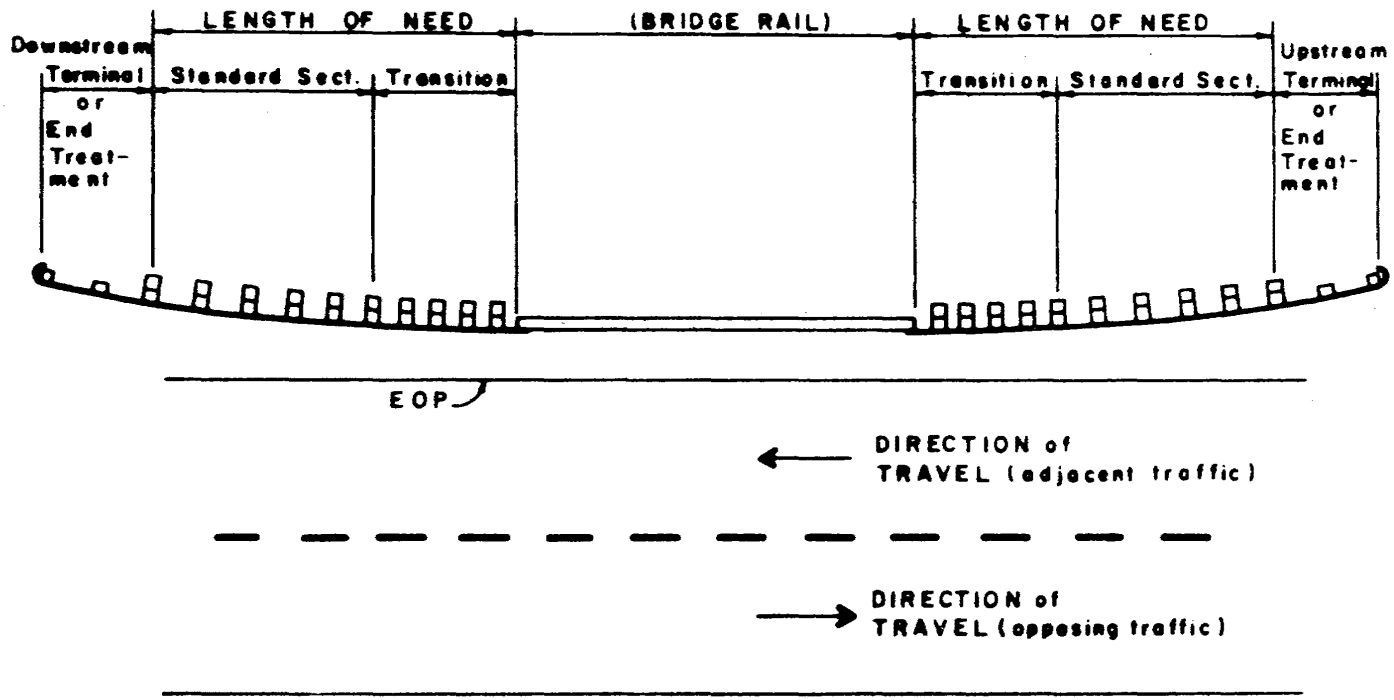
The length of the transition should be such that significant changes in the lateral stiffness do not occur within a short distance. The transition length should approximate 12 times the difference in dynamic deflection between joining barriers. For example, the dynamic deflection of system G4(1S) is 2.60 ft. (from table 8—6) and that for a bridge concrete parapet is zero. The transition from model G4(1S) to a bridge parapet should be: 12 (2.60—0.0) or 31.2 ft.

The stiffness of the transition should increase smoothly and continously from the more flexible to the less flexible system. This is accomplished in standard model No. 1—A by decreasing the post spacing from 6 ft. 3 inches at normal installation to 3 ft. 1 1/2 inches in the transition near the structure.



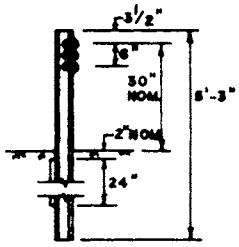
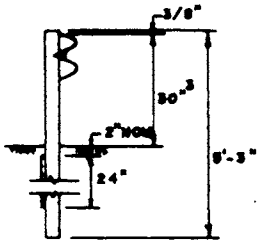
ILLUSTRATIVE EXAMPLE FOR ROADSIDE BARRIER WARRANTS, B

FIGURE 8-M



DEFINITION OF ROADSIDE BARRIER ELEMENTS.

FIGURE 8-N

Metric Conversions 1 ft. = 0.305m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454kg				
SYSTEM	G1 Cable Guardrail		G2 "W" Beam (Steel Weak Post)	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	16' 0" S3x5.7 steel Three 3/4" diameter Steel Cables ----- 5/16" diameter Steel hook bolts 1/4"x8"x24" steel plate welded to post		12' 6" Nominal) S3x5.7 steel Steel "W" Section, 12 GA. ----- 5/16" diameter Steel bolt 1/4"x8"x24" steel plate welded to post	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 25°	IMPACT ANGLE = 6°	IMPACT ANGLE = 27.8°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	NO TEST	44.0 3500	57.0 3500	59.2 4081
BARRIER Dynamic Deflection (ft.)		11.0	= 0	7.30
VEHICLE ACCLERATIONS (G's)[1] Lateral Longitudinal Total		UNAV UNAV 6.10	UNAV UNAV 1.00	3.80 3.10 UNAV
VEHICLE TRAJECTORY Exit Angle (deg) Roll Angle (deg.) Pitch Angle (deg.		15 UNAV UNAV	1 0 0	9 =20 =10
BARRIER DAMAGE		6 posts damaged	12' of "W" section and 2 posts	UNAV
REFERENCES		17	17	18
FIELD PERFORMANCE DATA 2	YES		YES	
REMARKS	Smooth redirection. System requires large recovery area due to large dynamic deflection. Limited crash test data.		In 27.8° test, vehicle was airborne for 50, however, smooth redirection and overall good barrier performance. Fairly large dynamic deflections.	

UNAV - unavailable

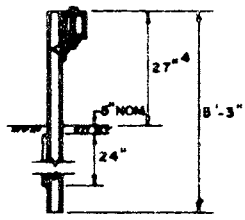
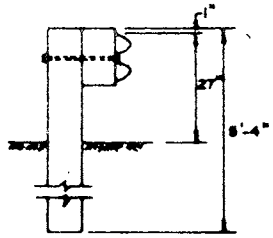
[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

[3] Through studies (137) subsequent to the tests reported here, the State of New York has concluded that the W-beam performs better at a height of 33 inches.

OPERATIONAL ROADSIDE BARRIER SYSTEMS, A.

TABLE 8-3

Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg				
SYSTEM	63 Box Beam		64 (1W) Blocked-Out "W" Beam (Wood Post)	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	6' 4" S3x5.7 steel 6"x6"x0.180" steel tube L5"x3 1/2"x1/4" steel angle 4 1/2" long 3/8" dia. steel bolt (beam to angle) 1/4"x8"x24" steel Plate welded to post		6' 3" 8"x8" Douglas Fir Steel "W" section, 12 GA. 8"x8"x14" Douglas Fir Block 5/8" diameter carriage bolts None	
IMPACT PERFORMANCE	IMPACT ANGLE = 18°	IMPACT ANGLE = 25°	IMPACT ANGLE = 18°	IMPACT ANGLE = 22.2°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	NO TEST	57.7 4051	NO TEST	60.1 4123
BARRIER Dynamic Deflection (ft.)		4.80		2.80
VEHICLE ACCELERATIONS(G's)[1] Lateral Longitudinal Total		5.80 2.80 UNAV		6.10 3.00 UNAV
VEHICLE TRAJECTORY Exit Angle (deg) Roll Angle (deg) Pitch Angle (deg.)		0.00 UNAV UNAV		15 UNAV UNAV
BARRIER DAMAGE		UNAV		UNAV
REFERENCES		18		18
FIELD PERFORMANCE DATA[2]	YES		YES[3]	
REMARKS	Excellent redirection, vehicle came to rest parallel to the rail.		Smooth redirection. Southern yellow pine is acceptable alternate to Douglas Fir. See 64(2w) System for smaller post size.	

UNAV - unavailable

[1] 50 milli second average unless otherwise noted

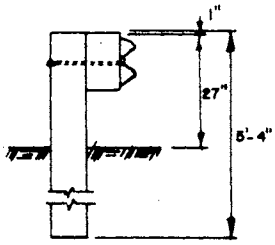
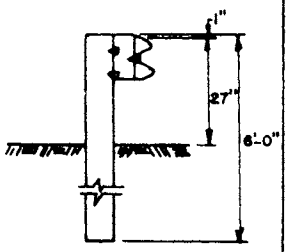
[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

[3] Data for 6-inch block-out.

[4] Through studies (137) subsequent to the tests reported here, the State of New York has concluded that the box beam performs better at a height of 30 inches.

OPERATIONAL ROADSIDE BARRIER SYSTEMS, B.

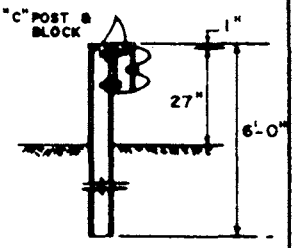
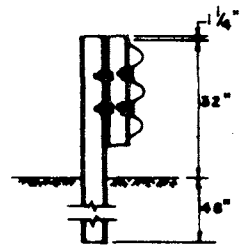
TABLE 8-4

Metric Conversions 1 ft. = 0.305 m. 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg.				
SYSTEM	G4(2W) Blocked-Out 'W' Beam (Wood Post)		G4(15) Blocked-Out 'W' Beam (Steel Post)	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	6' 3" 6" x 8" Douglas Fir Steel 'W' Section, 12 GA 6" x 8" x 14" Douglas Fir Block 5/8" diameter carriage bolts None		6' 3" W6x8.5 Steel Post Steel 'W' section, 12 GA W8x8.5x14" long Steel block[4] 5/8" diameter bolt None	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 24°	IMPACT ANGLE = 15°	IMPACT ANGLE 25° (28.4°)
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.) BARRIER Dynamic Deflection (ft.) VEHICLE Accelerations (G's)[1] Lateral Longitudinal TOTAL VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)	NO TEST	68.0 4960 2.33[3] 7.0 6.8 UNAV 14 =15 UNAV	NO TEST	66.0 (56.8) 4960 (3813) 2.60 (4.05) 6.85 (6.60) 3.78 (3.90) UNAV (UNAV) 16 (8) 0 (UNAV) 0 (UNAV)
BARRIER DAMAGE		25' of "W" Section and 4 posts		25' of "W" Section and 3 posts
REFERENCES		19		19, (18)
FIELD PERFORMANCE DATA[2]	NO		YES	
REMARKS	System is similar to G4(1W) except for smaller posts and block-out size. System performed well.		See text for explanation of differences in data shown for 25° and 28.4 tests. Smooth redirection.	

UNAV - unavailable
[1] 50 millisecond average unless otherwise noted
[2] If available, see summary in Appendix A (AASHTO Barrier Guide)
[3] Maximum permanent deflection
[4] Tests show that a "W" section back-up plate, 1 ft. in length, must be placed behind rail elements at intermediate posts (non-splice posts).

OPERATIONAL ROADSIDE BARRIER SYSTEMS, C

TABLE 8-5

Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg				
SYSTEM	84 (28) Blocked-Out "W" Beam (Steel "C" Posts)		89 "Thrie Beam" (Steel Post)	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	6' 3" 4 1/2"x8-5/8"x3/16" "C" steel Post Steel W section, 12 GA.[3] 4 1/2"x5 5/8"x3/16" "C" steel post 5/8" diameter bolt None		6' 3" W 6x8.5 steel Thrie Beam, steel W 6x8.5 and M14x17.2, steel 2 5/8" diameter steel bolts UNAV	
IMPACT PERFORMANCE	IMPACT ANGLE = 18°	IMPACT ANGLE = 25°	IMPACT ANGLE = 18°	IMPACT ANGLE = 23°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	NO TEST	38.0 4325	38.1 4500	56.4 4000
BARRIER Dynamic Deflection (ft.)		2.90	0.58	1.80
VEHICLE ACCLERATIONS(G's)[1] Lateral Longitudinal Total		6.80 3.70 UNAV	4.10 2.90 UNAV	7.90 3.90 UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)		UNAV less than 10 0	Less than 10 0 0	15 0 0
BARRIER DAMAGE		25' of "W" section and 5 posts	12' 6" of thrie beam and 4 posts	12' 6" of thrie beam and 4 posts
REFERENCES		20	21	21
FIELD PERFORMANCE DATA[2]	NO		NO	
REMARKS	Smooth redirection but with somewhat high exit angles (greater than 10°). Posts can be cold formed from steel sheets.		Smooth redirection. W6x8.5 block-out used in 18° test and M14x17.2 block-out was used in 23° test. Both systems performed well.	

UNAV - unavailable

[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

[3] Test show that a "W" section back-up plate, 1 ft. in length, must be placed behind rail elements at intermediate posts (non-splice posts).

OPERATIONAL ROADSIDE BARRIER SYSTEMS, D.

TABLE 8-6

TABLE 8-7 – ROADSIDE BARRIER DATA SUMMARY

System	Maximum Dynamic[1] Deflection (ft.)	Acceleration at 15° (G's)[2]			Accelerations at 25° (G's)[2]			Is Barrier Hardware Standardized?[3]
		Lateral	Longitudinal	Total	Lateral	Longitudinal	Total	
Flexible Systems								
G1	11.0	No Test	No Test	No Test	UNAV	UNAV	6.1	Yes
G2	7.3	UNAV	UNAV	1.0	3.8	3.1	UNAV	Yes
Semi-Rigid Systems								
G3	4.8	No Test	No Test	No Test	5.8	2.8	UNAV	Yes
G4(1W)	2.8	No Test	No Test	No Test	6.1	3.0	UNAV	Yes
G4(2W)	2.3[4]	No test	No Test	No Test	7.0	6.8	UNAV	Yes[5]
G4(1S)	4.1	No Test	No Test	No Test	6.9	3.8	UNAV	Yes[5]
G4(2S)	2.9	No Test	No Test	No Test	6.8	3.7	UNAV	Yes[5]
G9	1.5	4.1	2.9	UNAV	7.9	3.9	UNAV	Yes[5]

UNAV - Inavailable

[1] Based on 25° impact.

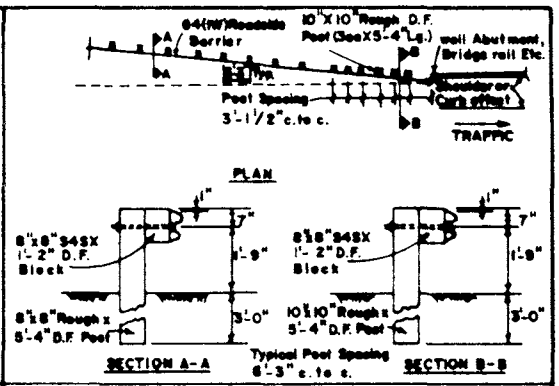
[2] 50 millisecond average.

[3] See reference 22, 23.

[4] Maximum permanent deflection.

Metric Conversion: 1 ft. = 0.305 m.

[5] To be included in a revised edition of reference 22 and 23.

Metric Conversions 1 ft. = 0.305m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb = 0.454 kg		
SYSTEM	TI 64(IW) Approach Rail to Concrete Parapet	
BARRIER DESCRIPTION	POST SPACING-as shown on sketch; POST TYPE-8"x8" and 10"x10" Douglas Fir; BEAM TYPE-steel "W" section, 12 GA.; OFFSET BRACKETS-8"x8" Douglas Fir block; MOUNTINGS-1" diameter steel bolt; FOOTINGS-none.	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 25°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	NO TEST	58.8 4297
BARRIER Dynamic Deflection (ft.)		UNAV
VEHICLE ACCELERATIONS[1] (G's) Lateral Longitudinal Total		19.0 8.8 UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)		UNAV UNAV UNAV
BARRIER DAMAGE		UNAV
REFERENCES		18
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	Severe vehicle damage. System that was tested had no flare.	

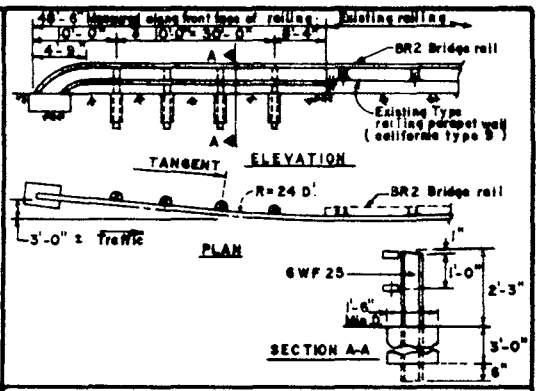
UNAV – unavailable

[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

OPERATIONAL ROADSIDE BARRIER TRANSITION SECTIONS, A.

TABLE 8-8

Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg		
SYSTEM	T2 Tubular Approach Rail to BR2 Bridge Rail	
BARRIER DESCRIPTION	POST SPACING - 10'10"; POST TYPE - W6 x 25, STEEL; BEAM TYPE - TS6"x2"x0.25" STEEL TUBING; OFFSET BRACKETS - NONE; MOUNTINGS - TWO 3/4" DIAMETER STEEL STUDS; FOOTINGS - 18" DIAMETER, 36" CONCRETE.	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 26°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	NO TEST	60.0 4540
BARRIER Dynamic Deflection (ft.)		0.23
VEHICLE ACCELERATIONS (G's)[1] Lateral Longitudinal Total		UNAV UNAV UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)		13 ≈5 ≈0
BARRIER DAMAGE		3 rail sections and 1 post
REFERENCES		24
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	Smooth redirection. Vehicle damage moderate with substancial sheet metal deformation.	

UNAV - unavailable

[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

OPERATIONAL ROADSIDE BARRIER TRANSITION SECTIONS, B

TABLE 8-9

8—05.03 END TREATMENTS

An untreated end of a roadside barrier is extremely hazardous if impacted, since the beam of the system tends to penetrate the passenger compartment and will generally stop the vehicle abruptly. A crashworthy end treatment is therefore recommended if the barrier terminates within the "clear zone". As shown in Figure 8—N both an upstream terminal and downstream terminal must be considered. The length of need for upstream terminal is dependent on the clear zone width for the adjacent traffic and the length of need for the downstream terminal is dependent on the clear zone width for the opposing traffic.

To be crashworthy, the end treatment should not spear, vault, or roll the vehicle for head-on or "nose" impacts. For impacts between the end and the standard section, the end treatment should have the same redirectional characteristics as the standard roadside barrier, which means that the end must be properly anchored. The end treatment must be capable of developing the full tensile strength of the standard rail element, whether a crashworthy end treatment is warranted or not.

Shown in Tables 8—12 and 8—13 are two operational end treatments. Standard model No. 1A, of the Puerto Rico Highway Authority is similar to the GET2 system, this system is designed for the G4(1S) and G4(2S) systems but it could be adapted for use with any of the G4 series systems or the G2 system. If possible, terminating and anchoring the roadside barrier in a backslope provides and excellent end treatment. In such cases, the approach rail should not violate the placement criteria developed in sections 8—08.03 and 8—08.04.

Turned down end treatment shall not be used to avoid impacting vehicles to vault and roll over.

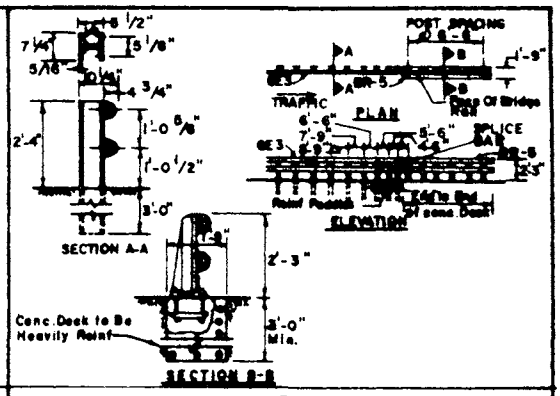
Other method to eliminate the problem of vehicle impalement on roadside barrier ends is to use a turned-down-barrier end. Standard model No. 1 of the Puerto Rico Highway Authority, uses this method. However, tests have shown that some turned-down end designs can cause impacting vehicles to vault and roll over.

8—06 MAINTENANCE CHARACTERISTICS

Table 8—14 contains a number of maintenance factors which should be considered before selecting a roadside barrier system. The factors are grouped in one of four categories: collision maintenance, routine maintenance, environmental conditions, and material storage requirements.

Collision maintenance concerns the activities required as a result of vehicle impacts. Such activities should play an important role in the selection of a barrier system since the majority of maintance costs are usually due to collision repairs.

The extent of barrier damage for given impact conditions will depend on the strength of the barrier. Where available, Tables 8—3 thru 8—6 give the barrier damage as a result of a crash test for specific impact conditions. Table 8—15 summarized the available field data from a gross survey made of several states.

Metric Conversions 1 ft. = 0.305m 1 in. = 23.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg		
SYSTEM	T3 GE3 Approach Rail to BR5 Bridge Rail	
BARRIER DESCRIPTION	POST SPACING – as shown on sketch; POST TYPE-5 1/2"x 7 1/4" section aluminum; BEAM TYPE-two standard aluminum extrusions; OFFSET BRACKETS -none; MOUNTINGS-standard hardware; FOOTINGS-none.	
IMPACT PERFORMANCE	IMPACT ANGLE 15°	IMPACT ANGLE 23°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb)	NO TEST	56.0 3965
BARRIER Dynamic Deflection (ft.)		1.4
VEHICLE ACCELERATIONS (Gs)[1] Lateral Longitudinal Total		7.8 6.6 UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)		20 UNAV UNAV
BARRIER DAMAGE		2 sections of rail and 3 Posts
REFERENCES		25
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	Some vehicle snagging. First post of bridge rail was taken out by impact.	

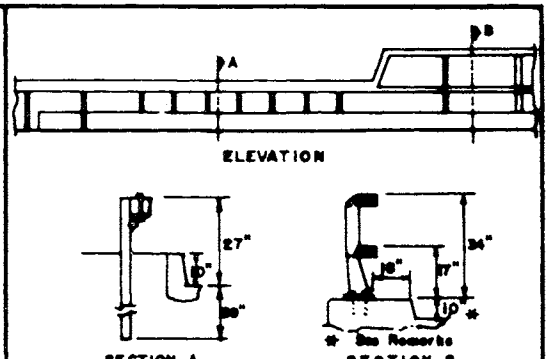
UNAV – unavailable

[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

OPERATIONAL ROADSIDE BARRIER TRANSITION SECTIONS, C.

TABLE 8-10

Metric Conversions 1 ft. = 0.305 m. 1 in. = 25.4 mm. 1 mph = 1.61 km/hr. 1 lb. = 0.454 kg.		
SYSTEM	T4 63 Approach Rail to BRS Bridge Rail	
BARRIER DESCRIPTION	POST SPACING 4'0"; POST TYPE-BS x 5.7 steel for approach rail, fabricated steel for bridge rail; BEAM TYPE 6"x6"x 0.188" steel tubing for approach rail, TS 6" x 3" x 1/4" Steel for bridge rail; OFFSET BRACKETS L6" x 3 1/2" x 1/4" steel angle; MOUNTINGS - 1/2" and 5/16" diameter bolts; FOOTINGS 1/4" x 8" x 24" steel plate welded to Post.	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 25°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.) BARRIER Dynamic Deflection (ft.) VEHICLE ACCELERATIONS (g's)[1] Lateral Longitudinal Total VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)	NO TEST	 54.0 3500 4.6 UNAV UNAV 9.4 2 less than 10 0
BARRIER DAMAGE		5 posts damaged
REFERENCES		17
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	It is recomended that the curb not be used in this design.	

UNAV – unavailable
[1]50 millisecond average unless otherwise noted
[2]If available, see summary in Appendix C (AASHTO Barrier Guide)

OPERATIONAL ROADSIDE BARRIER TRANSITION SECTIONS, D

TABLE 8- 11

8—07 SELECTION GUIDELINES

Once it has been determined that a barrier system is warranted, a selection must be made. The most desirable system is one that offers the best protection at the least cost, and is consistent with the given constraints. Table 8—16 presents eight items which should be considered before a selection is made. Of these, the deflection, strength, and safety requirements should never be compromised.

Initial costs and future maintenance costs in particular should be carefully evaluated. As a general rule, the initial cost of a system increases as the rigidity or strength increases but the maintenance costs usually decrease with increased strength.

As previously stated, the barrier that may withstand minor collision damages, should be considered as the best alternative due to the poor maintenance record in Puerto Rico. For roadside barriers the Department has currently adopted as standard the use of the corrugated steel beam guard rail with strong post as detailed in Standard Models 1, 1—A and 1—A—1 (See Chapter 19—07).

8—08 PLACEMENT RECOMMENDATIONS

Major factors to consider in the lateral placement of a roadside barrier, that will be discussed in following sections are:

1. Uniform clearance and distance between barrier and hazard being shielded.
2. Effects of terrain between edge of traveled way and the barrier on the errant vehicle's trajectory.
3. Probability of impact with barrier as a function of its distance off the traveled way.
4. Flare rate and length of need of transitions and approach barriers.
5. Slow moving vehicles on the shoulder of the roadway.

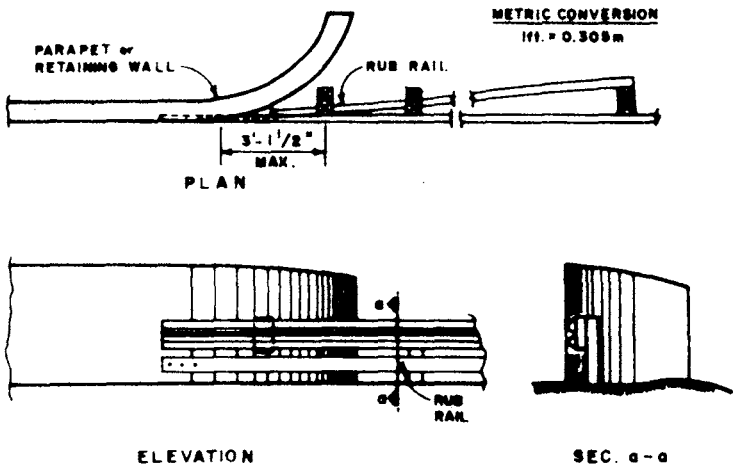
8—08.01 UNIFORM CLEARANCE AND DISTANCE BETWEEN BARRIER AND HAZARD

A highly desirable characteristics of any roadway is that it have shoulders of constant width, whether it is in cut, fill, or on a structure. Chapters 2 and 6, of this Manual, accomplish this with typical sections for roadways according to its classification. Also, to ensure the safe usage of the full shoulder width, longitudinal barriers are placed at a minimum distance of 2 ft. beyond the edge of the shoulder. In all cases the barrier should be located as far from the traveled way as conditions permit.

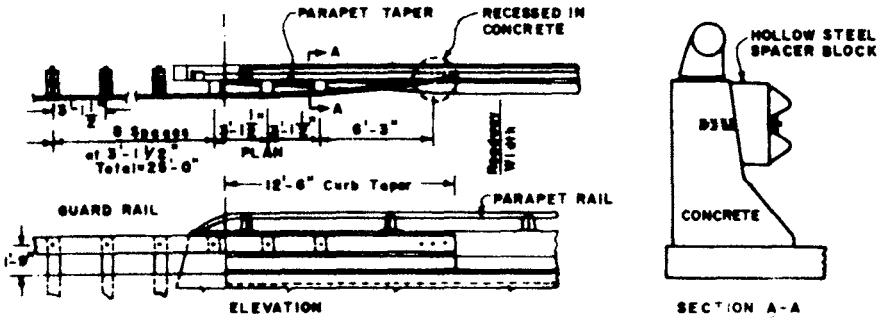
The amount a barrier will deflect upon impact is a critical factor in its placement. Figure 8—Q illustrates the two basic types of roadside configurations of concern. If the hazard being shielded is a rigid object, the barrier-to-hazard distance should be sufficient to avoid snagging by the vehicle on the rigid object. If the hazard is a drop off or a steep embankment (steeper than 3:1 slope), the barrier-to-hazard distance should be sufficient to prevent the wheels from dropping and thus causing the vehicle to roll excessively. However, limited test results indicate that the barrier-to-hazard distance for embankments is not as critical as it is to rigid objects. A 2 ft. minimum distance is recommended as shown in Figure 8—Q(b). This minimum distance is also needed to insure adequate lateral soil resistance for the posts during impact.

The barrier-to-hazard distance for rigid objects should not be less than the dynamic deflection of the barrier for impact by a full-size automovile at impact conditions of approximately 25 degrees and 60 mph.

In such cases that the available space between the barriers and the hazard, may not be attainable with the operational barrier systems, a more rigid scheme such as concrete barrier should be used. In following sections operational configurations of concrete barriers will be introduced.



(a)

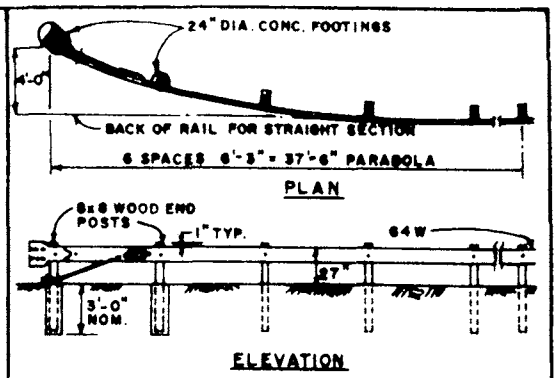


Typical Approach Roadside Barrier Layout

(b)

W-BEAM TO PARAPET CONNECTION CONCEPTS.

FIGURE 8-P

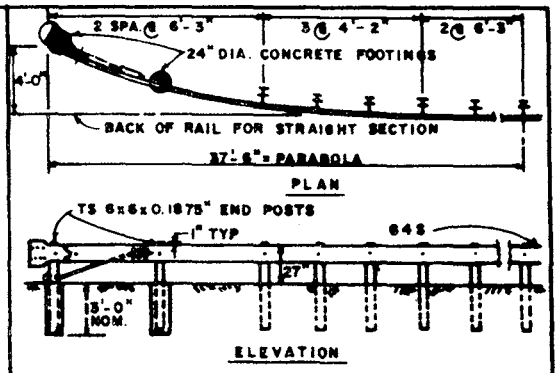
Metric Conversions 1 ft = 0.305m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg	
SYSTEM	SEY1 Breakaway Cable Terminal (Wood Post)
BARRIER DESCRIPTION	TYPICAL POST-8"x8" Douglas Fir; TERMINAL POTS-8"x8" Douglas Fir with 2-3/8" diameter hole through neutral axis; ANCHORAGE-Cable assembly (see sketch); FOOTING-24" diameter, 36" deep concrete for terminal Posts, other Posts require none; BEAM TYPE-steel "W" section, 12 GA.; OFFSET BRACKETS-8"x8" Douglas Fir block; MOUNTING-5/8" diameter steel bolt.

IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	60.7	62.0
Angle (deg.)	0	27
Vehicle Weight (lb.)	3800	3900
BARRIER		
Deceleration Distance (ft.)	UNAV	3.3[3]
VEHICLE ACCELERATIONS[1] (g's)		
Lateral	1.5	3.4
Longitudinal	9.2	7.2
Total	UNAV	UNAV
VEHICLE TRAJECTORY		
Exit Angle (deg.)	Behind rail	≈30
Roll Angle (deg.)	UNAV	≈0
Pitch Angle (deg.)	UNAV	≈0
BARRIER DAMAGE	20' of "W" section and 2 end Posts	20' of "W" section and 3 Posts
REFERENCES	26[4]	26[4]
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	This system was tested with the G4(1W) system. Details of end Posts, anchorage and footings are critical. Tests indicate that flare sections operate better than tangent sections. Although not documented by crash tests, it could be adapted for use with other G4 series systems.	

UNAV - unavailable
[1] 50 millisecond average unless otherwise noted
[2] If available, see summary in Appendix A (AASHTO Barrier Guide)
[3] Maximum dynamic deflection
[4] For recommended details see reference 145 (AASHTO Barrier Guide)

OPERATIONAL ROADSIDE BARRIER END TREATMENTS, A.

TABLE 8-12

Metric Conversions 1 ft = 0.305 m 1 in = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg		
SYSTEM	64T2 Breakaway Cable Terminal (Steel Post)	
BARRIER DESCRIPTION	TYPICAL POST- W6x8.5 steel; TERMINAL POSTS TS6"x6"x0.1875" steel breakaway design; ANCHORAGE-Cable assembly (see sketch); FOOTING-24" diameter, 36" deep concrete for terminal posts, other require none; BEAM TYPE-steel "W" section, 12 GA; OFFSET BRACKETS-W6x8.5 steel; MOUNTING-5/8" diameter steel bolt.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	62.0	58.0
Angle (deg)	0	24
Vehicle Weight (lb.)	4423	4202
BARRIER		
Deceleration Distance (ft.)	UNAV	≈4.0[3]
VEHICLE ACCELERATIONS (g's)[1]		
Lateral	2.4	5.6
Longitudinal	9.0	8.2
Total	UNAV	UNAV
VEHICLE TRAJECTORY		
Exit Angle (deg)	Behind rail	≈30
Roll Angle (deg)	≈0	11
Pitch Angle (deg)	≈0	≈0
BARRIER DAMAGE	25' of "W" section, 2 end posts and 2 W6x8.5 posts	25' of "W" section and 5 W6x8.5 posts
REFERENCES	27[4]	27[4]
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	This system was tested with the 64(1S) system. Details of end posts, anchorage system and footings are critical. Tests indicate that flare sections operate better than tangent sections. Although not documented by crash tests, it could be adapted for use with the 64(2S) and the 62 systems.	

UNAV- unavailable
1 50 millisecond average unless otherwise noted
2 If available, see summary in Appendix A (AASHTO Barrier Guide)
3 Maximum dynamic deflection
4 For recommended details see reference 145 (AASHTO Barrier Guide)

OPERATIONAL ROADSIDE BARRIER END TREATMENTS, B.

TABLE 8-13

CATEGORY	CONSIDERATIONS
A. Collision Maintenance	1. Typical crew size 2. Typical man-hours to repair (exposure) 3. Typical barrier damage 4. Special equipment 5. Ability of rail to be repaired or straightened 6. Salvage value 7. Level of working knowledge
B. Routine Maintenance	1. Cleaning and painting 2. Mowing and clearing vegetation 3. Checking and tightening blocks and fasteners
C. Environmental Conditions	1. Snow or sand drifting 2. Snow or sand removal 3. Weathering or corrosion due to environment or chemical effects
D. Material and Storage Requirements	1. Dependence on a number of parts 2. Availability of parts 3. Storage facilities required

MAINTENANCE FACTORS INFLUENCING ROADSIDE BARRIER SELECTION.

TABLE 8-14

TABLE 8-15 – COLLISION REPAIR DATA FOR ROADSIDE BARRIERS

System	Typical Crew Size	Typical Material Repaired or Replaced		Average Refurbishment Time (Man-Hours/Foot of Rail)
		Rail (ft.)	Posts	
G1-Cable Guardrail	UNAV	112	8	0.30
G2-W-Beam on Steel Weak Posts	UNAV	45	4	0.33
G3-Box Beam	5-6	32	5	0.92
G4(1W)-Blocked Out W-Beam on Wood Posts	4	35	4	0.35
G4(1S)-Blocked Out W-Beam on Steel Posts	3-4	38	4-5	0.32

[1]No data available for G4(2W), G4(2S), and G9 systems.

METRIC CONVERSION:

1 ft. = 0.305m

1 Man-Hour /ft = 3.28 Man-Hours/m

8–08.02 PROBABILITY OF IMPACT

A roadside barrier should be placed as far from the traveled way as conditions permit. As such, the probability of impact will be minimized.

Whenever posible a Barn Top Section as illustrated in Figure 8–S should be provided. The 6:1 slope should be extended 23 ft. beyond the edge of shoulder. The shoulder must be rounded following the requirements in Section 8–04.02. This configuration gives a clear zone width of about 35 ft. that complies with the recommended clear zones of Section 8–04.03.

8–08.03 TERRAIN EFFECTS

Terrain conditions between the traveled way and the barrier can have significant effects on the barrier's impact performance. Curbs and sloped roadsides are two prominent features which deserve special attention. A vehicle which traverse one of these features prior to impact may go over the barrier or submarine under it or snag on its support posts. A discussion of the effect of both curbs and sideslopes follows:

1. Curbs – In general, it has been found that curbs offer no safety benefit on highspeed roadways from the standpoint of vehicle behavior following impact. For this reason a curb should be used alone or when used in conjuctions with a traffic barrier, should be placed behind the barrier.

2. Roadside Slopes – As a general rule, a roadside barrier should not be placed on a embankment if the slope of the embankment is steeper than 6:1. In addition, if the difference between the shoulder slope rate and side slope is greater than 0.13 (see Figure 8–R), a barrier should not be placed on an embankment. For example a shoulder slope rate of 0.04 (4%) is generally used in Puerto Rico, if the side slope rate is 0.17 (6.1), this will give a difference of 0.13. Under such conditions the shoulder-side slope hinge point should always be rounded.

A barrier should be placed at least 12 ft. beyond the shoulder-side slope hinge point when the difference in slope rates between shoulder and side slope is greater than 0.13. The break at the shoulder hinge point must be rounded to avoid an errant vehicle could go over the barrier or impact them at an undesirable position.

8–08.04 FLARE RATE AND LENGTH OF NEED

Figure 8–T illustrates the variables of interest in the layout of an approach barrier to shield an area of concern or hazard. Length of need is equal to the length of the area of concern parallel to the roadway, plus the length of the approach barrier on the upstream side (and downstream side if needed).

Ends of roadside barriers should be flared to attain the following conditions:

1. To locate the barrier and its terminal as far from the traveled way as is feasible.
2. To redirect an errant vehicle without serious injuries to its occupants.
3. To minimize a driver's reaction to a hazard near the traveled way.

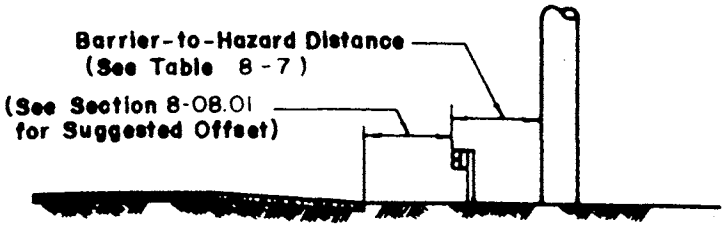
Table 8–17 contains the runout length (L_R), flare rate (a:b), and shy line offset (L_S) as a function of ADT (Average Daily Traffic) and design speed. Shy line offset is defined as a distance beyond which a roadside object will not be perceived as a threat by a driver. The roadside barrier should be placed beyond the shy line offset.

For highways with operating speeds between 40 and 60 mph the clear zone width (L_C) can be determined from Figure 8–D. The widths obtained from Figure 8–D are considered appropiate for high traffic volume highways. (Say a design average daily traffic volume of over 6,000 vehicles.) The clear zone widths (L_C) obtained from Figure 8–D may be adjusted for

ITEM	CONSIDERATIONS
A. Deflection	1. Space available behind barrier must be adequate to permit dynamic deflection of barriers.
B. Strength and Safety	1. System should contain and redirect vehicle at design conditions.
	2. System should be least hazardous available, consistent with costs and other considerations.
C. Maintenance	1. Collision maintenance.
	2. Routine maintenance.
	3. Environmental conditions.
D. Compatibility	1. Can system be transitioned to other barrier systems?
	2. Can system be terminated properly?
E. Costs	1. Initial costs.
	2. Maintenance costs.
	3. Accident costs to motorist.
F. Field Experience	1. Documented evidence of barrier's performance in the field.
G. Aesthetics	1. Barrier should have a pleasing appearance.
H. Promising New Designs	1. It may be desirable to install new systems on an experimental basis.

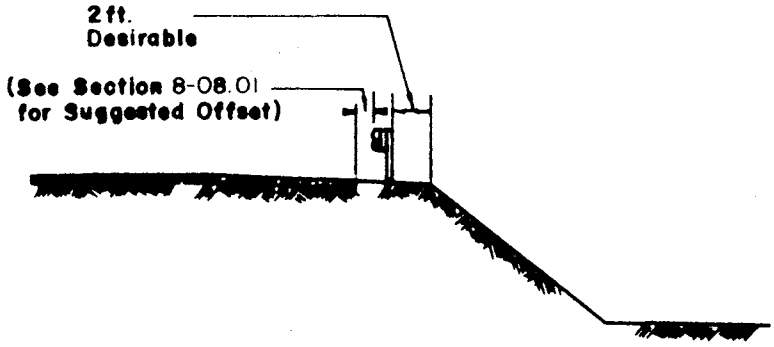
SELECTION CRITERIA FOR ROADSIDE BARRIERS.

TABLE 8-16



(a) Rigid Object Protection

METRIC CONVERSION:
1ft = 0.305 m.



(b) Embankment Protection

BARRIER-TO-HAZARD DISTANCE FOR ROADSIDE PROTECTION.

FIGURE 8-Q

BARRIER SHOULD NOT BE PLACED ON EMBANKMENT IF

$$\left| e - \frac{a}{b} \right| > 0.1 \quad \text{or if} \quad \frac{a}{b} > -0.1$$

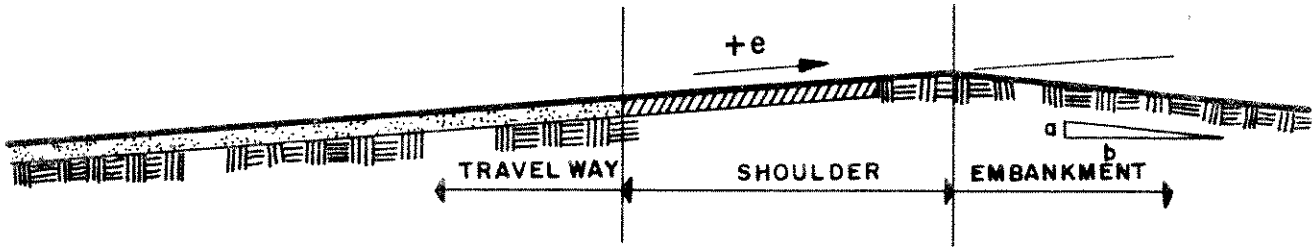
WHERE

e = Shoulder Slope Rate, Positive If Sloping Upward

$\frac{a}{b}$ = Embankment Slope Rate, Positive If Sloping Downward

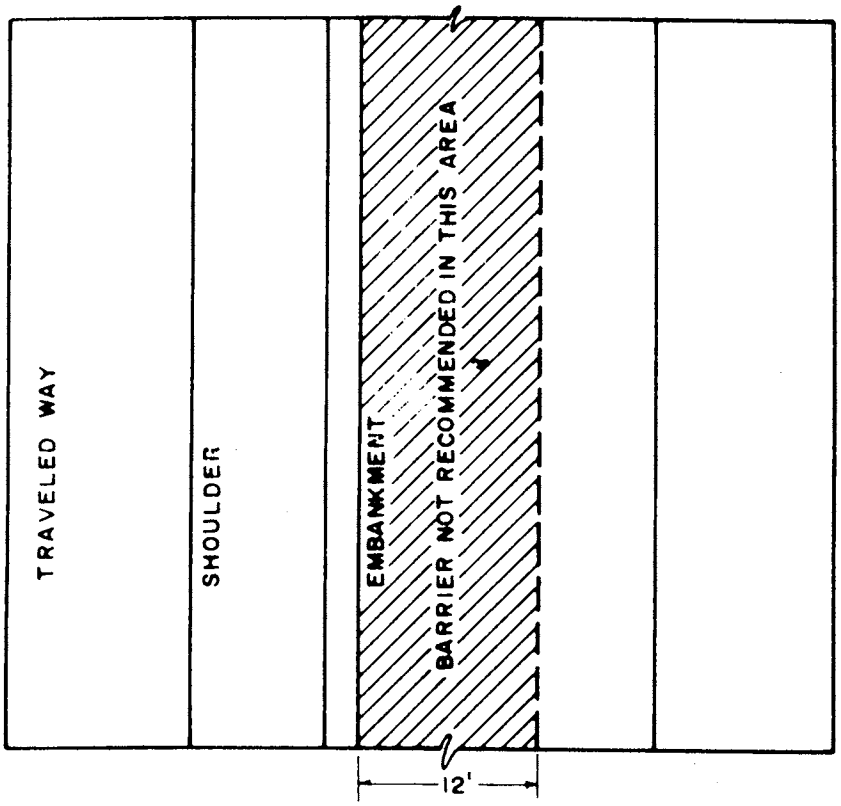
NOTE:

See Text For Exceptions To Criterion



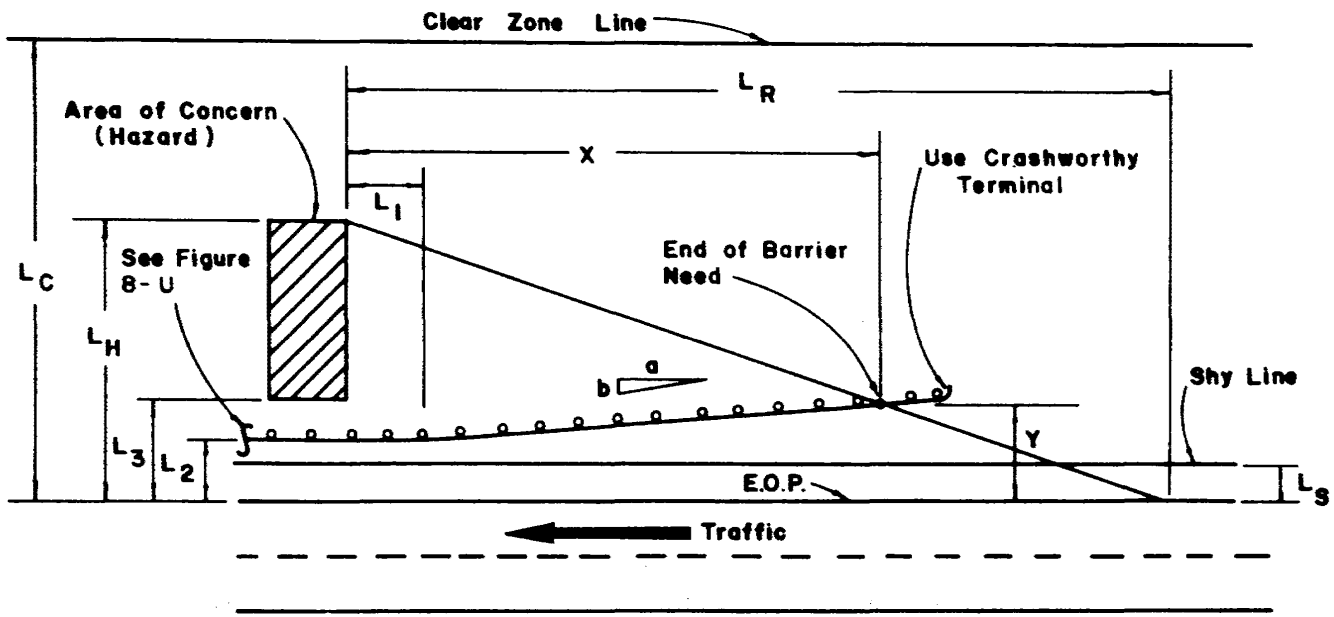
ROADSIDE BARRIER LATERAL PLACEMENT CRITERION.

FIGURE 8-R



ROADSIDE BARRIER LOCATION ON TYPICAL BARN TOP SECTION.

FIGURE 8 - S



APPROACH BARRIER LAYOUT VARIABLES.

FIGURE 8-T

lower traffic volumes or for speeds of 30 and 70 mph by proportioning the L_C value obtained by a ratio of L_R value obtained from Table 8—17. This adjusted clear zone width will be useful in the design of roadside barriers for low volume, low speed highways. Also for highways speeds up to 70 mph and different traffic volumes.

To illustrate the procedure to adjust the clear zone widths (L_C) for differente speeds and traffic volumes, the following examples are given:

(1) Find the clear zone width, L_C, for a rural freeway designed for over 6,000 vpd (ADT) and an operating speed of 70 mph. Assume a roadside slope of 10:1.

From Figures 8—D
L_C (60 mph, 10:1 slope)=30 ft.

From Table 8—17:
L_R (60 mph, over 6,000 vpd)=400 ft.
L_R (70 mph, over 6,000 vpd)=480 ft. therefore,
L_C (70 mph, 10:1 slope)= $\frac{480}{400} \times 30 = 36$ ft.

(2) Find the clear zone width, L_C, for a low volume highway (under 250 vpd), and an operating speed of 40 mph. Assume a 3:1 slope.

From Figure 8—D:
L_C (40 mph, 3:1 slope)=20 ft.
From Table 8—17:
L_R (40 mph, over 6,000 vpd)=240 ft.
L_R (40 mph, under 250 vpd)=160 ft. therefore,
L_C (40 mph, 3:1 slope, under 250 vpd)=20 x $\frac{160}{240}$=13.2 ft.

To determine the position (see Figure 8—T) of the end of need, the following equations apply:

$$\text{where, } X = \frac{L_H + \frac{b}{a}(L_1) - L_2}{\frac{b}{a} + \frac{L_H}{L_R}} \qquad \text{eq. III-E-1}$$

$$Y = L_H - \frac{L_H}{L_R}(X) \qquad \text{eq. III-E-2}$$

where,

L_H = distance from edge of traveled way (edge of pavement), to the lateral extent of the hazard.

$\frac{a}{b}$ = slope of flare (see Figure 8—T).

L_1 = length of tangent section of barrier upstream from hazard. (See diagram Table 8—17).

L_2 = distance from edge of pavement to barrier.

L_R = runout length (See Figure 8—T).

It should be noted that L_H should never exceed the clear zone distance obtained from figure 8—D, and the distance (L_3-L_2) should satisfy the criteria of section 8—08.01.

Coordinates X and Y will locate the end of need for the approach barrier, however, to terminate the barrier properly, some type of crashworthy end treatment should be used.

Figure 8—U illustrates the layout variables for an approach barrier for opposing traffic. The length of need and the end of the barrier are determined by use of Equations III—E—1 and

III—E 2, just discussed. However, note that all of the lateral dimensions are with respect to the edge of the traveled way of the opposing traffic. If there is a two-way divided highway, the edge of the traveled way for the opposing traffic would be the edge of pavement (EOP) on the median side.

There are three ranges of L_C which deserve special attention for an approach barrier for opposing traffic:

1. If L_3 is less than L_C, and L_C is less than L_H. In this case use L_H equal to L_C.

2. If L_2 is less than L_C, and L_C is less than L_3. In this case no approach barrier is needed, but a crashworthy terminal is needed.

3. If L_C is less than L_2. In this case no approach barrier is needed, and no crashworthy terminal is needed.

The lateral placement of the approach rail should also satisfy the criteria on embankment slopes in Section 8—08.03. If the existing slope is greater than 6:1, it is suggested that fill be provided to flatten the slope to 6:1, as illustrated in part A of Figure 8—V. An acceptable alternative is to flatten the slope of the flare so that the embankment slope criteria is not violated, as illustrated on part B of Figure 8—V. Note that in the latter alternative, a slightly longer length of approach barrier would be needed.

8—08.05 SLOW MOVING VEHICLES

In some areas there is a significant number of slow moving vehicles, primarily farm machinery, that travel on the shoulder of the roadway. In these areas the barrier should be placed at a lateral distance that will allow slow moving vehicles to travel on the shoulder without obstructing the normal traffic. In this cases a minimum 12 ft. shoulder should be provided, and the barrier should be placed at least 14 ft. from the edge of pavement, provided none of the recommendations in previous sections are violated.

8—09 UPGRADING SUBSTANDARD SYSTEMS

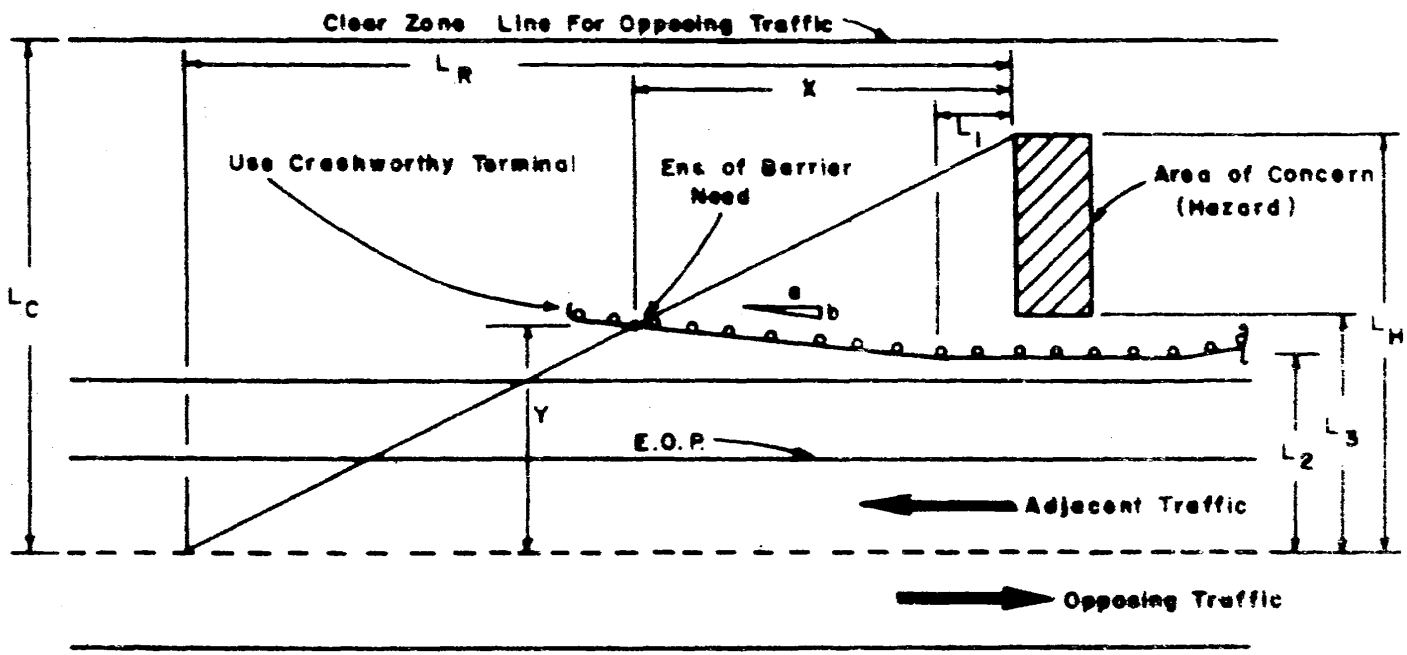
Some existing roadside barriers are not necessary while others are substandards and will not meet the minimum requirements discussed in previous sections. In this section a procedure is introduced for upgrading substandard systems and to eliminate the unnecessary ones.

8—09.01 GUIDELINES

Figure 8—X presents an inspection procedure designed to identify unnecessary or substandard barriers. It is suggested that this inspection be conducted on a regularly scheduled basis for maintenance operations. For reconstruction projects this inspection should be realized before the reconstruction plans are prepared. Again, this same procedure can be used as a final check of barrier placement in new construction projects.

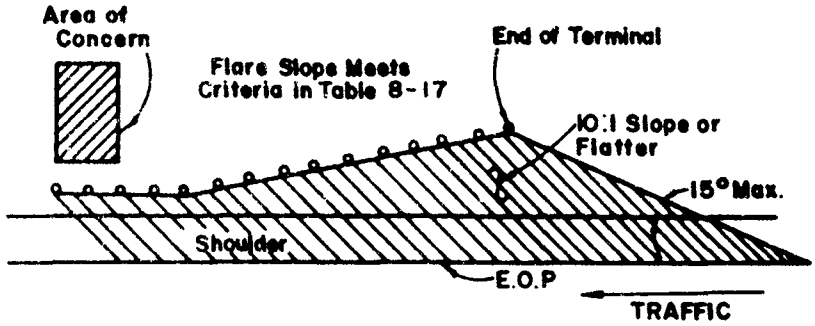
All personnel performing this inspection (design, construction or maintenance), should stay abreast of current traffic barrier standards and guidelines as well as promising new research findings.

With regard to item 3, the criteria presented in Section 8—05 should be used to evaluate existing systems. This should be complemented with field data and/or accident records to evaluate the performance of a system. If a barrier system is judged substandard, it should be modified to conform to an operational system, or be replaced by an operational system. Table 8—18 lists common standard inadequacies that occur and the remedial action.

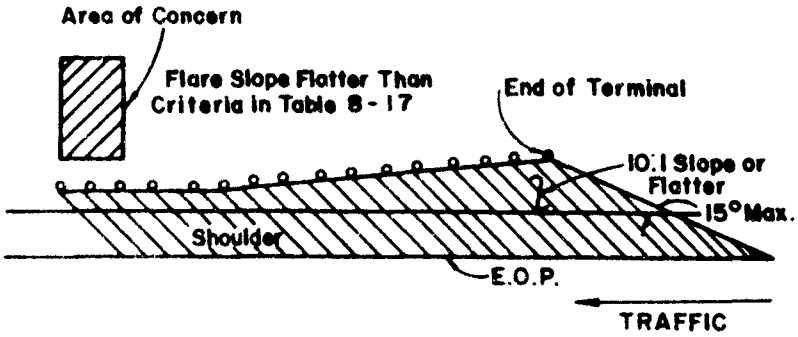


APPROACH BARRIER LAYOUT FOR OPPOSING TRAFFIC.

FIGURE 8-U



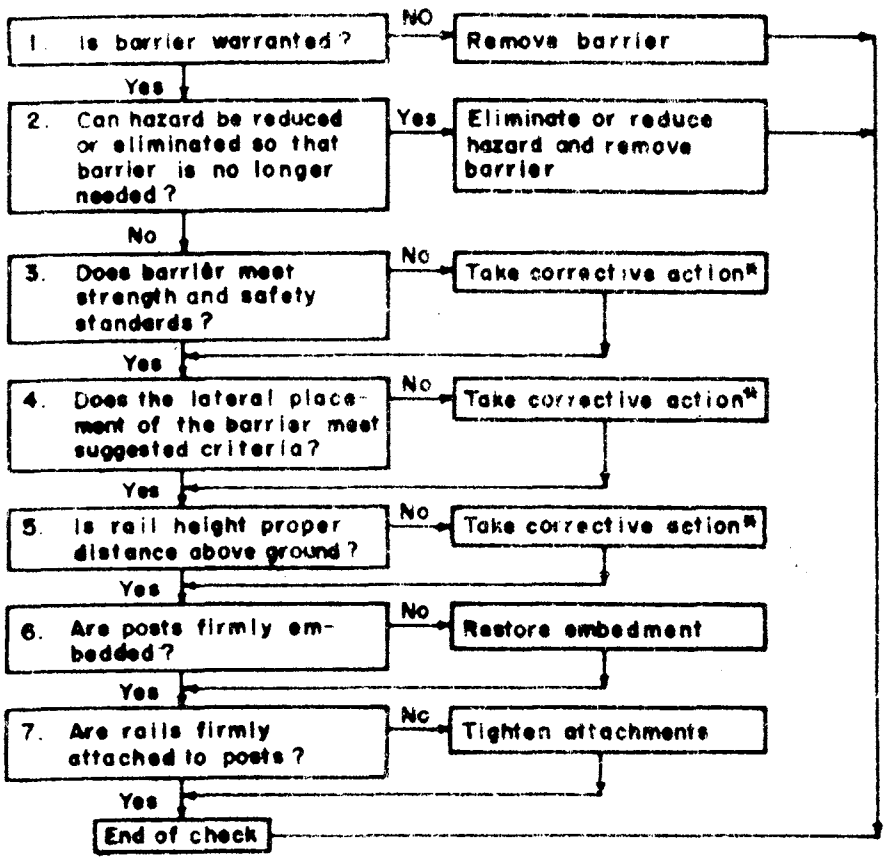
(A) Desirable



(B) Acceptable

SUGGESTED ROADSIDE SLOPES FOR APPROACH BARRIERS.

FIGURE 8-V



*See text for discussion

INSPECTION PROCEDURE FOR EXISTING ROADSIDE BARRIERS.

FIGURE 8 - X

The criteria given in Section 8—08 should be used to evaluate the adequacy of the lateral placement of existing barriers. If improperly located, corrective measures should be undertaken.

With regard to item 5, of Figure 8—X, the rail height an operational system should be equal to the recommended design height of the system. Height deviations greater than 2 inches from those recommended in Tables 8—3 thru 8—6, should be corrected.

Items 6 and 7 of Figure 8—X should be checked by maintenance personnel, regular maintenance operations, and by construction personnel before the final inspection on new construction projects.

8—09.02 EXAMPLE PROBLEM

The following example will illustrate how the guidelines should be used to upgrade a substandard system:

Given: Figure 8—Y shows a roadside barrier installation in which the design is substandard and the layout does not meet the criteria discussed in previous sections. Assume the design speed as 60 mph and the average daily traffic (ADT) to be 5,000 vpd. The observed problems are the following:

1. Flare rate too steep.
2. No end treatment for exposed rail.
3. The barrier is not structurally adequate since it is not anchored and it is too close to the piers for the post spacing.
4. There is no protection for the opposing traffic.

Requirements: It is required to upgrade the installation following the design criteria and guidelines included in previous sections.

Solution: The following steps should be followed to upgrade the barrier installation.

1. From Table 8—17;

L_R=360 ft.
L_S=8.0 ft.
a:b=13:1

2. To determine the end of need for the approach barrier for the adjacent traffic, Equations III—E—1 and III—E—2 are used with the following values obtained from Figures 8—D, 8—T, and Table 8—17:

$$L_C = \frac{360\ (L_R,\ \text{over } 6{,}000 \text{ vpd})}{340\ (L_R\ ,\ 2{,}000 - 6{,}000 \text{ vpd})} = 27 \text{ ft.}$$

L_H = 15 ft.
L_1 = 0.0 (no tangent section)
L_2 = 11.0 ft.

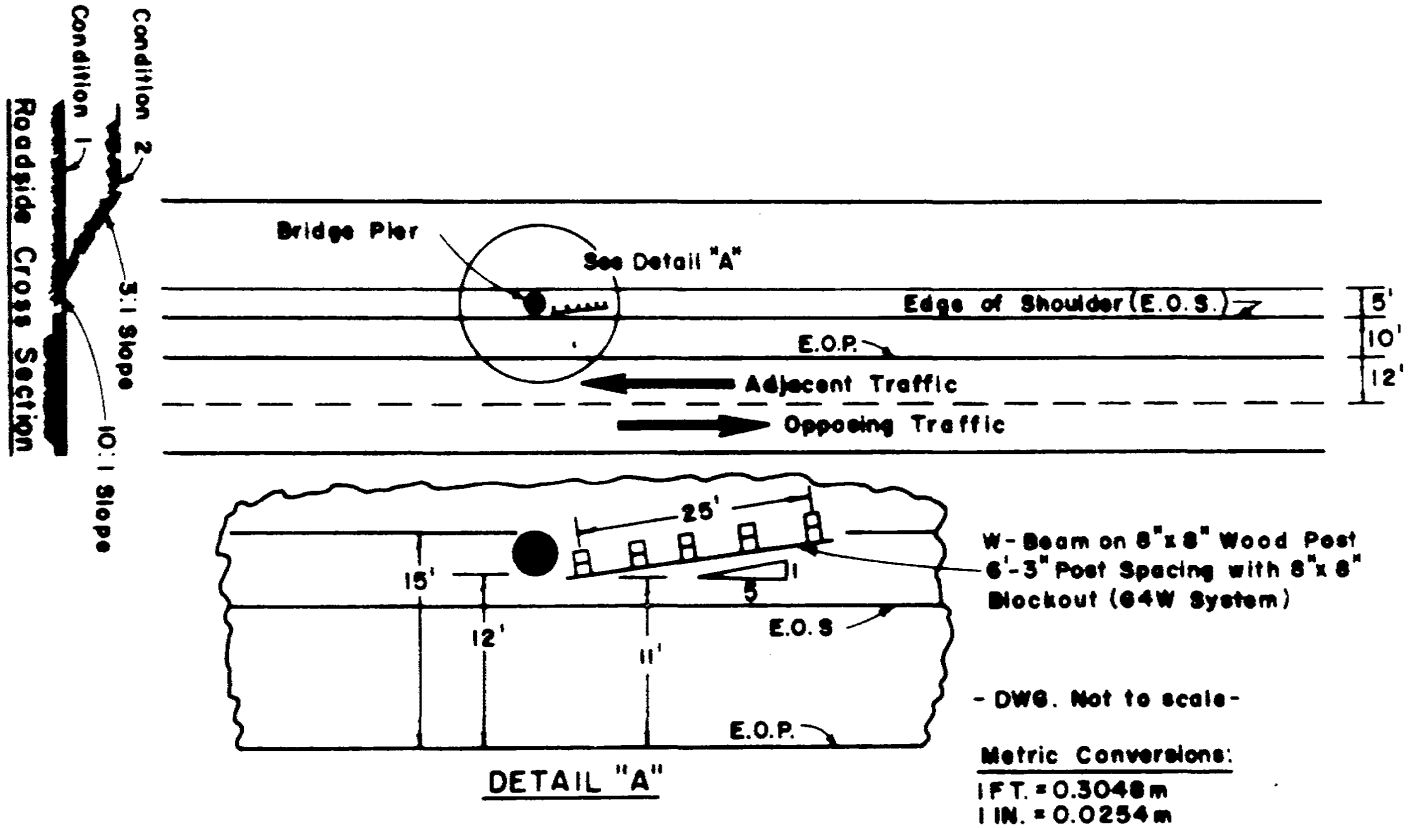
3. Due to the limited space between the edge of the shoulder and the pier, the barrier must be stiffened in the area of the pier (this system could also be replaced by a concrete barrier as will be discussed in following sections). The dynamic deflection of the G4(1W) system is 2.8 ft. Thus the W-beam rail will be attached to the pier but blocked out by an 8 inch by 8 inch wood block.

INADEQUACY	REMEDIAL ACTION
Transition Section	
·No rail continuity	·Attach to adjoining system to provide axial and flexure strength. May need new rail.
·Post too weak	·Increase post size or build up existing post.
·Post spacing too large	·Reduce post spacing to prevent pocketing or snagging of vehicle.
·No block out or rub rail	·Install block out and/or rub rail to prevent snagging by tires.
Terminal	
·Nonconforming end treatment	·Flare and anchor end of barrier in back slope if possible. ·Install crashworthy end treatment, such as ETI system described in Section III-B-3.
Longitudinal Section	
·Post spacing too large	·Post spacing for W-beam rail should not be greater than approximately 6'-3" (1.9 m) for high speed facilities.
·No block out or rub rail for strong post systems	·Install block out and/or rub rail to prevent snagging by tires. Use of Thrie Beam (see 66 system described in Section III-B-1 will eliminate need for rub rail.
·Too close to rigid object	·Move barrier to proper distance, or stiffen section near rigid object.

Sections III-B-1 and III-B-3 (AASHTO Barrier Guide)

STRUCTURAL INADEQUACIES OF ROADSIDE BARRIERS.

TABLE 8-18



EXAMPLE OF SUBSTANDARD DESIGN AND LAYOUT OF APPROACH BARRIER.

FIGURE 8-Y

4. From Equations III–E–1 and III–E–2,

X = 31.2 ft.
Y = 13.7 ft.

5. To determine the end of need for the approach barrier for the opposing traffic, Equations III–E–1 and III–E–2 are used with the following values obtained from Figures 8–D, 8–U, and Table 8–17:

L_C = 27 ft.
L_H = 27 ft. (15′ + 12′)
L_1 = 0.0 ft.
L_2 = 23.0 ft. (11′ + 12′)

6. It should be noted that an approach rail for the opposing traffic is needed since L_2 is less than L_C.

7. From equations III–E–1 and III–E–2,

X = 24.4 ft.
Y = 25.2 ft. (13.2′ + 12.0′)

The suggested design and layout is shown in Figure 8–Z. Note that in this example a T1 transition and an ET1 end treatment are recommended. In this case we could use the transition and end treatment depicted in Model 1–A of the Puerto Rico Highway Authority.

This solution is considered acceptable for roadside cross section condition 1. For cross section condition 2 the barrier should be extended at the given flare rate, to the back slope and anchored there. This would require more barrier but it would eliminate the possibility of an end impact with the barrier and eliminate any problem from vehicles getting behind the barrier.

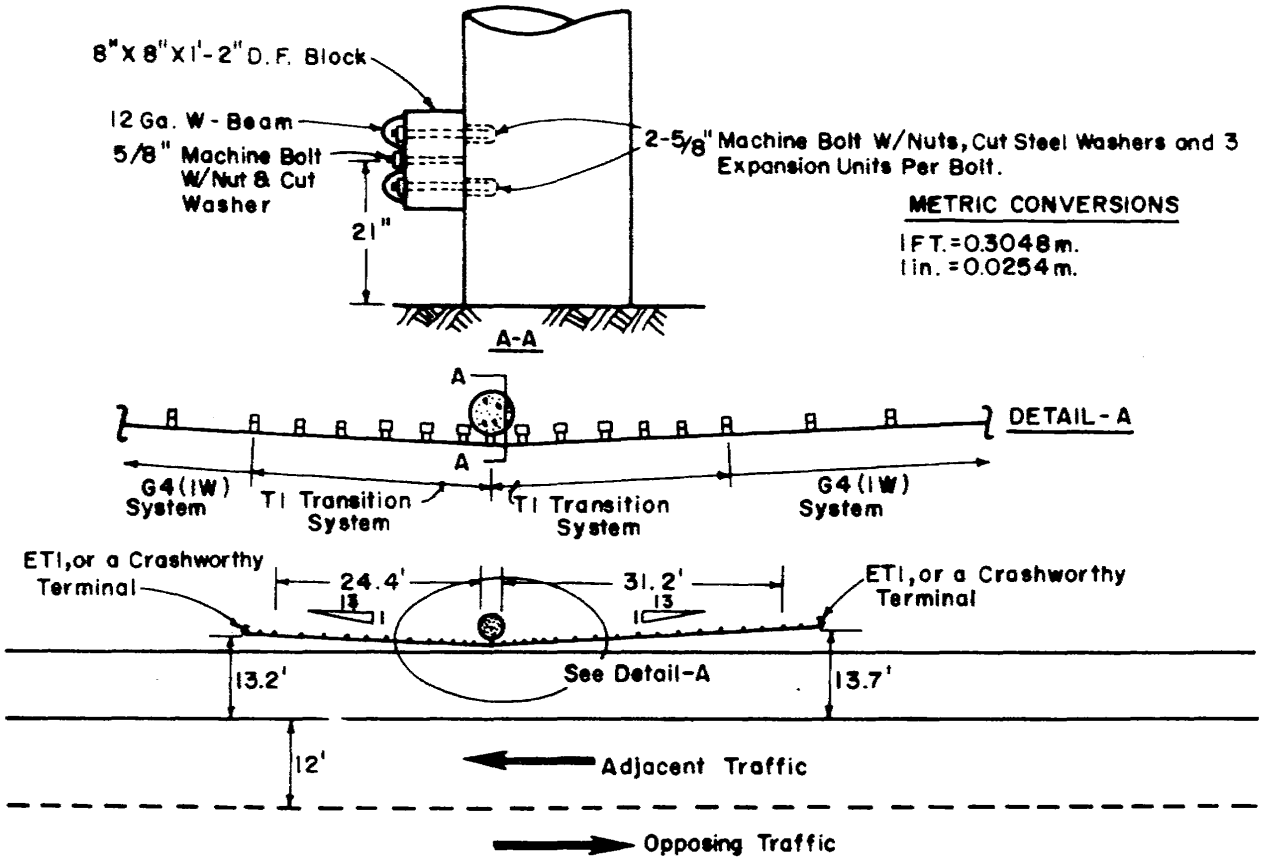
It should be emphasized that the suggested designs shown in this example are not the only one acceptable. There are other designs which would serve the intended purpose. A crash cushion layout might be appropiate or a concrete barrier half section, as will be discussed in following sections. However, proven systems should be used as was done in this example to upgrade substandard systems where possible.

8–10 MEDIAN BARRIERS

A median barrier is a longitudinal system used to prevent an errant vehicle from crossing the portion of a divided highway separating the traveled ways for traffic in opposite directions. It is the purpose of the following sections to delineate the criteria pertinent to the various elements of median barrier design, including warrants, structural and safety characteristics of operational systems, selection guidelines, placement recommendations, and guidelines for upgrading substandard installations. Figure 8–AA illustrates the three basic median barrier elements, namely, the standard section, the transition section and the end treatment.

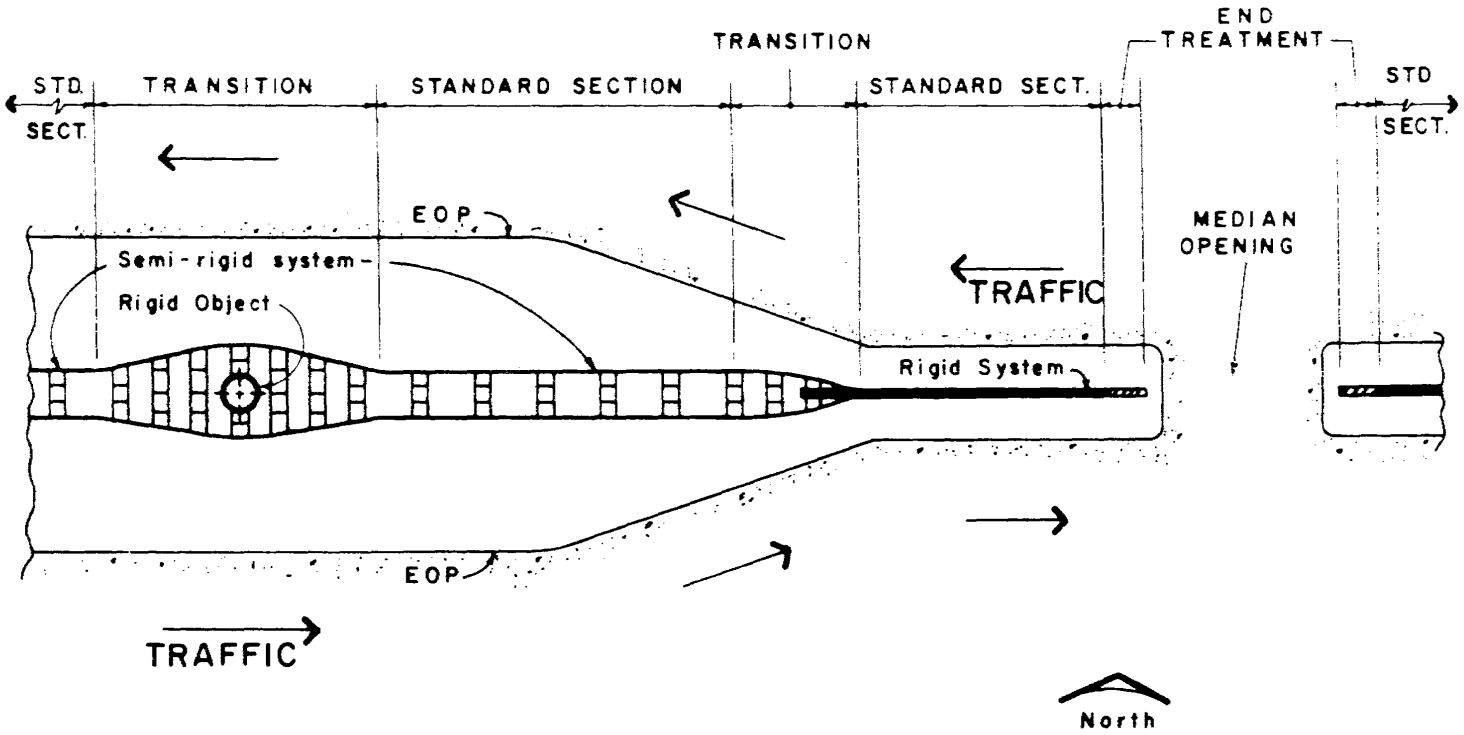
8–10.1 WARRANTS FOR MEDIAN BARRIERS

Figure 8–BB presents the warrants for median barriers on high speed, controlled access roadways which have relatively flat, unobstructed medians. At low ADT's, the probability of a vehicle crossing the median is relatively low. Thus, for ADT's less than 20,000 and median widths less than 20 feet, the median barrier use is optional. Likewise, for relatively wide medians, the probatility of a vehicle crossing the median is also relatively low. Thus, for median widths greater than 30 feet and ADT's below the warrant curve, median barrier use is optional. Medians wider than 50 feet do not warrant a barrier unless there is an adverse history of across-the-median accidents. It should be noted that after a warranted median barrier is installed, accident severity will decrease, however, accident frequency will generally increase since the space available for return-to-the-road maneuvers is decreased.



SUGGESTED DESIGN AND LAYOUT FOR EXAMPLE PROBLEM.

FIGURE 8-Z



DEFINITION OF MEDIAN BARRIER ELEMENTS

FIGURE 8-AA

Special consideration should be given to barrier needs for medians separating traveled ways at different elevations. The ability of an errant vehicle leaving the higher elevated roadway to return to the road or to stop diminishes as the difference in elevation increases. Thus, the potential for cross-over, head-on accidents increases. For such sections, the clear distance criterion given in Figure 8—D, should be used as a guideline for establishing barrier need.

Careful consideration should be given to the installation of median barriers on multilane expressways or other roadways with partial control of access. Problems are created at each intersection or median cross-over since the median barrier must be terminated at these points. In Section 8—11, and in the discussion of the concrete median barrier, a desirable layout will be discussed.

8—10.2 TRANSITION

Median barrier transition sections are warranted when it becomes necessary to connect median barriers of differing lateral stiffness.

Rigid objects in wide medians which separate the traveled ways for traffic in opposite direction require special attention. If the hazard warrants shielding for travel in one direction only, the criteria of Section 8—04 applies. If shielding is warranted for both directions of travel, the placement recommendations of Section 8—14 should be followed.

8—10.3 END TREATMENT

An untreated median barrier terminal is essentially a fixed-object hazard to the motorist. Therefore, a crashworthy end treatment is warranted if the median barrier is terminated within the clear distance (Figure 8—D).

8—11 STRUCTURAL AND SAFETY CHARACTERISTICS

This section presents operational median barrier systems and point out their structural and safety characteristics. It is subdivided according to standard sections of median barriers, transitions and end treatments. It is noted that the evaluation criteria for a median barrier are essentially the same as those for a roadside barrier, since both are longitudinal barriers whose functions are similar.

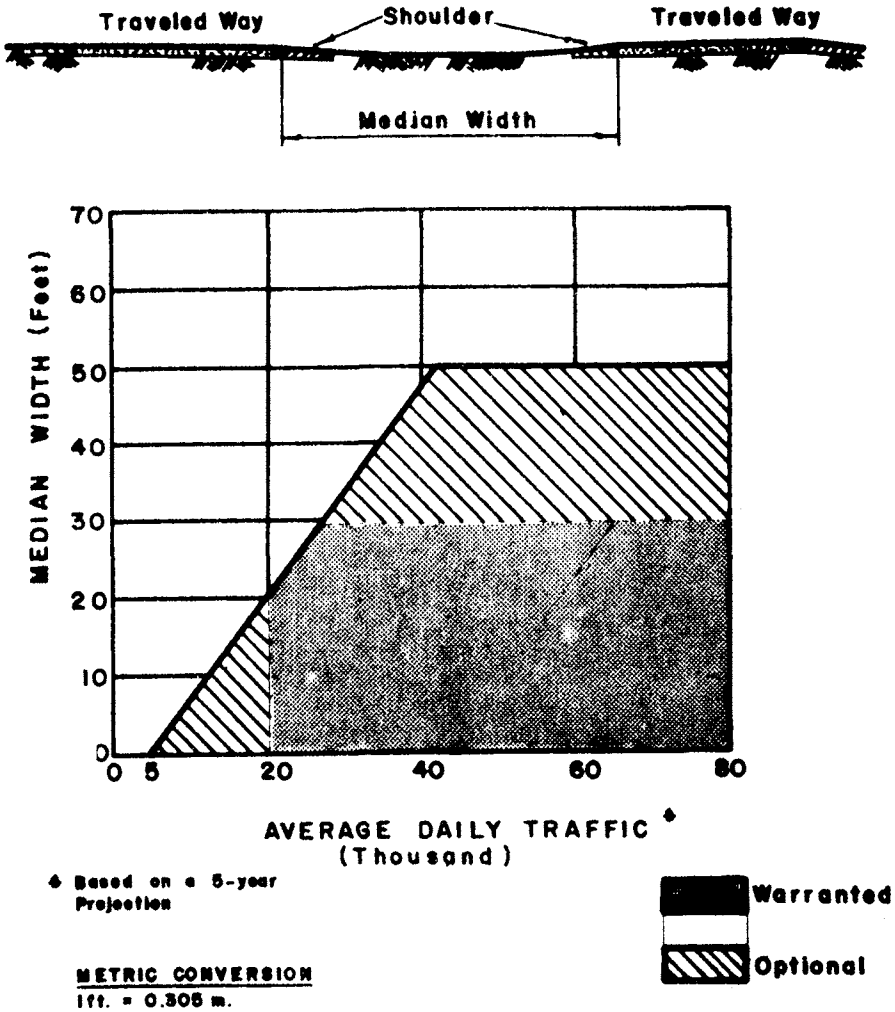
8—11.1 STANDARD SECTIONS OF MEDIAN BARRIERS

Tables 8—19 thru 8—23 present a summary of the structural and safety characteristics of current operational median barriers. Table 8—24 contains a summary of the impact performance data on each of the operational systems.

Systems MB1 and MB2 are considered flexible barriers. Systems MB3 through MB4S and systems MB7 through MB10 are considered semi-rigid barriers. The MB5 system or the Concrete Median Barrier (CMB) is the only operational rigid median barrier. However, variations in the footing and reinforcing of the MB5 have been tested and proven adequate. These variations are summarized in Table 8—25.

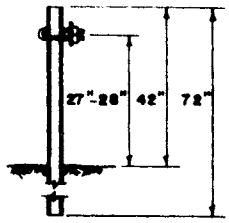
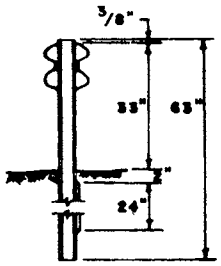
For median barriers the Department has currently adapted as Standards the use of the corrugated steel beam on strong post (MB—4S) and the concrete median barrier (MB—5). This are detailed in Standard Models 1—B and 1—C (See Chapter 19—07).

The Concrete Median Barrier (CMB) illustrated in Standard Model 1—C is a modification of previously used models. Its configuration is the New Jersey shape. Some variations have been made in the reinforcement and footings based in previous experience. Reference should be made to the Puerto Rico Highway Authority CMB Standard Models for the treatment at intersections and median cross-overs. In these models the median configuration has been modified to lessen



MEDIAN BARRIER WARRANTS.

FIGURE 8-BB

Metric Conversions 1 ft. = 0.305m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg				
SYSTEM	MB1 Cable		MB2 "W" Section (Steel Weak Post)	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	8' 0" H2-1/4"x4.1" Two 3/4" diameter steel cables ------ 1/2" diameter steel "U" bolt Varied		12' 6" S3x5.7 Two steel "W" sections None 5/16" bolts 8"x1/4"x24" Steel plate welded to post	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 25°	IMPACT ANGLE = 15°	IMPACT ANGLE = 25°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	NO TEST	87.0 4300	NO TEST	56.0 3680
BARRIER Dynamic Deflection (ft.)		17.0		7.00
VEHICLE ACCELERATIONS (G's)[1] Lateral Longitudinal Total		UNAV UNAV UNAV		UNAV UNAV UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)		UNAV UNAV UNAV		UNAV UNAV UNAV
BARRIER DAMAGE		UNAV		UNAV
REFERENCES		138		1
FIELD PERFORMANCE DATA[2]	YES		YES	
REMARKS	Barrier suitable for wide flat medians.		System suitable for wide medias.	

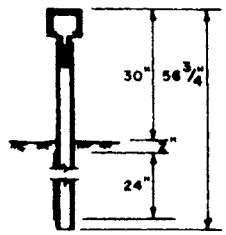
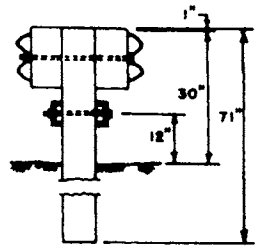
UNAV- unavailable

[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

OPERATIONAL MEDIAN BARRIER SYSTEMS, A.

TABLE 8-19

Metric Conversions 1 ft. = 0.305m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg				
SYSTEM	MB3 Box Beam		MB4W Blocked-Out "W" Beam (Wood Posts)	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	6' 0" S3x5.7 8"x6"x 1/4" Steel tube None Steel paddles 8"x1/4"x24" Steel plate welded to Post		6' 3" 8x8 Douglas Fir [3] Two "W" section, two C6x8.2 rubrails Two 8"x8"x14" Douglas Fir Blocks [4] 5/8" diameter bolts None	
IMPACT PERFORMANCE	IMPACT ANGLE=10°	IMPACT ANGLE=25°	IMPACT ANGLE=15°	IMPACT ANGLE=25°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	49.0 4540	56.0 3500	NO TEST	69.0 4570
BARRIER Dynamic Deflection (ft.)	0 75	5.50		≈2.00
VEHICLE ACCELERATIONS (G's) [1] Lateral Longitudinal Total	UNAV UNAV UNAV	UNAV UNAV 5.30		UNAV UNAV UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)	3 0 0	9 ≈5 ≈5		15 UNAV UNAV
BARRIER DAMAGE	3 posts only.	30' of steel tube beam and 10 posts.		UNAV
REFERENCES	14	17		140
FIELD PERFORMANCE DATA [2]	YES		YES	
REMARKS	System suitable for wide medians.		Southern yellow pine is acceptable alternate for Douglas Fir. A "W" beam centered at 10" above grade is an acceptable alternate rubrail.	

UNAV- unavailable

[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

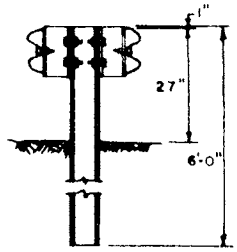
[3] 6"x8" post acceptable alternate based on G4(2W) test results.

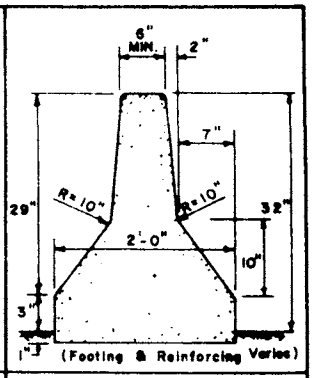
[4] 6"x8"x14" block acceptable base on G4(2W) test results.

OPERATIONAL MEDIAN BARRIER SYSTEMS, B

TABLE 8-20

Metric Conversions		
1 ft. = 0.305 m.		
1 in. = 25.4 mm		
1 mph = 1.61 km/hr		
1 lb. = 0.454 kg		





SYSTEM	MB4S Blocked-Out "W" Beam (Steel Posts)		MB5 Concrete Median Barrier	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	 6'-3" W6X8.5 [3] Two steel "W" sections Two W6X8.5 [4] 5/8" diameter steel bolts None		Continuously poured, reinforced, sloped face, concrete section. Barrier can be anchored by dowels or an asphalt key. See text for further details of various configurations tested.	
IMPACT PERFORMANCE	IMPACT ANGLE = 16°	IMPACT ANGLE = 25°	IMPACT ANGLE = 15°	IMPACT ANGLE = 25°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	 67.0 3500	NO TEST	 60.7 4210	 62.4 4000
BARRIER Dynamic Deflection (ft.)	 1.50		 0.00	 0.00
VEHICLE ACCELERATIONS (G's) [1] Lateral Longitudinal Total	 UNAV UNAV 5.70		 6.00 5.00 UNAV	 9.00 7.00 UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)	 9 0 0		 11.5 ±25 ±10	 7 ±35 ±20
BARRIER DAMAGE	25' of "W" section and 2 posts.		None	None
REFENCES	17		31	31
FIELD PERFORMANCE DATA [2]	YES		YES	
REMARKS			Good redirection for impact angles of 15° or less. At larger impact angles vehicle roll and pitch may be-come critical. Recommended use on narrow medians, retaining walls, rock cuts, etc. Several modified versions have been tested, see text.	

UNAV - unavailable

[1] 50 millisecond average unless otherwise noted

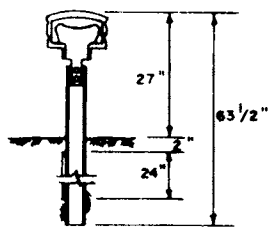
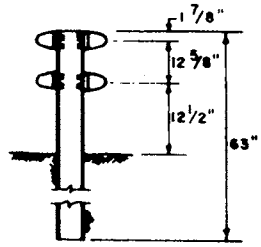
[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

[3] 4 1/3" x 5 5/8" x 3/16" "C" steel post acceptable based on G4(2S) test results.

[4] 4 1/3" x 5 5/8" x 3/16" "C" steel blockout acceptable based on G4(2S) test results.

OPERATIONAL MEDIAN BARRIER SYSTEMS, C

TABLE 8-21

Metric Conversions 1 ft = 0.305m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb = 0.454 kg				
SYSTEM	MB7 Aluminum Strong Beam		MB8 Aluminum Balance Beam	
BARRIER DESCRIPTION				
POST SPACING	6' 3"		12' 6"	
POST TYPE	Aluminum I or steel S3 x 5.7		5 1/2" x 7 1/4" H section aluminum	
BEAM TYPE	Aluminum extrusions		5 1/2" x 7 1/4" H section aluminum	
OFFSET BRACKETS	None		Four standard aluminum extrusions	
MOUNTINGS	Steel or aluminum paddles		None	
FOOTINGS	8" x 3/16 x 24 stee or aluminum Plate		Standard Hardware None	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 26.6°	IMPACT ANGLE = 7°	IMPACT ANGLE = 25°
IMPACT CONDITIONS				
Speed (mph)	53.0	62.7	51.0	56.0
Vehicle Weight (lb.)	4000	4057	4000	4000
BARRIER				
Dynamic Deflection (ft.)	1.50	7.20	UNAV	UNAV
VEHICLE ACCELERATIONS (G's)[1]				
Lateral	UNAV	4.10	0.70	4.0[3]
Longitudinal	UNAV	3.70	1.00	9.0[3]
Total	UNAV	UNAV	UNAV	UNAV
VEHICLE TRAJECTORY				
Exit Angle (deg.)	UNAV	UNAV	4	=0
Roll Angle (deg.)	UNAV	UNAV	UNAV	UNAV
Pitch Angle (deg.)	UNAV	UNAV	UNAV	UNAV
BARRIER DAMAGE	UNAV	UNAV	UNAV	UNAV
REFERENCES	1	1	1	1
FIELD PERFORMANCE DATA[2]	NO		NO	
REMARKS				

UNAV - unavailable

[1] 50 millisecond average unles otherwise noted

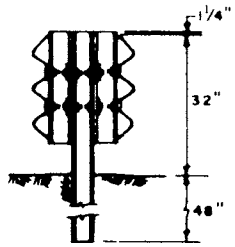
[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

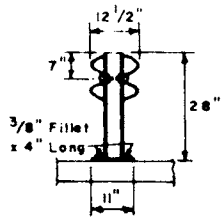
[3] From mechanical peak-g accelerometer

OPERATIONAL MEDIAN BARRIER SYSTEMS, D.

TABLE 8-22

Metric Conversions
1 ft. = 0.305 m
1 in = 25.4 mm
1 mph = 1.61 km/hr
1 lb = 0.454 kg





SYSTEM	MB 9 Blocked-Out Thrie Beam (Steel Post)		MB 10 Metal Beam Guard Fence (Steel "Breakaway" Post.)	
BARRIER DESCRIPTION				
POST SPACING	6' 3"		6' 3"	
POST TYPE	W6x8.5		W6x8.5 steel	
BEAM TYPE	Two Thrie Beams		Two steel "W" sections	
OFFET BRACKETS	W6x8.5		None	
MOUNTINGS	5/8" diameter steel bolts		5/8" diameter bolt	
FOOTINGS	UNAV		7"x11"x5/8" steel Plate	
IMPACT PERFORMANCE	IMPACT ANGLE = 17°	IMPACT ANGLE = 25°	IMPACT ANGLE = 14.7°	IMPACT ANGLE = 25°
IMPACT CONDITION				
Speed (mph)	54.1	66.1	63.4	57.3
Vehicle Weight (lb.)	2200	4500	4200	3640
BARRIER				
Dynamic Deflection (ft.)	0.33	3.17	1.00	1.50
VEHICLE ACCELERATIONS (G's)[1]				
Lateral	5.30	6.30	6.30	UNAV
Longitudinal	2.00	6.60	4.30	10.0
Total	UNAV	UNAV	UNAV	UNAV
VEHICLE TRAJECTORY				
Exit Angle (deg.)	≈2.0	less than 10	3.8	19.7
Roll Angle (deg.)	0	0	0	less than 10
Pitch Angle (deg.)	0	0	0	less than 10
BARRIER DAMAGE	None	25' of thrie beam and 3 Posts.	50' of "W" section and 3 Posts	50' of "W" section and 3 posts.
REFERENCES	21	21	32	31
FIELD PERFORMANCE DATA[2]	NO		NO	
REMARKS	Provides smooth redirection. Rub-rail not needed. Chance of vehicle snagging on post is minimal.		Good redirection. Some wheel snagging occurred in 25° test, but was not severe. Fillet weld at base is 3/8" weld along outside edge of flange only. This is critical for shearing at low impact energies.	

UNAV - unavailable

[1] 50 millisecond average unless otherwise noted

[2] If available see summary in Appendix A (AASHTO Barrier Guide)

OPERATIONAL MEDIAN BARRIER SYSTEMS, E

TABLE 8-23

TABLE 8-24 -- MEDIAN BARRIER DATA SUMMARY

System	Maximum Dynamic[1] Deflection (ft.)	Accelerations at 15° (G's)[2]			Accelerations at 25° (G's)[2]			Is Barrier Hardware Standardized?[3]
		Lateral	Longitudinal	Total	Lateral	Longitudinal	Total	
Flexible Systems								
MB1	17.0	No Test	No Test	No Test	UNAV	UNAV	UNAV	Yes
MB2	7.0	No Test	No Test	No Test	UNAV	UNAV	UNAV	Yes
Semi-Rigid Systems								
MB3	5.5	UNAV	UNAV	UNAV	UNAV	UNAV	5.3	Yes
MB4W	≈ 2.0	No Test	No Test	No Test	UNAV	UNAV	UNAV	Yes
MB4S	1.5[4]	UNAV	UNAV	5.7	7.1	7.6	UNAV	Yes
MB7	7.2	UNAV	UNAV	UNAV	4.1	3.7	UNAV	Yes
MB8	UNAV	0.7	1.0	UNAV	4.0[5]	9.0[5]	UNAV	Yes
MB9	3.2	5.3	2.0	UNAV	6.3	6.6	UNAV	Yes[6]
MB10	1.5	6.3	4.3	UNAV	UNAV	10.0	UNAV	No
Rigid System								
MB5	0.0	6.0	5.0	UNAV	9.0	7.0	UNAV	Yes

UNAV - Unavailable

Metric Conversion: 1 ft = 0.305 m.

[1] Based on 25° impact unless otherwise noted.
[2] 50 millisecond average unless otherwise noted.
[3] See reference 22, 23.
[4] Based on 15° impact data.
[5] Peak acceleration.
[6] To be included in a revised edition of reference 22, 23.

TABLE 8-25 – VARIATIONS IN THE CONTINUOUS CONCRETE MEDIAN BARRIER DESIGN (MB5)

Barrier Configuration	Length of Barrier Tested (ft.)	Reinforced?	Description of reinforcing	Description of Footing	Reference
A	150	Yes	8 – No. 5 continuous, grade 60, reinforcing bars.	System placed on grade. 1 in. layer of hot mix asphalt placed at base of barrier to provide lateral restraint.	31
B	160 (poured in 20 ft. segments)	No	None	Base of system (unreinforced concrete) is extended 10 in. below grade.	14
C	97	Yes	1 – No. 4 continuous, reinforcing bar. Additional reinforcing is provided by 3/4 in. diameter cable from existing lowered cable barrier.	System is placed on grade over existing lowered cable barrier. Footing of existing barrier provides lateral restraint.	33

Note: 1 ft. = 0.305 m; 1 in. = .0254 m

the probatility that an errant vehicle will ramp over the end section of the CMB. This is accomplished by off-setting the barrier about 12 feet from the traveled way. Also a shorter end section of 30 feet is recommended instead of the 80 feet end section originally used by the State of New Jersey and by various States. Included also in the Standard Model 1—C is an openning for Pedestrian Crossing which protects pedestrians while they are standing on the median to cross the roadway.

Figure 8—CC shows an acceptable modification to the CMB shape to provide for overlays up to 5 inches. This modification should be accomplished since modifications of the shape have been shown to be undesirable from a performance standpoint.

The spacing of posts and height of rail discussed in previous sections when presenting longitudinal barriers also apply to similar barriers when used as median barriers. Also, the structural adequacy and impact severity criteria, previously stated.

Shown in Table 8—26 are the types of median barriers recommended for the given median widths, when a median barrier is warranted. The primary consideration in establishing this guidelines was safety, both to the motorist and the maintenance personnel who must repair damage barriers.

8—11.2 MEDIAN BARRIER TRANSITIONS

Median barrier transition sections are needed between adjoining median barriers of significant differences in lateral stiffness, between a median barrier and another type of barrier, such as a bridge rail, or when a median barrier must be stiffened to shield fixed objects in the median such as bridge piers. Reference should be made to Figure 8—AA for examples of median barriers transitions.

There is not an operational system exclusively for median barriers currently in use in Puerto Rico. Model 1—A, of the Puerto Rico Highway Authority, gives transitions to fixed objects, such as bridge rails on twin bridges and bridge piers on the median.

Impact performance requirements of median barriers transitions are essentially the same as those for the standard median barrier section. Structural details of special importance are as follows:

1. Strong post median barrier systems must be used on transitions to the CMB System or to bridge rails, parapets, or rigid objects. Such systems should be blocked out to prevent vehicle snagging on the posts.

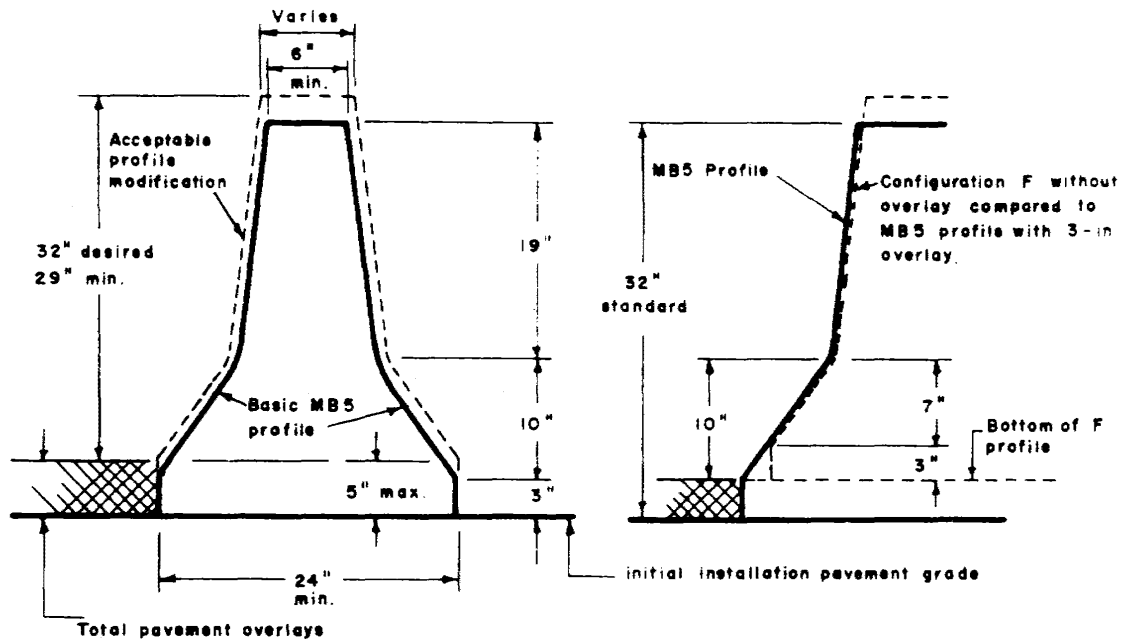
2. The length of the transition should be such that significant changes in the lateral stiffness do not occur within a short distance. The transition length should be at least 33 feet.

3. Post spacing should be decreased to 3'-1 1/2" in the transition length, to smoothly and continuously increase the stiffness of the transition from the weaker to the stronger system.

8—11.3 END TREATMENT OF MEDIAN BARRIERS

An untreated end of a median barrier is extremely hazardous. Impact with the untreated end of a metal beam type system may result in the beam penetrating the passenger compartment as well as an abrupt stop. Impact with the untreated end of a CMB system will result in untolerable impact forces. A crashworthy end treatment for a median barrier is essential if the barrier is terminated within the clear distance of travel from either direction.

The current practice of the Department, when the corrugated metal beam barrier is used, is to provide a variation of the crash-cushion systems illustrated in Figures 8—35 and 8—36 where the median barrier width in 18 feet or more. Standard model for this variation is under development.



(a) Special treatment if more than 3-in. overlay provision is anticipated.

(b) Illustration of 3-in pavement overlay at base of MB5 barrier.

METRIC CONVERSION

1 in. = .0254 m

PAVEMENT OVERLAY CONSIDERATIONS.

FIGURE 8-CC

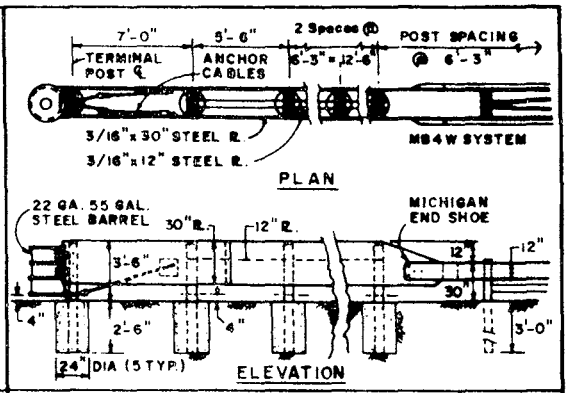
TABLE 8-26 – SUGGESTED MEDIAN BARRIES AS RELATED TO MEDIAN WIDTH

Median Width	Suggested Barrier [1]
Up to 18 feet	MB 4-S or MB-5
18 to 30 feet	MB 4-S or MB-5
30 to 50 feet	MB 4-S or MB-3

[1] If warranted by Figure 8-BB

Metric Conversion:

1 ft = 0.3048 m

Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr. 1 lb. = 0.454 kg.	
SYSTEM	**MBETI** Median Barrier Breakaway Cable Terminal (Wood Post)
BARRIER DESCRIPTION	TYPICAL POST - 6"x8" Douglas Fir; TERMINAL POST - 6"x8" Southern Pine with 2 3/8" diameter hole drilled through neutral axis; ANCHORAGE - Cable assembly (see sketch); FOOTING - 24" diameter, 30" deep concrete for terminal posts, other posts require none; TYPICAL RAIL - steel "W" section, 12 GA.; TERMINAL RAIL - 3/16"x30" steel plate; OFFSET BRACKETS - 6"x6" Southern Pine block.

IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	64.8	NO TEST
Angle (deg.)	1.2	
Vehicle Weight (lb.)	3900	
BARRIER		
Deceleration Distance (ft.)	22.0	
VEHICLE ACCELERATIONS (G's)[1]		
Lateral	5.0	
Longitudinal	11.6	
Total	UNAV	
VEHICLE TRAJECTORY		
Exit Angle (deg.)	Behind rail	
Roll Angle (deg.)	=0	
Pitch Angle (deg.)	=0	
BARRIER DAMAGE	Entire terminal rail and 4 terminal posts	
REFERENCES	27[3]	
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	System was tested with MB4W system. Details of the end posts, anchorage and footings are critical.	

UNAV - unavailable

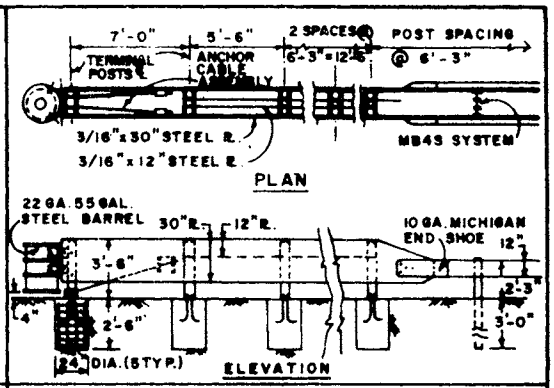
[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

[3] For most recent recommendations see Reference 148

OPERATIONAL MEDIAN BARRIER END TREATMENTS, A

TABLE 8-27

Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr. 1 lb. = 0.454 kg.		
SYSTEM	MBET 2 Median Barrier Breakaway Cable Terminal (Steel Post)	
BARRIER DESCRIPTION	TYPICAL POST-W6x8.5 steel; TERMINAL POST-TS 6"x6"x0.1875" steel breakaway design; ANCHORAGE-Cable assembly (see sketch); FOOTING-24" diameter, 30" deep concrete for terminal posts, other posts require none; TYPICAL RAIL-steel "W" section, 12 GA. TERMINAL RAIL-3/16" x 30" steel plate; OFFSET BRACKETS-6"x6" steel blocks.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	56	62
Angle (deg.)	0	26
Vehicle Weight (lb.)	4500	4500
BARRIER		
Deceleration Distance (ft.)	=25	5.3[4]
VEHICLE ACCELERATIONS (G's)[1]		
Lateral	3.0	6.5
Longitudinal	9.7	6.0
Total	UNAV	UNAV
VEHICLE TRAJECTORY		
Exist. Angle (deg.)	NOAP[3]	=0
Roll Angle (deg.)	UNAV	=10
Pitch Angle (deg.)	=16	=20
BARRIER DAMAGE	Entire terminal rail and 5 terminal posts	12' of terminal rail and 20' of typical rail, 4 terminal posts and 4 typical posts
REFERENCES	27[5]	27[5]
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	This system was tested with the MB4S system. Other documented tests have been conducted with the MB3 and MB4S systems but with the terminal posts (TS 6"x6"x0.1875" and W6x8.5) welded to a base plate at grade. See Appendix E. Although not documented by crash tests, this system could also be adapted for use with the MB2 and MB5 systems.	

Appendix E (AASHTO Barrier Guide)

UNAV - unavailable

[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

[3] NOAP - not applicable

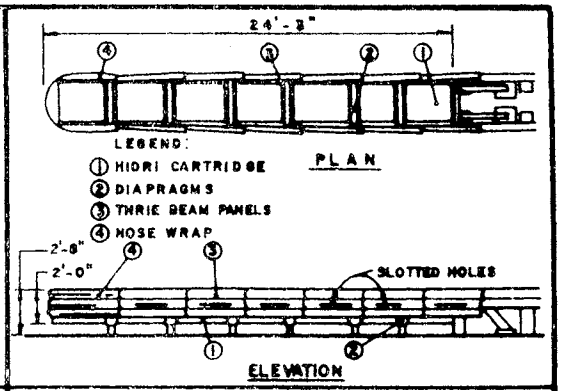
[4] Maximum dynamic deflection

[5] For most recent test results and recommendations see Reference 146 (AASHTO Barrier Guide)

OPERATIONAL MEDIAN BARRIER END TREATMENTS, B

TABLE 8-28

Metric Conversions
1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg



SYSTEM	MBET 3	
BARRIER DESCRIPTION	Hi-dri Cell Cartridges Used in Conjunction With telescoping Steel thrie beam fender panels.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	62.0	63.0
Angle (deg.)	0	20
Vehicle Weight (lb.)	Pontiac Sedan	1968 Buick LeSabre
BARRIER		
Deceleration Distance (ft.)	UNAV	UNAV
VEHICLE ACCELERATIONS (G'S[1])		
Lateral	UNAV	8.0[3]
Longitudinal	15.0[3]	5.0[3]
Total	UNAV	UNAV
VEHICLE TRAJECTORY		
Exit Angle (deg.)	UNAV	8
Roll Angle (deg.)	less than 10	0.
Pitch Angle (deg.)	less than 10	0
BARRIER DAMAGE	Hi-dri cell cartridges destroyed. Thrie beam not damaged.	None
REFERENCES	34	34[4]
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	Vehicle yawed 48° in head-on test. Slight barrier damage reported in all tests	

UNAV - unavailable

[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

[3] Peak acceleration

[4] For data on connection to MBS see Reference 57 (AASHTO Barrier Guide)

OPERATIONAL MEDIAN BARRIER END TREATMENTS, C

TABLE 8-29

For median barrier end treatment where the median width is under 18 feet either of the systems in Tables 8--28 and 8--29 may be used.

Further discussion of such treatment will be given in the sections related to Crash Cushions in this Chapter.

As discussed in Section 8--11.1, a layout of the CMB construction is included in the standard model. When the median width doesn't accommodate a crash cushion arrangement, the barrier is offset 12 feet from the traveled way to diminish the probability off an opposing errant vehicle to hit it. This solution is not desirable since the hazard is located within the clear zone width. This clear zone is 20 feet for a highway with operating speed of 50 mph and a 10:1 slope.

The user of this Manual should keep in touch with the Design,Area of the Puerto Rico Highway Authority, for the latest development in median barriers end treatment.

Emergency openings in median barriers are to be avoided whenever possible. When necessary, the opening should be designed so as not to introduce an undesirable hazard or to compromise the impact performance of the median barrier. If the median is 20 feet or wider, a design similar to that shown in Figure 8–DD may be used for semi-rigid and rigid systems.

Note that,

$$W = 2a + d \sin \theta + 2B$$

where

b = barrier width

and

W, a, d, and θ are defined in Figure 8--DD

Minimum values for these parameters should be as follows:

a = 4.0 feet
d = 20.0 feet
θ = 25 degrees

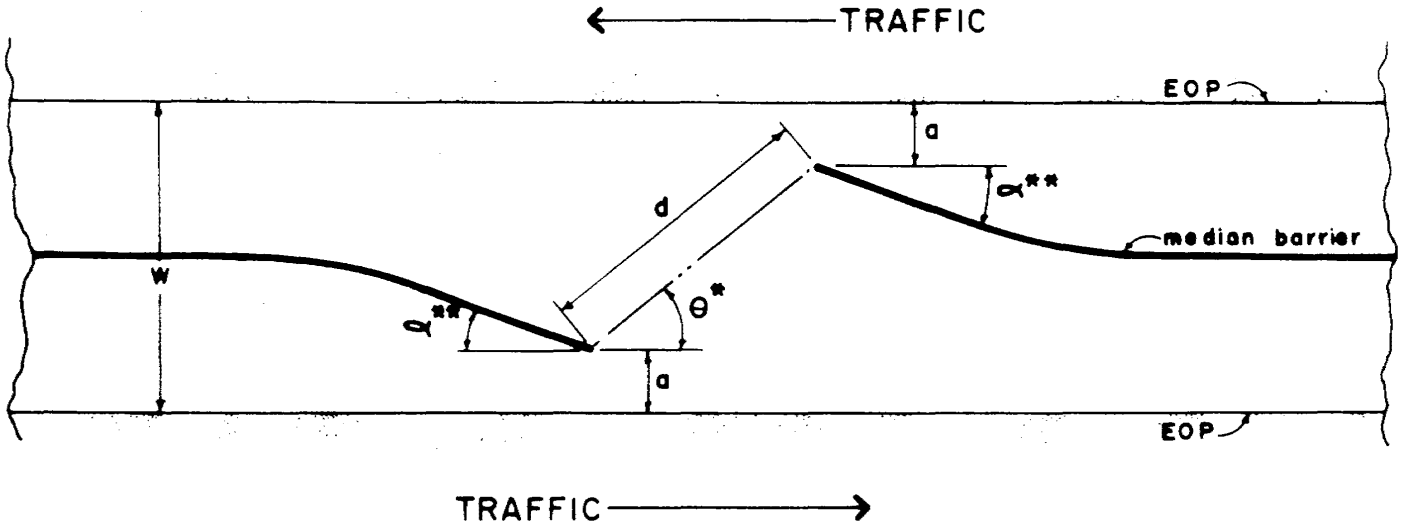
The flare rate of the terminals in this opening should adhere to the criteria given in Section 8--08.04.

8--12 MAINTENANCE CHARACTERISTICS OF MEDIAN BARRIERS

Section 8--06 contains a discussion of the maintenance factors to consider before selecting a roadside barrier. Those factors are essentially the same ones that should be considered before selecting a median barrier. There are, however, some differences in maintenance considerations between the two types of barriers and the discussion follows:

Tables 8--30 and 8–31 summarize the available field data based on a survey of several states to determine typical collision repair values experienced. It should be remembered that these are average values needed to repair a damaged section and not average values based on all hits. Many hits are only brushes and cause no appreciable barrier damage. It is also necessary to note that this values were obtained from various states and not from Puerto Rico. Whenever this information can be gathered, from experience in Puerto Rico barrier maintenance costs, the values should be used instead of those included in Tables 8--30 and 8–31.

It must be noted that the relatively high refurbishment time for the MB5 system can be misleading. It i widely known that the MB5 system requires less maintenance than any other longitudinal barrier.



* θ must be ≥ 25 degrees.

** The flare rate of the terminal section should not exceed the flare rates suggested in Section 8-08.04 (Table 8-17).

SUGGESTED EMERGENCY OPENING DESIGN FOR SEMI-RIGID OR RIGID SYSTEMS.

FIGURE 8-DD

TABLE 8-30 – COLLISION REPAIR DATA FOR MEDIAN BARRIERS, A

System	Typical Crew Size	Typical Material Repaired or Replaced		Average Refurbishment Time (Man-Hours/Foot or Rail)
		Rail (ft.)	Posts	
MB1-Cable Barrier [a]	3-4	75	8	0.10
MB1-Cable Barrier [b]	3-4	75	8	0.13
MB1-Cable Barrier [c]	3-4	75	8	0.055
MB1-Cable Barrier [d]	3-4	75	8	0.083
MB2-W-Beam on Steel Weak Posts	3-4	53	4-5	0.32
MB3-Box Beam	UNAV	36	4	0.61
MB4W-Blocked Out W-Beam on Wood Posts	4-5	25	4	0.36

[a] Post in asphalt, with glare screen
[b] Post in PCC, with glare screen
[c] Post in asphalt, without glare screen
[d] Post in PCC, without glare screen

Metric Conversion: 1 ft = 0.305 m

TABLE 8-31 – COLLISION REPAIR DATA FOR MEDIAN BARRIERS – B

System	Typical Crew Size	Typical Material Repaired or Replaced		Average Refurbishment Time (Man-Hours/Foot of Rail)
		Rail (ft.)	Posts	
MB4S—Blocked Out W—Beam on Steel Posts	4-5	57	4-5	0.36
MB5—Concrete Median Barriers	4-5	UNAV	Not Applicable	3.50
MB7—Aluminum Strong Beam*	4	66	11	0.48
MB7—Aluminum Strong Beam†	4-6	66	11	0.73
MB8—Aluminum Balanced Beam	NO DATA AVAILABLE			
MB9—Blocked Out Thrie Beam	NO DATA AVAILABLE			
MB10—W—Beam on Steel Breakway Posts	5-7	56	2	0.59

* Summer conditions (data from a north central area)

† Winter conditions (data from a north central area)

Metric Conversion: 1 ft = 0.305 m

8—13 MEDIAN BARRIER SELECTION GUIDELINES

Once it has been determined that a median barrier is warranted, a selection must be made. In general, the most desirable system is one that offers the best protection at the least cost and is consistent with the given constraints. Table 8—32 presents nine items which should be considered before a selection is made.

As previously stated, the systems currently in used by the Department for new designs are the MB5 and MB—5.

It should be kept in mind, when selecting the MB4S system, that the width of the median should be sufficient to accommodate the dynamic deflections, as given in Tables 8—20, from both sides of the roadway.

For system MB4S, a minimum median width of 12 feet is necessary.

System MB5 (CMB), given in Model 1—C of the Puerto Rico Highway Authority, should be used whenever a median width of less that 12 feet is to be provided. A minimum median width of 6.5 feet is necessary for the installation of the CMB.

8—14 MEDIAN BARRIER PLACEMENT RECOMMENDATIONS

Major factors to consider in the lateral placement of a median barrier are the effects of the terrain between the edge of the traveled way and the barrier on the errant vehicle's trajectory, and the flare rate of transition sections. Another factor of concern is rigid objects in the median.

A discussion of these factors follows in subsequent sections.

8—14.1 TERRAIN EFFECTS IN MEDIAN BARRIER PLACEMENT

Terrain conditions between the traveled way and the barrier can have significant effects on the barrier's impact performance. Curbs and sloped medians (including superelevated sections) are two prominent features which deserve special attention. A vehicle which traverse one of this features prior to impact may go over the barrier or submarine under the barrier or snag on its support posts.

Curbs — In general, it has been found that curbs offer no safety benefits on high speed roadways from the standpoint of vehicle behavior following impact. A curb should never be used for purposes of redirecting an errant vehicle. If special conditions require the use of a curb, the face of the curb should be placed behind the face of the barrier.

Sloped Medians — The most desirable median is one that is relatively flat (slope less than 10:1) and free of rigid objects. If warranted, the barrier can then be placed at the center of the median.

Figure 8—EE shows three basic median sections for which placement guidelines are presented. In each section it is assumed that a median barrier is warranted. Section I applies to depressed medians or medians with a ditch section. Section II applies to stepped medians or medians that separate travel ways with significant differences in elevation and Section III applies to raised medians or median berms. As previously discussed, slope rounding affords the driver more control of an errant vehicle since it reduces the potential for the vehicle to become airborne. Therefore, sharp breaks or hinges in median slopes should be rounded.

The following provisions should be necessary when any of these situation occurs:

1. Section I — The slopes and the ditch section should be checked by the criteria in Section 8—04 to determine if a roadside barrier is warranted. If both slopes require protection, a roadside barrier should be placed near the shoulder on each side of the median ("b" and "d"). If only one slope requieres protection, e.g., S3, a median barrier should be placed at "c". In this

TABLE 8-32 – SELECTION CRITERIA FOR MEDIAN BARRIERS

Item	Consideration
A. Median Width and Deflection	1. Criteria in Table IV-B-4 should be used. 2. Dynamic deflection of barrier should not be greater than one-half of median width. 3. Cable barrier should be place on flat medians.
B. Strength and Safety	1. System should contain and redirect vehicle at design conditions. 2. System should be least hazardous available, consistent with costs and other considerations.
C. Maintenance	1. Collision maintenance. 2. Routine maintenance. 3. Environmental conditions.
D. Compatibility	1. Can system be transitioned to other barrier system? 2. Can system be terminated properly?
E. Costs	1. Initial costs. 2. Maintenance costs. 3. Accidents cost to motorists.
F. Field Experience	1. Documented evidence of barrier's performance in the field.
G. Aesthetics	1. Barrier should have pleasing appearance.
H. Promosing New Design	1. It may be desirable to install new systems on an experimental basis.

situation a MB4S or CMB barrier should be used. A rub rail should be installed in the MB4S system, on the ditch side of it to aid in redirecting errant vehicles which approach the barrier from the ditch side.

If neither slope requires protection but the difference in the slope is greater than 0.13, a median barrier should be placed on the side with the larger DS. (where DS is the difference of slope between shoulder and median). If we have a shoulder with a 4% slope (0.04), the maximum side slope without the need of a median barrier, will be 6:1 (0.17), because DS will be equal to 0.13 (DS = 0.17 - 0.04 = 0.13). The need of a median barrier in the side with the larger DS, is assured, if for example:

Tan DS_b = 0.21 (corresponds to a 4% shoulder and a 4:1 side slope)
Tan DS_b = 0.16 (corresponds to a 4% shoulder and a 5:1 side slope) the barrier would be placed at "b". A MB4S or CMB system should be used in this situation.

If Tan DS_b and Tan DS_d are both less than 0.13, a median barrier should be placed at or near the center of the median (at "c"). A MB3, MB4S or CMB could be used, provided its dinamic deflection is not greater than (W + 4) feet.

2. Section II — If Tan DS_b is greater than 0.13, a median barrier should be placed at "b". If the slope is not travesable (rough rock cut, etc.) a roadside barrier should be placed at "b" and "d". In case that a retaining wall is needed at "d", its base should be contoured to the exterior shape of a CMB.

If Tan DS_b is less than 0.13, a median barrier should be placed at or near the center of the median.

3. Section III — This cross-section if high enough and wide enough, can itself redirect vehicles. If the cross-section in itself is inadequate for redirecting errant vehicles, a MB4S system should be placed at the apex of the cross-section. If the slopes are not travesable (rough rock cut, etc.), a roadside barrier should be placed at "b" and "d". If retaining walls are used at "b" and "d", it is recommended that the base of the wall be contoured to the exterior shape of the CMB.

The CMB vertical axis should be oriented as illustrated in Figure 8—FF on superelevated sections. The axis of the CMB should be vertical when riding the upper part of the superelevation. It should be perpendicular to the superelevation when riding the lower part of it.

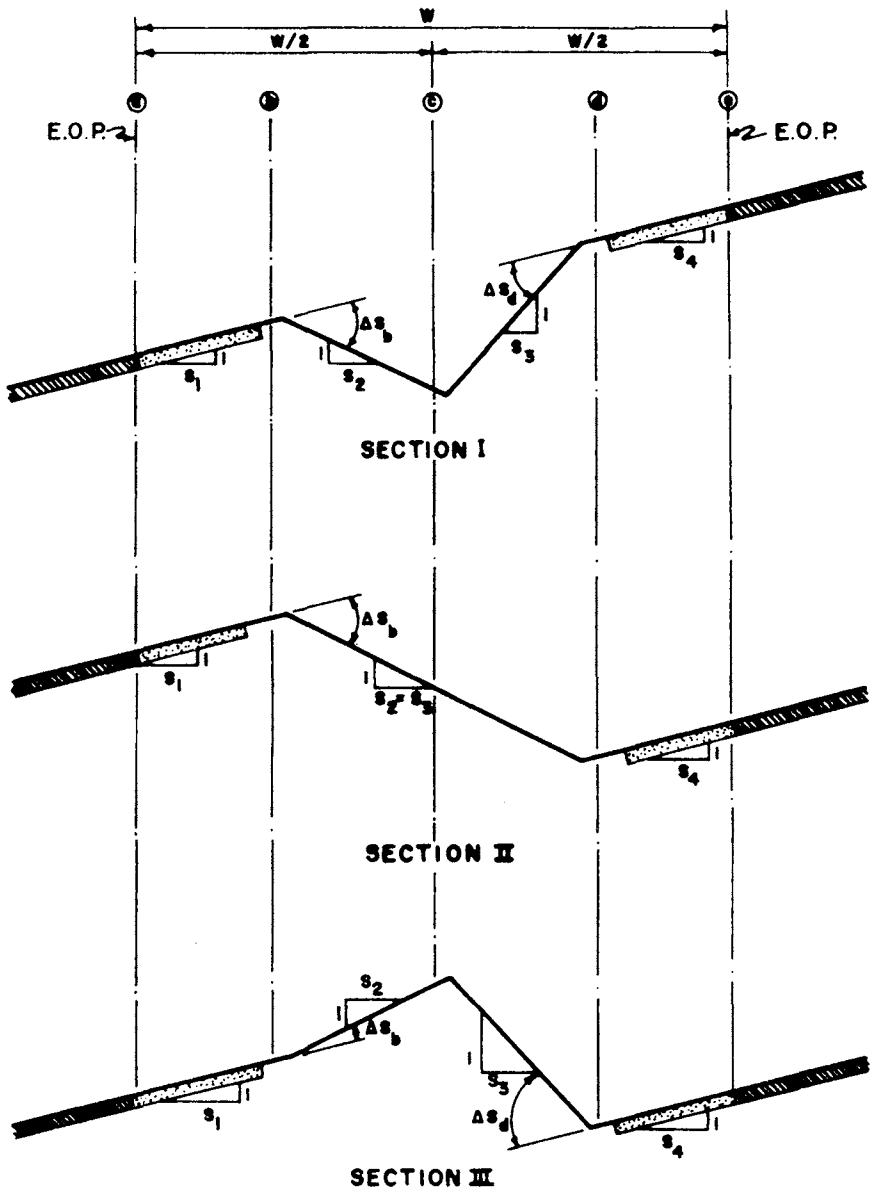
When a median barrier is warranted, the same barrier type should be used throughout the length of need, and the barrier should be placed in the middle of a flat median. However, in some situations as indicated in Sections I and II of Figure 8—EE, a barrier may be required at both sides of the median. In this case the median should be "split" so that continuity is mantained (for example a half CMB could be used at both sides and transitioned to a complete CMB when it is needed only at the center of the median).

Figure 8GG illustrates how the median barrier could be "split" to satisfy the conditions just discussed. The W-beam types systems (MB4S, etc.) and the MB5 (CMB) system can be split this way.

A layout similar to that of Figure 8—GG could be used where depressed medians require barriers on both sides of the median, or at the approach to a divided structure.

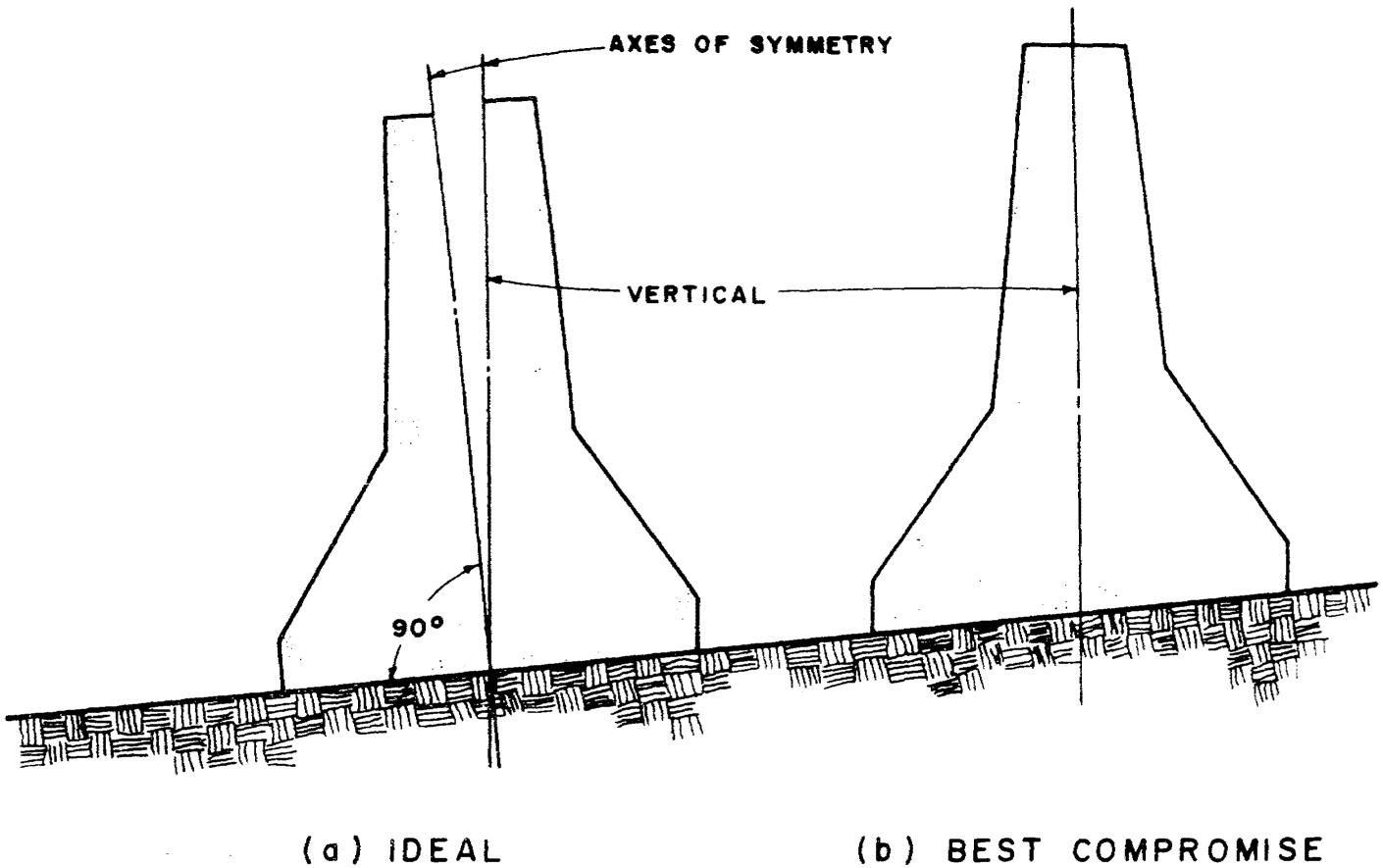
8—14.2 MEDIAN BARRIER FLARE RATES

When it becomes necessary to flare a median barrier, such as at a rigid object in a median, at divided structures, etc., the flare rate should not significantly increase the hazard potential of the barrier. The flare rates given in Table 8—17 for roadside barriers apply to median barriers also.



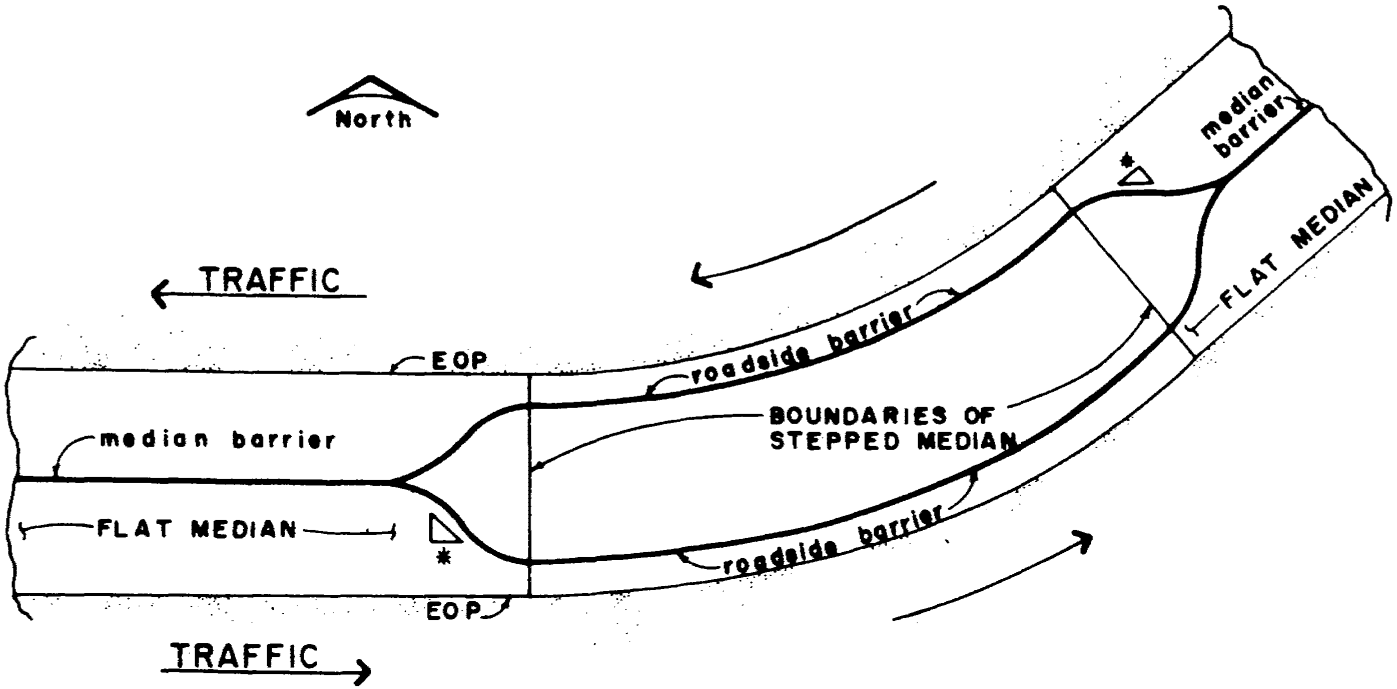
DEFINITIONS OF MEDIAN SECTIONS.

FIGURE 8-EE



SUGGESTED ORIENTATION OF MB5 SHAPE ON SUPERELEVATED SECTION.

FIGURE 8-FF



* Flare rate should not exceed suggested limits (Table 8-17).

EXAMPLE OF MEDIAN BARRIER PLACEMENT AT SUPERELEVATED SECTION.

FIGURE 8-GG

Another special layout problem concerns medians whose widths are such that a median barrier is not warranted but that have a rigid object which warrants shielding. Typical examples are bridge piers at underpasses and an overhead sign support structure. If shielding for both directions of travel is necessary and if the median is flat two means of protection are recommended. In the first case, Model 1E of the Puerto Rico Highway Authority, uses a CMB and crash cushions combinations to shield the object.

Figure 8—HH shows the second case. In this case a MB4S system or a MB5 (CMB) could be used to shield the hazard. When using the MB4S system, the dynamic deflection of the system should be less than the barrier-to-hazard distance. If the MB5 (CMB) is used (as in Model 1E of the Puerto Rico Highway Authority), the barrier can be placed adjacent to the hazard. The MB5 system should not be used when the distance from the edge of pavement to the hazard is greater than 15 feet.

8—15 UPGRADING SUBSTANDARD BARRIER SYSTEMS

Some existing median barriers are not necessary while others are substandard and will not meet suggested performance levels. Substandard barriers usually fall into one of two categories, namely, those that have structural inadequacies and those that are improperly located.

Figure 8—X of Section 8—09 presents an inspection procedure designed to identify unnecessary or substandard roadside barriers. The same inspection procedure should be followed for median barriers in a regularly scheduled basis. Personnel performing this inspection should stay abreast of current traffic barrier standards and guidelines included in this chapter, as well as promising new research findings.

With regard to strength and safey standards, the criteria presented in Section 8—11 should be used to evaluate existing systems.

If a barrier system is judged substandard, the barrier must be modified to conform to an operational system, or should be replaced by an operational system.

The criteria given in Section 8—14 should be used to take necessary corrective measures of the adequacy of the lateral placement of existing barriers. Steep flare rates for approach and transition sections should be flattenned to conform to the suggested criteria.

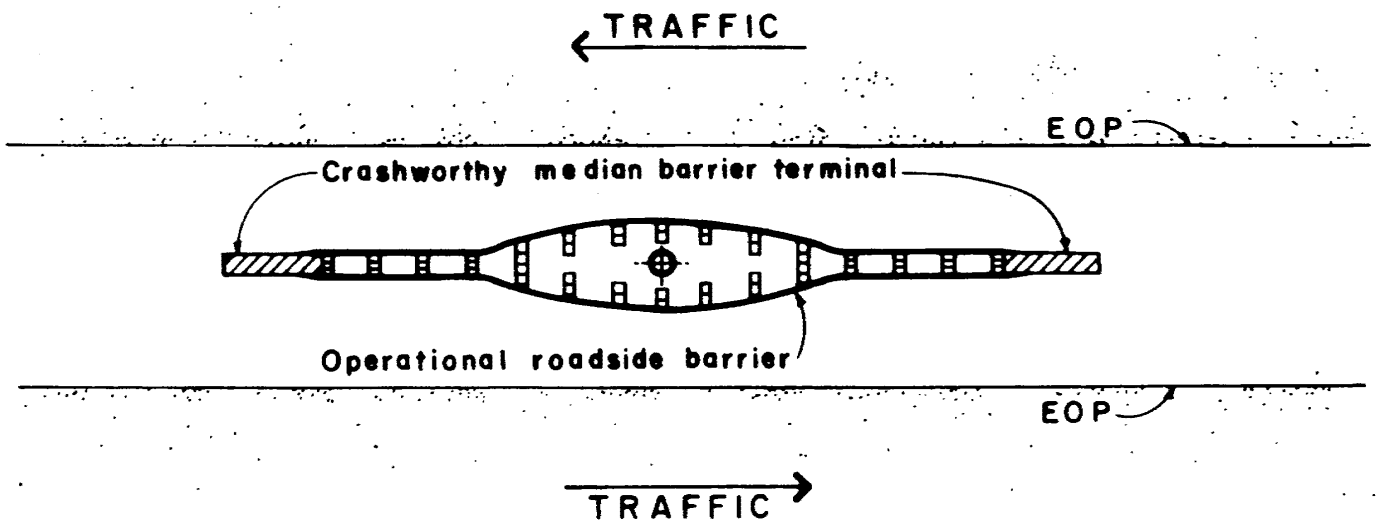
In some cases, the effective rail height will be decreased due to an accumulation of dirt, pavement overlays, etc. Dirt should be removed to return the barrier to its correct height. If necessary, and if the length and strength of the post and foundation permits, the rail can be raised to meet height standards. If not, taller posts with added strength and deeper embedment to accommodate the increased rail height, should be installed.

Maintenance personnel in routine maintenance and construction personnel in the final inspection of the barrier installation, can make sure that the posts are firmly embedded and that the rails are firmly attached to the posts.

The recommendations discussed so far in this chapter and that apply to the barrier system been standardized, should be followed to meet the upgraded safety conditions they are intended for.

8- 16 CRASH CUSHIONS

Crash cushions are protective systems which prevent errant vehicles from impacting hazards by either smoothly decelerating the vehicle to a stop when hit head-on, or by redirecting it away from the hazard for glancing impacts. These barriers are used to shield rigid objects or hazardous conditions that cannot be removed, relocated, or made breakaway. The relatively low cost and potentially high safety payoff offered by crash cushions justifies emphasis on their installation.



NOTE: Designer should also investigate use of crash cushion to shield hazard.

SUGGESTED LAYOUT FOR SHIELDING OF RIGID OBJECT IN MEDIAN.

FIGURE 8-HH

In following sections a delineation of criteria pertinent to the various elements of design, including warrants, structural and safety characteristics of operational systems, maintenance characteristics of operational systems, selection guidelines, and placement and site considerations, is presented.

Standard Model 1E, of the Puerto Rico Highway Authority give details of the Fitch Inertial Barrier System. This crash cushion barrier system, that will be discussed in section 8–16.5, is the most commonly used in Puerto Rico. Nevertheless, other crash cushion systems will be discussed. The user of this Manual should be aware of the advantages and disadvantages of the various systems in determining the final selection. He should also obtain, since most of the systems are patented, the standard installation layout details, design guides, and installation procedures from the manufacturers. This will entitle him to make the proper selection and installation.

8–16.1 WARRANTS FOR CRASH CUSHIONS

Crash cushions have proven to be a cost effective and safe means of shielding rigid objects. Their use is, therefore, warranted to shield rigid objects within the clear distance that cannot be removed or shielded by more cost-effective means. Studies indicate that crash cushions are considerable more cost effective than conventional longitudinal barriers in many instances.

The most common application of a crash cushion is in the ramp exit gore wherein practical design for the site calls for a bridge rail end in the gore. A crash cushion should, also, be considered for shielding rigid objects such as bridge piers, overhead sign supports, abutments, and retaining wall ends. It may, also, be used to shield roadside and median barrier terminals, specially, concrete median barriers.

A crash cushion or a vehicle arresting device may also be warranted at the end of a dead-end street or beyond a "T" intersection. Need should be based on an evaluation of the probability and consequence of an errant driver going beyond the intersection.

8–17 STRUCTURAL AND SAFETY CHARACTERISTICS OF CRASH CUSHIONS

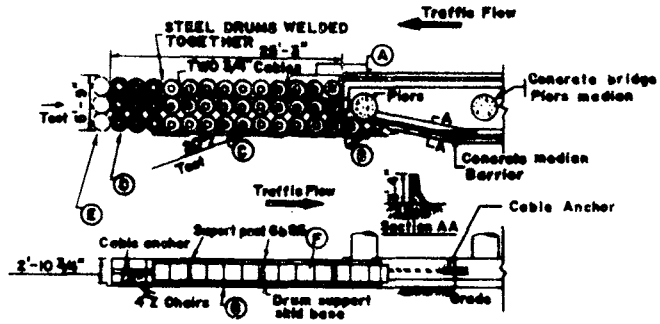
The following sections present the operational crash cushions and summarizes desirable structural and safety characteristics of a crash cushion. Also, discussed are the different crash cushion design concepts.

Shown in Tables 8–33 through 8–38 are the operational crash cushions. Information on each system consists of a sketch, a system designation, barrier description, impact performance, barrier damage, references, field performance data and remarks. It is noted that the particular configurations shown in each sketch represent the as-tested configurations and are not necessarily typical installations. Each system can be designed for a wide range of performance requirements.

None of the crash cushions have been standardized. It should be noted that all of the operational crash cushions are patented with the exception of the steel drum system.

8–17.1 SYSTEM C1, STEEL DRUMS

This system, see Table 8–33; sometimes referred to as the "Texas Barrels", dissipates the kinetic energy of the impacting vehicle primarily through the plastic deformation or crushing of the steel drums. The drums are restrained vertically and laterally by steel cables, but are free to move to the rear during impact. A rigid back-up structure (usually the rigid object being shielded) is necessary at the rear of the cushion. The drums are either bolted or welded together. As a consequence, there are no loose elements, fragments or other debris following an impact. It is desirable that the cushion be placed on a level concrete or asphalt pad to facilitate free movement of the U-bolt support chairs during impact.

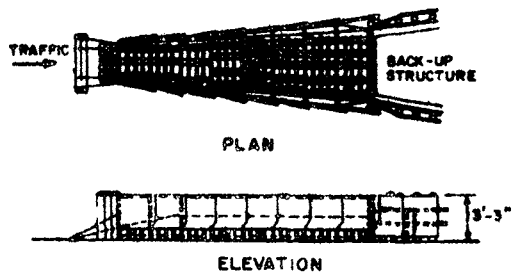
Metric Conversions 1 ft. = 0.305 m 1 in = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg		
SYSTEM	CI Steel Drums	
BARRIER DESCRIPTION	55 gallon light head drum arranged in modular clusters, fender panels or "fish scales" fastened to sides for side impact redirection. 3/4" cable used to secure drums for side impacts, "u" bolt chairs used to ensure uniform sliding of drums.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS Speed (mph) Angle Vehicle Weight (lb.)	55.8 0 1750	54.7 20 4150
BARRIER Dynamic Deflection (ft.)	11.3	1.25
VEHICLE ACCELERATIONS (g's) Lateral Longitudinal Total	UNAV 9.2[3] UNAV	4.0[4] 3.9[4] UNAV
VEHICLE TRAJECTORY Exit Angle (deg) Roll Angle (deg) Pitch Angle (deg)	NOAP 0 0	=20 =10 =5
BARRIER DAMAGE	Most of cushion damaged	Moderate barrier damage
REFERENCES	42	42
FIELD PERFORMANCE DATA[2]	YES	
REMARKS	Good performance at head-on and side impacts. Recent accident surveys indicate that elimination of the fender panels may be desirable (see text). Other, less sophisticated, designs with side panels have also been used with good results.	

UNAV – unavailable
[1] 50 millisecond average unless otherwise noted
[2] If available, see summary in Appendix (AASHTO Barrier Guide)
[3] Averaged over 0.257 sec.
[4] Averaged over 0.27 sec.

-LEGEND-
A-Three rows of 18-GA drums with 8" dia. holes (T & B)
B-16-GA. Corrugated pipes segments
C-55-GAL. steel drums with 8" dia. holes (T & B) (20-Gal. steel)
D-55-GAL. steel drums with twelve 3" dia. holes (T & B) (20-Gal. steel)
E-Additional row of drums used in head on test
F-2x4' Plywood redirectional panels
G-Smooth hard surface (concrete or min. 1" asphalt)

OPERATIONAL CRASH CUSHION SYSTEMS, A

TABLE 8-33

Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr. 1 lb. = 0.454 kg		
SYSTEM	C2 Hi-Dro Cell Sandwich	
BARRIER DESCRIPTION	6" diameter, polyvinyl chloride plastic cells filled with water. Fender panels (fish scales) are provided for redirection.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS Speed (mph) Angle (deg) Vehicle Weight (lb.)	 61.8 0 4690	 57.0 9.0 4790
BARRIER Deceleration Distance (ft.)	 18.0	 UNAV
VEHICLE ACCELERATIONS (g's)[1] Lateral Longitudinal Total	 UNAV 9.8 UNAV	 5.2 5.4 UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)	 NOAP 0 less than 10	 less than 10 0 0
BARRIER DAMAGE	Slight permanent damage	Several fender panels and 5 cells
REFERENCES	43	43
FIELD PERFORMANCE DATA[2]	YES	
REMARKS	Barrier performs well for head-on and side impacts.	

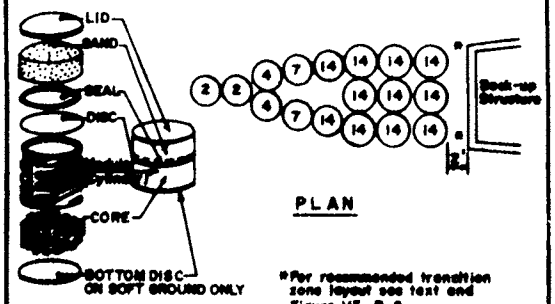
UNAV - unavailable, NOAP - not applicable

[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in appendix A (AASHTO Barrier Guide)

OPERATIONAL CRASH CUSHION SYSTEMS, B

TABLE 8-34

Metric Conversions 1 ft = 0.305m 1 in = 25.4mm 1 mph = 1.61km/hr 1 lb = 0.454kg		
SYSTEM	C3 Fitch Inertial Barrier	
BARRIER DESCRIPTION	Specially manufactured plastic containers (36" in diameter and height) filled with sand. Standard weights are 200, 400, 700, 1400 and 2100 lb. Volume and density of sand may vary.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS Speed (mph) Angle (deg) Vehicle Weight (lb.)	 59.0 0 1940	 57.0 15 4770
BARRIER Deceleration Distance (ft.)	19.0	UNAV
VEHICLE ACCELERATIONS[1] (G's) Lateral Longitudinal Total	 UNAV 8.7 UNAV	 UNAV 7.9 UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)	 NOAP 0 15	 No redirection 0 ≈10
BARRIER DAMAGE	14 of 17 barrels either damaged or destroyed	15 of 17 barrels were either damaged or destroyed
REFERENCES	44	44
FIELD PERFORMANCE DATA[2]	YES	
REMARKS	Good performance for head-on impact tests. No redirection capabilities with this type of barrier.	

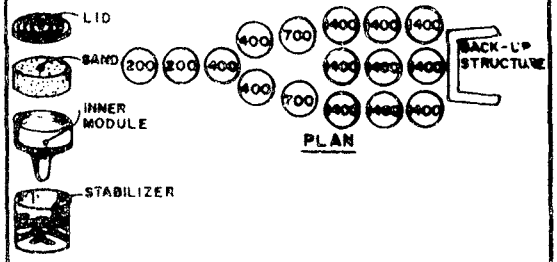
UNAV - unavailable, NOAP - not applicable

[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

OPERATIONAL CRASH CUSHION SYSTEMS, C

TABLE 8-35

Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg		
SYSTEM	C4 Energite Inertial Barrier	
BARRIER DESCRIPTION	Specialty manufactured plastic containers filled with sand. Standard size of container is 26" diameter top, 32" diameter base and 28 3/4" height. Standard weights of modules are 200, 400, 700 and 1400 lb.	
IMPACT PERFORMANCE	**HEAD ON IMPACT**	**SIDE IMPACT**
IMPACT CONDITIONS Speed (mph) Angle (deg.) Vehicle Weight (lb.)	59.4 0 4490	59.3 10 4430
BARRIER Deceleration Distance (ft.)	36.0	46.0
VEHICLE ACCELERATIONS[1] Lateral Longitudinal Total	UNAV 3.35 UNAV	6.0[3] 3.0[3] UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)	NOAP less than 10 less than 10	No redirection 0 0
BARRIER DAMAGE	All barrels were damaged extensively	All barrels were damaged extensively
REFERENCES	46	46
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	Good performance for head-on impact tests. No redirection capabilities with this type of barrier.	

UNAV - unavailable, NOAP - not applicable

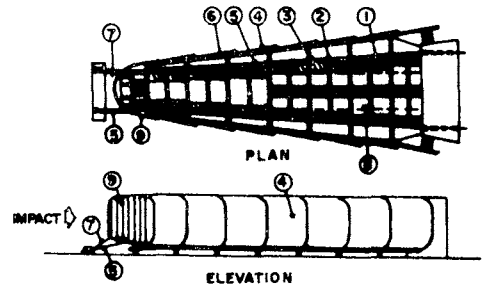
[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

[3] Deceleration calculated from stopping distance

OPERATIONAL CRASH CUSHION SYSTEMS, D

TABLE 8-36

Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg	 -LEGEND- 1 HELICELL CARTRIDGE 4 FENDER PANELS 7 SECONDARY CABLES 2 DIAPHRAMS(CARTRIDGE) 5 RESTRAINING CABLES 8 SLIDE STRAPS 3 DIAPHRAMS (UNIT) 6 PULL OUT CABLES 9 BELTING	
SYSTEM	CS Hi-Dri Cell Sandwich	
BARRIER DESCRIPTION	Hell-cell cartridges are arranged in a cluster along with fender panels (fish scales) to provide capabilities for head-on and side impacts.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	56.0	60.0
Angle (deg.)	0	20
Vehicle Weight (lb.)	3700	4000
BARRIER		
Deceleration Distance (ft.)	14.5	UNAV
VEHICLE ACCELERATIONS (g's)[1]		
Lateral	UNAV	4.5[3]
Longitudinal	7.2[3]	4.0[3]
Total	UNAV	UNAV
VEHICLE TRAJECTORY		
Exit Angle (deg.)	NOAP	9
Roll Angle (deg.)	0	UNAV
Pitch Angle (deg.)	UNAV	UNAV
BARRIER DAMAGE	UNAV	UNAV
REFERENCES	46	47
FIELD PERFORMANCE DATA[2]	YES	
REMARKS	Barrier performs well for head-on and side impacts.	

UNAV - unavailable, NOAP - not applicable

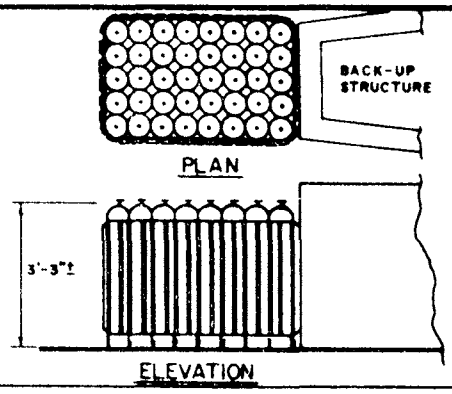
[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

[3] Acceleration calculated from stopping distance

OPERATIONAL CRASH CUSHION SYSTEMS, E

TABLE 8-37

Metric Conversions 1 ft = 0.305m 1 in = 25.4mm 1 mph = 1.61 km/hr 1 lb = 0.454 kg	
SYSTEM	CS Hi-Dro Cell Cluster
BARRIER DESCRIPTION	6" diameter, polyvinyl chloride plastic cells arranged in a cluster and filled with water.

IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS Speed (mph) Angle (deg) Vehicle Weight (lb.) BARRIER Deceleration Distance (ft.) VEHICLE ACCELERATIONS (G's)[1] Lateral Longitudinal Total VEHICLE TRAJECTORY Exit Angle (deg) Roll Angle (deg) Pitch Angle (deg)	NO TEST	NO TEST
BARRIER DAMAGE		
REFERENCES		
FIELD PERFORMANCE DATA[2]	YES	
REMARKS	This system is considered operational for speeds less than 45 mph based on tests of the C2 system. It should be used at hazards with limited space available for barrier protection and low vehicle speeds	

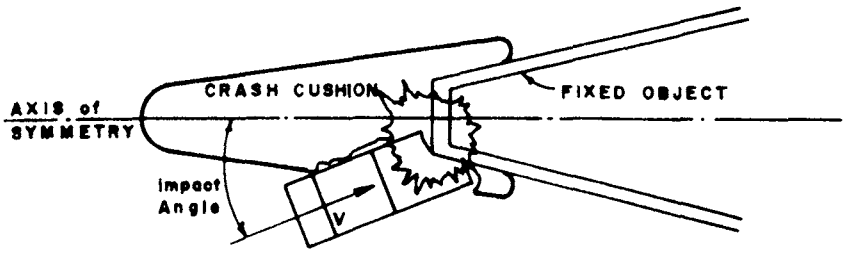
UNAV – unavailable

[1] 50 millisecond average unless otherwise noted

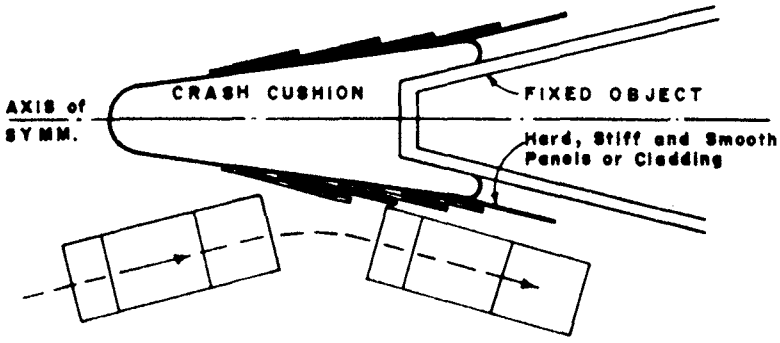
[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

OPERATIONAL CRASH CUSHION SYSTEMS, F

TABLE 8-38



(a) Potential impact with fixed object without redirection panels.



(b) Redirection with side panels.

ILLUSTRATION OF SIDE IMPACTS TRANSITION ZONES.

FIGURE 8-JJ

The cushion is composed of 55 gallon, 20 gauge steel tight-head drums. Each drum has an 8 inch diameter hole centered in the top and bottom. A "softer nose" is archieved by placing drums with 12 3 inch diameter holes around the periphery of the top and bottom, at the front of the cushion (as shown in Table 8 33).

The C1 system can be designed to meet the recommended dynamic performance criteria with regard to direct-on and side-angle impacts for a wide range of design conditions. The user of this Manual should obtain further design aids for this system in Appendix D of the, "Guide for Selecting, Locating and Designing Traffic Barriers", AASHTO 1977; and in the publication, "Crash Cushions Selection and Design Criteria", Office of Engineering, FHWA, Washington D.C., 1975.

The steel drum system is one of three operational systems designed to redirect a vehicle if hit from the side, i.e., for side impacts it functions essentially as a longitudinal barrier. This is illustrated in Figure 8 JJ. Impact in the "transition zone" can result in an impact with the fixed object if redirection panels are not provided.

8 17.2 SYSTEM C2, HI–DRO CELL SANDWICH

This system dissipates the kinetic energy of the impacting vehicle by the discharge of water from plastic filled tubes through orifices in the tube, and by the transfer of momentum (movement of the water mass). It is a patented device and is manufactured and distributed by Energy Absortion Systems, Inc. Standard installations, detailed design guides and installation procedures should be obtained from them

The system is composed of 6 inch diameter, 42 inch polyvinil plastic cells filled with water (see Table 8 34). These cells are arranged in cluster or bays to make up the cushion for a given set of design conditions. A rigid back-up structure (usually the rigid object to be shielded) is necessary at the rear of the cushion. The cells are restrained vertically and laterally by steel cables, but are free to move to the rear during impact. As a consequence, there are no loose elements, fragments, or other debris following an impact. However, there will be water on the pavement. The cushion should be placed on a level concrete or asphalt pad to facilitate is movement during impact.

Energy dissipation with this crash cushion system is a complex interaction of events since several things are happening at varying rates during impact. The three most predominant things are:

1. Fluid is being forced up through orificies at varying pressure.
2. The mass of the cushion is being moved at varying velocities and accelerations.
3. The mass of the system changes as it is compressed because of the loss of fluid.

Some energy is also dissipated as the cushion slides along the supporting surface and as the different parts of the system are deformed.

The Hi-Dro cell system is the second of three operational systems designed to redirect a vehicle if hit from the side, i.e., for side impacts it functions essentially as a longitudinal barrier. This is illustrated in Figure 8 HH. Impact in the "transition zone" can result in an impact with the fixed object if redirection panels are not provided.

8 17.3 SYSTEMS C3 AND C4, SAND FILLED PLASTIC BARRELS

These systems dissipate the kinetic energy of the impacting vehicle by a transfer of the vehicle's momentum to the mass of the cushion. Both systems consist of an array of plastic containers filled with varying weights of sand.

The C3 system is patented and is manufactured and distributed by FIBCO, Inc. The C4 system is also patented and is manufactured and distributed by Energy Absortion Systems, Inc.

Although the two systems differ in the container details, both function essentially the same. Standard installation details, design guides and installation procedures should be obtained from the manufacturers. The user of this Manual should consult with the manufacturer to determine availability of designs and to insure proper selection and installation.

In Standard Model 1E, of the Puerto Rico Highway Authority, the FIBCO System is used in two applications. These are: to shield bridge piers at underpasses and to protect end sections in Concrete Median Barriers.

A back-up device is not required for either system since the force that the vehicle exerts on the crash cushion units is not transmitted through the cushion. Also, note that neither crash cushion system is designed to redirect vehicles upon side-on impacts. Careful consideration must, therefore, be given to the placement of the units in the transition zone between the barrier and the fixed object. Figure 8—KK shows a layout for the last three exterior modules in an inertial barrier.

Both of the systems (C_3 and C_4) generate debris upon impact, consisting of sand and remnants of the plastic barrels. However, there is not documented evidence that these characteristics is a significant deficiency in inertial barriers.

Design aids and examples of the application of these systems are given in Appendix D of the Guide. The user of this Manual should also refer to the publication, "Crash Cushions-- Selection an Design Criteria", published by Office of Engineering, FHWA, 1975.

Standard sizes and weights of available modules are given in the "barrier description" on Tables 8—35 and 8—36. Sand heights and center of gravity data of modules are given in Table 8—39.

The width of the back row of modules should always be greater than the width of the fixed objects. This will soften the impacts of those vehicles striking the rear portion of the barrier at an angle and provide some deceleration prior to striking the fixed object. Space should be left behind the last row of modules so the sand and debris will not be confined and produce a ramp effect in the vehicle. This space should be two feet.

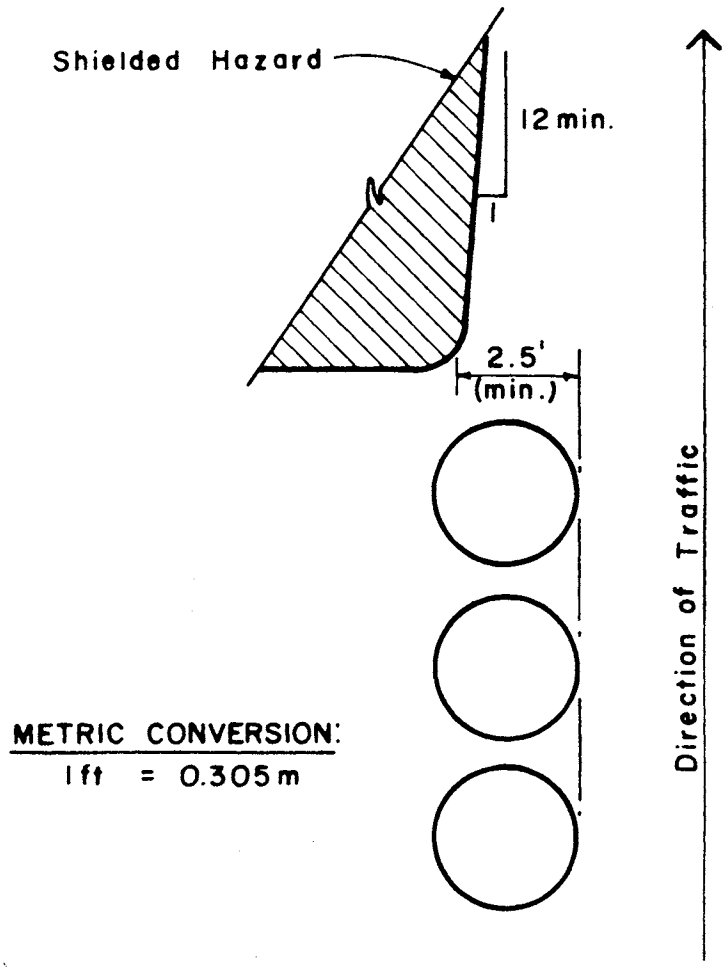
8—17.4 SYSTEM C5, HI-DRI CELL SANDWICH

This system dissipates the kinetic energy of the impacting vehicle through the crush of the lightweight concrete components and through the transfer of momentum (movement of the cushion mass). It is a patented device, manufactured and distributed by Energy Absorption Systems, Inc. Standard installation procedures are available from the manufacturers. The user of this Manual should consult with the manufacturer to determine availability of designs, appropiate selections, and installation procedures.

The energy absorbing elements of this system are 7 inch diameter cylindrical cells made of lightweight concrete. The cell has a hole in its center and steel wire wound around the outside. Each cell is wrapped with a weatherproof covering to keep water out and to prevent pieces of concrete from being scattered about during impact.

The Hi-Dri cells are installed in bays similar to the Hi-Dro cell bays as discussed in Section 8—16.4. Side panels, diaphragms, cables, and some of the hardware are the same as used in the Hi-Dro cell sandwich crash cushion. This is the third operational system designed to redirect a vehicle if hit from the side. Redirection is archieved through the fender panels attached to the side of the barrier. This is illustrated in Figure 8—HH. It generates minimal debris upon impact. A rigid back-up structure (usually the rigid object being shielded) is required at the rear of the cushion.

Upon impact, the lightweight concrete cell crush. The void in the center of the cell fills with concrete pieces as the cell is compressed. Then the concrete is forced outward between the



METRIC CONVERSION:
1 ft = 0.305 m

SUGGESTED LAYOUT FOR LAST THREE EXTERIOR MODULES IN AN INERTIAL BARRIER.

FIGURE 8-KK

steel wires. This action converts the kinetic energy of the impacting vehicle into work. Simultaneously, other actions are taking place that absorb the kinetic energy of the impacting vehicle. These are:

1. The mass of the crash cushion is being moved.
2. The crash cushion parts are being dragged along the pavement surface.
3. The parts of the crash cushion are being physically deformed.

This system has been extensively tested and a mathematical model has been developed enabling the manufacturer to develop standard bay arrangements which will suit most typical crash cushion requirements.

8—17.5 SYSTEM C6, HI-DRO CELL CLUSTER

This system functions along the same principle as the Hi-Dro cell sandwich cushion discussed in Section 8—16.4. It is also a patented device and is manufactured and distributed by Energy Absortion, Inc. Standard installation procedures are available from the manufacturer. The user of this Manual should consult the manufacturer to determine availability of designs, appropiate selections, and installation procedures.

Its application is limited to roadways with design speeds of 45 mph or less. It can be used where there are space limitations and it can be arranged in various patterns to fit the object to be protected. Typical applications are to shield gore walls, bridge abutments, traffic control devices, toll booths, etc.

A back-up structure is required at the rear of the cushion. It has minimal redirection capabilities when impacted from the side. There is no debris, with the exception of water, produced upon impact.

Design aids for this system are included in Appendix D of the Guide.

8—17.6 SUMMARY OF CRASH CUSHIONS

All of the operational crash cushions, with the exception of the Hi-Dro cell cluster, can be designed to satisfy the recommended head-on impact performance criteria of Table 8—40 for a wide range of design conditions. The Hi-Dro cell cluster cushion is limited to roadways with a design speed of 45 mph or less. Table 8—41 summarizes the structural and safety characteristics of the operational systems.

There are several promising crash cushion systems which at present are not considered operational. Reference should be made to Appendix B of the Guide for a summary of these systems.

Although, the Fitch Inertial Barrier System is the most commonly used crash cushion barrier in Puerto Rico, the user of this Manual should be aware of the advantage of other systems for specific situations. These will be advantageous in the proper selection and installation of a crash cushion barrier.

In following sections other characteristics of the crash cushion systems are presented to aid the designer in the selection of the proper system.

8—18 MAINTENANCE CHARACTERISTICS OF CRASH CUSHIONS

Since all the operational systems can be designed to meet the recommended impact performance criteria for a wide range of design conditions, the maintenance characteristics of the barriers can and should play a very important role in the selection process. To aid the user of this Manual, an attempt has been made to summarize the pertinent maintenance characteristics of each crash cushion. The data is presented in Tables 8—41 and 8—42. The data in the tables was obtained from state maintenance records where available. However, as can be seen,

TABLE 8-39 – CENTER OF GRAVITY DATA FOR INERTIAL SYSTEM MODULES

Module Weigth (1b)	FITCH INERTIAL SYSTEM			ENERGITE INERTIAL SYSTEM		
	Core Height (in.)	Sand Depth (in.)	Height of Center of Gravity (in.)	Wine Glass Core*	Sand Depth (in.)	Height of Center of Gravity (in.)
200	20.5	3.5	22.5	A	28.0	24.0
400	20.5	7.0	24.5	A	31.5	26.0
700	16.5	12.0	23.0	B	32.5	24.5
1,400	11.5	24.0	24.0	C	36.0	22.0
2,100	0	36.0	18.0	None**	36.0	18.0

* Energite designations

** Special container

METRIC CONVERSIONS: 1 in. = 0.0254 m
1 1b = 0.454 kg

TABLE 8-40 – DYNAMIC PERFORMANCE CRITERIA FOR TRAFFIC BARRIERS

Dynamic Performance Factors	Evaluation Criteria	Applicable Criteria		
		Longitudinal Barriers		Crash Cushions
		Standard Sections and Transitions	Terminal	
I. Structural	A. The test article shall redirect the vehicle; hence, the vehicle shall not penetrate or vault over the installation.	XXX		
	B. The test article shall no pocket or snag the vehicle causing abrupt deceleration or spinout or shall no cause the vehicle to rollover. The vehicle shall remain upright during and after impact although moderate roll and pitching is acceptable. there shall be no loose elements, fragments or other debris that could penetrate the passenger compartment or present undue hazard to other traffic.	XXX	XXX	XXX
	C. Acceptable test article performance may be by redirection, containment, or controlled penetration by the vehicle.		XXX	XXX
	D. The terminal shall develop tensile and/or flexural strength of the standard section.		XXX	
II. Impact Severity	A. Where test article functions by re-directing vehicle, maximum vehicle acceleration (50 msec avg) measured near the center of mass should be less that the following values: Maximum Vehicle Accelerations (g's) Lat. / Long. / Total / Remarks 3 / 5 / 6 / Preferred 5 / 10 / 12 / Acceptable These rigid body accelerations apply to impact tests at 15 deg, or less.	XXX	XXX	XXX
	B. For direct impacts of test article, where vehicle is decelerate to a stop and where lateral accelerations are minimum, the maximum average permissible vehicle deceleration is 12 g as calculated from vehicle impact speed and passenger compartment stopping distance.		XXX	XXX
III. Vehicle Trajectory Hazard	A. After impact, the vehicle trajectory and final stopping position shall intrude a minimum distance into adjacent traffic lanes.	XXX	XXX	XXX
	B. Vehicle trajectory behing the terminal is acceptable.		XXX	

TABLE 8-41 – SUMMARY OF STRUCTURAL AND SAFETY CHARACTERISTICS OF CRASH CUSHIONS

Item	Steel Drums (C1)	Hi-Dro Cell Sandwich (C2)	Fitch Inertial (C3)	Energite Inertial (C4)	Hi-Dri Cell Sandwich (C5)	Hi-Dro Cell Cluster (C6)
1. Tolerable accelerations?	Yes[1]	Yes[1]	Yes[1]	Yes[1]	Yes[1]	Yes[2]
2. Redirection capabilities?	Yes	Yes	No	No	Yes	No
3. Back-up structure required?	Yes	Yes	No	No	Yes	Yes
4. Debris produced upon impact?	No	No[3]	Yes	Yes	No	No[3]
5. Anchorage required?	Yes	Yes	No	No	Yes	Yes

[1] For any reasonable design speed.

[2] For a speed of 45 mph (72.4k/h) or less.

[3] Except water. Water on the roadway can increase the potential for accidents by reducing skid resistance of pavement.

some of the data is based in subjective evaluations. Figures given in the tables are based on average values of several agencies in the states, and not from values of Puerto Rico. This values should be used as "indicators", and values obtained from maintenance operations in Puerto Rico used whenever possible. The three major categories given in the tables are discussed below.

8—18.01 COLLISION MAINTENANCE FOR CRASH CUSHIONS

Special consideration should be given to this phase of crash cushion maintenance since it will require the most effort and expenditure. Careful evaluation of items I—A, I—C, and I—F in Table 8—41 should be performed since these items have a large influence on the maintenance costs. Item I—F is also, significant in terms of the hazard the maintenance crew is subjected to while repairing the barrier and the disruption of normal traffic flow.

When a particular site has a relatively high frequency of accidents, consideration should be given to the installation of a reusable crash cushion. Hardware in the Hi-Dro cell (C2) and the Hi-Dri cell (C5) sandwich systems is reusable for many impact conditions (head-on impacts by automobiles traveling at 60 mph or less). Of course, water must be added to the C2 system and the damaged cartridges must be replaced in the C5 system. A cushion with redirection panels may be appropiate for sites with a high frequency of brush hits (or nuisance hits), or where the potential for such hits exists.

8—18.02 REGULAR MAINTENANCE OF CRASH CUSHIONS

In general, the operational systems require relatively little regular or routine maintenance. However, periodic maintenance checks should be performed to accomplish the appropiate checks outlined in Requirements II—A of Table 8—42. Several instances of vandalism have been reported with the sand inertial barriers. It is more prevalent where pedestrians have access to the roadside. Item II—A—5 is a particularly critical item for the Hi-Dro systems (particularly in areas where large evaporation occurs due to climatological conditions). For minor impacts, the Hi-Dro cell cluster system and the nose of the Hi-Dro cell sandwich system can return to its original position and thus appear outwardly that it had not been hit. However, with each impact, water can be lost, thereby diminishing its crash attenuating capabilities for the next hit. Checks should, also, be made to determine if leaks have occurred. Damages to any of the systems which diminish their original attenuating capabilities should be repaired immediately.

8—18.03 MATERIAL STORAGE FOR CRASH CUSHIONS

It will be necessary to store a certain amount of hardware and supplies for each of the operational systems. The point to be emphasized is that a sufficient stockpile of parts must be maintained to avoid delays in restoring a damaged barrier. Availability of parts and delivery times should be considered before selecting a system.

In summary, the criteria in Tables 8—41 and 8—42 should be used as guidelines in evaluating the maintenance characteristics of the operational crash cushions.

8—19 SITE CONSIDERATIONS IN INSTALLING CRASH CUSHIONS

Following is a discussion on the considerations to be followed for the considerations to be followed for the selection and installation of crash cushions in different sites. This will aid the user of this Manual in the design of crash cushion system in new locations and in corrective measures to existing locations.

8—19.01 CRASH CUSHION INSTALLATION IN NEW ROADWAYS

It is recommended that space be reserved on all new construction for potential crash cushion installation. This recommendation is presented in Table 8—43. Under the "minimum" column, the "restricted conditions" represent the absolute minimums and should only be

TABLE 8-42 -- MAINTENANCE CHARACTERISTICS OF OPERATIONAL CRASH CUSHIONS

Maintenance Requirement	Steel Barrel Cushion	Hi-Dro Cushion	Fitch Barrier	Energite System	Hi-Dri Cell
I. Collision Maintenance					
A. Manpower and Equipment					
1. Crew Size	6 men	4 men[5]	5 men	4 men[5]	4 men[5]
2. Expertise required	welding[4]	hardware training	very little	very little	hardware training
3. Special equipment	flat-bed truck, welding equipment	water truck, maintenance truck, pick-up	loader, maintenance truck	loader, maintenance truck	pick-up
B. Collision after math					
1. Inmediate removal of scattered debris, water, anti-freeze-needed?	no	yes, anti-freeze[1]	yes, sand and plastic	yes, sand and plastic	no
2. Inmediate problem created?	no	yes[2]	yes, debris	yes, debris	no
3. Lane closure necessary	yes, to repair	yes, to repair	yes, clean and repair	yes, clean and repair	yes, to repair
C. Restoration					
1. Overall difficulty	above average	average[3]	average	average	average[3]
2. Any salvageable hardware?	yes	usually	very little	very little	usually
3. Energy absorption unit reusable?	usually not	usually	no	no	no
D. Considerable maintenance due to the nuisance hit?	no	no	yes	yes	no
E. Disposal of debris a problem?	yes	no	very little	very little	very little
F. Average exposure time per hit (man-hour)	34	8[5]	10	8[5]	4[5]

[1] certain types of anti-freeze.
[2] only if "oil slick" develops from anti-freeze or water freezes.
[3] "average", assuming most of hardware reusable.
[4] Bolt-on fastening devices, which eliminate the need for welding, are available.
[5] Based on data from manufacturer's representative.

TABLE 8-42 – (Continued)–

Maintenance Requirement	Steel Barrel Cushion	Hy-Dro Cushion	Fitch Barrier	Energite System	Hy-Dri Cell
II. Regular Maintenance					
A. General Condition checks					
1. Cushion in position?	no	no	yes	yes	no
2. Vandalism damage?	no	yes	yes	yes	no
3. Hardware and cables intact?	yes	yes	no	no	yes
4. nuisance hit?	yes	yes	yes	yes	yes
5. Water level and antifreeze quantity adequate?	no	yes	no	no	no
B. Painting, cleaning, and other treatments to assure adequate appearance/performance needed?	yes, paint and clean	yes, paint and clean	yes, clean	yes, clean	yes, paint and clean
C. Weathering/corrosion problem due to environmental/chemical effects?	yes, salt corosion may be a problem	yes	yes	yes	UNAV
III. Material Storage and/or Availability Requirements					
A. Dry sand stock pile necessary?	no	no	yes	yes	no
B. Modules/barrels for replacement?	yes, 55 gallon drums	yes, cells enough to replace damaged	yes, Fitch or Energite Modules	yes, Energity or Fitch Modules	yes, vermiculite cell replacement
C. Water supply and anti-freeze?	no	yes	no	no	no
D. Hardware and connections for assembly?	yes	yes	no	no	yes
E. Paint and/or aesthetic coverings for appearance /performance?	if desired	if desired	if desired	if desired	if desired

considered where there are extremely tight geometric controls. The "unrestricted conditions" represents the minimum for all projects except for those sites where it can be shown that the increased cost for accommodating this dimension, as opposed to those for restricted conditions, will be unreasonable. The "preferred" values should be considered optimum. There is no implication that if space is provided in accordance with these dimensions that the space will be fully occupied by a crash cushion device. The reason for proposing these dimensions is so that if experience shows that devices should be designed for greater ranges of vehicle weights and/or for lower deceleration forces there will be space available for installation of such devices in the future. In the meantime, the unoccupied reserve crash cushion space will provide valuable additional recovery area.

The use of crash cushions, at the design stage of new projects, should also be considered at other locations. These would be hazardous sites that could not be avoided in the project. Examples are bridge piers, overhead sign supports, and other non-avoidable rigid objects. These sites should be designed to facilitate the installation of a crash cushion.

8—19.02 SELECTION OF CRASH CUSHIONS FOR EXISTING ROADWAYS

The selection of a crash cushion for some existing roadways may be dictated by site conditions. The following factors should be considered in the selection.

1. Dimensions of object or hazard to be shielded — The width of object or hazard is an important factor. While the C1, C2, and C5 crash cushions can be designed for a range of object widths, they are not normally used to shield relatively wide objects. The C1 is usually limited to widths of 12 feet, and the C2 and C5 systems are usually limited to widths of 7.5 feet. Inertial barriers (C3 and C4) are more adaptable to the wider objects.

2. Structural details of object to be shielded — Systems C1, C2, C5, and C6 require a back-up structure that is capable of withstanding the impact forces. If the object to be shielded is structurally inadequate, provisions will have to be made to support or restrain the barrier during impact if these systems are used. Site preparations on existing structures can be extensive. This usually involves removing a concrete gore nose. In some instances, bridge railing ends are revised and a concrete wall or backstop is built. A backstop or secondary barrier is needed for inertial crash cushions where the vehicle could penetrate the cushion and plunge down a slope.

3. Space available for crash cushion — Two dimensions must be considered with regard to the available space. They are the length ("L" in Figure 8—LL) over which the barrier can be placed, and the distance on either side of the barrier to the hazard ("F" in Figure 8—KK). When length is an important design consideration, the space efficiency of a barrier throughout the design vehicle speed and weight range will be important. The steel drum system (C1) is the least space efficient. The other systems have mixed advantages and deficiencies in this respect.

As shown in Figure 8—JJ, the minimum distance "F" for inertial crush cushions (C3 and C4) is 2.5 feet. Where this cannot be accomplished, a cushion with redirectional capabilities should be considered (C1, C2 and C5). Care must be exercised, however, when the fendering systems to insure that a structurally adequate transition is used between the cushion and the object it shields. Snag points are not acceptable. If the cushion requires special anchorage, it will have to be provided in the available space.

4. Physical conditions of the available space — The following site conditions should be considered:

a. The presence of a curb which could affect the performance of the crash cushion.
b. The existing surface material and condition thereof.
c. The longitudinal and transverse slope of the crash cushion area.
d. Expected temperatures and climatological conditions since some of the systems are sensitive to them.

TABLE 8-43 – RESERVE AREA FOR GORES

Design Speed on Mainline (m.p.h.)	Dimensions for Crash Cushion Reserve Area (Feet)								
	Minimum						Preferred		
	Restricted Conditions			Unrestricted Conditions					
	N	L	F	N	L	F	N	L	F
30	6	8	2	8	11	3	12	17	4
50	6	17	2	8	25	3	12	33	4
70	6	28	2	8	45	3	12	55	4
80	6	35	2	8	55	3	12	70	4

Metric Conversions:

1 ft. = .305 m

1 mph = 1.609 km/hr

e. High wind and/or abnormal conditions.

f. The existence of construction or expansion joints in the crash cushion area.

Reference should be made to Section 8—20 for more discussion of items "a" and "c". With regard to item "b", it is desirable that all systems be placed on a concrete or asphalt surface, but it is essential for the steel drums (C1), Hi-Dro cell sandwich (C-2), and the Hi-Dri cell sandwich (C5). This permits the systems to slide back with uniform response during an impact. In the case of the inertial crash cushions (C3 and C4), the paved surface provides uniform support for the modules. In addition it provides a surface on which the pattern and weights of the modules can be marked. This help maintenance forces in subsequent restorations after impacts. The following comments are offered with regard to items "d" and "e":

1. When the Hi-Dro cell sandwich and cluster crash cushion is installed where extremely hot weather is prevalent, extra consideration of water loss due to evaporation is needed. A thin layer of mineral oil on top of the water will provide added protection against evaporation loss.

2. Some models of the sand filled barrels deteriorate when subjected to vibration such as occur on bridges. High winds might contribute to this problem or cause crash debris control and cleanup problems.

With regard to item "f", special design accomodations may be necessary for those systems that require anchorage.

8- 20 CRASH CUSHIONS SELECTION GUIDELINES

The number and complexity of factors which enter the selection process for crash cushions prelude the development of a simple selection procedure. Each operational system has its own unique physical and functional characteristics. In some cases, one crash cushion will stand out as the most appropiate, while in other cases two or more crash cushions may be considered essentially equal in performance. Listed and discussed below are factors which should be evaluated before marking a selection. The factors should be evaluated in the order given, although they are not necessarily listed in order of importance.

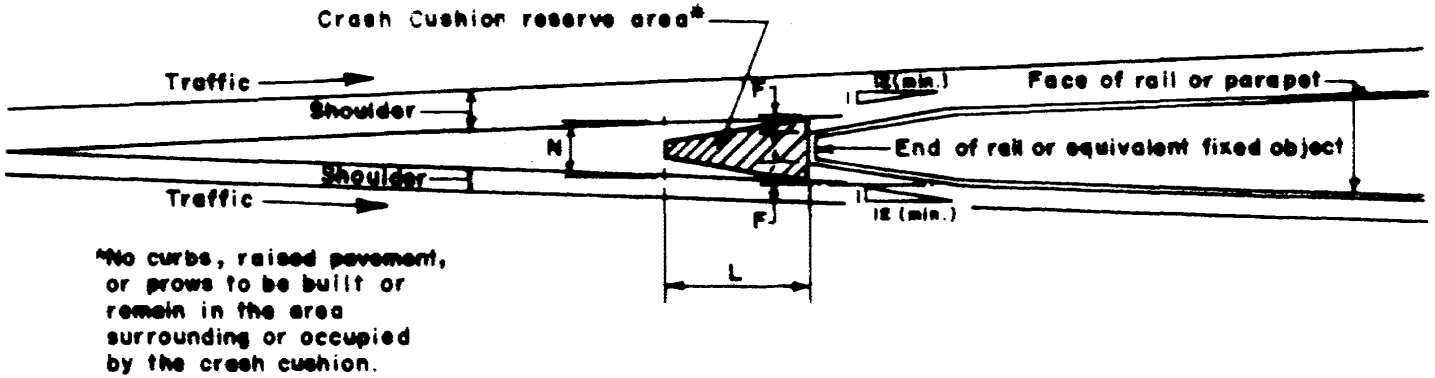
It is assumed, that a crash cushion is warranted and that a selection must be made.

1. Site considerations — The first item to be evaluated is the site conditions. Factors to evaluate include dimension of object being shielded, structural characteristics of object to be shielded, available space for cushion, and physical conditions of site. Reference should be made to Section 8—19 for a discussion of all the factors related there to. In many cases, the site conditions will establish the type of barrier needed.

2. Structural and safety characteristics of candidate systems — If more than one system can be used, the designer should carefully evaluate the structural and safety characteristics of each candidate system. These include factors such as impact decelerations, redirection capabilities, anchorage requirements, debris produced by impact, and back-up structure requirements. The most crashworthy system should be installed. Reference should be made to Section 8—17 for a discussion of the structural and safety characteristics of operational systems. Table 8—44 through 8—46 summarizes crash cushion accident data. These tables should be used with discretion since this data is from various states and not from Puerto Rico. There are wide geographic and time variations in unit costs of labor and material.

3. Maintenance characteristics and aesthetic appeal — Not too infrequently the most appropiate barrier will still not be evident after evaluating items 1 and 2 above. The maintenance characteristics of each barrier may therefore play an important role in the selection.Section 8—18 identifies the pertinent facts and provides guidelines to aid in evaluating the maintenance and aesthetic characteristics of the operational systems.

4. Cost - Limited cost data has indicated that some crash cushions are more expensive than others. This variation in cost can readily be seen in the components in which go to make



*No curbs, raised pavement, or prows to be built or remain in the area surrounding or occupied by the crash cushion.

RESERVE AREA FOR GORES.

FIGURE 8-LL

up the systems and the installation effort required. The designer should, if other design factors for the site under consideration have not indicated the one best crash cushion, employ engineering economics so as to arrive at the least expensive system over the estimated life of the system. The economic factors to be considered are initial cost, maintenance costs, vehicle damage and occupant injury costs, time value of money, life of the system, and salvage value. A procedure is included in Chapter VII of the Guide that can be used to evaluate these factors. The user of this Manual should refere to that procedure.

Table 8—47 shows initial cost indications based on a very few installations. Reference should be made to Section 8—18 and Tables 8—41 and 8—42 to aid in estimating maintenance costs and salvage value. All of the approved systems will produce damage to impacting vehicles whether hit on the nose or on the side. Experience does not indicate that one system is better than the other in this respect. Naturally, the higher the impact speed, the higher the degree of damage. Field experience has shown that most vehicles which impact crash cushions are driven away.

8—21 CRASH CUSHIONS PLACEMENT RECOMMENDATIONS

It must be recognized that all of the crash cushions were designed and tested for relatively level terrain conditions. Adverse and unacceptable performance can be expected if the barrier is placed on or behind certain terrain conditions. The crash cushion should be placed on a relatively flat surface (5 percent slope or less) and that there be no appurtenances between the traveled way and the barrier.

Two prominent roadside features which the designer must often contend with are curbs and slopes. Both of these features can cause an errant vehicle to rise above the terrain and become airborne and reach undesirable roll and pitch angles. Curbs should never built where crash cushions are to be installed. Existing curbs where cushions are to be installed should be removed.

For roadside or median installations, it is desirable that the shoulder be extended to provide a relatively flat approach area to the cushion.

Unanchored crash cushions (C—3 and C—4), when placed on elevated gores, may crack due to vibration of the structure. The designer should assure the adequacy of their design from manufacturers.

Figure 8—MM shows examples of median and roadside hazards which can be shielded either totally or partially by crash cushions. The approach area should be flat and have no appurtenances between the traveled way and the cushion. Selection of the barrier angle, θ, should be based on the probable impact angle of encroaching vehicles. For most roadside conditions, an angle of 10 degrees should be used for design purposes.

All of the operational crash cushions can probably be adapted to shield rigid objects such as those shown in Figure 8—LL. However, with the possible exception of the median barrier end treatments, the inertial barriers (C3 and C4) are more easily adapted to shield rigid objects than others. Standard model IE of the Puerto Rico Highway Authority, make use of the Fitch Inertial Barrier System (C3), to shield bridge piers and concrete median barrier (CMB).

These crash cushions do not require a back-up structure. Also, if exposed, the rear part of other barrier systems may itself be a significant hazard. Such problems would arise for median installations. With the inertial barriers (C3 and C4) this problem does not exists. For non-inertial systems a careful design of transition and attachment details should be adapted to overcome this problem.

If the conditions for the installation of a crash cushion barrier system can not be met, then a longitudinal roadside barrier with the transitions and crashworthy end treatments, as previously discussed in this chapter, should be installed.

8—22 COST OF FLATTENING A SLOPE VERSUS PROVIDING A TRAFFIC BARRIER

Before specifying the use of a traffic barrier, a study should be made to determine the feasability of flattening the embankment slope to eliminate the need for the barrier. In some instances it may be possible to flatten the slope through the use of waste excavation material, additional excavation material or even borrow at little or no additional cost, thus providing a safer roadside by avoiding the use of a traffic barrier.

In comparing the cost of flattening a slope versus providing a traffic barrier two basic elements can be readily quantified and analyzed — the additional embankment material and the additional right-of-way width required. Figure 8—NN includes the basic equations to compute the additional fill volume and additional R.O.W. width required to flatten an embankment slope placed on level ground. Figure 8—PP includes the equations for these computations for the conditions where the existing ground slopes upward or downward.

An example of the application of the above analysis is illustrated in Table 8—48 and 8—49. Table 8—48 shows the additional fill volume and R.O.W. width required per lineal meter of roadway (one-side only) to flatten a fill slope from 2:1 to 4:1 for various heights of fill and various existing ground slopes. It should be noted that as the upward ground slope increases in steepness the additional fill volume and R.O.W. width required to flatten the slope decrease substantially from those required for level terrain. Conversely, as the downward ground slope increases in steepness the additional fill volume and R.O.W. width required increase substantially.

Table 8—49 shows the net additional costs of flattening the fill slopes for the conditions given in Table 8—48 and applying the basic formula ($K=AC_F+WC_R-C_G$) given in Figure 8—NN using unit costs of $2 /Cu.M. for fill material, $1/Sq. M. for R.O.W. and $35/L.M. for guardrail. It should be noted that, under these units costs, it is actually more economical to flatten fill slopes up to 3 meters high in level terrain, 4 meters in moderately upward sloping terrain and 6 meters in steep upward sloping terrain, than to use guard rail. For moderately downward sloping terrain the additional cost of flattening for fill heights of 3 meters is only $1/L.M. of roadway but increases to $165/L.M. for the same height in steep downward sloping terrain.

For rural highways with relatively low R.O.W. costs, as in the above example, the cost of the additional fill material required has a more predominant effect in the economic evaluation than the additional R.O.W. width required. However, at urban locations the R.O.W. width requirement becomes the predominant factor in the analysis.

The above example considered only the initial costs of the fill material and guardrail. Actually the analysis should consider that the guardrail will have to be replaced at least once during the life of the fill and, therefore, double the unit price of guardrail should be used in the economic evaluation. Introducing this change in the above example would show that, on level terrain, the flattening of the fill slope would result in the net savings in cost for embankments up to about 5 meters in height.

Furthermore, the economic benefits of a reduction in accidents and the reduction in future maintenance costs attained by the elimination of the guardrail and the flatter side slopes will justify the flattening of fill slopes even at a modest increase in initial roadway costs.

In Chapter VII of the Guide another Cost-Effective Selection Procedure is presented. This procedure takes in consideration initial costs, maintenance costs, and accident costs.

With regard to traffic barriers, the cost-effective procedure can be use to evaluate three alternatives:

TABLE 8-44 - FIELD DATA ON CRASH CUSHIONS, A

System	Reference (Publication Date)	Average Initial Cost 1	Average Repair Cost/Hit 2	Accident Data				Comments
				No. of Hits	Hit Severity			
					P.D.O. 3	Injury	Fatal	
C-1 Steel Drums	115 (1973)	$ 5,323 (8)	$ 295 (15)	66	53	12	1	Only barrier failure occured when 6 ton truck rolled over after impact.
	118, 180 (1974, 1974)	$ 8,000 to $10,000 (3)	$ 750 (25)	25	17	7	1	
	117 (1975)	$ 5,800 (3)	$1,110 (8)	8	UNAV	UNAV	UNAV	
	99 (1975)	$ 5,600 (49)	UNAV	160	96	25	1	Data for 1974 only (in Texas).
	125 (1973)	$ 7,500 (2)	$ 400 (2)	2	UNAV	UNAV	UNAV	
	127 (1974)	UNAV	$ 666 (19)	19	UNAV	UNAV	UNAV	
	112 (1976 Est.)	Data from referenced report no available at this writing						
	131 (1974)	UNAV	$ 421 (5)	5	UNAV	UNAV	UNAV	
C-2 Hi-Dro Cell Sandwich	115 (1973)	$ 4,941 (23)	$ 221, (42)	106	89	16	1	Three barrier failures (all rollovers); auto at 60 mph. tractor-trailer. truck, auto vaulted by 10-Inch curb.
	118, 130 (1974, 1974)	$14,000 to $21,000 (22)	$ 237 (59)	59	42	16	1	Fatility resulted when open gas can in front of passenger compartment ignited.
	117 (1975)	$15,700 (11)	$ 103 (22)	22	UNAV	UNAV	UNAV	
	116 (1970)	UNAV	$ 452 (2)	2	2	0	0	
	121 (1974)	UNAV	$ 395 (17)	17	16	1	0	
	123 (1974)	$12,500 (10)	$ 113 (26)	26	UNAV	UNAV	UNAV	
	125 (1973)	$10,500 (22)	$ 260 (17)	64	UNAV	UNAV	UNAV	

[1]Number in parenthesis is number of installations on which average installation cost is based.

[2]Number in parenthesis is number of hits on which average repair cost is bases.

[3]Property damage only.

TABLE 8-45 – FIELD DATA ON CRASH CUSHIONS, B

System	Reference (Publication Date)	Average Initial Cost [1]	Average Repair Cost/Hit [2]	Accident Data				Comments
				No. of Hits	Hit Severity			
					P.D.O. [3]	Injury	Fatal	
C-2 (Continued)	127 (1974)	UNAV	$ 257 (17)	17	UNAV	UNAV	UNAV	
	112 (1976 Est.)	---------- Data from referenced report not available at this writing ----------						
	132 (1974)	UNAV	$ 211 (72)	72	63	9	0	
	133 (1973)	$ 6,188 (2) [4]	$ 112 (5)	5	5	0	0	
C-3 Fitch Inertial	115 (1973)	$ 2,557 (25)	$ 986 (62)	198	180	16	2	Three barrier failures (all rollover); auto at 70 mph. 2 1/2 ton truck, auto at 90-100 mph.
	118, 130 (1974, 1974))	$ 3,000 to $ 7,000 (10)	$ 730 (40)	40	38	2	0	
	117 (1975)	$ 5,550 (4)	$ 484 (9)	9	UNAV	UNAV	UNAV	
	99 (1975)	UNAV	UNAV	13	6	7	0	Data for 1974 only (in Texas).
	120 (1975)	UNAV	UNAV	42	30	12	0	
	121 (1974)	UNAV	$ 356 (59)	59	58	1	0	
	122 (?)	UNAV	$ 947 (23)	29	28	1	0	
	123 (1974)	$ 3,000 (44)	$ 850 (254)	254	UNAV	UNAV	UNAV	
	124 (1974)	UNAV	$ 938 (53)	53	45	8	0	
	125 (1973)	$ 2,500 (4)	$1,500 (4)	1	UNAV	UNAV	UNAV	
	126 (1976 Est.)	$ 1,812 (15)	$ 667 (54)	54	UNAV	UNAV	UNAV	
	127 (1974)	UNAV	$ 408 (27)	27	UNAV	UNAV	UNAV	
	112 (1976 Est.)	---------- Data from referenced report not available at this writing ----------						

[1] Number in parenthesis is number of installations on which average installation costo is bases.
[2] Number in parenthesis is number of hits on which average repair cost is bases
[3] Property damage only.
[4] Does not include site preparation.

FIELD DATA ON CRASH CUSHIONS, C – TABLE 8-46

System	Reference Publication Date)	Average Initial Cost [1]	Average Repair Cost/Hit [2]	Accident Data				Comments
				No. of Hits	Hit Severity			
					P.D.O.[3]	Injury	Fatal	
C-3 (Continued)	131 (1974)	UNAV	$1,408 (28)	28	UNAV	UNAV	UNAV	
	132 (1974)	UNAV	$ 568 (6)	6	4	2	0	
	133 (1973)	$3,743 (3)[4]	$ 980 (24)	24	22	2	0	
C-4 Energite Inertial Barrier	No data available on this system							
C-5 Hi-Dri Cell Sandwich	118 (1974)	UNAV	$ 325 (3)	3	2	1	0	Initial cost reported to be "similar" to C-2 system
C-6 Hi-Dro Cell Cluster	131 (1974)	UNAV	$ 70 (24)	24	UNAV	UNAV	UNAV	

1 Number in parenthesis is number of installations on which average installation cost is based.
2 Number in parenthesis is number of hits on which average repair cost is based.
3 Property damage only.
4 Does not include site preparation.

INITIAL COST INDICATIONS FOR CRASH CUSHIONS TABLE 8-47

System	Low Initial Costs	Moderate Initial Costs	High Initial Costs
C1 – Steel Drums		✓	
C2 – Hi-Dro Cell Sandwich			✓
C3 – Fitch Inertial	✓		
C4 – Energite Inertial	✓		
C5 – Hi-Dri Cell Sandwich			✓
C6 – Hi-Dro Cell Cluster		✓	

1. To remove or reduce hazard so that shielding is unneccessary.
2. To install a barrier.
3. Leave the hazard unshielded.

The third option would normally be cost effective only on low volume and/or low speed facilities, or where the probability of accidents is low. With regard to item 2, the procedure allows the designer to evaluate any number of barriers that can be used to shield the hazard. Each location and its alternatives should be approached on an individual basis. Through this method the effects of average daily traffic, offset of barrier or hazard, size of barrier or hazard, and the relative severity of the barrier or the hazard can be evaluated.

The user of this Manual should have present the cost-effective procedure presented in this section and the one in the Guide when designing traffic barriers. The recommendation given at the beginning of this Chapter should always be kept in mind, "a barrier should be installed only if it is clear that the barrier offers the least hazard potential of all alternatives considered".

8-23 FENCING

Fencing is a longitudinal barrier erected to prevent unwanted intrusion of animals, people, vehicles, etc. from outside the right-of-way into the vicinity of moving traffic. It is also used within the right-of-way to control pedestrian movements and to prevent vehicles and people from entering or leaving controlled-access traveled ways at unauthorized places. Special fencing may also be used to eliminate headlight glare.

8-23.01 FENCE TYPES

The Department has two basic types of fences covered by standard model plans as follows:

1. Barbed Wire Fence

This is a four-strand barbed wire fence using three types of posts: A— Reinforced Concrete Posts, B— Timber Posts, and C— Steel Posts. The barbed wire fence is used along the ROW line in rural areas primarily to prevent the encroachment to animals into the traveled way and becoming a menace to traffic. It is also used on controlled-access highways in sparsely populated rural areas to prevent the intrusion of people, vehicles, animals into the controlled-access lanes.

2. Chain Link Fence

There are two types of standard chain link fence. The ROW type (2A) has a top pipe rail and is to be used only at locations well removed from the highspeed traveled ways where there is little likelihood of it being struck by errant vehicles.

The other type (2B) has a galvanized steel wire cable as the top longitudinal element. This type is to be used at all locations requiring chain link fence where its proximity to the traveled ways exposes it to possible impacting by errant vehicles.

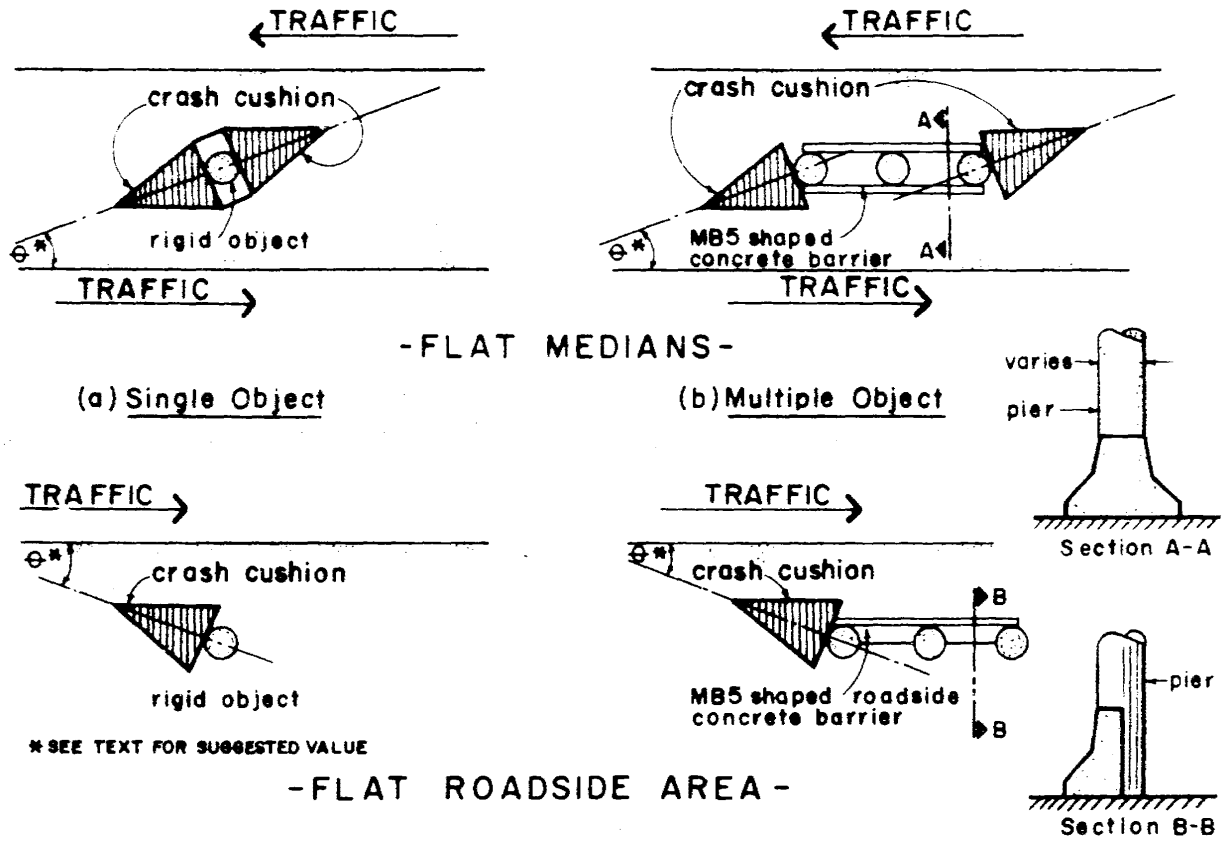
Chain link fence is primarily used on controlled-access highways in urban and suburban areas, and in rural areas in the vicinity of schools, industrial plants, clusters of dwellings and other generation of pedestrian and vehicular traffic.

A third type of fence will be prepared in a near future, to be used also as a standard, in the Commonwealth. This will provide for the utilization of woven wire fence as an alternate to the chain link fence just discussed.

Special purpose fencing shall be used for controlling headlight glare but not for screening junkyards.

8-23.02 WARRANTS FOR USE

The basic warrant for fencing is the safety of traffic movement, both vehicular and pedestrian. On this basis the appropriate type of fencing shall be installed:



EXAMPLES OF POSSIBLE CRASH CUSHION APPLICATION ON THE ROADSIDE OR IN THE MEDIAN.

FIGURE 8 - MM

1. On all controlled-access highways.
2. Along the right-of-way line of all other rural highways.
3. At any location, urban or rural, where needed to protect pedestrians from adjacent hazards such as steep embankments, wall drop-offs, etc. At some of these locations a bridge type railing may be appropriate or a combination of guardrail and fencing may be required.
4. At locations where pedestrian overpasses or underpasses are provided and fencing is needed to prevent hazardous at-grade crossing of the highway by pedestrians.

8—23.03 LOCATION

Fencing is normally installed along the right-of-way line. However, on controlled-access highways with frontage roads or streets within the right-of-way, the controlling fencing is erected in the outer separators between the through lanes and the service road but as close to latter as possible.

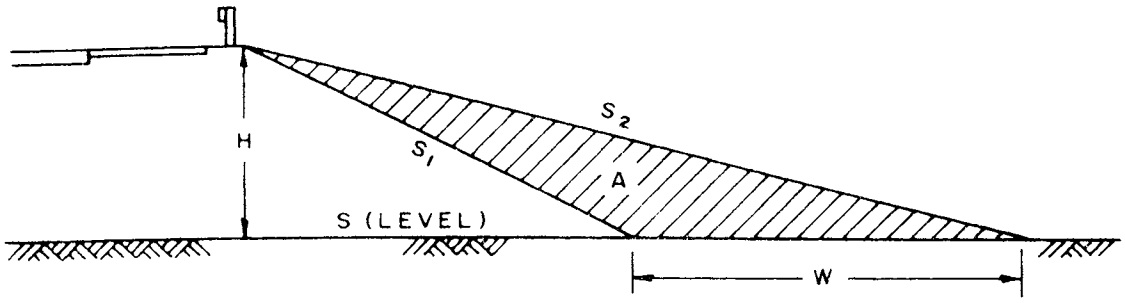
Care must be taken in the design and location of fencing at intersection to avoid unsafe restriction of sight distances.

8—24 REFERENCES

The designer of traffic barriers should have access to and be familiar with the following guides.

1. AASHTO
   a. Guide for Selecting, Locating, and Designing Traffic Barriers — 1977. When "AASHTO Barrier Guide" title appears in Figures and or Tables of this Chapter, it refers to this publication.
   b. A Policy on Design of Urban Highways and Arterial Streets — 1973
   c. An Informational Guide on Fencing Controlled Access Highways — 1967
   d. Highway Safety Design and Operational Practices Related to Highway Safety — 1974
2. Transportation Research Board
   a. NCHRP Report 118 on Location, Selection and Maintenance of Highway Traffic Barriers — 1971
   b. NCHRP Report 129 on Guardrail Crash Test Evaluation — New concepts and End Designs — 1972
3. American Road Builders Association
   a. Technical Bulletin 268 — A Guide to Standardized Highway Barrier Rail Hardware — 1971
   b. Technical Bulletin 268-A — A Supplement to Technical Bulletin 268
4. Federal Highway Administration
   a. Crash Cushions — Selection Criteria and Design — 1975
   b. Handbook of Highway Safety Design and Operating Practices — 1973
   c. Roadside Safety Design — 1975

The technology of traffic barriers is still developing through continuing research and experimental installations. The designer should be alert for publications covering new concepts and hardware, particularly those of the AASHTO, Transportation Research Board, and the FHWA.



DEFINITIONS:

H – HEIGHT OF FILL (M.) BELOW EDGE OF SHOULDER.

S, S_1, S_2 – GROUND AND FILL SLOPES EXPRESSED AS THE RATIO OF HORIZONTAL TO VERTICAL.

A – ADDITIONAL VOLUME (CU. M.) OF FILL REQUIRED PER LINEAL METER OF ROADWAY.

W – ADDITIONAL WIDTH (M) OF R.O.W. REQUIRED BY FLATTER FILL SLOPE.

C_F – COST OF FILL PER CU. M.

C_R – COST OF R.O.W. PER SQ. M.

C_G – COST OF GUARDRAIL PER L.M.

K – ADDITIONAL COST TO FLATTEN FILL SLOPE AND ELIMINATE GUARDRAIL PER L.M. OF ROADWAY.

BASIC EQUATIONS:

$$W = H(S_2 - S_1)$$

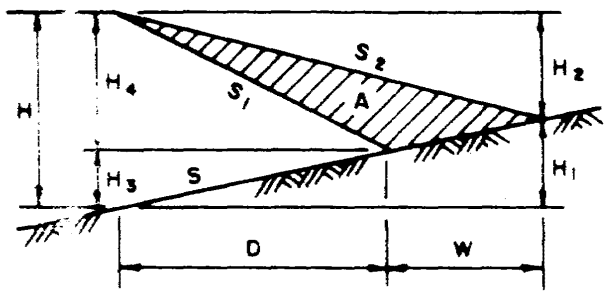
$$A = \frac{1}{2} HW = \frac{1}{2} H^2 (S_2 - S_1)$$

$$K = AC_F + WC_R - C_G$$

NOTE – FOR EQUATIONS WHEN FILL IS ON SLOPING TERRAIN SEE FIGURE 8-D.

GUARDRAIL VS. FLATTER FILL SLOPE IN LEVEL TERRAIN

FIGURE 8-NN



GROUND SLOPE UPWARD

$$H_1 = H \left(\frac{1}{S/S_2 + 1} \right)$$

$$H_2 = H - H_1$$

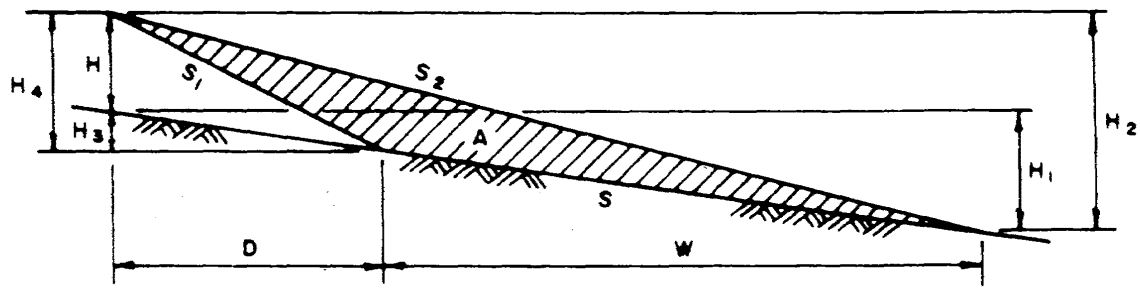
$$H_3 = H \left(\frac{1}{S/S_1 + 1} \right)$$

$$H_4 = H - H_3$$

$$D = H_3 S = H_4 S_1$$

$$W = H_2 S_2 - D$$

$$A = \tfrac{1}{2} H W$$



GROUND SLOPE DOWNWARD

$$H_1 = H \left(\frac{1}{S/S_2 - 1} \right)$$

$$H_2 = H + H_1$$

$$H_3 = H \left(\frac{1}{S/S_1 - 1} \right)$$

$$H_4 = H + H_3$$

$$D = H_3 S = H_4 S_1$$

$$W = H_2 S_2 - D$$

$$A = \tfrac{1}{2} H W$$

COMPUTATION OF ADDITIONAL R.O.W. WIDTH AND FILL AREAS FOR VARIABLE FILL SLOPES ON SLOPING TERRAIN

FIGURE 8-PP

TABLE 8-48

ADDITIONAL FILL AND R.O.W. WIDTH REQUIRED PER LINEAR METER OF ROADWAY BY FLATTENING FILL SLOPE FROM 2:1 TO 4:1 FOR VARIOUS HEIGHTS OF FILL AND GROUND SLOPES

GROUND SLOPE (S)			(H) HEIGHT OF FILL IN METERS AT EDGE OF SHOULDER							
			3	4	5	6	7	8	9	10
UPWARD	STEEP (5:1)	ADDITIONAL FILL (M^3)	3.6	6.4	9.9	14.3	19.5	25.2	32.2	39.7
		ADD. R.O.W. WIDTH (M.)	2.4	3.2	4.0	4.8	5.6	6.3	7.2	7.9
	MODERATE (20:1)	ADDITIONAL FILL (M^3)	6.9	12.2	19.2	27.0	36.8	48.3	61.2	75.6
		ADD. R.O.W. WIDTH (M.)	4.6	6.1	7.7	9.0	10.5	12.1	13.6	15.1
LEVEL		ADDITIONAL FILL (M^3)	9.0	16.0	25.0	36.0	49.0	64.0	81.0	100.0
		ADD. R.O.W. WIDTH (M.)	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0
DOWNWARD	MODERATE (20:1)	ADDITIONAL FILL (M^3)	12.6	22.4	34.5	49.8	67.9	88.8	112.5	139.0
		ADD. R.O.W. WIDTH (M.)	8.4	11.2	13.8	16.6	19.4	22.2	25.0	27.8
	STEEP (5:1)	ADDITIONAL FILL (M^3)	75.0	133.3	208.4	300.0	408.3	533.4	675.0	833.3
		ADD. R.O.W. WIDTH (M.)	50.0	66.7	83.4	100.0	116.7	133.4	150.0	166.7

TABLE 8-49

NET ADDITIONAL COST (DOLLARS) PER LINEAL METER OF ROADWAY OF FLATTENING FILL SLOPE FROM 2:1 TO 4:1 FOR VARIOUS HEIGHTS OF FILL AND GROUND SLOPES*

GROUND SLOPE		HEIGHT OF FILL IN METERS AT EDGE OF SHOULDER							
		3	4	5	6	7	8	9	10
UP (+)	STEEP (5:1)	- 25	- 19	- 11	- 1	9	22	37	52
	MODERATE (20:1)	- 17	- 4	9	28	49	74	101	131
LEVEL		- 1[illegible]	5	25	49	77	109	145	185
DOWN (-)	MODERATE (20:1)	1	21	48	81	120	165	215	271
	STEEP (5:1)	165	298	465	665	898	1165	1465	1798

* BASED ON FILL AT $2/CU.M., R.O.W. AT $1/SQ.M., AND GUARDRAIL AT $ 35/L.M. NET COSTS ROUNDED TO NEAREST DOLLAR.

CHAPTER 9

TRAFFIC CONTROL DEVICES

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CHAPTER 9

TRAFFIC CONTROL DEVICES

9–01 GENERAL

Traffic control devices include signs, signals, markings and other devices placed on or adjacent to a highway or street to regulate, warn or guide traffic. The legal authority to install traffic control devices on Commonwealth highways is vested in the Secretary of Transportation and Public Works.

The Federal Highway Administrator adopted the 1971 "Manual of Uniform Traffic Control Devices", referred to as the MUTCD, developed with the cooperation of the AASHTO and the National Joint Committee on Uniform Traffic Control Devices, as a national standard for application on all classes of highways. The Secretary of Transportation and Public Works has officialy adopted the MUTCD as a guide for the design and application of traffic control devices in Puerto Rico subject to the requirements of the Vehicle and Traffic Act (Law No. 141 of 1960 as subsequently amended) and to such modifications as required to meet local conditions, including the translation to spanish of all word messages on signs and markings. The Department is now in the process of developing its own manual of uniform traffic control devices in spanish, based on the MUTCD, to provide an official guide for application throughout the Commonwealth.

In addition to the MUTCD, the designer has available the Department's 1964 "Manual of Traffic Signs" which provides fabrication and installation details for standard traffic signs. This manual is supplemented by standard plans covering signs not included in the original edition or since revised and new details on sign posts and supports. A revision and updating of this manual is now in process.

This chapter is intended for the use of the highway designer as a supplement to the above manuals.

9–02 TRAFFIC SIGNS

9–02.01 SPECIAL SIGNING STANDARDS

The Department's Bureau of Traffic Engineering has issued a set of instructions, to be used as a supplement to the MUTCD, which cover special standards for signing of expressways and other highways in Puerto Rico. These special standards are in general conformance with the MUTCD but provide specific instructions on sign sizes, location, messages, letter series and sizes, and other details for use on various types of highways and conditions.

9–02.02 COORDINATION WITH HIGHWAY DESIGN

Effective signing is essential for the proper operation and safety of highspeed arterial highways, particularly expressways and freeways. The signs must be designed and located so that the drivers can react promptly, naturally and safely to the design conditions. However, good signing cannot correct a poor highway design. During the early stages of the design of an expressway, a preliminary signing plan should be prepared and analyzed to ascertain that the facility can be clearly signed. When this is not possible, modifications of the geometric layout may be warranted. Urban expressways with restricted geometrics, complex layouts and closely spaced interchanges require careful consideration of signing during the early design stages since they often pose special problems in sign location and spacing.

9—02.03 SIGN LOCATION AND SUPPORTS

The locations of the various types of signs are specified in the MUTCD, the Department's Manual of Traffic Signs and the special instructions issued by the Department. The design of sign supports, other than for overhead sign structures, are covered in the standard model plans.

All ground-mounted signs on rural highways and on all expressways and freeways shall be of the breakaway design or yielding type posts in the case of small signs. They should be placed behing guardrail whenever possible. However, guardrail should not be installed merely for the protection from sign supports except in the case of large overhead sign installations for which breakaway supports cannot be provided. Also, care must be excercised that sufficient offset of the sign support from the face of the guardrail is provided to allow for the expected deflection of the rail.

The lateral offsets from edge of traveled way for sign panels placement on rural highways indicated in the signing manuals are to be considered as minimums. On high-type rural highways with wide sections, large traffic signs should be offset from the traveled way further distances than the minimum for increased safety and still communicate effectively. However, care must be taken to obtain a satisfactory angle for the sign face in relation to the approaching traffic and to provide favorable viewing conditions. A minimum of six (6) feet shall be provided from the left edge of sign panels and the curb or edge of shoulders to avoid traffic damage on urban areas.

Full advantage should be taken of overcrossing structures on expressways for sign placement whenever possible. Such installations are more effective and safer than ground mounting, and more economical than a separate sign bridge.

Breakaway sign supports generally should not be used on sidewalks on streets and avenues since falling posts and signs can be hazardous to pedestrians. The need of breakaway supports to protect vehicle occupants is not as essential on streets since accidents are generally less severe due to the lower operating speeds.

9—02.04 GORE AREAS

Gore areas are probably the portions of a highway most vulnerable to frequent encroachment by errant vehicles. For this reason they should be kept clear of sign installations except for the ground-mounted gore EXIT sign which should always be on breakaway supports. The supports for other signs required in the vicinity of the gore should be located ahead of the clear gore area and outside the right shoulder. Some overhead sign structures may require a support to be located in the median.

9—02.05 OVERHEAD SIGNS

1. WARRANTS—Overhead sign installations are expensive because of the cost of the support structure. However, overhead signs are very effective, particularly for directional signs and lane use control on high-speed multilane highways. The use of overhead signs on expressways should be considered on the basis of the following factors:

a. Complex interchange design.
b. Three or more lanes in each direction.
c. Closely spaced intersections and interchanges.
d. Multilane exits.
e. Insufficient space for ground signs.
f. Restricted sight distance.
g. Traffic volume at or near capacity.
h. Large percentage of trucks.
i. Consistency of sign message location throughout a series of intersections or interchanges.

2. VERTICAL CLEARANCE—Signs located over any portion of the roadway shall have a vertical clearance of at least 0.30 m. more than the minimum vertical clearance provided for other structures along the same highway sections, but in no case less than 5.0 meters. When the overhead sign is attached to an overpassing structure, the vertical clearance to the sign need not exceed the vertical clearance to the structure.

3. HORIZONTAL CLEARANCE—The minimum horizontal clearance from edge of traveled way to a non-breakaway overhead sign support shall be 4.2 meters with guardrail protection provided. The guardrail installation shall be designed in accordance with the requirements included in Chapter 8. However, whenever feasible this minimum clearance should be exceeded for greater safety. A horizontal clearance of 9.0 M. is very desirable on high-speed highways. An impact attenuator or guardrail immediately adjacent to the overhead support shall be provided no matter how much the clearance is.

4. STRUCTURAL DESIGN—The structural design of the structural supports for overhead signs shall conform to the requirements of the AASHTO "Specifications for the Design and Construction of Structural Supports for Highway Signs". The wind pressure shall be determined using a wind speed of 120 mph (50 year mean recurrence interval) in the formula.

5. ILLUMINATION—All overhead signs shall be reflectorized in accordance with the Department's requirements. In addition, all overhead signs shall be illuminated on expressways and other high-speed highways except at locations where it can be positively shown that reflectorization alone will provide adequate visibility and contrast at night. Sign illumination, when provided, shall conform to the requirements covered in Standard Specification 613. Sign luminaires shall be bottom mounted to avoid daytime shadows on the sign. They shall be designed to produce a brightness of no less than 25 footlamberts on the white legend with a maximum to minimum ratio of brightness of not more than 3:1.

9—02.06 KILOMETER AND HECTOMETER MARKERS

Kilometer and hectometer markers shall be installed on all numbered Commonwealth highways. These markers indicate the distances along the highway from its point of origin as defined by the official route description approved by the Department. The designation and location (station) of the initial marker for a particular project is to be established by the Design Area in coordination with the Planning Area. The kilometer and hectometer markers are to be fabricated and installed in accordance with Standard Model No. 3 and Standard Specification 621.

9—02.07 PLAN REQUIREMENTS

The signing plans for a project shall include the following:

1. SIGN LOCATION PLAN—This is a plan showing the location of each sign or sign assembly. Signs are identified by a symbol giving the location number and the type code number. A sample portion of a location plan is illustrated in Figure 9—A. The approximate station location of each sign should be indicated. The standard project plan sheets (Scale 1:1000 or 1:500) may be used for the sign location plan. For intersections or interchanges with a lot of signing, the larger scale detail plan sheets may be used. The designer should provide plans showing all necessary traffic control devices for the anticipated detours, or special conditions that are expected during the construction phase.

2. TRAFFIC SIGNS DATA SHEET—This is a tabulation of all the signs required for the project. A portion of a sign data sheet is illustrated in Figure 9—B. The following is an explanation of the column headings:

Code Number — The code for each particular type of sign indicated in the upper portion of the symbol used in the location plan.

Location Number – The number(s) of the location(s) where each type sign is to be installed as indicated in the lower portion of the symbol used in the location plan.

Legend – A graphic illustration of the legend for the particular sign used.

Letter Size – For standard signs reference is made to the DTPW "Traffic Signs Manual" or a standard model plan as appropriate. In the case of guide signs or other signs for which a specific design must be made, the size and series of letters to be used is given and reference is made to the appropriate guide sign detail sheet.

Size of Sign – The overall dimensions of each sign are indicated. In the case of assemblies of two or more signs, the dimensions of each sign are shown.

DTPW Number – This refers to the identifying number for each particular type of sign used in the DTPW signs manual or standard models.

Colors – The colors of the background and characters are shown and reflectorization, if any, indicated.

Type of Mounting – For ground mounted signs reference is made to the particular standard model applicable (3–E–1, 3–E–2, etc.). For overhead signs reference is made to the plan sheet where design data for the support structure is shown.

Total Signs – Indicates the total number of signs (or sign assemblies) of each particular type needed. This number should correspond to the total number of locations shown in the second column.

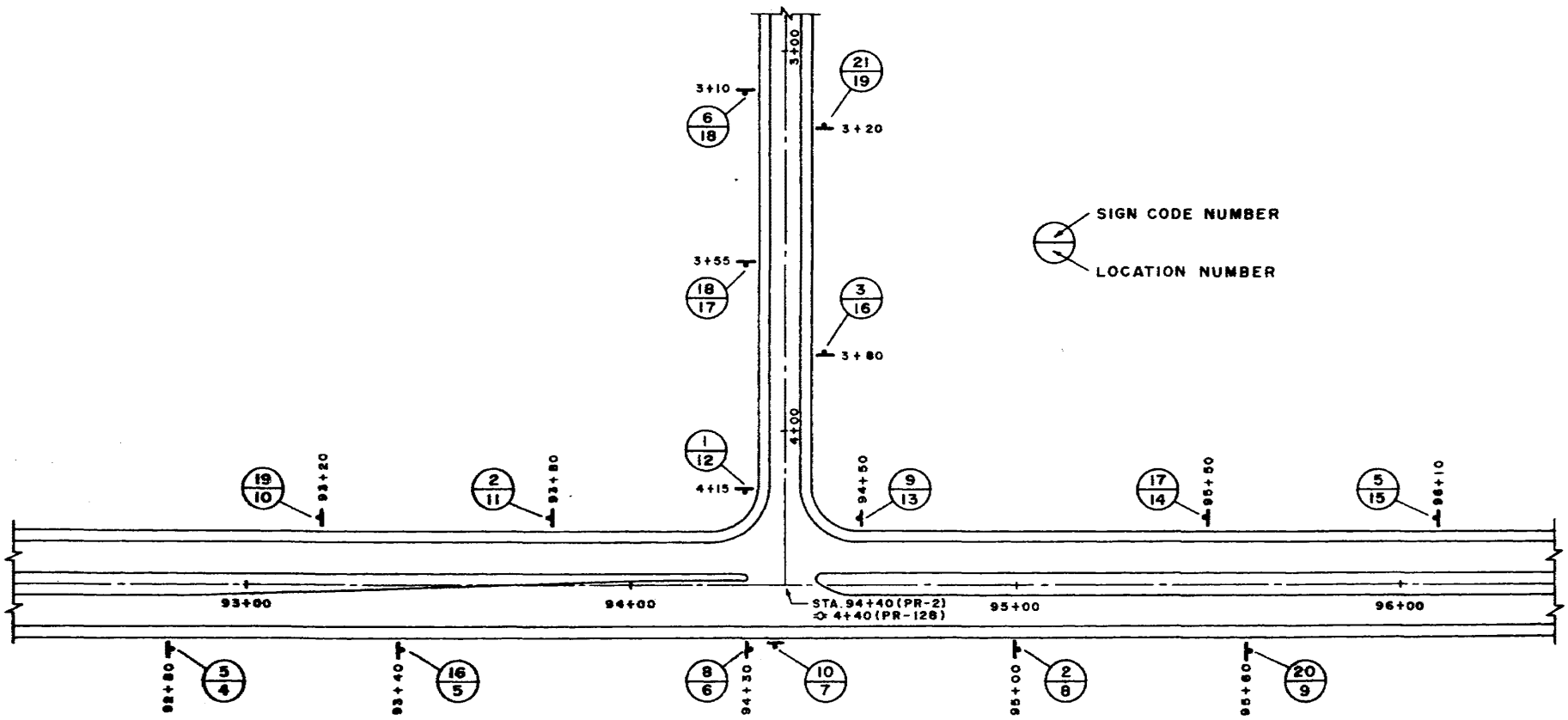
3. GUIDE SIGNS DETAILS–For each guide sign a layout will be included showing the overall sign dimensions, the letter sizes and series, and the dimensions and spacing for the legend. A sample of a typical guide sign layout is illustrated in Figure 9–C.

4. OVERHEAD SIGN STRUCTURES–A general layout and elevations shall be included for each overhead sign structure showing the type and dimensions, location with respect to roadway section, clearances, foundations, and positioning of signs. In addition, all necessary design criteria will be indicated, including illumination requirements, to enable the contractor to develop the detailed design of the structure and subsequent shop drawings. For illuminated signs, the location of underground conduits and lines to power source shall be indicated on a plan layout.

5. SPECIAL DETAILS–Design details of any special type of sign supports not covered by the standard models shall be shown. This includes such items as special brackets for supporting signs from overpassing structures or from roadside walls.

9–03 MARKINGS

Markings include all pavement and curb markings and other devices, other than signs, which are used to guide traffic or warn of an obstruction such as delineators and object markers. The Department adheres to Part III of the MUTCD in the design and application of traffic markings.



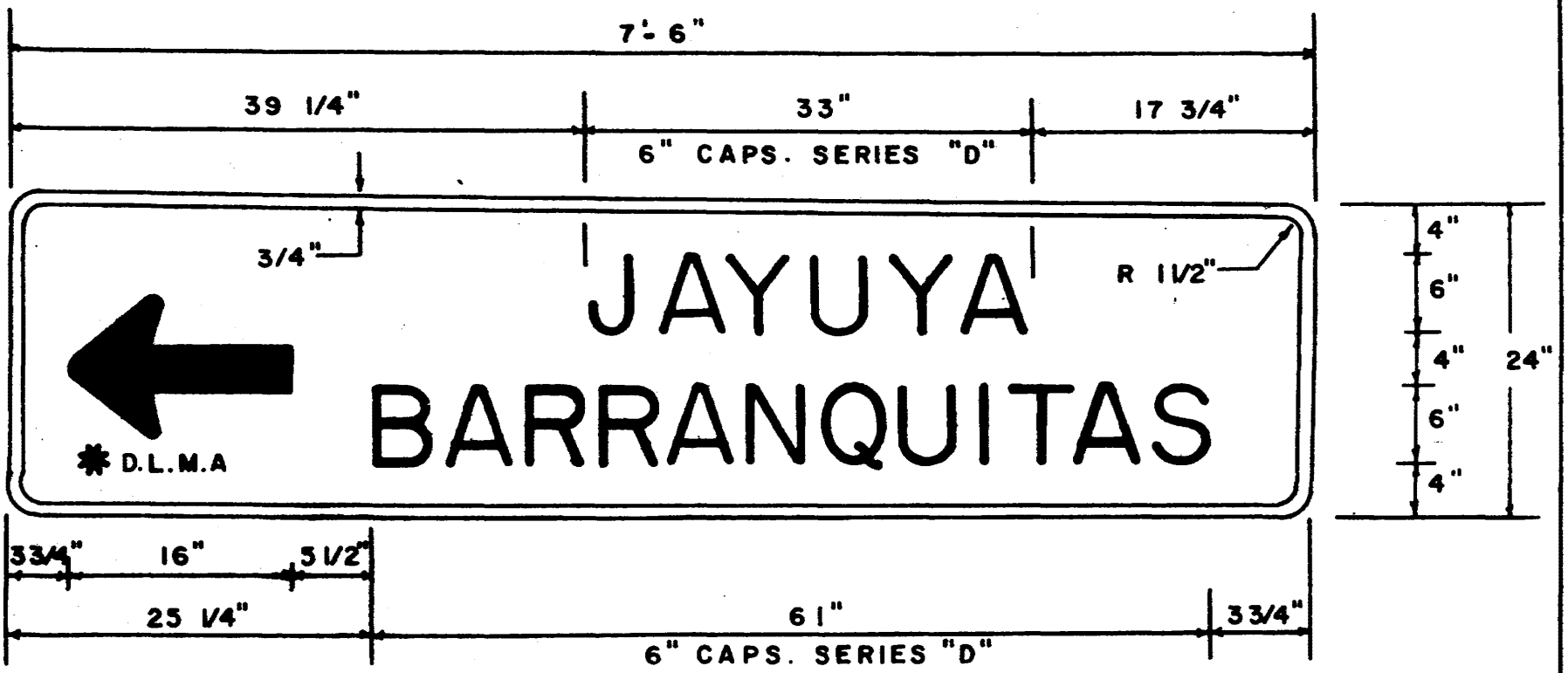
PORTION OF A SIGNS LOCATION PLAN

FIGURE 9-A

CODE NUMBER	LOCATION NUMBER	LEGEND	LETTER SIZE	SIZE OF SIGN	DTPW NUMBER	COLORS		TYPE OF MOUNTING	TOTAL SIGNS
						BACKGROUND	CHARACTERS		
1	1, 2, 15, 16	PARE	SEE DTPW MANUAL	30"x 30"	R1-1	RED REFLECTORIZED	WHITE REFLECTORIZED	STD. MODEL 3-E	4
2	3, 6	INT 155	SEE DTPW MANUAL	21"x 15" 24"x 24"	M2-1 M1-1	WHITE REFLECTORIZED	BLACK	STD. MODEL 3-E	2
3	4	↑ BARRANQUITAS ← OROCOVIS COAMO →	6" CAPS. SERIES D SEE PLAN SHEET NO. 52	7'-6"x 2'-8"	D1-3	GREEN REFLECTORIZED	WHITE REFLECTORIZED	STD. MODELS 3-E-3,4,5	1
4	5, 7	155 ↔ 143 ↑	SEE DTPW MANUAL	24"x 24" 21"x 15" — 24"x 24" 21"x 15"	M1-1 M4-4 — M1-1 M4-3	WHITE REFLECTORIZED	BLACK	STD. MODEL 3-E-1	2
5	8, 9, 17, 18	VELOCIDAD MAXIMA 50	SEE DTPW MANUAL	24"x 30"	R2-1	WHITE REFLECTORIZED	BLACK	STD. MODEL 3-E	4

PORTION OF TRAFFIC SIGNS DATA SHEET

FIGURE 9-B



TYPICAL GUIDE SIGN LAYOUT

FIGURE 9_C

D.L.M.A. _ DOUBLE LINE MESSAGE ARROW

9–03.01 PAVEMENT MARKING MATERIALS

The Department uses three types of pavement marking materials; paint, thermoplastic compound, and raised markers.

Paint with embedded glass beads to provide reflectorization is the most commonly specified material for pavement markings. Paint and bead requirements are covered in Standard Specification 618.

The use of extruded thermoplastic compounds is normally limited to expressways and other heavily traveled multilane rural and urban highways. Thermoplastic markings are also reflectorized by the use of embedded glass beads.

Raised pavement markers are currently being used on some freeways for lane line marking in lieu of paint or thermoplastic. Two types of markers are used in combination. These are a non-reflectorized ceramic marker (Special Provision 802) and a retro-reflective plastic marker (Special Provision 801).

9–03.02 PAVEMENT LINES – WIDTHS AND PATTERNS

Center lines, lane lines, pavements edge lines and no-passing zone lines shall be 4" (10 cm) wide. Broken lines shall have 15' (4.6 m) segments and 25' (7.6 m) gaps. Space between double lines shall be 4" (10 cm).

Stop lines shall be 24" (60 cm) wide on high-speed highways and 12" (30 cm) on all other roads and streets.

Crosswalk boundry lines shall be 12" (30 cm) wide where no advance stop line is provided and 6" (15 cm) at all other locations. At other than signal controlled crossings, the crosswalk area may be marked with 12" diagonal lines at a 45° angle or transverse lines at 90°, with 24" spacing.

Channelizing lines for painted islands and ramp terminals shall be 8" (20 cm) wide. Hatch lines, when used, shall be 8" at 24" spacing.

Raised pavement markers when used for lane lines shall have the same segment and gap pattern as for painted lines. Each 15' segment shall consist of a retro-reflective marker at each end enclosing three ceramic markers, all spaced at 3.75' (1.14 m).

9–03.03 PLAN REQUIREMENTS

The signing and markings plan sheets group (TS group, see Chapter 19) of the project plans shall show the proposed markings. Details shall be included of the pavement markings at intersections, ramp terminals, pavement transitions, pedestrian crosswalks and any other location requiring special markings. The plans shall indicate the marking material, colors, widths and spacing of all markings. Reference shall be made to the applicable standard specification or special provision.

9–04 TRAFFIC SIGNALS

Traffic signals are power-operated traffic control devices used to warn or direct vehicular and/or pedestrian traffic to take some specific action. This includes traffic control signals, lane-use control signals, flashing beacons, speed control signals, railroad crossing signals and other similar devices. Traffic control signals are basically to direct traffic as to when to stop or proceed. The Department's practice on the design and use of traffic signals conforms to the standards prescribed in the MUTCD.

The design of traffic signal installations is a specialized field which should be performed by qualified traffic engineers. When traffic control signals are required, the highway designer should work closely with the traffic engineer to integrate the geometric elements of the highway design with the traffic signals design and to insure that adequate space and facilities are provided for the installation of the signal equipment.

9—04.01 WARRANTS

The warrants for the installation of traffic signals are specified in Part IV—C of the MUTCD. In the case of new construction or reconstruction of a highway facility, the traffic study data may indicate the immediate need for traffic signals. In such cases the design of the signal installations shall be incorporated into the overall design.

In many other cases, signal installation may not be initially warranted but the traffic data may show that eventual signalization of some intersections will be required. Such intersections shall be designed as if under signal control and the geometric layout should be developed in conjunction with a signalized intersection analysis. Such a procedure will help insure that an adequate number of lanes and a suitable arrangement of turning roadways is provided to meet the design traffic requirements.

Table 4—1 in Chapter 4 on "Intersections at Grade" shows suggested design hour volume combinations for which signal control should be assumed in the design or rural highways.

Guides for determining which urban intersections may warrant traffic control signal installation on the basis of estimated average daily traffic are given in Tables 9—1 and 9—2. These are based on a study made by the Department of the daily traffic volumes at existing signalized intersections. If on the basis of these guides it is determined that an urban intersection may require traffic signal control, then provisions should be made in the design to provide for the signal installation either initially or in the future.

TABLE 9—1

WARRANT 1 – MINIMUM VEHICULAR MOVEMENT

No. of Moving Lanes Each Approach		VPH on Major St. (Both Directions)	VPH on Minor St. (One Direction	Estimated ADT	
Major St.	Minor St.			Major St.	Minor St.
1	1	500	150	9,000	2,600
2 or more	1	600	150	10,200	2,700
2 or more	2 or more	600	200	10,400	3,800
1	2 or more	500	200	8,600	3,500

NOTE: Refer to Section 4C—3 of the MUTCD (1971).

TABLE 9–2

WARRANT 2 – INTERRUPTION OF CONTINOUS TRAFFIC

No. of Moving Lanes Each Approach		VPH on Major St. (Both Directions)	VPH on Minor St. (One Direction	Estimated ADT	
Major St.	Minor St.			Major St.	Minor St.
1	1	750	75	13,600	1,300
2 or more	1	900	75	15,300	1,300
2 or more	2 or more	900	100	15,500	1,900
1	2 or more	750	100	11,900	1,800

NOTE: Refer to Section 4C–4 of the MUTCD (1971).

9–04.02 GEOMETRIC CONTROLS

Geometric controls which are applicable to signal installations and which may influence the design of intersections and their approaches include the following:

1. There shall be a minimum of two signal faces for through traffic at intersections.

2. Unless physically impractical, at least one and preferably both of the signal faces should be located 12 to 36 meters beyond the stop line an within a field of view of approximately 20° right and left, measured from the approach centerline of the stop bar.

3. Over the raodway mounting, either on a mast arm or span wire, is preferred. The bottom of the signal housing shall be not less than 4.6 M nor more than 5.8 M above the roadway.

4. The alignment and profile of the highway approach should permit the driver an adequate continuous view of the signal faces. The minimum distance may be calculated by the formula:

$$D = 30 + 4.6\ (V-20)$$

where D = meters
V = 85 percentile speed in mph

5. Signal supports should be located as far as practicable from the edge of the traveled way. As a minimum they should be 0.6 meters behind the curb line. Where there are no curbs they should be located at least 0.6 meter beyond the usable shoulder.

6. Ground mounted controller cabinets shall be located well away from the traveled way.

9–04.03 PLAN AND SPECIFICATION REQUIREMENTS

When signal installations are to be included in a highway project the contract documents shall include:

1. Location plan of traffic signal supports, controllers, signal heads, power source, conductor cables and conduits, detectors, and any related auxiliary equipment. This may be included in the lighting and/or signing plan. Clearances from curb or shoulder lines shall be indicated.

2. Details of supports, mast arms, support foundations, pullboxes and other appurtenances as may be necessary.

3. Initial phasing tables for each intersection.

4. Since there are no current DTPW standard specifications for traffic signal equipment, special provisions are required for each project. These special provisions shall conform to the requirements of Section 19—04.03 of Chapter 19 of this manual.

9—05 REFERENCES

The following is a list of selected references on traffic control devices.

1. Manual on Uniform Traffic Control Devices for Streets and Highways — Federal Highway Administration, 1971.
2. Transportation and Traffic Engineering Handbook — Institute of Traffic Engineers, 1976.
3. Traffic Control Devices Handbook — Federal Highway Administration, 1975.
4. Standard Alphabets — Federal Highway Administration, 1966.
5. Standard Highway Signs — Federal Highway Administration, 1972.
6. Manual of Traffic Engineering Studies — Institute of Traffic Engineers, 4th. Edition.
7. Capacity Analysis Techniques for Design of Signalized Intersections — Federal Highway Administration, 1967.
8. Highway Capacity Manual — Highway Research Board SR—87, 1965.
9. Roadway Delineation Systems — Highway Research Board, NCHRP Report 130, 1972.
10. Specifications for the Design and Construction of Structural Supports for Highway Signs — AASHO, 1968.

CHAPTER 10

HIGHWAY LIGHTING

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CHAPTER 10

HIGHWAY LIGHTING

10-01 GENERAL

This chapter provides details and guidance on the policies and standards of the Highway Authority on highway lighting including warrants on use, illumination design values, luminaire arrangements, lighting equipment, pole location, general illumination design procedure and plan requirements.

Lighting systems for Highway Authority projects shall be designed by qualified licensed electrical engineers. In addition to the requirements specified in this chapter, the lighting systems shall comply with all applicable standards and requirements of the Puerto Rico Water Resources Authority (PRWRA) and in particular their Public Lighting Standard Manual. The plans and specifications for lighting projects are subject to PRWRA approval.

10-02 HIGHWAY LIGHTING TERMS

The Illuminating Engineering Society (IES) has prepared a glossary of technical terms pertaining to roadway lighting. The following are brief definitions of several of the technical terms used in this chapter; most of these have been adopted from the IES glossary.

ASYMMETRIC DISTRIBUTION — A light distribution in which the curves of vertical distribution are not the same for all planes.

BALLAST — A device used with an electric-discharge lamp to obtain the necessary circuit conditions for starting and operating.

BRACKET (Mast Arm) — An attachment to a lamp post or pole from which a luminaire is suspended.

CANDELA (cd) — The unit of luminous intensity.

CANDLEPOWER (cp) — The luminous intensity of a light source in a specified direction expressed in candelas.

COEFFICIENT OF UTILIZATION (CU) — The ratio of the luminous flux (lumens) from a luminaire received on the roadway surface to the lumens emitted by the luminaire's lamps alone.

CONVENTIONAL LIGHTING — A highway lighting system in which the luminaires mounting heights do not exceed 50 feet.

FOOTCANDLES (fc) — The illumination on a surface one square foot in area on which there is a uniformly distributed flux of one lumen, or the illumination produced on a surface all points of which are at a distance of one foot from a directionally uniform source of one candela.

Average footcandles are calculated by dividing net lumens by the area over which they are distributed. They are also measured by averaging the individual footcandle readings along the center of each traffic lane at ten foot intervals.

Maintained footcandles values are determined for conditions when the luminaire is the most dirty and the lamp has reached its life replacement point.

FOOTLAMBERT (fl) — A unit of luminance (brightness). The uniform luminance of a perfectly diffusing surface emitting or reflecting light at the rate of one lumen per square foot. Footlamberts equals the product of footcandles multiplied by the coefficient of reflection (or refraction).

GLARE - The sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort or visual loss. Glare is further defined as:

Direct — glare resulting from high luminances or insufficiently shielded light sources within the field of view.

Reflected — glare resulting from specular reflections of high luminances in polished surfaces in the field of view.

Discomfort — glare producing discomfort but which does not necessarily interfere with visual performance or visibility.

Disability — glare which reduces visual performance and visibility and which is often accompanied by discomfort.

HIGH-INTENSITY DISCHARGE LAMPS — A general group of lamps consisting of mercury, metal halide and high-pressure sodium lamps.

HIGH MAST LIGHTING —Lighting units consisting of a cluster of luminaires mounted on a pole or tower at heights of 60 feet or more.

ILLUMINATION — The density of the luminous flux incident on a surface.

ISOCANDELA LINE — A line plotted on any appropriate coordinates to show directions in space, about a source of light, in which the candlepower is the same.

ISOCANDELA LINE — A line plotted on any appropriate coordinates to show directions in all points of equal illumination on a surface.

LAMP — A generic term for a man-made source of light. Often called a "bulb" or "tube" if it is electrically powered.

LAMP LUMEN DEPRECIATION FACTOR (LLD) — The multiplier to be applied to the initial rated output of a light source to obtain the anticipated minimum rated output based on the relamping program to be used.

LIGHTING UNIT —The assembly of pole or post with bracket and luminaire.

LONGITUDINAL ROADWAY LINE (LRL) — Any line along the roadway parallel to the curb or pavement edge lines.

LUMEN (lm) — The unit of luminous flux. It is equal to the flux on a unit surface all points of which are at a unit distance from a uniform point source of one candela. The term by which the output of a light source is frequently expressed.

LUMINAIRE — A complete lighting device consisting of the lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps and to connect the lamps to the power supply. It does not include the post, pole or bracket.

LUMINAIRE DIRT DEPRECIATION FACTOR (LDD) — The multiplier to be applied to the initial illumination provided by clean, new luminaires to obtain the reduced illumination value that they will provide due to dirt accumulation on the luminaires at the time that cleaning is anticipated.

LUMINAIRE EFFICIENCY — The ratio of luminous flux (lumens) emitted by a luminaire to that emitted by the lamp or lamps used therein.

MAINTENANCE FACTOR (MF) — The product of the lamp lumen depreciation factor and the luminaire dirt depreciation factor (MF = LLD x LDD).

MOUNTING HEIGHT (MH) — The vertical distance between the roadway surface and the center of the apparent light source of the luminaire.

OVERHANG — The distance between a vertical line passing through the luminaire and the curb or edge of the traveled way.

REFERENCE LINE — Radial lines where the surface of the cone of maximum candlepower is intersected by a vertical plane parallel to the curb line and passing through the light center of the luminaire.

REFLECTANCE — The ratio of the light reflected by a surface to the light incident upon it.

REFLECTOR — A device used to redirect the luminous flux from a source by the process of reflection.

REFRACTOR — A device, such as a globe or glass band, used to redirect the luminous flux from a source, primarily by the process of refraction.

SPACING — The distance between successive lighting units measured along the center line of the highway.

SYMMETRICAL LIGHT DISTRIBUTION - A light distribution in which the curves of vertical distribution are substantially the same for all planes.

TRANSVERSE ROADWAY LINES (TRL) — Lines across the roadway perpendicular to the curb or pavement edge line.

UNIFORMITY OF ILLUMINATION — The ratio of average illumination level on the roadway to the minimum illumination level at any point on the roadway.

UTILIZATION EFFICIENCY — A plot of the quantity of light falling on a horizontal plane both in front and behind the luminaire. It shows only the percent of base lamp lumens which fall on the horizontal surface and is plotted as a ratio of width of area to mounting height of luminaire.

10—03 POLICY ON USE

It is not practical to establish specific conditions covering all cases as to when it is warranted to provide highway lighting. It is recognized that highway lighting will contribute to the safety, efficiency and comfort of vehicular and pedestrian traffic. On the other hand, the installation of lighting systems can involve a substantial investment of public funds and subsequent maintenance and power costs.

In this section general warrants are given for guidance in determining when lighting should be provided. These warrants are in conformance with the requirements of Highway Safety Program Standard No. 12 and generally follow the AASHTO "Informational Guide for Roadway Lighting" (1976).

10-03.01 AREA CLASSIFICATION

The following definitions apply to area classifications used in this chapter:

DOWNTOWN — That portion of a municipality in a business development where ordinarily there are large numbers of pedestrians and a heavy demand for parking space during periods of peak traffic or a sustained high pedestrian volume and a continously heavy demand for off-street parking space during business hours. This definition applies to densely developed business areas outside of, as well as those within, the central business district.

INTERMEDIATE – That portion of a municipality which is outside of a downtown are but generally within the zone of influence of a business or industrial development, characterized often by a moderately heavy nightime pedestrian traffic and a somewhat lower parking turnover than is found in a downtown area.

OUTLYING – A residential development, or a mixture of residential and commercial establishments, characterized by few pedestrians and a low parking demand or turnover at night.

10–03.02 WARRANTING CONDITIONS – FREEWAYS

1. CONTINOUS LIGHTING

Continous freeway lighting should normally be provided under any of the following conditions:

a. Sections 3 or more kilometers in lengthpassing through urbanized areas where the adjacent street system visible from the freeway is lighted.

b. Sections where three or more successive interchanges are located at an average spacing of 1 kilometer or less.

c. On sections where the ratio of night to day accidents experience is higher than the average for all similar unlighted sections and a study indicates that lighting may result in a substantial reduction in the night accident rate.

2. INTERCHANGE LIGHTING ON UNLIGHTED SECTIONS

Interchange lighting on unlighted freeways should normally be provided under any of the following conditions:

a. Complete lighting at interchanges where existing substantial commercial or industrial development in the immediate vicinity is lighted or where the crossroad approach legs are lighted for 0.5 kilometer or more on each side.

b. Complete lighting at interchanges where the current ADT on the crossroad, or the total ADT ramp traffic entering and leaving the freeway within the interchange, exceeds 5,000 vehicles.

c. Complete or partial interchange lighting where the ratio of night to day accident experience is higher than the average for similar unlighted interchanges and a study indicates that lighting may result in a significant reduction of the night accident rate.

10–03.03 WARRANTING CONDITIONS – OTHER HIGHWAYS

On highways other than freeways, including expressways with partial control of access, lighting should normally be provided under any of the following conditions.

1. All streets and highways in urbanized where the adjacent existing street system is lighted.

2. At junctions of major arterials in outlying or rural areas.

3. On sections in outlying and rural areas having ratios of night-to-day accidents higher than the average and where studies indicate the lighting may significantly reduce the night accident rate.

10—03.04 WARRANTING CONDITIONS – UNDERPASSES

1. SHORT UNDERPASSES (less than 30 meters)

Short underpasses along unlighted highways do not normally require illumination. However, when the highway is lighted the underpasses should also be lighted. For underpass lengths up to about 22 meters lighting can usually be provided from luminaires outside the underpass. For over 22 meters supplemental underpass lighting is usually required.

2. LONG UNDERPASSES (30 meters or longer)

All long underpasses require nightime illumination. They also normally require daytime illumination if their length exceeds 100 meters. Between 30 and 100 meters the possible need for daytime illumination should be analyzed. Daytime lighting is not required if the facility is straight, level and has a high width to length ratio which allows adequate daylight penetration.

10—04 ILLUMINATION DESIGN VALUES

1. HIGHWAYS

Recommended illumination values for the various highway classes through downtown, intermediate and outlying areas are shown in Table 10—1. The values given represent average footcandles on the traveled way when the lamp is at its lowest output and when the luminaire is in its dirtiest condition.

TABLE 10—1

RECOMMENDED ILLUMINATION VALUES FOR HIGHWAYS (1)
AVERAGE MAINTAINED HORIZONTAL FOOTCANDLES (2)

Highway Classification	Area Clasification (3)		
	Downtown	Intermediate	Outlying
Freeways (4)	0.6	0.6	0.6
Other Arterials (5)	0.8	0.8	0.8
Collectors	0.8	0.8	0.6
Local	0.8	0.6	0.2
Uniformity Ratio: 0.6 fc or higher — 3:1 maximum Less than 0.6 fc — 6:1 acceptable			

Notes:

(1) These guide values apply to highway sections which are generally straight and nearly level.

(2) Average illumination on the traveled way after applying the LLD (Lamp Lumen Depreciation) and (Luminaire Dirt and Depreciation).

(3) See Section 10—03 for definitions.

(4) Both mainline and ramps.

(5) Includes expressways with partial control of access.

The values in Table 10-1 are considered adequate for the safe and efficient flow of pedestrian and vehicular traffic under normal conditions. However, there may be specific conditions under which somewhat greater illumination may be warranted as indicated by the notes. In addition, there may be other conditions under which somewhat higher values may be desirable such as at sections with restrictive geometric features and intersections with introduced raised medians or channelizing islands. The lighting designer should consider all pertinent information in determining the lighting level to be provided for any specific highway or street section.

To insure effective visibility it is necessary to provide an adequate uniformity of illumination. The uniformity ratio, which is the ratio of the average illumination of the roadway design area between two adjacent luminaires to the lowest value at any point in the area should not exceed 3 to 1. The only exception is when an average illumination level of less than 0.2 fc is authorized when a uniformity ratio as high as 6:1 is acceptable.

2. TRANSITION LIGHTING

Where adaptation lighting is required when passing from a lighted section to an unlighted section, a transition section of about 300 meters should be provided with an illumination level of one-half the design level of the lighted section but the terminal illumination should be not less than 0.25 fc nor more than 0.5 fc.

3. UNDERPASSES

When underpass illumination is required the following should be used as a guide.

a. Short Underpasses (less than 30 meters)

If lighting is warranted, the illumination on the roadway should be no more than two times that on the roadway outside the underpass unless additional illumination is required for pedestrian and policing purposes.

b. Long Underpasses (30 meters or longer)

(1) Nightime — The average maintained illumination on the walls should be in the range of 0.7 to 2.0 fc. These values are based on a wall reflectance factor of at least 70 percent. When the reflectance factor is less than 70% the designed footcandles should be increased accordingly.

(2) Daytime — When daytime lighting is required the interior average maintained illumination on the walls should be in the range of 30 to 60 fc provided the wall reflectance factor is 70% or better.

10-05 LUMINAIRE LIGHT DISTRIBUTIONS

Luminaire light distributions are classified on the basis of three criteria by the IES. These include vertical light distribution, lateral light distribution and control of light distribution above maximum candlepower. Classification of light distribution is made on the basis of an isocandela diagram which on its rectangular coordinate grid has superimposed a series of Longitudinal Roadway Lines (LRL) identified by multiples of Mounting Height (MH) and a series of Transverse Roadway Lines (TRL) also in multiples of Mounting Height. This is illustrated in Figure 10—A.

10-05.01 VERTICAL LIGHT DISTRIBUTION

Vertical light distribution is by three groups as follows:

1. SHORT (S) — A luminaire for which the maximum candlepower point on the roadway lies between the 1.0 and the 2.25 MH-TRL grid zone.

2. MEDIUM (M) — A luminaire for which the maximum candlepower point on the roadway lies between the 2.25 and the 3.75 MH-TRL grid zone. See Figure 10—A.

3. LONG (L) — A luminaire for which the maximum candlepower point lies between the 3.75 and the 6.0 MH-TRL grid zone.

10—05.02 LATERAL LIGHT DISTRIBUTION

The various patterns of lateral light distribution are illustrated in Figure 10—B. Types I, I-4-way, and V are normally used for luminaires located near the center of the roadway and have a similar light distribution on both the house side and the street side of the reference line. These types are not normally used by the Highway Authority except for Type V which may be used on high mast designs.

Types II, II-4-way, III, and IV are used for luminaires located near the edge of the traveled way. Types II and III are the most frequently used in Highway Authority designs for conventional lighting systems.

The EIS definitions of lateral distribution types are related to the location of the 1/2 maximum candlepower isocandela trace with respect to the LRL grid and the location of the point of maximum candlepower, except for Type V, as follows:

TYPE I — Its 1/2 max. cp. isocandela trace lies within the Type I width range (See Fig. 10—A) on both sides of the reference line which is bounded by the 1.0 MH house side LRL and the 1.0 MH street side LRL within the longitudinal distribution range (S, M or L) where the point of max. cp. falls.

TYPE I — 4-way — It has four beams of the width as defined for Type I.

TYPE II — the street side segment of the 1/2 max. cp. isocandela trace within the longitudinal range (S, M or L) in which the point of max. cp. falls does not cross the 1.75 MH street side LRL. (Illustrated in Fig. 10—A)

TYPE II — 4-way — It has four beams each of the width on the street side as defined for Type II.

TYPE III — The street side segment of the 1/2 max. cp. isocandela trace within the longitudinal range (S, M or L) in which the point of max. cp. falls lies partly or entirely beyond the 1.75 MH street side LRL but does not cross the 2.75 MH street side LRL.

TYPE IV — The street side segment of the 1/2 max. cp. isocandela trace within the longitudinal range (S, M or L) in which the point of max. cp. falls lies partly or entirely beyond the 2.75 MH street side LRL.

TYPE V — Its pattern has a circular symmetry of candlepower distribution which is essentially the same at all lateral angles.

10—05.03 CONTROL ABOVE MAXIMUM CANDLEPOWER

The control of the candlepower in the upper portion of the beam above maximum candlepower is classified into three categories as follows:

CUTOFF — When the candlepower per 1000 lamp lumens, at any lateral angle around the luminaire, does not exceed 25 (2—1/2%) at an angle of 90° and 100 (10%) at a vertical angle of 80°. (See Fig. 10—A).

SEMI-CUTOFF — When the candlepower per 1000 lamp lumens, at any lateral angle around the luminaire, does not exceed 50 (5%) at an angle of 90° and 200 (20%) at a vertical angle of 80°.

LUMINAIRE LIGHT DISTRIBUTION

EXAMPLE: IES TYPE II, MEDIUM, SEMI-CUTOFF

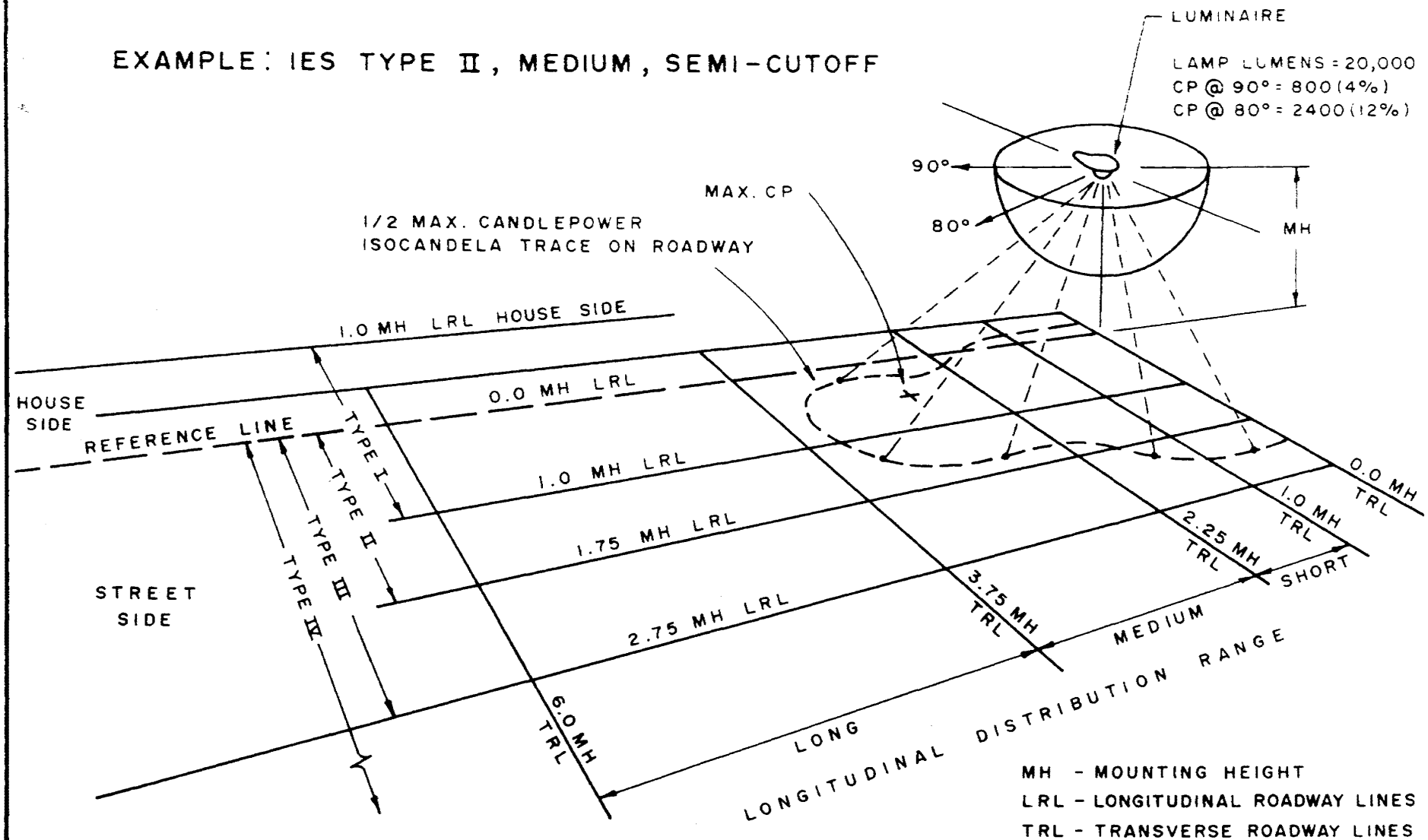
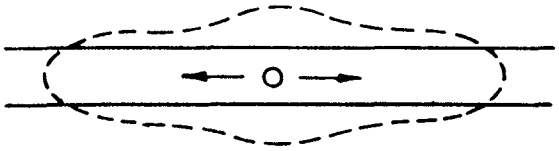
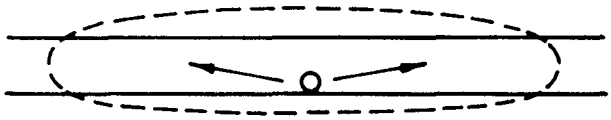


FIGURE 10-A

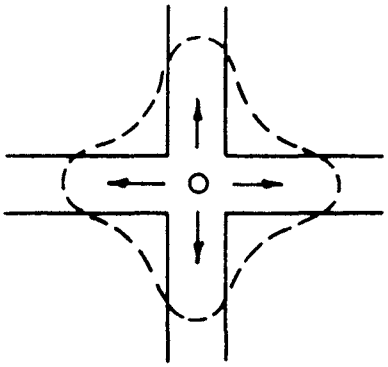
ROADWAY COVERAGE BY LUMINAIRE TYPES



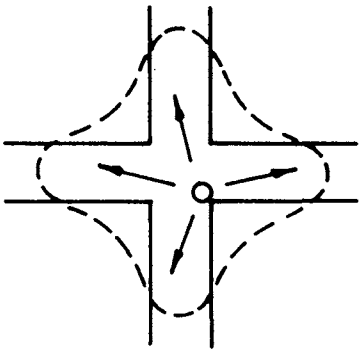
TYPE I



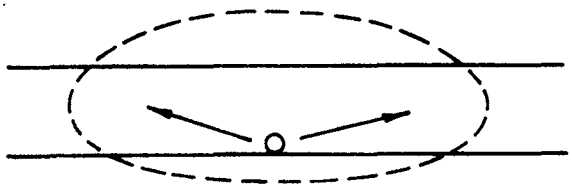
TYPE II



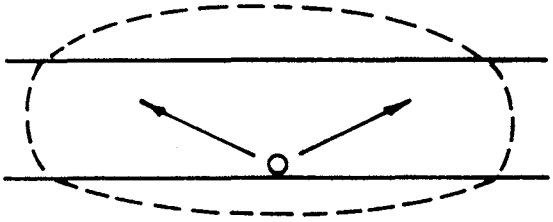
TYPE I - 4-WAY



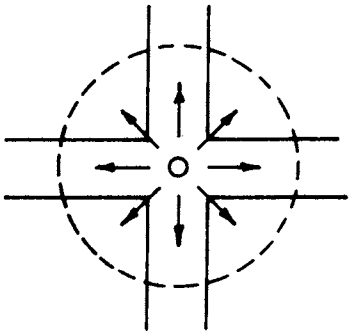
TYPE II - 4-WAY



TYPE III



TYPE IV



TYPE V

FIGURE 10 - B

NON-CUTOFF – When there is no candlepower limitation in the zone above maximum candlepower.

10-06 CONVENTIONAL LIGHTING SYSTEMS

Many alternate configurations are possible to meet the lighting requirements for a highway. This section includes a discussion of the arragements of luminaries, spacing of poles, mounting heights, luminaire types and other equipment currently in use by the Highway Authority for the design of conventional overhead lighting systems.

10-06.01 LUMINAIRE ARRANGEMENTS

The four basic types of luminaire arrangements most commonly used by the Highway Authority for conventional overhead lighting include one side, both sides-opposite, both sides-staggered and median as shown in Figure 10—C. The type of arrangement and spacing selected for a given highway section will depend primarily on the highway class, roadway width, desired level of illumination, mounting height, light source and luminaire type.

1. ONE SIDE – This arrangement is used mainly with Types II or III luminaires on ramps, frontage roads and undivided local roads and streets.

2. OPPOSITE – Used mainly with Type III or IV luminaires on multilane divided highways with wide medians.

3. STAGGERED – Used mainly with Type III or IV luminaires on multilane undivided highways or streets, and on multilane divided highways with narrow medians. This is the preferred type of arrangements for most expressways.

4. MEDIAN – Used on multilane divided urban highways, with curbed medians up to 6.0 meters in width, but on which operating speeds are normally under 35 mph. May also be used on urban expressways in special cases (see Section 10—06.03).

10-06.02 LUMINARE MOUNTING HEIGHT

The current standard mounting height of the Highway Authority for conventional lighting systems is 30 feet. However, the P.R.H.A. is considering the use of increased mounting heights to obtain increased pole spacing, better uniformity of illumination, and generally more economical and effective lighting systems.

10-06.03 POLE LOCATION AND SAFETY CONSIDERATIONS

Lighting poles constitute roadside obstacles and should be so placed and constructed as to minimize their potential hazard to out-of-control vehicles. Ideally they should be located outside of the clear roadside area, desirably at least 9 meters from the edge of the traveled way. However, this separation is not normally attainable in most installations.

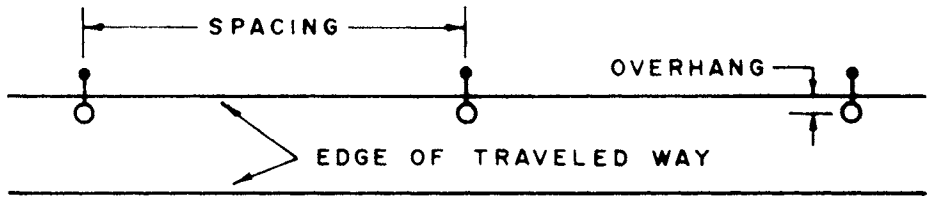
1. EXPRESSWAYS AND MULTILANE RURAL HIGHWAYS

Figure 10—D shows the normal pole locations for conventional lighting used by the Highway Authority for all expressways and rural multilane highways. These locations are also applicable to other high-speed highways where lighting is to be provided.

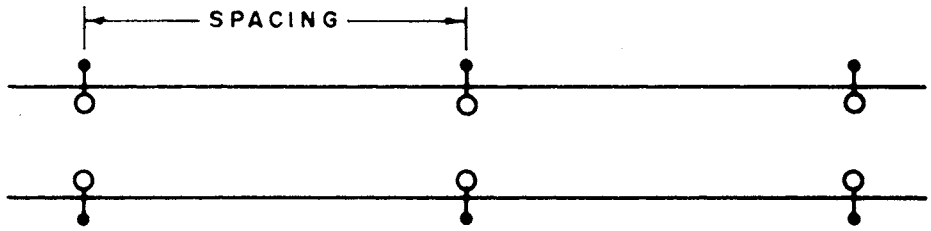
a. Mainline

Along the mainline the preferred pole location is on the right side in the direction of traffic a distance of 4.2 meters from the edge of the traveled way as shown in Figure 10—D (1). Where the shoulders are less than 3.0 meters in width and the highway section is restricted, the poles may be located closer but not less than 1.2 meters outside the normal shoulder width.

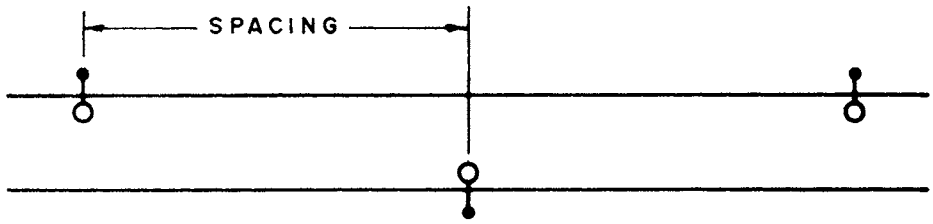
LUMINAIRE ARRANGEMENTS



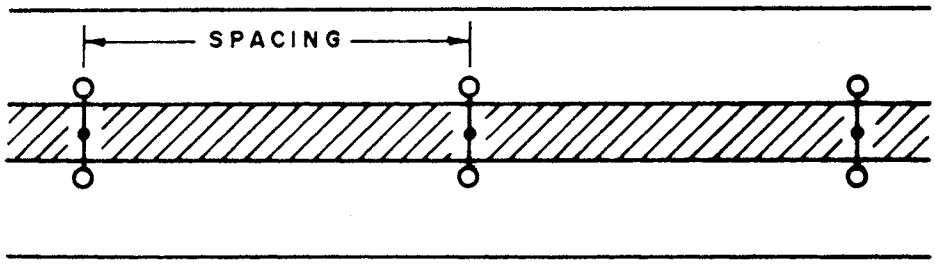
(1) ONE SIDE



(2) OPPOSITE



(3) STAGGERED

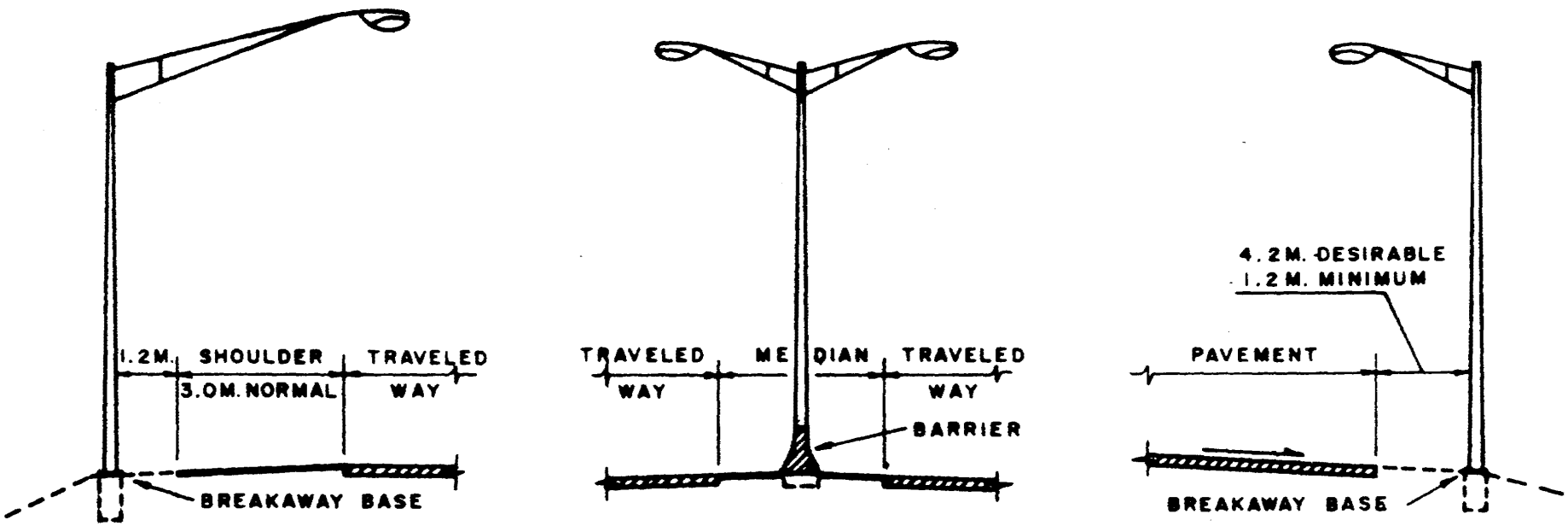


(4) MEDIAN

FIGURE 10-C

LOCATION OF CONVENTIONAL LIGHTING UNITS

ALL EXPRESSWAYS AND OTHER MULTILANE RURAL HIGHWAYS



(1) MAINLINE NORMAL INSTALLATION

(2) ALTERNATE FOR NARROW MEDIAN WITH BARRIER

(3) RAMPS

FIGURE 10-D

Although median pole location, Figure 10—D (2), normally results in lower initial construction costs, this location shall not be used unless the highway design calls for a median barrier for other safety reasons. When median location is used, the pole design must be coordinated with the barrier design to insure that the effectiveness of the barrier is not jeopardized.

Where the roadway design calls for guardrail installation adjacent to the outside shoulders, the poles shall be located at least 0.6 M. back of the guardrail. However, guardrail or other type barrier shall not be installed solely for the protection of motorists against collision with lighting poles.

All lighting poles located adjacent to the outside shoulders shall have breakaway bases. This does not permit the use of the current standard concrete poles at such locations. This requirement applies regardless of the presence of guardrail between the pole and the traveled way unless the offset between the guardrail and the post is sufficient to allow for the full deflection of the rail element under impact.

Lighting poles located in narrow medians within the barrier system should be of the rigid type since a post falling on the roadway after impact can be a great hazard to traffic.

b. Ramps

Along ramps, lighting poles should desirably be located at least 4.2 M. from the edge of the traveled way as shown in Figure 10—D (3) but where space limitations or the configuration of the roadway section do not permit it, they may be placed closer but not less than 1.2 meters from pavement (shoulder) edge. If there is guardrail provided, the poles shall be offset at least 0.6 M. back of the rail.

On tangent alignment or on curved alignment where the ramp curve radius exceeds 250 M. the lighting poles should be placed on the right side in the direction of traffic. However, along loops or curves less than 250 M. in radius, the poles should be located on the inside of the curve.

At exit ramp terminals at interchanges no lighting poles should be placed in the gore area within 15 meters of the approach nose.

c. Structures

Lighting poles on bridges and overpasses should be located either on or preferably behind the railings or parapets.

Where there are retaining walls parallel to the roadway, the lighting units should be placed either on top or on the side of the walls as appropriate for the design. Lighting poles in front of such walls should be avoided since they could increase the severity of an accident for a vehicle sliding along the wall.

2. OTHER URBAN HIGHWAYS AND STREETS

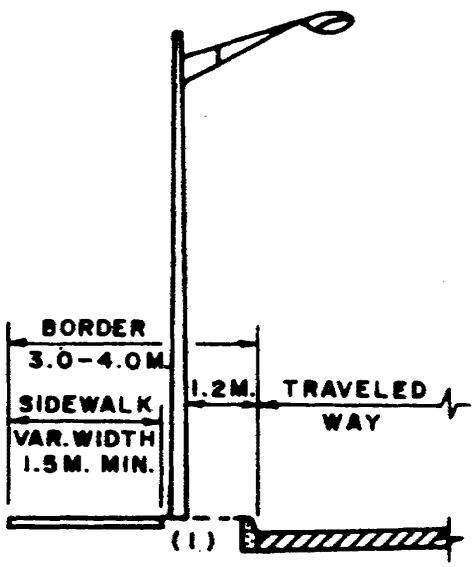
Figure 10—E shows the normal lighting pole locations on avenues, principal and local streets.

On avenues and principal streets the preferred location is along the border or house side with the pole placed at least 1.2 M. from the curb line. On avenues and divided principal streets with a median width of 4.25 M. or more, the lighting poles may be placed in the median without a barrier if normal operating speeds will not exceed 35 mph.

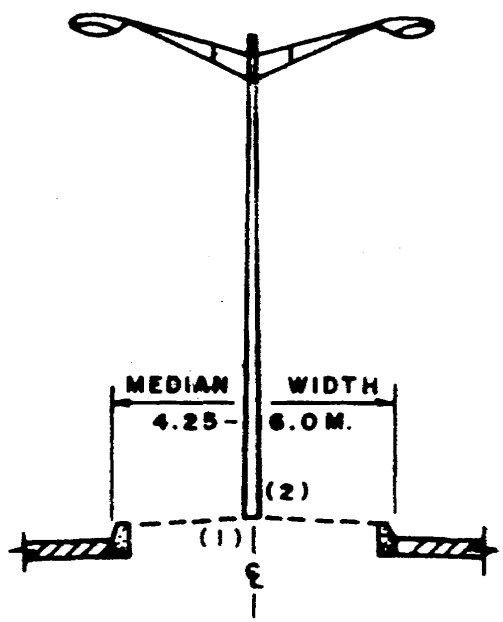
Median pole locations without a barrier are objectionable because they are exposed to the total two-way traffic flow, a pole may fall in the oppossite traffic lanes after impact, the poles are closer to the higher speed traffic of the inner lanes, maintenance operations are more hazardous, and the poles may conflict with median lanes.

LOCATION OF CONVENTIONAL LIGHTING UNITS

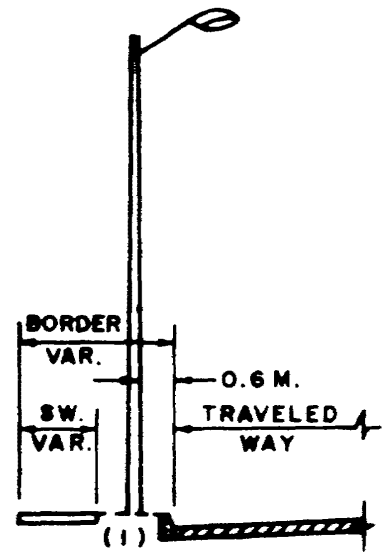
AVENUES, PRINCIPAL AND LOCAL STREETS



PREFERRED LOCATION
HOUSE SIDE



ALTERNATE LOCATION
MEDIAN



LOCAL STREETS

AVENUES AND DIVIDED PRINCIPAL STREETS

NOTES: (1) USE NON-BREAKAWAY SUPPORTS.
(2) USE BARRIER PROTECTION WHEN WARRANTED BY TRAFFIC VOLUMES AND/OR OPERATING SPEEDS.

FIGURE 10-E

On local streets the poles shall be placed at least 0.6 M. from the curb line.

All lighting poles in these facilities shall be of the non-breakaway type since a falling pole may strike pedestrians, fall on the roadway or on a building, and cause property damage.

10 06.04 LIGHTING EQUIPMENT AND INSTALLATIONS

The requirements and details on poles, brackets, luminaires, lamps, ballasts, conductors, transformers and other equipment and materials for lighting systems are covered in the specifications and standard plans of the Highway Authority and in the Public Lighting Standards Manual of the Puerto Rico Water Resources Authority.

All highway lighting systems shall be designed for underground distribution. Overhead lighting distribution will only be allowed for temporary lighting systems to illuminate detours or temporary relocations of existing lighting systems.

On all expressways the transformers should be pad mounted and installed at protected locations at least 9.0 meters from the edge of the nearest traveled way. On other streets and highways, the transformers may be pole mounted.

10-07 HIGH MAST LIGHTING

High mast lighting is the systems preferred by the Highway Authority for the illumination of major interchanges and toll plazas.

The pole or mast in current use is a weathering steel type for 80-foot mounting height. It shall be provided with a circular ring for mounting the luminaire cluster. The ring shall be provided with a suitable raise-lower device to allow the lowering of the cluster for luminaire maintenance.

High mast units should be located at not less than 9.0 meters from the edge of the nearest traveled way. If because of space limitations if becomes necessary to place them closer to the pavement, guard rail protection shall be provided. The guard rail shall be placed at a sufficient distance from the pole base to allow for the full deflection under impact of the particular guard rail design used. Normally this distance should be about 2.5 meters.

The transformers or power centers shall be pad mounted and should be placed at protected locations, at least 9.0 meters from the nearest traveled way.

10-08 UNDERPASS LIGHTING

For underpass lighting, where required, the Highway Authority normally uses clear mercury vapor wall type luminaires of 175 or 250 watts as required to provide the illumination level desired. Normal mounting height is 15 feet above the pavement.

For underpass lengths of up to 22 meters, adequate illumination can usually be provided by the outside roadway luminaires when a conventional system is used. The outside luminaires adjacent to the underpass must be properly positioned for maximum light penetration into the underpass area. This is attained by selecting a location at which the vertical angle of maximum candle power will just miss the overhead portal structure.

10-09 GENERAL ILLUMINATION DESIGN PROCEDURE

A basic guide for the design of highway lighting systems is provided by the "American National Standard Practice for Roadway Lighting" published by the Illuminating Engineering Society (IES). In addition, the leading manufacturers of highway lighting equipment provide technical data and publications that facilitate the design process.

10—09.01 CONVENTIONAL LIGHTING SYSTEM

The following general procedure may be followed to arrive at a satisfactory design for any specific highway section.

1. Determine the initial controlling factors which include:

   a. Level of illumination and uniformity required. See Section 10—04 and Table 10—1.
   b. Width of roadway to be illuminated.
   c. Width of shoulders or sidewalk.

2. Select a mounting height. Current Highway Authority practice is to use 30 feet.

3. Select a lamp type and wattage, and determine from manufacturer's data its initial lamp lumens and lamp lumen depreciation factor (LLD). The Highway Authority is normally requiring 400 watt lamps, HPS Code H—51.

4. Select a compatible luminaire with a light distribution type appropriate for the ratio of roadway width to mounting height of the highway section. See Section 10—05.

5. Select an appropriate luminaire arrangement. See Section 10—06.01.

6. Specify pole location. See Section 10—06.03.

7. Select bracket length to position luminaire approximately at edge of traveled way. Standard bracket lengths used by the Highway Authority are 4, 8, 12 and 15 feet.

8. Calculate the street side and house ratios for use with the utilization curves as follows:

$$\text{Street Side Ratio} = \frac{\text{Pavement Width} - \text{Luminaire overhang}}{\text{Mounting Height}}$$

$$\text{House Side Ratio} = \frac{\text{Luminaire Overhang}}{\text{Mounting Height}}$$

9. Using the above ratios determine coefficients of utilization (CU) from the utilization curve (photometric data) supplied by the manufacturer for the particular luminaire type previously selected.

10. Calculate the longitudinal spacing as follows:

$$\text{Spacing (S)} = \frac{\text{lm x CU x MF}}{\text{Average fc x Width}}$$

where lm = initial lamp lumens
CU = total coefficient of utilization (street side + house side)
MF = Maintenance factor (= LLD x LDD) Normally use values suggested in the PRWRA manual.
Average fc = level of illumination desired
Width = width to be lighted

Roundout the calculated value of S as appropirate.

11. After locating the lighting units, determine the minimum illumination at representative points using the isofotcandle diagrams for the particular luminaire type selected.

12. Adjust the minimum illumination value by the MF to correct for the effects of aging and dirt and, if necessary, by a correction factor for mounting height.

13. In determining the minimum illumination at any point be sure to add up the light contributed by the various lighting units in the vicinity of the point.

14. Calculate the uniformity ratio by dividing the average illumination by the minimum illumination.

15. If the maximum uniformity ratio allowed is exceeded, try a new spacing and compute the average illumination by the equation:

$$\text{Average fc} = \frac{\text{lm x CF x MF}}{\text{S x Width}}$$

Then repeat steps 11 through 14.

16. If a satisfactory configuration is not obtained, if may be necessary to try with a different type luminaire and/or lamp.

10—09.02 HIGH MAST LIGHTING

For high mast lighting design it is necessary to obtain the photometric data (isofootcandle and utilization curves) from the lumaire/lamp manufacturers. The following general design procedure may be followed:

1. Determine the initial controlling factors which include:

   a. Level of illumination and maximum uniformity ratio. See Table 10—1

   b. Area to be illuminated, from project plans.

2. Select the light source and mounting height. The Highway Authority is currently using 1000 W. metal halide or mercury vapor luminaires at 80-foot mounting heights.

3. Assume a number of luminaires per pole. Design a template, at the same scale as project plan, with all points on the perimeter representing the minimum initial illumination which is required from one luminaire. Use the appropriate photometric data and MF to arrive at the size of the template.

4. Cut out a number of templates. Place some first at critical areas such as gores and structures, then fill in the rest of the area so that all traveled ways are covered. Use a minimum number of templates. Make sure that the center of each, representing the lighting unit, is located no less than 9 meters from any traveled way.

5. Determine the number of templates required and the total area covered by these templates.

6. Calculate the average illumination as follows:

$$\text{Average fc} = \frac{\text{(Total Lumens) x CU x MF}}{\text{Area}}$$

where Total Lumens = (no. of Luminaires/Pole) x (Lumens/Lamp) x (no. of Poles)

7. Determine the uniformity ratio.

8. Check for conformance with required average maintained illumination and uniformity ratio. Requirements are not met, the number of luminaires per pole may have to be increased or the distribution patterns modified. Several configurations may need to be tried before arriving at the most satisfactory design. Some configurations may call for varying numbers of luminaires rather than a uniform number on all poles. Also, although symmetric (circular) distribution patterns are normally used for interchanges, some layouts may be better served by an asymmetric (elongated) design.

10—09.03 SPECIAL CONDITIONS

Whenever the construction or alteration of a highway lighting system in the vicinity of an airport is proposed, the design must be coordinated and cleared with the airport authorities to insure that the lighting installation does not violate the required airway-highway clearances and that the illumination does not interfere with the safe night operations of aircraft.

10—10 PLAN REQUIREMENTS

The construction plans for a highway lighting system shall include the following:

1. Layout of the complete system on a plan of the roadway showing the location of each lighting unit, conductors, conduits, power centers, tie to power systems, and other system appurtenances. The location of the lighting units with respect to the traveled ways shall be identified by giving the station and offset.

2. The design criteria shall be shown on the first sheet and shall include:

   a. Luminaire and lamp type and wattage
   b. Lumens
   c. Design illumination levels
   d. Uniformity ratio
   e. Luminaire mounting height
   f. Maintenance factor
   g. Photometric curve number
   h. Circuit type

3. The legend of symbols used shall also be included in the first sheet. Figure 10—F shows suggested standard plan symbols.

4. All necessary details, not covered by standard plans, of poles, brackets, pole foundations, transformers or power centers, wiring diagrams, underpass luminaire installations, and other system appurtenances.

5. Appropriate notes needed to clarify the design and installation details.

6. Signature, name and license number of the electrical engineer responsible for the design.

10—11 REFERENCES

The highway lighting designer should be familiar with and have access to the following references.

1. "American Standard Practice for Roadway Lighting", D 12.1 — 1972, Illuminating Engineering Society.

2. "An Informational Guide for Roadway Lighting", 1969, American Association of State Highway and Transportation Officials.

3. "Public Lighting Standards Manual", 1974, P.R. Water Resources Authority.

4. "Lighting of Tunnels", 1972, Illuminating Engineering Society.

5. "IES Lighting Handbook", 1972, Illuminating Engineering Society.

6. "Specifications for the Design and Construction of Structural Supports for Highway Luminaires", 1970, AASHTO. (This will be superseded by the "Standard Specification for Structural Supports for Highway Signs, Luminaires, and Traffic Signals" when approved and published by AASHTO.)

7. "Handbook of Highway Safety Design and Operating Practices", 1973, Federal Highway Administration, USDOT.

STANDARD ILLUMINATION PLAN SYMBOLS

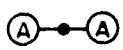
LIGHTING UNIT. LETTER DENOTES THE POLE TYPE, MOUNTING HEIGHT, LENGTH AND TYPE OF BRACKET, AND LUMINAIRE DATA AS PER NOTES.
EXAMPLE :
TYPE A – ALUMINUM POLE WITH 12 FT. BRACKET, 30 FT. MOUNTING HEIGHT, 400 W. MERCURY VAPOR LUMINAIRE – TYPE III.

EXISTING LIGHTING UNIT TO BE REMOVED.

EXISTING LIGHTING UNIT TO REMAIN.

EXISTING LIGHTING UNIT TO BE RELOCATED AS INDICATED ON PLANS.

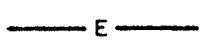
RELOCATED EXISTING LIGHTING UNIT.



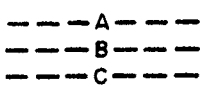
LIGHTING UNIT WITH TWO BRACKETS. LETTER DENOTES POLE TYPE, MOUNTING HEIGHT, LENGTH AND TYPE OF BRACKETS, AND LUMINAIRE DATA AS PER NOTES.

HIGH MAST LIGHTING UNIT. LETTER IDENTIFIES POLE TYPE, HEIGHT, AND LUMINAIRE DATA AS PER NOTES. ARROWS INDICATE LIGHT DISTRIBUTION ARRANGEMENT FOR ORIENTATION OF LUMINAIRES.
EXAMPLE :
TYPE A – WEATHERING STEEL POLE, 80 FT. MOUNTING HEIGHT, SIX 1000 W. TYPE IV METAL HALIDE LUMINAIRES.

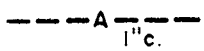
UNDERPASS LUMINAIRE. PROVIDE PERTINENT DATA ON LUMINAIRE TYPE AND MOUNTING HEIGHT.



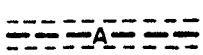
EXISTING UNDERGROUND CONDUCTOR CABLE.



UNDERGROUND CONDUCTOR CABLE TO BE INSTALLED. USE A DIFFERENT LETTER TO IDENTIFY EACH CONDUCTOR TYPE AND SHOW APPLICABLE DATA IN NOTES.



CONDUCTOR IN CONDUIT IN STRUCTURES. IDENTIFY SIZE AND TYPE OF CONDUIT.



CONDUCTOR IN CONDUIT UNDER ROADWAY. IDENTIFY SIZE AND TYPE OF CONDUIT.

JUNCTION BOX. LETTER ABOVE SYMBOL DENOTES TYPE AS PER NOTES.

POLE MOUNTED TRANSFORMER. SHOW APPLICABLE DATA.

PAD MOUNTED TRANSFORMER. SHOW APPLICABLE DATA.

FIGURE 10-F

8. Manufacturers technical literature on poles, brackets, luminaires, lamps and other lighting hardware and equipment.

Other references and guides may be found in publications of the National Cooperative Highway Research Program of the Transportation Research Board, the Federal Highway Administration, and research reports of the Texas Transportation Institute at Texas A & M University. In addition, the lighting equipment manufacturers such as General Electric, Westinghous, McGraw-Edison, and Holophane, publish reports and manuals on various aspects of highway lighting design and equipment.

This chapter is in conformance with FHWA requirements for Federal-aid projects. However, on projects that will be partly financed with Federal-aid funds the designer should consult the latest directives of the Federal Highway Administration pertaining to lighting installations.

CHAPTER 11

HIGHWAY DRAINAGE

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CHAPTER 11

HIGHWAY DRAINAGE

11–01 GENERAL

Drainage is one of the most essential elements to be considered in highway design. Inadequate drainage facilities can result in considerable damage to the highway and to adjacent properties during storm and flood conditions. The need for adequate drainage design is of particular importance in Puerto Rico since the island is highly urbanized, is exposed to relatively high rainfall intensities and severe storms, and has experienced extensive flood damage in past years.

Highway drainage includes: (1) the disposal of surface runoff from the highway section and adjacent land; (2) the provision for the flow of rivers, streams and channels crossed by the highway (cross-drainage); and (3) the control of subsurface waters that may affect the stability of the highway section and pavement structures.

The design of drainage structures should be performed by an engineer experienced in highway drainage design who has a sound working knowledge of the hydrologic and hydraulic principles involved.

The purpose of this chapter is to provide guidance on the basic policies and procedures of the Department to be followed in the design of minor drainage structures (Bridge-size structures are covered in Chapter 6) with emphasis on the hydrologic and hydraulic considerations. It includes culverts, channels and roadside ditches, storm sewers, and underdrains. It is not intended to be a complete drainage design manual but only a basic guide with references to the various design methods and tools available to the highway drainage designer.

11–02 REFERENCES

The following is a list of selected publications which will provide valuable guidance to the designer of highway drainage structures.

This chapter does not include all the detailed procedures, formulas, charts and figures needed to completely design a highway drainage system but rather refers the user to the appropriate publications. Therefore, the drainage designer should have access to and be familiar with those specific publications to which reference is made throughout the chapter.

Other publications listed below but not specifically referred to in the text provide useful information on hydrology, hydraulics and the design of drainage structures which will aid the designer in the development of his knowledge and competency in these fields. In addition, there are many good textbooks and handbooks available on the subject of hydraulic engineering. It should also be remembered that continuing research and investigagions are yielding improved data, procedures and practices for highway drainage design and the designer should be alert to new publications issued, particularly those of the Transportation Research Board and the Federal Highway Administration.

1. AASHTO, Highway Drainage Guidelines:
    a. Volume I — Guidelines for Hydraulic Considerations in Highway Planning and Location, 1973.
    b. Volume II — Guidelines for Hydrology, 1973.
    c. Volume III — Guidelines for Erosion and Sediment Control in Highway Construction, 1973.
    d. Volume IV — Guidelines for the Hydraulic Design of Culverts, 1975.

2. AASHTO, Standard Specifications for Highway Bridge, 1973 and subsequent amendments.

3. Federal Highway Administration, Hydraulic Engineering Circulars:

a. No. 1 — Selected Bibliography of Hydraulic and Hydrologic Subjects, 1970.
b. No. 3 — Hydrology of a Highway Stream Crossing, 1961.
c. No. 5 — Hydraulic Charts for the Selection of Highway Culverts, 1965.
d. No. 9 — Debris-Control Structures, 1971.
e. No. 10 — Capacity Charts for the Hydraulic Design of Highway Culverts, 1965.
f. No. 11 — Use of Riprap for Bank Protection, 1967.
g. No. 12 — Drainage of Highway Pavements, 1969.
h. No. 13 — Hydraulic Design of Improved Inlets for Culverts, 1972.
i. No. 14 — Hydraulic Design of Energy Dissipators for Culverts and Channels, 1975.
j. No. 15 — Design of Stable Channels with Flexible Linings, 1975.

4. Federal Highway Administration, Hydraulic Design Series:

a. No. 1 — Hydraulics of Bridge Waterways, 1970.
b. No. 2 — Peak Rates of Runoff from Small Watersheds, 1961.
c. No. 3 — Design Charts for Open — Channel Flow, 1961.
d. No. 4 — Design of Roadside Drainage Channels, 1965.

5. Bureau of Public Roads (now FHWA), Reinforced Concrete Pipe Culverts — Criteria for Structural Design and Installation, 1963.

6. FHWA, Corrugated Metal Pipe — Structural Design Criteria and Recommended Installation Practice, 1970.

7. FHWA, Implementation Package 73—3 — Slotted CMP Surface Drains, 1973.

8. FHWA, Computation of Uniform and Nonuniform Flow in Prismatic Conduits, 1972.

9. FHWA, Handbook of Highway Safety Design and Operating Practices, 1973.

10. FHWA, Roadside Safety Design, 1975.

11. FHWA, FA Program Manual, Vol. 6, Chap. 7, Sect. 3, Subsection 2 — Hydraulic Design of Highway Encroachment on Flood Plains.

12. U.S. Weather Bureau, Technical Paper No. 42 — Generalized Estimates of Probable Maximum Precipitation and Rainfall-Frequency Data for Puerto Rico and Virgin Islands, 1961.

13. U.S. Soil Conservation Service, National Engineering Handbook, Section 4 — Hydrology, 1972.

14. U.S. Soil Conservation Service, National Engineering Field Manual, Chapter 2 — Estimating Runoff, 1971.

15. U.S. Soil Conservation Service, SCS—TP—149, A Method for Estimating Volume and Rate of Runoff in Small Watersheds, 1973.

16. U.S. Soil Conservation Service, Technical Release No. 55, Urban Hydrology for Small Watersheds, 1975.

17. U.S. Geologic Survey, Water Resources Division (Contact P.R. Distric Office):

a. Water Resources Data for Puerto Rico, Part I — Surface Water Records. Published for 1958-63, 1964-67 and yearly from 1968 on.

b. Hydrologic Investigation Atlases covering floods in most of the major river basins of Puerto Rico.
c. A Proposed Stream Flow-Data Program for Puerto Rico (Open-file report), 1970.
d. Flood Frequencies in Puerto Rico—to be published.

18. U.S. Corps of Engineers — Flood plain information reports for various rivers in Puerto Rico. (Consult P.R. Area Office).

19. U.S. Water Resources Council - Flood Hazard Evaluation Guidelines, 1972.

20. P.R. Planning Board, Planning Regulation No. 13 — Regulation on the Control of Buildings and Land Development in Areas Susceptible to Flooding, 1971 (Spanish).

21. P.R. Planning Board, Resolution JP—211, Standards for the Design of Storm Sewer and Drainage Systems, 1975 (Spanish).

22. Transportation Research Board, National Cooperative Highway Research Program:

a. Synthesis of Highway Practice No. 3 — Traffic-Safe and Hydraulically Efficient Drainage Practice, 1969.
b. Synthesis of Highway Practice No. 5 — Scour at Bridge Waterways, 1970.
c. Report No. 108 — Tentative Design Procedure for Riprap-Lined Channels, 1970.
d. Report No. 136 — Estimating Peak Runoff Rates from Ungaged Small Rural Watersheds, 1972.

23. American Concrete Pipe Association — Concrete Pipe Design Manual.

24. American Iron and Steel Institute — Handbook of Steel Drainage and Highway Construction Products.

25. Highway Research Board — Highway Research Record No. 373, Design of Culverts, Energy Dissipators and Filter Systems, 1971.

11—03 HYDROLOGIC ANALYSIS

The design of adequate drainage for highways and across highways involves two basic steps:

1. The determination of the volume of runoff or flow rate from the area drained; that is, the hydrologic analysis which is discussed in this section. The design frequency of flow rates to be used for various drainage structures are covered in Section 11—04.

2. The determination of the geometric features and other details of the structures needed to efficiently and economically accommodate the runoff in such manner as to provide adequate protection for the public highway and abbuting properties. This is discussed in subsequent sections in this chapter.

The hydrologic analysis for a drainage facility should be commensurate with the size and characteristics of the area, and the importance of the structure. For small pipe culverts and channels draining only a very few acres the hydrology can be simple but for the larger culverts and expensive storm sewer systems a more complex and detailed analysis is required. Volume II — Guidelines for Hydrology of the AASHTO Drainage Guidelines (Ref. 1.b.) provides an excellent approach to the hydrologic analysis for highway drainage structures.

There are various sources of hydrologic data and several methods of estimating the rate of runoff or design discharge are available to the drainage designer which should be investigated during the hydrologic analysis. Rates of runoff have already been investigated and documented for a number of large drainage basins in Puerto Rico. However, for most small watersheds the designer will have to estimate the rate of runoff using one or more of the methods cited in this chapter.

11—03.01 SOURCES OF RUNOFF DATA

The following are the major sources of runoff data for Puerto Rico for use in highway drainage design.

1. Bureau of Design of the Flood Control Area, P.R. Department of Transportation and Public Works — Data is available for a number of drainage basins. In addition they have implemented computer programs for developing hydrographs and flood-frequency analyses.

2. P.R. Department of Natural Resources — Data is available on runoff for a number of drainage basins which have been compiled as part of their inventory of water resources. In addition, they have implemented a number of computer programs (available at the Computer Center of the DTPW) for hydrologic analysis such as those developed by the U.S. Soil Conservation Service and the U.S. Corps of Engineers.

3. District Office of the Water Resources Division, U.S. Geological Survey — This agency collects basic information through its hydrologic-data stations, areal hydrologic and interpretive studies, and research projects. This data is available through publications such as those indicated in Reference 17.

4. Highway Design Area of the Department of Transportation and Public Works — Runoff computations and design discharge data are available for areas studied for previous highway projects.

11—03.02 COMPUTATION OF DESIGN DISCHARGE

Prior to computing the rate of runoff or design discharge, a careful review of the drainage area and its characteristics should be made. Particular attention must be given to those factors that affect runoff such as size and shape of area, slopes, soils, geology, land use (both present and future), and natural or artificial controls. Much of the data will be available to the designer from the field surveys, topographic maps, geologic and soil maps, aerial photographs and other sources. However, a field inspection is necessary to become acquainted with the drainage and existing conditions which will have a bearing on the runoff and in the subsequent hydraulic design of the facility. Special consideration should be given in the field review to the effect that the highway and its drainage system will have on existing drainage patterns and on any future flood conditions upstream and downstream.

After the necessary information has been obtained during the office and field review, the design discharge can be calculated for each highway drainage facility. Through the years several methods for computing runoff rates have been developed by various organizations and researchers. The various methods currently in use by the Highway Design Area are described in this section. Care and sound engineering judgement must be applied in the use of these various methods. Special characteristics of an area may have a major effect in the reliability of the results as, for example, the limestone area along the north coast with its underground caves and its peculiar topography and drainage patterns.

In the design of cross drainage culverts it is recommended that two or more of the methods be used except for the smaller watersheds requiring pipe sizes of 36″ or less. A single method may be used if in the designer's judgement it is the most reliable for the particular case being studied. Design discharges computed by two methods may be reasonably close in which case an average value should be used. However, when the results differ by more than 30% further analysis should be made to determine which of the answers is more reliable.

1. RATIONAL METHOD

The rational method is used to estimate the design discharge from drainage areas of less than 200 acres (0.31 sq.mi) for the design of roadside ditches and channels, storm sewers, inlets, cross drainage structure in urban and composite areas, and erosion control structures. The rational method may also be used to check the design discharge values computed by other methods for rural watersheds of less than about 200 acres.

In special cases the rational method can provide reliable results for areas up to about 1,000 acres (1.56 sq. mi) when used with a good knowledge of the storm patterns, rainfall intensities and hydrologic characteristic of the drainage area. However, in such cases it is best to compare with some alternate method of estimation.

A good explanation on the use of the rational method for estimating the storm runoff for small drainage areas is given in the FHWA Hydraulic Design Series No. 4 (Ref. 4.d.). The rational formula is as follows:

$$Q = CIA$$

when Q = peak rate of runoff in cubic feet per second (c.f.s.).

C = weighted runoff coefficient expressing the ratio of rate of runoff to rate of rainfall.

I = average rainfall intensity, in inches per hour, for the selected frequency and for the duration equal to the time of concentration.

A = the drainage area, in acres, tributary to the point under design.

Runoff coefficients for various types of drainage area surfaces are shown in Table 11—1. In many cases the drainage area will be composed of several types of ground cover and a weighted coefficient should be computed.

The rainfall intensity for any given time of concentration from 5 minutes to 24 hours and for frequencies of from 2 to 100 years may be estimated through the use of Figures 11—A and 11—B. Figure 11—A shows the rainfall intensity — duration — frequency curves for the San Juan area. Figure 11—B is used to obtain a rainfall factor for other locations in Puerto Rico to apply to the values obtained from Figure 11—A.

The time of concentration is the time required for the surface runoff from the most remote part of the drainage area to reach the point under design. This time varies with the size and shape of the area, the land slope, the type of surface, the intensity of rainfall, whether flow is overland or channelized, and other factors. Time of concentration can be estimated by various methods such as the ones described in Reference 4.d. and in Reference 16. A value of 5 minutes is the minimum recommended for finding the intensity to be used for estimating the design discharge.

The P.R. Planning Board has adopted a method for the design of storm sewer systems in urban development projects based on the rational method which is describe in Reference 21. The designer of a storm sewer system for a highway project in an urban area or an area undergoing urban type development must insure that his estimated design discharge is no less than that required under the Planning Board's method.

2. SOIL CONSERVATION SERVICE METHOD

The U. S. Soil Conservation Service has developed a method for estimating the runoff from small watersheds, ranging in size from 5 to 2,000 acres, which is described in Chapter 2 of the SCS Engineering Field Manual (Ref. 14) and in SCS-TR-55 (Ref. 16). The SCS method provides tables and charts for a quick and reliable way to estimate peak rates of discharge for a range of rainfall frequencies considering the soil types, land use, cover condition and average slope of the watershed.

The SCS method should be used for estimating the design discharge from rural and composite drainage areas of 5 to 1,000 acres in size for the design of cross drainage structures. It may also be used to estimate the design discharge from urban areas of 200 to 1,000 acres.

The SCS method involves the use of the following factors in addition to the size of the drainage area:

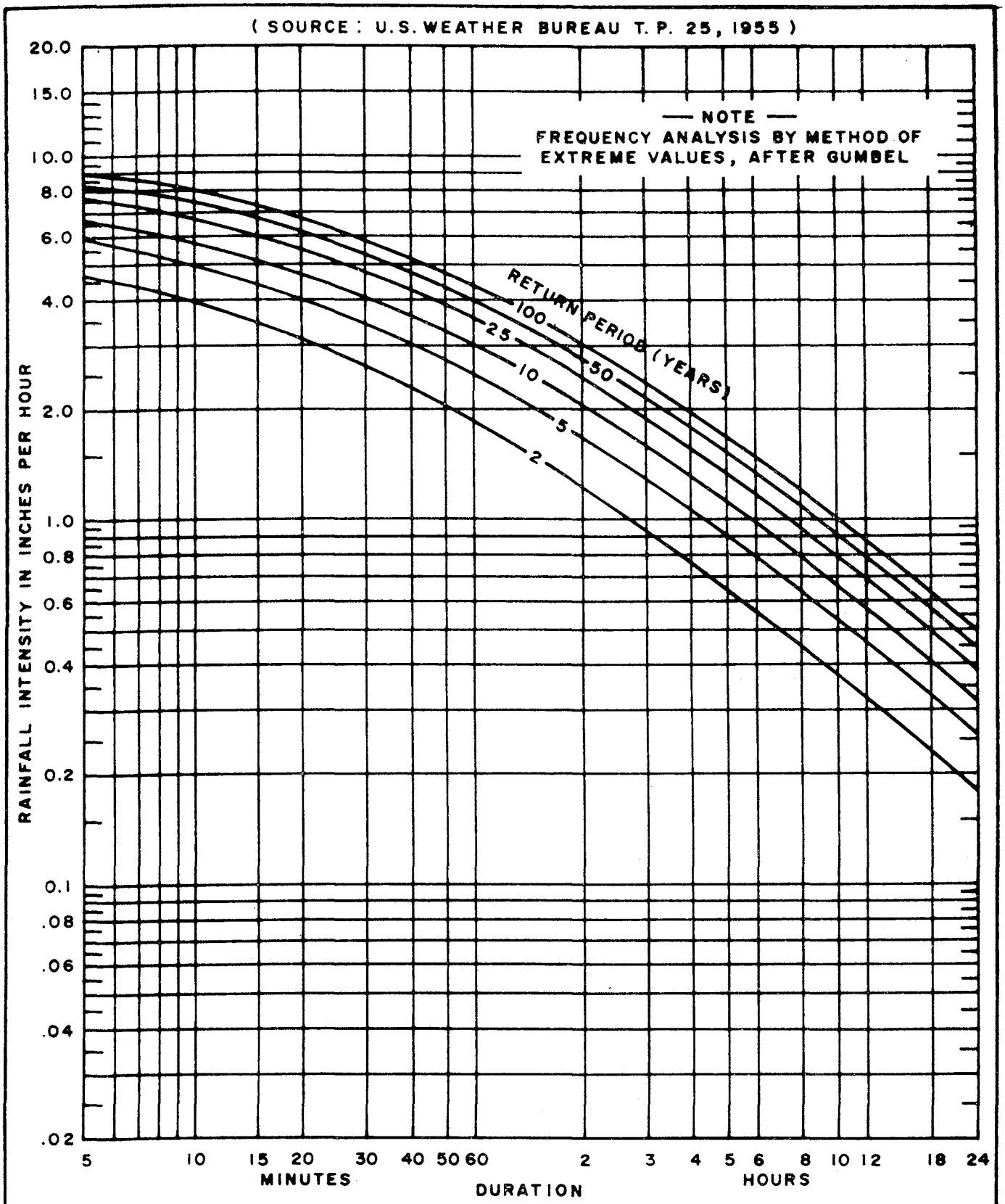
a. Hydrologic Classification of the Soils in the Drainage Area — The types of soils in the area are obtained from the soil surveys and maps published by the Soil Conservation Service. The hydrologic classification for the various soil series of Puerto Rico is shown in Table 11—2.

TABLE 11-1

RUNOFF COEFFICIENT (C) FOR USE IN RATIONAL METHOD

TYPE OF DRAINAGE AREA	RUNOFF COEFFICIENT* Min.	Max.
Rural Areas		
P. C. Concrete or Asphaltic Concrete Pavements	0.80	0.95
Crushed Stone or Gravel Roadways	0.40	0.60
Bare Earth Surfaces — Sandy Soil	0.15	0.50
—Loamy Soil	0.20	0.60
—Clayey Soil	0.30	0.80
Steep Grassed Areas (2:1 or steeper)	0.50	0.70
Pastures and Turf Meadows	0.10	0.40
Cultivated Fields	0.20	0.40
Forest Areas	0.10	0.30
Urban Areas		
Commercial and Industrial Areas	0.70	0.95
Dense Residential Areas	0.55	0.80
Suburban Residential Areas	0.40	0.65
Parks, Golf Courses, Lawns	0.15	0.40

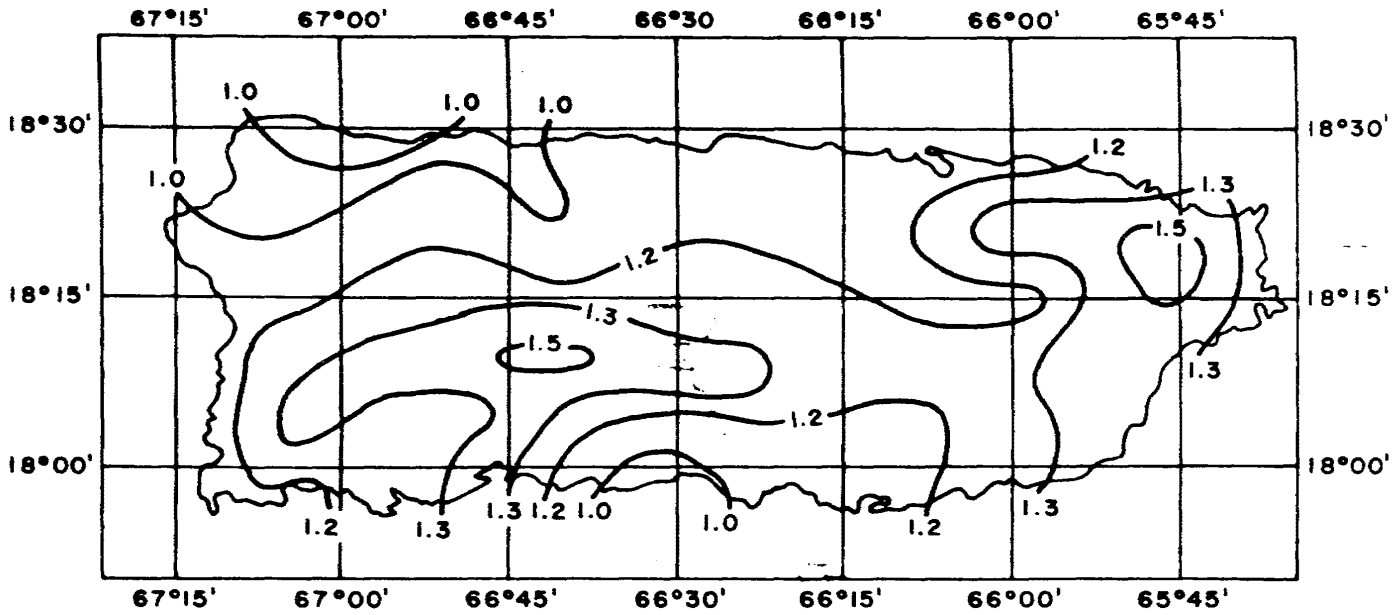
*Runoff coefficient varies with slopes and permeability of cover. For flat slopes and/or permeable soils use the lower values while for the steeper slopes and/or impervious soils use the higher values.



RAINFALL INTENSITY-DURATION-FREQUENCY CURVE

FOR SAN JUAN, P. R. (1931-1950)

FIGURE 11-A



NOTE — FOR VIEQUES USE 1.3 , FOR CULEBRA USE 1.0

RAINFALL FACTOR MAP FOR PUERTO RICO

FIGURE II -B

b. Runoff Curve Numbers (CN's) — These are selected from Tables 11—3 and 11—4 on the basis of the land use in the area, the hydrologic classification of the soils, and, for rural areas, the hydrologic condition. The latter is primarily determined by its moisture condition at the time of the storm. A poor condition which will reflect a higher runoff should normally be used.

c. Peak Rates of Discharge Graphs — These are a series of graphs developed by the SCS that show the peak rate of discharge in c.f.s. for various 24-hr. rainfall rates for drainage areas ranging from 5 to 2,000 acres. The graphs are identified by curve numbers (CN's) 60, 65, 70, 75, 80, 85 and 90, and by average slope (flat, moderate and steep). The ES-1027 series is the one applicable to Puerto Rico. A sample graph is shown in Figure 11—C. The complete ES-1027 series consisting of 21 graphs is included in Reference 14.

d. Interpolating Factors for Slopes — The ES-1027 graphs are based on terrain slopes of 1% for flat, 4% for moderate, and 16% for steep. In order to obtain a closer estimate of the peak discharge, the graph values should be corrected by applying the interpolating factors shown in Table 11—5 as indicated by the example given.

e. Storm Frequency — The rainfall curves in the ES-1027 graphs to be used for the design of a specific culvert shall be the 24-hr. rainfall of the specified design frequency. This data can be obtained from the U.S. Weather Bureau Technical Paper No. 42 (Ref. 12) which includes 24-hr. rainfall maps for Puerto Rico for frequency or return periods of 1, 2, 5, 10, 25, 50 and 100 years. The maps for the 10, 25 and 50-year frequencies, the most commonly used in highway culvert design, are reproduced in Figure 11—D.

A computation sheet for estimating the design discharge by the SCS method and an illustrative example are shown in Figure 11—E.

3. HYDROGRAPHS

For areas in excess of 1,000 acres the hydrologic analysis should include the development of a hydrograph which will show the design storm runoff rate as a function of time and provides the peak rate of flow for the point under study. Several computer programs have been formulated for developing hydrographs. Some of these have been adopted and implemented by the Department's Flood Control Area and by the Department of Natural Resources, and are available at the Department's Computer Center. A detailed description of the use of these computer programs is beyond the scope of this manual. The designer should refer to the previously mentioned agencies for advice and assistance on their application.

TABLE 11—2

HYDROLOGIC CLASSIFICATION OF SOIL SERIES PUERTO RICO

(Source — U. S. Soil Conservation Service)

Aceitunas	B	Cuchillas	D	Lirios	B
Adjuntas	C	Cuyón	A	Llanos	C
Aguadilla	A	Daguao	C	Los Guineos	C
Aguilita	B	Dagüey	C	Mabí	D
Aguirre	D	Delicias	B	Machete	C

Aibonito	C
Algarrobo	A
Almirante	B
Alonso	B
Amelia	B
Anones	C
Arecibo	A
Arenales	A
Bajura	D
Bayamón	B
Bejucos	B
Cabo Rojo	C
Caguabo	D
Callabo	C
Camagüey	D
Candelero	C
Caracoles	D
Carrizales	A
Cartagena	D
Catalina	B
Cataño	A
Cayagua	C
Ciales	D
Cidral	C
Cintrona	D
Coamo	C
Colinas	B
Coloso	D
Consejo	C
Constancia	D
Consumo	B
Córcega	C
Corozal	C
Corozo	A
Cortada	B
Cotito	C
Coto	C
Reparada	D
Río Arriba	D
Río Lajas	A
Río Piedras	B
Rosario	C
Sabana	D
Sabana Seca	D
Saladar	D
San Antón	B
San Germán	D
San Sebastián	B
Santa Clara	C
Santa Isabel	D

Descalabrado	D
Dique	B
Durados	A
Ensenada	B
Espinal	A
Espinosa	B
Estación	B
Fajardo	C
Fe	D
Fortuna	D
Fraternidad	D
Garrochales	D
Guamaní	B
Guanábano	B
Guanajibo	C
Guánica	D
Guayabo	B
Guayabota	D
Guayama	D
Guerrero	C
Humacao	B
Humatas	C
Igualdad	D
Ingenio	C
Islote	B
Jacaguas	B
Jácana	D
Jagüeyes	B
Jareales	D
Jaucas	A
Jobos	C
Juana Díaz	B
Juncal	C
Juncos	D
Junquitos	C
Lares	C
Limones	B
Santa Marta	C
Santoni	D
Serrano	D
Soller	D
Sosa	C
Talante	D
Tanamá	D
Teja	D
Teresa	D
Tiburones	D
Toa	B
Torres	A
Tuque	B

Machuelo	D
Maguayo	D
Malaya	D
Maleza	B
Maní	C
Maragüez	B
Maresúa	B
Mariana	C
Maricao	B
Martín Peña	D
Matanzas	B
Maunabo	D
Mayo	B
Meros	A
Moca	D
Montegrande	D
Morado	C
Múcara	D
Naranjito	C
Naranjo	C
Nipe	B
Palmarejo	C
Palmas Altas	D
Pandura	D
Parasol	B
Parcelas	D
Paso Seco	D
Patillas	B
Pellejas	B
Perchas	D
Picacho	C
Piñones	D
Plata	B
Ponceña	D
Pozo Blanco	B
Quebrada	C
Reilly	A
Utuado	B
Vayas	D
Vega Alta	C
Vega Baja	C
Vía	B
Vieques	B
Vigía	D
Vives	B
Viví	B
Voladora	B
Yauco	C
Yunes	D
Yunque	C

Definitions of Hydrologic Groups:

A— (Low runoff potential) — Soils that have high infiltration rates even when wetted. They consist chiefly of deep, well to excessively drained sands and gravels. These soils have a high rate of water transmission.

B— Soils that have moderate infiltration rates when thoroughly wetted. They consists chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

C— (Moderately high runoff potential) — Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, soils with moderately fine to fine texture, or soils with moderate water tables. These soils may be somewhat poorly drained.

D— (High runoff potential) — Soils that have very slow infiltration rates when thoroughly wetted. They consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

In addition, the designer may refer to appropriate publications of the U.S. Soil Conservation Service, the U.S. Geological Survey and the U.S. Corps of Engineers covering the various computer programs developed by these agencies.

4. U.S. GEOLOGICAL SURVEY REGRESSION EQUATION

The USGS Water Resources Division has developed a regression equation that can be used to compute the flow properties at any point on natural streams in Puerto Rico within standard errors of estimate and subject to certain limitations. The analysis is described in Reference 17.c.

The regression equations for peak flows of 10, 25, 50 and 100 year frequency are as follows:

$$Q_{10} = 2230\ (A)^{0.60} \qquad Q_{50} = 3230\ (A)^{0.71}$$

$$Q_{25} = 2840\ (A)^{0.66} \qquad Q_{100} = 2900\ (A)^{0.78}$$

where A is the drainage area in square miles.

The regression equation may be used to check design discharges estimated by hydrographs or other methods for areas from 1.3 to 200 sq. mi. in size except in the north coast limestone area and in small drainage basins at elevations lower than 500 meters. It is not to be used as the only method of estimation.

5. ANALYSIS OF EXISTING CHANNELS AND STRUCTURES

An approximation to the maximum discharge of a stream that has a well defined channel can be made through a hydraulic analysis if the high water elevations can be determined from existing records and/or field inspection. The calculations involve the use of the Manning equation and require a determination of the cross sectional area of flow, the hydraulic radius, the roughness coefficient and the hydraulic slope. The designer may refer to References 4.a. and 4.d. for procedures.

If there is an existing structure at or near the site, the peak discharge may be similarly estimated through a hydraulic analysis. The information needed is the approximate depth of the headwater, the approximate depth of the tailwater, and the type, size and slope of the existing structure. The analysis can follow the design procedure given in Hydraulic Engineering Circulars Nos. 5 and 10 (References 3.c. and 3.e.)

After estimating the peak discharge for a well defined channel or an existing structure, the question of frequency may remain. This will require an analysis of dates obtained from field interviews and correlation with available records for the general area to estimate the frequency. Adjustments to the estimated discharge may then be necessary to provide for the desired design frequency.

TABLE 11–3

RUNOFF CURVE NUMBERS (CN's) FOR GENERAL AGRICULTURAL AREAS PUERTO RICO

AREA DESCRIPTION	HYDROLOGIC CONDITION	HYDROLOGIC SOIL GROUP			
		A	B	C	D
Fallow	—	77	86	91	94
Minor Crop					
Contour	—	65	75	82	86
Minimum Tillage	—	70	79	84	88
Conventional	—	72	81	88	91
Sugar Cane					
Straight Row	Mulch	44*	66	77	82
Straight Row	Burned	46*	67	78	83
Contour	—	32*	58*	72	79
Coffee					
No cover	—	48*	68*	79	83
Cover	—	32*	52*	68	75
Pasture or Range	Poor	68	79	86	89
	Fair	49*	69	79	84
	Good	39*	61	74	80
Woods	Poor	45*	66	77	83
	Fair	36*	60	73	79
	Good	25*	55*	70	77
Farm Yards	—	59*	74	82	86
Roads (Including ROW)					
Dirt	—	72	82	87	89
Hard Surface	—	74	84	90	92

* Use a CN value of 60 for these conditions unless the area warrants computing the peak discharge by special procedures.

TABLE 11–4

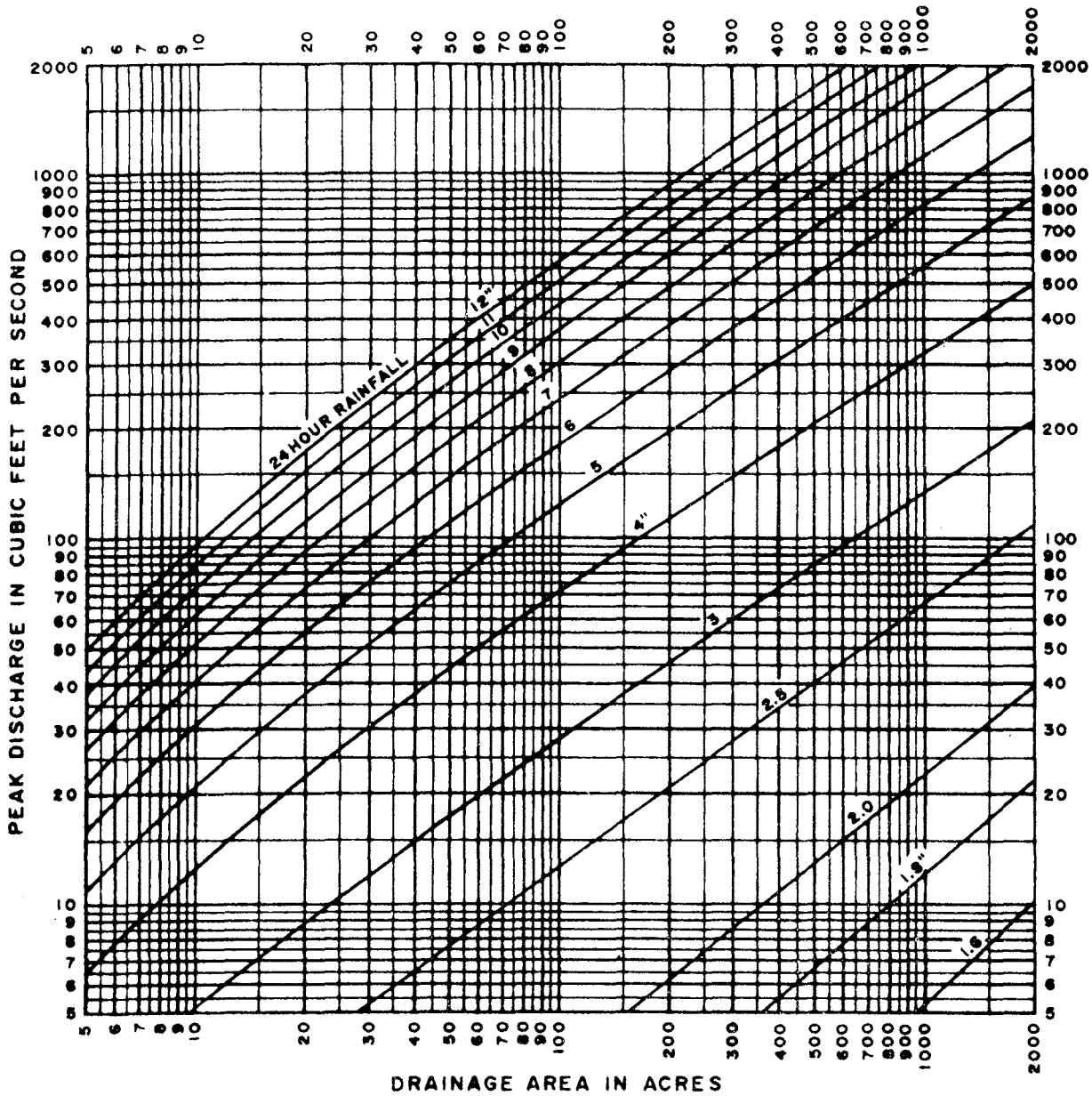
RUNOFF CURVE NUMBERS (CN's) – URBAN AREAS)

AREA DESCRIPTION	HYDROLOGIC SOIL GROUP			
	A	B	C	D
Newly graded area — no vegetation	81	89	93	95
Lawns, parks, golf courses, cemeteries, etc. — vegetation established	39*	61	74	80
Row houses, town houses, and residential with lots under 500 Sq. M.				
No vegetation	93	96	97	98
Vegetation established	80	85	90	95
Pavements and Roofs — Commercial and Industrial areas	98	98	98	98
Residential by lot sizes				
1000 Sq. M. — no vegetation	88	93	95	97
(1/4 acre) — vegetation established	61	75	83	87
2000 Sq. M. — no vegetation	85	91	94	96
(1/2 acre) — vegetation established	53*	70	80	85
4000 Sq. M. — no vegetation	82	90	93	95
(1 acre) — vegetation established	60	68	79	84
8000 Sq. M. — no vegetation	81	89	92	94
(2 acres) — vegetation established	47*	66	77	81

* Use CN value of 60.

SLOPES - STEEP CURVE NUMBER - 65

(24-HOUR RAINFALL FROM USWB TP-42)



SOURCE: U. S. SOIL CONSERVATION SERVICE
ENGINEERING FIELD MANUAL - CHAPTER 2
STANDARD DRAWING NO. ES-1027
(ALSO INCLUDED IN SCS-TP-149)

SAMPLE CURVE FOR ESTIMATING PEAK RATES OF DISCHARGE FOR SMALL WATERSHEDS BY SOIL CONSERVATION SERVICE METHOD

FIGURE II-C

TABLE 11-5

INTERPOLATING FACTORS FOR VARIOUS SLOPES AND DRAINAGE AREAS FOR USE WITH THE SCS ES-1027 GRAPHS

Flat Slopes-round to nearest % slope shown

(Use discharge values from ES sheets labeled "Flat")

Slope %	Acres 1-50	51-500	501-2000
.1	.47	.43	.40
.2	.58	.55	.53
.3	.66	.64	.62
.4	.74	.71	.70
.5	.79	.77	.76
.7	.89	.88	.87
1.0	1.00	1.00	1.00
2.0	1.13	1.16	1.18

Moderate Slopes-round to nearest % slope shown

(Use discharge values from ES sheets labeled "Moderate")

Slope %	Acres 1-50	51-500	501-2000
3	.96	.95	.94
4	1.00	1.00	1.00
5	1.04	1.05	1.06
6	1.07	1.10	1.11
7	1.09	1.13	1.15

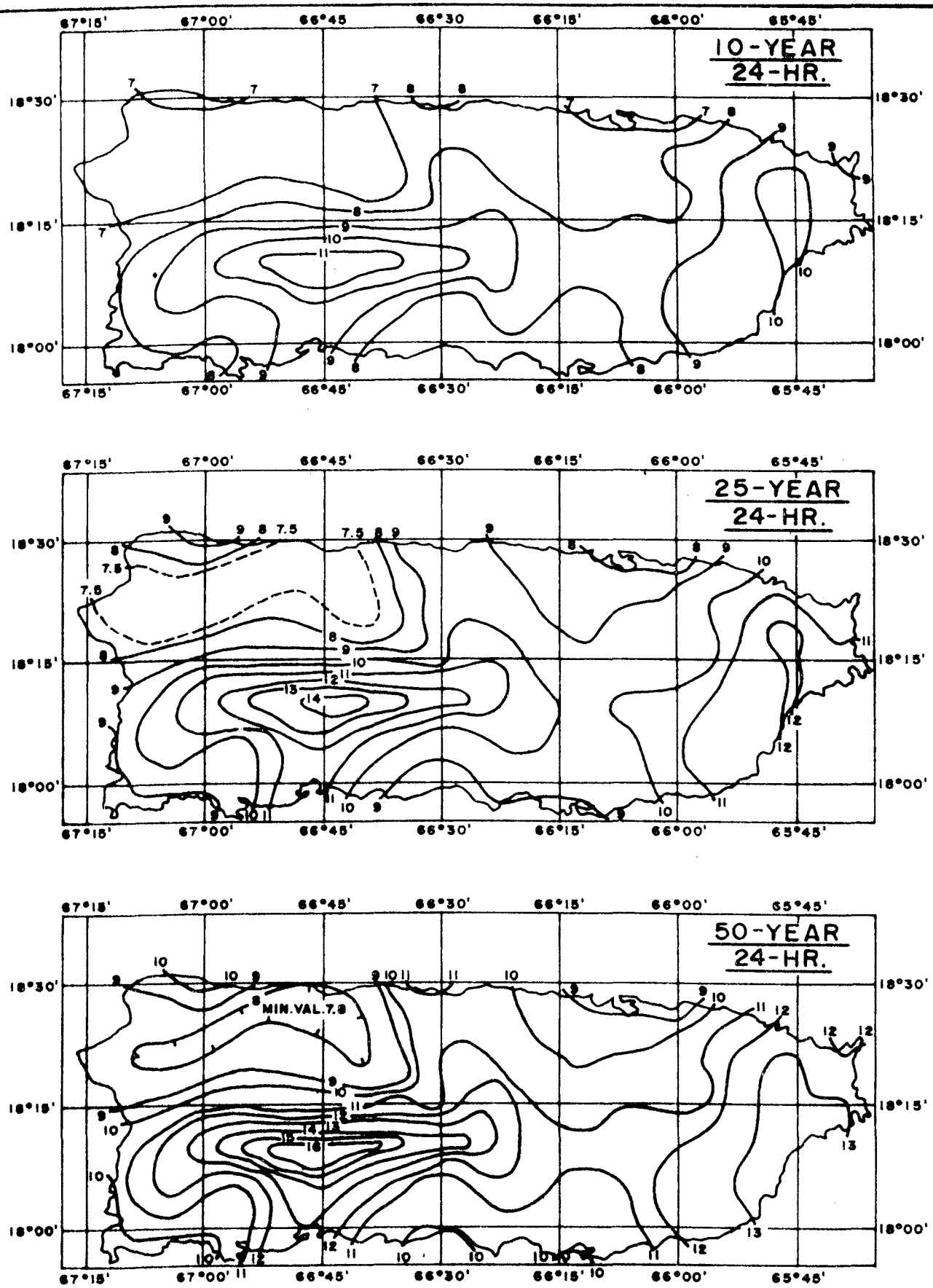
Steep Slopes-round to nearest % slope shown

(Use discharge values from ES sheets labeled "Steep")

Slope %	Acres 1-50	51-500	501-2000
8	.92	.88	.83
9	.93	.90	.85
10	.94	.91	.87
11	.95	.93	.89
12	.96	.94	.91
13	.97	.96	.94
14	.98	.97	.96
15	.99	.99	.98
16	1.00	1.00	1.00
17	1.01	1.02	1.02
18	1.02	1.03	1.04
19	1.03	1.05	1.06
20	1.04	1.06	1.08
25	1.08	1.14	1.17
30	1.11	1.20	1.23
35	1.13	1.24	1.28
40	1.16	1.29	1.33
45	1.18	1.31	1.37
50	1.21	1.34	1.40
55	1.23	1.35	1.43
60	1.26	1.37	1.46
65	1.28	1.39	1.48
70	1.30	1.40	1.50
75	1.32	1.42	1.52

EXAMPLE: Comput peak discharge for a drainage area of 400 acres with a 24-hr. rainfall of 9", an average slope of 30% and a curve number (CN) of 65.
Solution —The slope is in the steep category. From ES-1027 for Steep Slopes and CN—65 the peak discharge is 950 cfs. From above table for Steep Slopes and under 51—500 acres column, the factor for 30% slope is 1.20. Then the peak discharge is:

950 x 1.20 = 1140 cfs



10-YR., 25-YR. AND 50-YR. 24 HR. RAINFALL (IN.)

FOR PUERTO RICO

FIGURE II-D

COMPUTATION OF PEAK RATE OF DISCHARGE

(SCS METHOD FOR AREAS OF 5 TO 2,000 ACRES)

PROJECT PR-119, San Germán-Las Marías COMPUTED BY M.A.P. DATE 11/8/76

STATION Km. 11.2 CHECKED BY L.E.L. DATE 11/10/76

STREAM No name DRAINAGE AREA 152 ACRES

QUADRANGLE MAP San Germán RAINFALL FREQUENCY 25 YEARS

LATITUDE 18°-09' 24-HR. RAINFALL 11 INCHES

LONGITUDE 67°-02' AVE. WATERSHED SLOPE 20 %

1 SOIL SERIES AND HYDROLOGIC GROUP	2 LAND USE	3 TREATMENT OR PRACTICE	4 HYDRO-LOGIC COND.	5 RUNOFF CURVE NO.	6 AREA IN ACRES	7 COL. 5 X COL. 6
Consumo Clay-B	Pasture	none	Fair	69	30	2070
	Woods	none	Fair	60	122	7320
				TOTALS =	152	9392

WEIGHTED RUNOFF CURVE NO. = $\frac{\text{TOTAL COL. 7}}{\text{TOTAL COL. 6}}$ = 61.78, USE 62

Q_1 (FOR CN_1 60) = Q (ES-1027 FOR S SLOPES) X SLOPE CORRECTION FACTOR (TABLE II-5)

= 550 X 1.08 = 594 CFS

Q_2 (FOR CN_2 65) = 680 X 1.08 = 734 CFS

PEAK DISCHARGE Q = 652 CFS (INTERPOLATE BETWEEN Q_1 AND Q_2)

NOTES: Q_1 AND Q_2 ABOVE REFER TO RUNOFF FOR NEAREST CN's BELOW AND ABOVE (60-65, 65-70, ETC.) THE WEIGHTED RUNOFF CURVE NO. COMPUTED FOR THIS AREA.

RUNOFF COMPUTATION DATA SHEET

(SCS METHOD)

FIGURE II-E

11–03.03 DESIGN FLOOD FREQUENCIES

The flood frequency to be used for the computation of the design discharge for a highway drainage structure is related to the functional importance of the highway, the type and importance of the structure, and the potential flood hazards. The flood frequency used should provide sufficient safety factors to minimize damage to adjacent properties, prevent damage to the highway, and reduce to a minimum the probability of risk to the traveling public by flood waters.

The following design flood frequencies are to be followed as minimums. However, in some cases values greater than these minimums should be considered because of possible danger to life and property, the possibility of damage to the structure, and the extent and duration of traffic delays. Special conditions apply to where the highway encroaches on a flood plain; these are covered in Section 11–03.04. The classification as to urban or rural shall be based on the expected development and land uses by the design year of the highway.

1. CROSS DRAINAGE STRUCTURES – CULVERTS

a. Rural Arterials and Collectors: Use the 50-year flood. Check for the 100-year or maximum flood of record, whichever is greater, and design for it if economically feasible.

b. Local Rural Roads: The normal minimum is a 25-year frequency. A 10 to 15-year frequency may be used in special cases when justified in the hydraulic analysis on the basis of economics and minimum flood hazards to life and property.

c. Urban Highways: Use a 100-year frequency in all cases. Check for the flood of record if larger and design for it if economically justified.

2. ROADSIDE DITCHES AND CHANNELS

a. Rural and Urban Arterials: 25-year.
b. Other Highways: 10-year.

3. ROADWAY SURFACE DRAINAGE SYSTEMS

These include gutters, inlets and storm sewer systems. The design frequency applies to just full pipe flow.

a. All highways in commercial and industrial areas: 25-year.
b. Highways in Residential and Rural Areas: 10-year but 25-year for main drains.

4. UNDERPASSES AND DEPRESSED HIGHWAYS

At all underpasses and on all depressed highways where the ponded water can only be removed through a storm drainage system the following minimums apply:

a. All Arterials and Collectors: 50-year.
b. Other Highways: 25-year.

11–03.04 FLOOD PLAIN ENCROACHMENTS

Highway locations should avoid, whenever practicable, areas subject to flooding. When encroachment on a flood plain is necessary, an evaluation shall be made on the basis of the 100-year flood or the maximum flood of record, whichever is greater, of the flood hazard to the highway, the stream, the adjacent properties and the flood plain environment. Such an evaluation should consider the effects and changes in stream velocities, scour and erosion of the roadway embankment and the stream channel in order to design adequate channel and embankment protection measures.

The design of the highway encroaching on a flood plain shall preferably provide for conveyance of the 100-year or maximum flood through the highway structures unless the cost is excessive. In the latter case the design may provide for conveyance to be partially over the highway provided it can be accomplished without causing significant damage to the highway and adjacent properties.

The designer involved with locations encroaching on flood plains should review References 11, 19, and 20. He should also consult with the Flood Control Area of the Department (See Chapter 6).

11—04 DESIGN OF CULVERTS

A culvert is a conduit for the conveyance of water across an embankment. Culverts can have various shapes (circular, elliptical, arches, rectangular or box) and are made of various materials such as concrete, steel and aluminum. Normally the culvert is under an embankment and its top does not serve as a road surface; however, small bridges with total spans under 20 feet (6.1 meters) are by definition also classified as culverts.

In addition to its hydraulic function, a culvert must also carry earth and traffic loads. Therefore, culvert design involves both hydraulic and structural design aspects. This chapter is primarily concerned with the hydraulic design of culverts. For the structural design it is recommended that the designer consult References 2, 5, 6, 23 and 24.

11—04.01 GENERAL DESIGN PROCEDURE

An excellent discussion of the various factors to consider in the hydraulic design of culverts is included in the AASHTO Highway Drainage Guidelines — Volume IV (Ref. l.d.). The culvert designer should be thoroughly familiar with this publication.

Culverts should be designed to carry the design flood frequency discharge without property damage upstream or downstream from the site. They may be designed to discharge under head provided the damage criteria is not violated. The general design procedure is as follows:

1. Obtain all necessary field and office data on the location, topographic features, drainage area, channel characteristics, highwater and existing structures which will determine the design controls. A field reconnaissance should be made by the designer and is required for all large culverts to become familiar with the site conditions.

2. Compile the various design features of the roadway such as plan and profile, design class and design criteria pertinent to the selection of the culvert type (cross section, shape, material) and its alignment, length and profile.

3. Complete the hydrologic analysis including the computation of the design discharge.

4. Select the tentative culvert type and size. The Rational Equation, regression techniques and the Potter Method may be used as a guide for the selection of a tentative size. Table 11—6 shows the cross section area for circular, arch and elliptical pipe culverts of various typical sizes. For additional sizes and details the designer should consult References 23 and 24.

5. Complete the hydraulic analysis considering the possible culvert types and sizes appropriate to the design criteria, hydrologic conditions, site controls and economic considerations. Make a final selection and complete the preliminary design.

6. Final plans may be completed after the drainage report and preliminary plans have been approved by the Design Area and, in the case of Federal aid projects, by the Federal Highway Administration.

11–04.02 SELECTION OF CULVERT TYPE

The type of culvert selected shall normally be the most economical that meets the hydraulic and physical conditions at the site and the structural requirements of the installation. Factors to be considered include the available headroom, earth and traffic loads, foundation conditions, durability, abrasion and corrosion resistance requirements, rigidity, allowable headwater, shape of existing channel, velocity of discharge, presence of debris, inlet and outlet treatment, availability of type, and maintenance requirements.

Circular pipe culverts are the most common type used for small drainage areas. Pipe arches and elliptical shapes should only be used where special conditions such as limited cover or overfill preclude the use of a circular pipe. Rectangular box culverts or multiple pipe installations are used for larger drainage areas but a cost comparison between these types should normally be made.

For cross drains culverts the following minimum sizes shall apply:

Culvert Lenght	Min. Pipe Diameter
Less than 30 M.	30″
30 to 40 M.	36″
Longer than 40 M.	42″

Where minimum cover cannot be maintained the above minimum sizes may be reduced by 6 .

For Pipe installations with slopes under 1% under very high fills, the culvert pipe diameter determined from the hydraulic analysis shall be increased by 6″ if there is any possibility of settlement of the pipe under the fill.

Pipe culverts draining median inlets shall have a minimum size of 18″.

11–04.03 HYDRAULIC DESIGN

The hydraulic design shall follow the AASHTO Guidelines for the Hydraulic Design of Culverts (Ref. l.d.) and the procedures discussed in the FHWA Hydraulic Engineering Circular No. 5 (Ref. 3.c.) which includes charts for selecting a conventional culvert size for a given set of conditions. Companion publications are HEC No. 10 (Ref. 3.e.) that provides capacity charts supplementing those of HEC No. 5, HEC No. 13 (Ref. 3.h.) that covers improved inlet design, and HDS No. 3 (Ref. 4.c.) on Design Charts for Open Channel Flow. The designer should have available and be familiar with these publications.

The hydraulic design may be performed by electronic computer methods. Programs HY-4 on Hydraulics of Bridge Waterways, HY-6 on Hydraulic Analysis of Culverts (Box and Circular) and HY-2 on Hydraulic Analysis of Pipe-Arch Culverts, developed by FHWA, are available at the Department.

A suggested format for tabulating the hydraulic analysis and the selection of culvert type and size is shown in Figure 11—F. The designer shall document his design with this or a similar form, or by the computer printouts when performed by electronic computer methods.

11–04.04 CULVERT ALIGNMENT

The following principles should be observed in designing the horizontal and vertical alignment of a culvert.

TABLE 11–6

CROSS SECTION AREA OF TYPICAL CULVERT PIPES AND ARCHES

PIPE CULVERTS		PIPE ARCH CULVERTS		ELLIPTICAL PIPE CULVERTS	
DIAMETER INCHES	AREA SQ. FT.	SPAN X RISE INCHES	AREA SQ. FT.	HEIGHT X WIDTH INCHES	AREA SQ. FT.
18	1.8	22 x 13	1.6	23 x 14	1.8
21	2.4	25 x 16	2.2		
24	3.1	29 x 18	2.8	30 x 19	3.3
30	4.9	36 x 22	4.4	38 x 24	5.1
36	7.1	43 x 27	6.4	45 x 29	7.4
42	9.6	50 x 31	8.7	58 x 34	10.2
48	12.6	58 x 36	11.4	60 x 38	12.9
54	15.9	65 x 40	14.3	68 x 43	16.6
60	19.6	72 x 44	17.6	76 x 48	20.5
66	23.8	73 x 55	22	83 x 53	24.8
72	28.3	81 x 59	26	91 x 58	29.5
78	33	87 x 63	31	98 x 63	35
84	38	95 x 67	35	106 x 68	40
90	44	103 x 71	40	113 x 72	46
96	50	112 x 75	46	121 x 77	52
102	57	117 x 79	52	128 x 82	59
108	64	128 x 83	58	136 x 87	66
114	71	137 x 84	64	143 x 92	74
120	78	142 x 91	71	151 x 97	82

1. Horizontal Alignment

a. Locate the culvert along the natural channel unless and excessively long culvert on skewed alignment would be required.

b. Provide the stream with a direct entrance and exit. Avoid severe or abrupt changes in channel alignment upstream or downstream of the culvert.

c. Channel relocations required to avoid excessively long culverts should be designed to improve the channel alignment and avoid siltation and erosion problems.

2. Vertical Alignment

a. The ideal grade slope for a culvert is one that does not result in excessive velocities and scour, does not produce silting, and results in the shortest culvert length.

b. Culvert profile should follow the natural stream slope unless a modification is desired to improve hydraulic performance, shorten the culvert, reduce structural requirements, avert stream degradation or induce sedimentation.

c. Horizontal channel changes are often shorter and steeper than the natural channel. A modified culvert slope can be used in such cases to provide a flatter gradient in the new channel so that channel degradation may be avoided.

PROJECT: _____ DESIGNED BY _____ DATE _____

CULVERT AT STA. _____ CHECKED BY _____ DATE _____

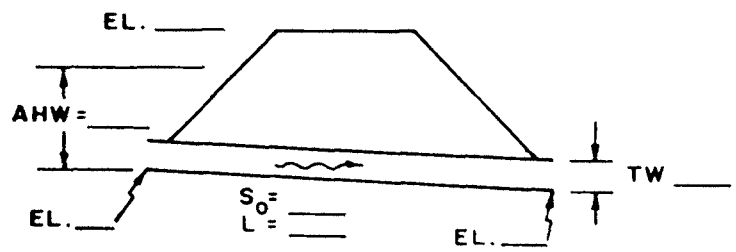
HYDROLOGIC AND CHANNEL INFORMATION

Q_1 = _____ TW_1 = _____

Q_2 = _____ TW_2 = _____

(Q_1 = DESIGN DISCHARGE, Q_2 = CHECK DISCHARGE)

SKETCH



ALLOWABLE OUTLET VELOCITY _____

CULVERT DESCRIPTION (ENTRANCE TYPE)	Q	SIZE	HEADWATER COMPUTATION										CONTROLLING HW	OUTLET VELOCITY	COST	COMMENTS
			INLET CONT.		OUTLET CONTROL $HW = H + h_o - LS_o$											
			$\frac{HW}{D}$	HW	K_e	H	d_c	$\frac{d_c+D}{2}$	TW	h_o	LS_o	HW				

SUMMARY & RECOMMENDATIONS :

CULVERT DESIGN WORK SHEET

FIGURE 11-F

11-04.05 ALLOWABLE HEADWATER

The maximum depth of water that can be tolerated at the entrance to a culvert, the allowable headwater, is determined from existing field conditions and must consider the risks of damage to human life, adjacent property, the culvert, the roadway, the stream and the floodplain environment. Therefore, the selection of the maximum allowable headwater is one of the key factors in the hydraulic design of a culvert.

In the case of low fills the allowable headwater may be controlled by the highway profile. As a general rule the maximum high water elevation should be at least 0.30 M., but preferably 0.60 M., below the outside edge of shoulder.

11—04.06 CULVERT INLET DESIGN

The inlet shape and edge geometry have a marked effect on the flow capacity of culverts operating under inlet control conditions. A poor inlet design may produce a lower maximum flow than the potential capacity of the culvert barrel. Thus, providing a more efficient inlet may allow for the use of a smaller barrel which can result in substantial savings, particularly in the case of large box culvert installations.

HEC No. 5 (Ref. 3.c.) includes a discussion of inlet edge geometry. However, the designer should refer to HEC No. 13 (Ref. 3.h.) which includes design methods and charts for improved inlets for culverts.

The Standard Model No. 4—D illustrates an improved inlet design for RC pipe culverts ranging in size up to 72" in diameter.

11—04.07 VELOCITY OF FLOW AND SCOUR

A culvert, because of its hydraulic characteristics, increases the velocity of flow over that in the natural channel. High velocity flow can cause scour at the outlet channel which may require protective measures. As an aid in evaluating this need, culvert outlet velocities should be computed.

At many locations where the outlet velocity does not substantially exceed the estimated channel velocity, the outlet end can be protected from scour by simple treatment such as the standard headwalls, cutoffs and aprons. At other locations a flatter culvert slope may be sufficient to prevent damage from scour.

When the outlet velocity greatly exceeds the maximum velocity in the downstream channel, consideration should be given to providing special energy disipation devices such as impact basins, drop structures, stilling pools and riprap basins. A thorough discussion and design procedures for energy dissipators are included in HEC No. 14 (Ref. 3.i.). Additional discussion and design data on energy dissipators are included in Reference 25. Energy dissipators are costly and, therefore, the selection and design of such a device for a particular site should be based on a thorough evaluation of the hydraulic conditions and an assessment of the seriousness of the erosion hazard.

11—04.08 DEBRIS-CONTROL STRUCTURES

Accumulation of debris at a culvert inlet will prevent the structure from performing as designed and can result in damages from innundation of the highway and upstream properties. Debris can be controlled by: (1) intercepting the debris at or upstream of the inlet, (2) deflecting the debris for detention near the inlet, (3) passing the debris through the culvert, or

(4) by providing a bridge. The choice of a method depends upon the size, quantity and type of debris; the potential hazard to life and property; the costs involved and the maintenance proposed.

A discussion of debris-control structures, basis for their selection and details of design are included in HEC No. 9 (Ref. 3.d.). Debris-control structure are not normally provided in the initial design unless the particular stream and site have a history of debris accumulation with a high potential for damage to life and property.

11–04.09 MULTIPLE BARRELS

At some locations a decision must be made on whether to use a single barrel structure or a multiple barrel structure. The decision must be based on a careful analysis of the site, the hydraulic conditions and cost comparisons.

If the allowable headwater is high, the initial design will normally require a single barrel. However, if the allowable headwater is low and is controlled by flooding of low overbank areas, the design may require a multiple barrel structure. Multiple barrels are also useful in wide channels where the constriction or concentration of flow should be kept to a minimum.

A single pipe culvert is usually more economical than the equivalent multiple pipe installation since the total pipe length is reduced by 1/2 or more. However, in the case of box culverts it is usually more economical to use a multiple barrel structure than a wide single span.

Under high fills a multiple pipe installation may be more economical than a single pipe design because the smaller pipe sizes will allow the use of a lighter metal gauge for CM pipe or a lower class for the RC pipe.

11–04.10 TRAFFIC SAFETY

Culverts should be so located and designed as to present a minimum hazard to traffic. Safe culvert ends are hard to design since they must be kept open to meet their hydraulic function. However, several measures can be taken to reduce their hazard potential. These include:

1. Culverts can be extended so that the ends are located outside the safe recovery area. That is, at least 9.0 M. from the edge of traveled way on side slope of 3:1 or flatter.

2. Headwalls should be constructed flush with the adjacent embankment to avoid a projecting fixed object.

3. Some culvert ends can be provided with traversable grates but only if the grates will not clog with debris and cause the highway to flood.

4. Guardrail protection should be provided where the culvert ends can not be located outside the safe recovery area or where traversable grates would be impractical.

Care should be excercised that any safety measures proposed do not impair the hydraulic efficiency of the culvert. The designer should refer to the NCHRP Synthesis of Highway Practice No. 3 on Traffic-Safe and Hydraulically Efficient Drainage Practice (Ref. 22.a.) and to the FHWA Handbook of Highway Safety (Ref. 9).

11–04.11 ECONOMIC ANALYSIS

The final selection of a culvert design between comparable alternate types will be based on economics. Cost analysis shall include all items pertinent to the installation in addition to cost of the culvert proper such as excavation, backfill and any special features.

Normally the basis for selection shall be the lowest initial cost unless other factors such as increased service life or reduced maintenance requirements can be documented to support the

selection of a type with a higher initial cost. Since cost estimates are usually based on previous bid unit price data susceptible to variations, total cost differences under 10% for comparable culvert types will not be considered significant.

A discussion of the economic analysis and justification for the final selection shall be included in the hydraulic report.

11–05 ROADSIDE DITCHES AND CHANNELS

Roadside ditches and channels are provided to remove or divert surface water from the highway right-of-way. These include roadway side ditches, median ditches, toe-of-slope channels, interceptor ditches and other diversion channels. The design of roadside drainage channels is well covered in the FHWA's Hydraulic Design Series No. 4 (Ref. 4.d.) which is the guide followed by the Design Area. In additon, HDS No. 3 (Ref. 4.c.) provides design charts for open-channel flow. The highway drainage designer should be familiar with and have available these two publications. The designer should also refer to References 9 and 22a. for safety aspects of roadside channel design.

11–05.01 ROADWAY SIDE DITCHES

Chapter 2 includes generalized typical sections for the various classes of rural and urban highways which illustrate minimum standard side ditches. For safety purposes, these standard roadway ditches provide a maximum inslope of 6:1 for the high-speed expressways and other multilane highways and 4:1 for other classes except for the very low-speed, low-volume local rural road classes R–10 and 11. In addition, the typical sections call for a rounding of the ditch bottom to make them more traversable by errant vehicles.

The standard ditch sections provide for a minimum depths of about one meter below the outside edge of shoulder for the higher type design classes. This depth can be sufficient to prevent saturation of the pavement subgrade provided the water flow is maintained and is disposed of at sufficiently close intervals to prevent exceeding the ditch capacity. The runoff carried by the side ditches should be checked at the outlets and compared with the ditch capacity to ascertain the adequacy of the ditch section being provided. If additional ditch depth or width is required, care should be exercised to maintain a safe traversable slope and cross section. Figure 11–G illustrates a drainage computation sheet for roadway ditches.

Where side road connections or driveways require routing the side ditch flow through a culvert, the design of the latter shall follow the normal culvert design procedure. Side ditch culverts shall be no less than 18" in diameter.

11–05.02 MEDIAN DITCHES

Median ditches are illustrated in the typical sections in Chapter 2. Median ditches normally have a limited depth and capacity because of the relatively flat slopes and swale shape used to provide a traversable median. A hydraulic analysis of the flow in the median ditch should be made to determine the drain spacing needed to control the quantity of water flowing in any one section.

Median ditches are drained through grate inlets and storm drains discharging into roadside ditches or channels. The inlet spacing is dependent on the design discharge, the longitudinal slope, the capacity of the median channel and the allowable velocity in the median channel. It is desirable to shape the median downstream from each inlet into a small dike so as to cause some ponding at the grate for a better hydraulic operation and to minimize the overflow past the inlet. However, care must be exercised to insure that the median shape remains safely traversable by errant vehicles.

DRAINAGE COMPUTATION SHEET - ROADWAY DITCHES

PROJECT _____ COMPUTED BY _____ DATE _____

STORM FREQUENCY _____ YEARS CHECKED BY _____ DATE _____

STATION TO STATION		LOCATION	AREA-ACRES		RUNOFF COEFF "C"		TOTAL C x A	TIME OF CONCENTRATION (MINUTES)	RAINFALL INTENSITY INCHES HOUR	DISCHARGE Q	CROSS SECTION OF DITCH	GRADE OF DITCH	DEPTH OF FLOW	HYDRAULIC RADIUS	MANNINGS N	MEAN VELOCITY	TYPE OF EROSION CONTROL
			PERVIOUS	IMPERVIOUS	PERVIOUS	IMPERVIOUS											

FIGURE II-G

The minimum pipe size for the storm drains from the median inlets shall be 18" diameter. Where possible a median inlet may discharge directly through a drop structure into a cross drainage culvert provided the hydraulic operation of the culvert is not adversely affected.

11-05.03 TOE-OF-SLOPE CHANNELS

Toe-of-slope channels are often required along fill sections to convey surface water to the points of disposal which are usually natural water courses. A trapezoidal section should be used for these channels with maximum side slopes of 2 horizontal to 1 vertical to prevent large flow velocities and for easier construction and maintenance.

Toe-of-slope channels should be located as far away as possible from the traveled way and outside the designated safe recovery area of 9.0 M. from the edge of pavement.

11-05.04 INTERCEPTOR DITCHES

To prevent erosion of high cut slopes it is often desirable to place interceptor ditches at the top or along the face of the cut slope. However, interceptor ditches should not be incorporated into the design without prior consultation with the soils engineer since under certain conditions they might cause slope failure and slides. Interceptor ditches should be designed to dispose of the water flow as rapidly as possible to reduce the possibility of saturation of the cut slope.

11-05.05 CHUTES

Chutes (also called flumes or spillways) are steeply inclined open or closed channels which convey collected water to a lower level. Interceptor ditches normally outlet into a chute. Median drainage outlet pipes and roadway side ditches sometimes discharge through a chute along a fill slope.

Chutes generally have steep slopes and carry water at high velocities requiring protective lining and, frequently, energy dissipators at the outlet. On long slopes, closed pipe chutes are preferred to open chutes because the water is prevented from jumping outside the channel, eroding the slope and destroying the chute.

Care must be excercised in designing the outlet from the roadside channel to the chute to insure that the water is effectively guided into the chute through a smooth transition in alignment. Similarly, sharp changes in alignment of open chutes must be avoided to prevent wave action and overtopping of the channel. In addition, the channel section and protective lining must be of sufficient size to carry the design flow with a generous freeboard allowance to insure that the chute will not be overtopped.

11-05.06 CHANNEL AND DITCH PROTECTION

Erosion of highway drainage channels is one of the most frequent problems encountered in highway construction and maintenance. Erosion and scour of the channel are likely to occur when the velocity of flow exceeds the maximum permissible velocities for the channel soil and cover. Maximum permissible velocities for various soil types and grass cover types are given in HDS No. 4 (Ref. 4.d.).

Flow velocities should be calculated for all drainage channels and ditches. If the design flow velocity does not exceed the permissible maximum for the particular soil type no special channel protection is needed other than normal seeding. However, if the velocity exceeds the maximum permissible then the design must include measures to protect the channel from erosion.

Several types of channel protective linings are available. These include sodding, jute mesh, dry rock riprap, grouted stone riprap, asphalt paving and concrete paving. Protective linings can

be very expensive and a special effort should be made to develop the most economical design for the particular location. Flexible linings of erosion resistant vegetation and rock riprap are preferred over rigid type linings such as concrete paving, and should be used whenever feasible. The designer should refer to References 3.f., 3.j., 4.c. and 4.d. for the design of channels with protective linings.

11—06 STORM SEWERS

In urban areas the removal of surface water from the highway must normally be accomplished through closed storm sewer systems. In a storm sewer system the storm runoff is routed along gutters or ditches into inlets and then conveyed through subsurface drainage structures, usually pipes, to discharge into natural streams, bodies of water, or other appropriate locations. In some areas the required storm sewer system can be very costly and may include such special items as pumping stations. It is the purpose of this section to cover only the basic design principles and standards applicable to storm sewer design.

11—06.01 GENERAL DESIGN PROCEDURE

The design of a storm sewer system includes the following basic operations.

1. Determine drainage areas and the storm flow patterns.

2. Determine inlet location and spacing as discussed in Section 11—06.03.

3. Make a preliminary plan layout of the sewer system including the location of outfalls, the direction of flow, and the location of main sewer lines and stub lines.

4. Complete the hydraulic design of the system to include the final determination of pipe sizes, locations and slopes.

11—06.02 INLET TYPES

The following are the basic types of inlets used by the Department.

1. CURB-OPENING INLETS

The curb-opening inlet is detailed in Standard Model No. 4. It is used where an inlet is required next to the traveled way on a curbed highway section because it offers little interferance to roadway traffic. At low points where the runoff approaches from both directions a double apron inlet is used.

The main disadvantage of the curb-opening inlet is that it loses capacity rapidly as the longitudinal grade increases, particularly in grades over 2%. Therefore, as the highway grade increases closer inlet spacing is required.

2. GRATE INLETS

The typical pavement grate inlet is shown in Standard Model 4—B. Other grate inlet types include S.M. 4—A for use in median ditches and S.M. 4—C for use under concrete median barriers.

Curb side grate inlets on the traveled way are highly objectionable and shall not be used on high-speed highways. Where paved shoulders are provided and curbing along the outside edge of the shoulder is required, grate inlets may be used at the back of the shoulder.

The capacity of grate inlets generally decreases with increase in longitudinal grades but to a lesser extent than for curb-opening inlets. Also, changes in pavement cross slope have a lesser effect on the capacity of grate inlets than on the capacity of curb-opening inlets. On the other hand, grate inlets are more susceptible to clogging by waterborne debris than curb-opening inlets.

3. SLOTTED CM PIPE DRAINS

Slotted CMP surface drains, detailed in S.M. 4—H, have recently been adopted by the Department for draining pavement runoff at special locations. They perform as a continous, narrow, longitudinal inlet which is very effective in intercepting sheet flow. These drains are used primarily along narrow, flush paved medians on superlevated curved sections and ramps where median barriers are installed. Their design is covered in Reference 7.

Special inlets are designed as needed by the site and hydraulic requirements of any specific location.

11—06.03 INLET LOCATION AND SPACING

The location and spacing of inlets shall be determined in accordance with the principles and design procedures discussed in the FHWA Hydraulic Engineering Circular No. 12 on Drainage of Highway Pavements (Ref. 3.g.). The designer should also refer to the P.R. Planning Board procedures and requirements included in Reference 21.

The design discharge shall be estimated using the Rational Method as covered in Section 11—03.02 of this chapter. The design frequency shall be as indicated in Section 11—03.03.

Inlet location and spacing normally require a trial and error approach because of varying grades, pavement widths and cross slopes. It is desirable to follow a tabular system to develop and document the hydraulic design. A typical inlet computation sheet is illustrated in Figure 11—I. Other tabulation formats are acceptable.

In designing the inlet locations and spacing the following principles and standards should be followed:

1. The inlet capacity governs both the rate of water removal from the gutter and the amount of water that can enter the storm-drain system. The storm sewer pipes may have ample capacity but inadequate inlet capacity and/or poor inlet spacing may prevent the system from working efficiently, causing flooding of the traveled way. Although a balanced design is the ideal, in practice it is better to have excess inlet capacity over pipe capacity than the reverse condition.

2. The inlet spacing shall be governed by the following limiting conditions on puddle encroachment on the pavement:

a. Travel lane next to curb — 4 ft. (1.2 M.) maximum encroachment or a maximum depth of flow of 4" (0.10 M.), whichever controls.

b. Parking lane next to curb — The full width of the parking lane or a maximum depth of flow of 4" (0.10 M.), whichever controls.

3. Where a grate inlet is used at the low point of a sag vertical curve it is desirable to install a grate with twice the opening of the design requirement because of the vortices and the tendency to collect trash at these low points.

4. At intersections, the location and capacity of inlets should be such as to intercept the full gutter flow before it reaches the pedestrian crosswalks.

5. At pavement superalevation transitions, inlets should be so located as to pick up the gutter flow before the cross slope becomes too flat so as to reduce water flowing across the highway.

6. Water should not be carried across intersections and should not be allowed to overflow at driveway openings where the latter are on a descending grade from the gutter.

7. In some cases the maximum distance between inlets may be controlled by the maximum spacing allowed between manholes according to size of pipe. See Section 11—06.04.

STORM SEWER COMPUTATION SHEET

PROJECT _____ COMPUTED BY _____ DATE _____

STORM FREQUENCY _____ YEARS CHECKED BY _____ DATE _____

STATION		LENGTH FEET	DRAINAGE AREA-A (ACRES)		RUNOFF COEFFICIENT C	A x C		FLOW TIME MIN.		RAINFALL INTENSITY I (IN/HOUR)	TOTAL RUNOFF A x C x I (C.F.S.)	DIAMETER PIPE INCHES	CAPACITY FULL C.F.S.	VELOCITY F.P.S.		INVERT ELEV.		MANHOLE INVERT DROP	SLOPE OF SEWER FT/FT
FROM	TO		INCREMENT	TOTAL		INCREMENT	TOTAL	TO UPPER END	IN SECTION					FLOWING FULL	DESIGN FLOW	UPPER END	LOWER END		

FIGURE II-H

INLET COMPUTATION SHEET

PROJECT _____ COMPUTED BY _____ DATE _____

STORM FREQUENCY _____ YEARS CHECKED BY _____ DATE _____

LOCATION				RUNOFF DISCHARGE							GUTTER DISCHARGE						INLET DISCHARGE						REMARKS
INLET NUMBER	STATION	ROADWAY	DISTANCE OUT	DRAINAGE AREA (ACRES)	RUNOFF COEFF. C	A x C		TIME OF CONC. (MINUTES)	RAINFALL INTENS. (IN./HR.)	DISCHARGE C.F.S.	GRADE (%)	CROSS SLOPE (FT/FT)	PREVIOUS BYPASS C.F.S.	TOT. GUTTER FLOW C.F.S.	DEPTH OF FLOW (IN. AT CURB)	WIDTH OF SPREAD (FT.)	INLET TYPE	OPENING SIZE (FT.)	INTERCEPTION C.F.S.	CARRYOVER FLOW C.F.S.	CARRYOVER FLOW	INLET INTERVAL	
						PERVIOUS & IMPERVIOUS	TOTAL																

FIGURE II-I

11 06.04 PIPE LOCATIONS, SIZES AND SLOPES

After the inlets have been located, the connecting pipe system to carry the runoff to the point or points of discharge is designed. The design follows standard procedures bases on the Manning formula. Convenient monographs and other design aids for quick direct solutions are available in such publications as HDS No. 3 (Ref. 4.c.) and HEC No. 5 (Ref. 3.c.). The design computations should be tabulated on a format such as illustrated in Figure 11—H.

The location and elevations of all existing underground utilities should be shown on the plans on which the storm sewer system is being laid out to identify and provide for any possible interferences. The storm sewer lines should be located outside roadway pavement areas to the extent feasible. The sewer lines may be located behind the curb in the planting strip area, in the median where these are wide enough to allow maintenance vehicles, or under the sidewalks. When sewer lines have to be placed under the pavement, the minimum cover required by the pipe structure used shall be checked and provided in the design. Normally, a minimum cover of at least 0.30 M. between the top of the pipe and the bottom of the pavement structure should be provided.

The minimum pipe size for all main line and laterals shall be 18". However, for short laterals less than 30 M. in length a 12" size may be used if required by limited cover space.

Minimum pipe size and slope shall be such as will provide for a minimum velocity of 3 feet per second at the design flow rate to prevent deposition of sediment. Storm sewer slopes that produce velocities in excess of 10 feet per second when flowing full should be avoided. When full flow creates higher velocities the use of drop structures should be considered.

Storm sewer systems on critical or subcritical flow are designed for full flow conditions, and with application of pressure flow when consistent with other hydraulic elements of the design. The pressure line or hydraulic gradient elevations at inlets and manholes must be determined for storm sewers on supercritical slopes, and such elevations are to be shown on the storm sewer computation sheets. The calculated water surface elevation must be kept below the top of the inlet grate or curb opening inlet lip, and at least 0.60 M. below the top of manhole covers.

The maximum length of pipe without an access structure (manhole, inlet, etc.) shall be as follows:

Pipe Diameter	Max. Distance
12"	30 M.
18" — 30"	100 M.
36" — 54"	150 M.
60" or larger	200 M.

An equivalent requirement shall apply to elliptical pipes and box culverts.

Curved alignment will be permitted only for pipe size of 48" or larger. The minimum radius permitted for curved sewer alignment, without manholes, shall be 60 meters.

11—06.05 MANHOLES

The principal purpose of manholes is to permit the inspection and cleaning of sewer lines. Standard manhole designs are detailed in Standard Models 4F, 4F—1 and 4F—2. Special types are to be designed as required.

In general, manholes are to be located at the ends of all existing and future lines and at changes in direction, size or slope of sewer lines. They are also to be located where the line

exceeds the maximum lengths specified in Section 11—06.04 unless access to the line is provided by an inlet structure.

Manholes should not be located in traffic lanes. If manholes have to be located under the pavement, care should be taken that the manhole cover is not placed in the normal wheel tracks.

11—07 SUBGRADE DRAINAGE

Effective control of ground water in highway subgrades can usually be attained through the design of suitable side ditches. On most rural highway projects the ditch depth provided by the standard ditches of the typical sections will lower the water table sufficiently to protect the base and subgrade. However, the designer should check the soils report for water table information and potential problem areas, and consult with the soils engineer on ground water control measures.

Where the grade line cuts through impervious soils of the A—6 or A—7 groups, it is usually necessary to remove these unsuitable materials to a depth of 0.3—0.5 meters and replace with a selected subgrade material. Such undercut sections require that the side ditches be low enough to drain the pervious backfill.

Subgrade drainage systems normally consist of pervious soil blankets and/or perforated pipe underdrains. Pipe underdrains must be surrounded by a filter material permeable enough to allow water and moisture to flow freely from the subsoil but which will not allow the fine soil particles to enter.

There are also available durable plastic filter fabrics which will retain the fine soil particles while allowing the passage of the ground water. These fabrics permit the design and construction of subsurface drains without pipes.

The use of underdrains is normally considered under the following conditions:

1. Where impervious material is undercut in urban type sections, underdrains are used to avoid entrapment of water entering the undercut by overhead or underground seepage.

2. Where ground water table in previous subgrade is within the stabilized area on urban type sections, underdrains are used to effect local drawdown in the pavement area.

3. Where the soil survey indicates that the roadway foundation contains seepage strata or springs, underdrains are placed at the proper elevation to intercept the ground water and convey it to the nearest outlet.

4. Where capillary water is expected to reach the pavement subbase, the water table may be lowered by means of subsurface drains.

5. In heavy cut sections where seepage from backslopes creates "sluffing", underdrains may be used to remove water before it emerges from the slope.

In all cases the Soils Engineer should be consulted on locations requiring the use of pipe underdrains or other special method of providing proper subgrade drainage to protect the roadway structure.

11—08 DRAINAGE REPORT

A drainage report shall be prepared for each project containing all pertinent design information concerning all the drainage structures and channels in the project. The report should conform to the following general outline:

1. General hydrology

   a. Design frequencies used.
   b. Methods used for determining design discharges.

c. Anticipated future development.
d. Reference to graphs, tables and other guides used to determine rainfall intensity, runoff, time of concentration, etc.
e. Any special information used by the designer establishing hydrologic criteria for the project.

2. For each culvert and channel or ditch

   a. Hydrologic data and computations including drainage area maps.
   b. Complete hydraulic design criteria, data and computations.
   c. Structural design criteria, data and computations as applicable.
   d. Basis for selection of materials and/or special features including economic comparison of alternates where applicable.
   e. Any special design considerations.

3. For storm sewer systems

   a. Basic hydrologic data, layout of system and contributing areas.
   b. Detail tabulations of the computations for gutter and inlet flow rates and spacing.
   c. Detail tabulations of the computations for hydraulic design of the pipes or other conduits.
   d. Basis for selection of materials and/or any special features if applicable.
   e. Any special design considerations.

The report should be developed as the design of the project progresses and should be cross referenced to the plans. It shall be supplemented and updated as the project design develops until the final report documents and supports the final design and plans. A complete, concise and accurate drainage report is an essential project record for future reference, particularly as a source of information for evaluation of design policies and procedures, the design of replacement structures or other structures in the vicinity, and in the event of litigation.

CHAPTER 12

SOILS

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CHAPTER 12

SOILS

12–01 GENERAL

Earth materials —soils and rock— are the principal materials utilized in the construction of most highway projects and represent a very substancial portion of the project costs. Earthwork engineering —the art of the efficient utilization of earth materials for the construction of engineering works and foundation engineering— the art of the efficient utilization of the earth for the support of engineering works, play a most important role in highway design.

The engineering properties of soils are more variable than those of any other material used in highway construction. Therefore, the study of the soils along the highway corridor is an essential part of the highway design process from early route location phase through the final construction plans phase. Soil exploration, testing and evaluation should be performed under the direction of personnel trained in soils mechanics and foundation engineering who can provide to the highway designer recommendations compatible with the specific soil and rock conditions in the project corridor. It is the responsibility of the highway designer to solicit the necessary soils data and recommendations and to incorporate these into the development of an adequate, sound and economical design.

The Soils Engineering Division of the Department's Soils and Materials Office normally provides the necessary soils study services to the Survey and Design Area. This division is staffed with trained soils engineers and geologits, and has a number of field crews equipped for soil and rock exploration work. Testing services are provided by the materials Testing Division. The services of outside geotechnical consulting firms are used when autorized by the Director of the Design Area.

This chapter is intended to acquaint the highway designer with the role of soils in the design process including general information on soils investigations and reports, soil considerations in design, and plan and specifications requirements.

12–02 SOILS INVESTIGATIONS AND REPORTS

Soil and rock surveys are made to obtain data on the subsurface materials and conditions in a project corridor. The data obtained is evaluated and its engineering significance correlated to the design of the project and presented in a report.

The extent of investigation and the detail of the evaluation and report will normally be related to the stage of project development. As the project progresses through the various phases of planning and design, the investigations and reports will become more refined and definite in scope and will include more detailed recommendations on the engineering aspects of the soil conditions in the final highway location.

12–02.01 TERRAIN RECONNAISSANCE REPORT

The development of soils information should begin during the early planning stages when a corridor has been selected and the route location and geometrics are being studied. At this stage a terrain reconnaissance report should be requested. This initial report will normally be based on a field reconnaissance and on a survey of available soils data. Subsurface explorations are not normally performed at this stage unless needed for major problem evaluation.

Sources of existing terrain data include:

1. Geologic maps and surveys published by the U.S. Geological Survey.
2. Agricultural soil maps and surveys published by the U.S. Soil Conservation Service.

3. Topographic maps published by the U.S. Geological Survey.
4. Aerial photographs.
5. Construction materials resources maps and reports published by P.R. Department of Transportation and Public Works.
6. Previous soils studies made in the corridor area by the DTPW and other agencies.
7. Geologic literature of the area published in technical and professional publications.

The initial reconnaissance report concentrates on the engineering aspects of the geology of the area under study and normally includes a geologic strip map of the corridor. Major soil and rock deposits are identified and evaluated as to engineering significance affecting highway design, construction, performance and costs. The report will include general information on such items as methods of excavation, cut and fill slopes, probable sources of borrow and aggregates, groundwater conditions stability of foundations for embankments, foundations for structures, erosion control requirements, and expected problem areas (faults, underground caves, marshes, etc.). The report may be also include recommendations on subsurface explorations, including locations and methods, that should be made prior to or during the preliminary design stage.

An example of a geologic strip map is shown in Figure 12—A. The geologic strip map also may be plotted on a topographic map or an aerial photograph of the route corridor with the various formations identified by colors.

12—02.02 PRELIMINARY SOILS REPORT

A preliminary soils survey report shall be prepared during the highway preliminary design stage. Since this stage may involve the consideration and evaluation of more than one location or alignment within the corridor, the preliminary soils survey report shall include data and recommendations on each alternate.

The highway designer will furnish the Soils Engineering Division (or the geotechnical consultant) the tentative plan and profile, typical sections, key cross sections (if available) and location of proposed structures as soon as these are available. The designer may indicate areas or items for which specific evaluations and recommendations by the soils engineer are needed.

The preliminary soil survey involves amplifying and refining the data developed in the soils reconnaissance report. At this stage subsurface explorations, if not previously made, are undertaken to the extent that all major soil and rock deposits for each alternate are identified and their basic engineering characteristics determined. Special attention is also given to any major problem areas so that possible solutions may be evaluated the preliminary soils report will cover all items previously indicated for the reconnaissance report but usually in more detail and will include the boring logs. It may also include a soils profile for each alternate under consideration on major projects.

A separate subsurface exploration report is normally prepared for each bridge and major structure site. The Bureau of Structural Design or the consultant developing the design submits a special request including a layout of the structure showing the locations of boring desired and indicating items and questions for which specific data and recommendations are desired (See Chapter 6). However, the soils engineer may alter the location and number of borings in line with his experience and judgement of the site conditions, and will include such other items in his study and report that he considers to have significance in the design of the structure and its foundations.

The preliminary soils report is made a part of the highway preliminary location and/or design report. It is one of the key factors considered in the final selection of the highway alignment, both horizontal and vertical.

TABLE 12-1

CLASSIFICATION OF SOILS AND SOIL-AGGREGATE MIXTURES

GENERAL CLASSIFICATION	GRANULAR MATERIALS (35% OR LESS PASSING 0.075 mm)							SILT-CLAY MATERIALS (MORE THAN 35% PASSING 0.075 mm)			
GROUP CLASSIFICATION	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5, A-7-6
SIEVE ANALYSIS: PERCENT PASSING:											
2.000 mm (No. 10)	50 MAX.	—	—	—	—	—	—	—	—	—	—
0.425 mm (No. 40)	30 MAX.	50 MAX.	51 MIN.	—	—	—	—	—	—	—	—
0.075 mm (No. 200)	15 MAX.	25 MAX.	10 MAX.	35 MAX.	35 MAX.	35 MAX.	35 MAX.	36 MIN.	36 MIN.	36 MIN.	36 MIN.
CHARACTERISTICS OF FRACTION PASSING 0.425 mm (No. 40):											
LIQUID LIMIT	—		—	40 MAX.	41 MIN.	40 MAX.	41 MIN.	40 MAX.	41 MIN.	40 MAX.	41 MIN.
PLASTICITY INDEX	6 MAX.		N.P.	10 MAX.	10 MAX.	11 MIN.	11 MIN.	10 MAX.	10 MAX.	11 MIN.	11 MIN.*
USUAL TYPES OF SIGNIFICANT CONSTITUENT MATERIALS	STONE FRAGMENTS, GRAVEL AND SAND		FINE SAND	SILTY OR CLAYEY GRAVEL AND SAND				SILTY SOILS		CLAYEY SOILS	
GENERAL RATING AS SUBGRADE	EXCELLENT TO GOOD							FAIR TO POOR			

* PLASTICITY INDEX OF A-7-5 SUBGROUP IS EQUAL TO OR LESS THAN LL MINUS 30.
PLASTICITY INDEX OF A-7-6 SUBGROUP IS GREATER THAN LL MINUS 30.

12—02.03 FINAL SOILS REPORT

After agreement is reached on the preliminary design the preparation of the project construction plans is initiated. Advance detail plans are first prepared and these are subsequently developed into final construction plans.

During the development of the advance detail plans the soils engineers will be requested to amplify the preliminary soils report and furnish more specific data and recommendations. The Soils Engineering Division or the geotechnical consultant shall be furnished plans, profiles, typical sections and cross sections.

At this stage, additional subsurface explorations, laboratory testing and analyses will be made to refine all subsurface information affecting the design and construction. This will include such items as embankment foundations, cut and fill slope design, top of slope ditches, benching, structure foundations, subsurface drainage, removal of unsuitable material, undercutting or special treatment of unstable materials, slope protection treatment, subbase and pavement design, topsoil sources, granular material sources, borrow sources, earthwork factors (shrinkage and swell) erosion control measures, and additional ROW requirements.

As the preparation of the final construction plans progresses, it is desirable to consult with the soils engineer on the action taken on his recommendations and suggestions, particularly on the solutions proposed for problem areas. It is recommended that the soils engineer be called on to assist in the drafting of any special construction procedures and specifications for earthwork items that may be required. The soils engineer shall furnish the final soils profile (if warranted), boring locations and data, and results from any special type subsurface explorations made for inclusion in the final plans.

12—02.04 SUBSURFACE EXPLORATION METHODS

Subsurface explorations and sampling are made by a variety of methods depending on the nature of the terrain and the intended use of the data. The methods currently in use in Puerto Rico include:

1. SIMPLE BORINGS—This is the most common method. It involves driving a pipe casing to a desired depth while recording the driving blows count, removing the loosened material from inside the casing, and sampling the material below the casing with any one of a variety of tube-like samplers. This method produces a distubed sample and is generally used for soil identification and classification purposes. The blow counts are evaluated as an indication of the properties of the soil.

2. UNDISTURBED SAMPLE BORINGS—This method is similar to simple boring except that the sample is obtained by pressing a tube into the soil to be sampled and then sealing it for transportation to the laboratory in as near an undisturbed condition as possible. The sample is can then be tested to determine the density and moisture content, strenght properties and consolidation characteristics of the soil being investigated. This method is used primarily in deposits of cohesive soils.

3. ROCK CORE DRILLING—Rock coring is performed with rotary drilling. A cylindrical sample of the rock is obtained using a sampler fitted with a cutting bit. The core sample can be examined to determine the type of rock and its condition.

4. AUGER HOLES—This involves advancing, either manually or mechanically, an auger intthe ground and then extracting a disturbed sample for identification and classification. The depth of auger exploration is limited by the material encountered and the ground water level.

5. TEST PITS—A test pit is an open excavation large enough to permit access for a man to examine the subsurface materials in their natural condition. It is used to investigate the

subsurface strata, determine groundwater conditions and sample material sources. Test pits are expensive and usually limited in depth.

6. GEOPHYSICAL METHODS—The basic principle of geophysical exploration is that changes in subsurface conditions can be detected by the nature of the physical characteristics of the material. The two methods in current use are "seismic refraction" and "electrical resistivity". These methods allow remote determination of depth to various subsurface materials and are well suited for use in areas inaccessible to other equipment. However, their use requires a good knowledge of the geology of the area and its formations, and some borings are needed for monitoring and verification due to the parameters and assumptions involved.

a. Seismic Refraction — Consists of introducing sound or vibration waves within the earth and measuring the travel time of these waves from their point of origin to detectors located at known distances from the source. The velocity of the waves is related to the various earth strata traversed.

b. Electrical Resistivity — This method is based upon the difference in electrical conductivity or resistivity of subsurface materials. It is performed by measuring the resistance of the various strata and the underlying rock to the flow of electricity.

Geophysical methods are primarily used for area surveys, to determine the presence and depth to rock, to help plan a boring program, and to supplement data obtained from drill holes.

12—02.05 SOIL PROFILE

A soil profile is a graphical representation of the subsurface materials found along the project survey or center line. A portion of a typical soil profile is illustrated in Figure 12—A.

A soil profile is really definite only at the individual boring, test pit or other point explored. The remainder is developed by the soils engineer or engineering geologist by interpolation and interpretation of the available soils and geologic data. Since subsurface explorations are time consuming and expensive, a soil profile should be developed by detailed subsurface investigations only when a determination of the continous relationship of the depth and locations of the various types of soils and rocks to the design of the project is economically justified.

Soil profiles are warranted on all major highway projects. However, the extent and spacing of subsurface exploration performed to develop the necessary data will depend on the geologic complexity of the project area, the presence of particular problem areas, and the importance of soil and rock continuity to the project design. The extent and depth of subsurface exploration and the detail of the soil profile should be enough to develop the engineering data needed to allow analysis of the items listed under Section 12—02.

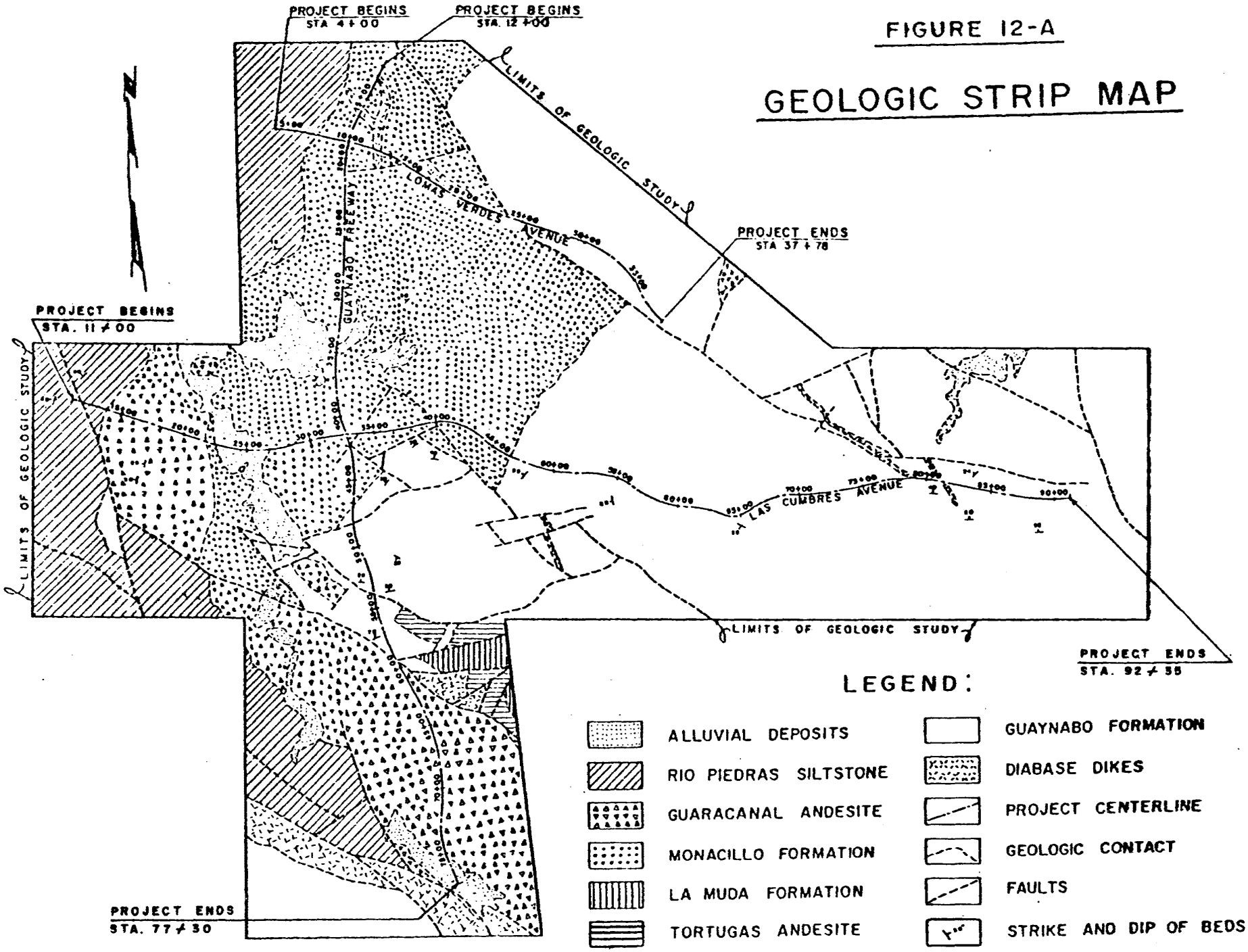
12—03 SOIL CLASSIFICATION

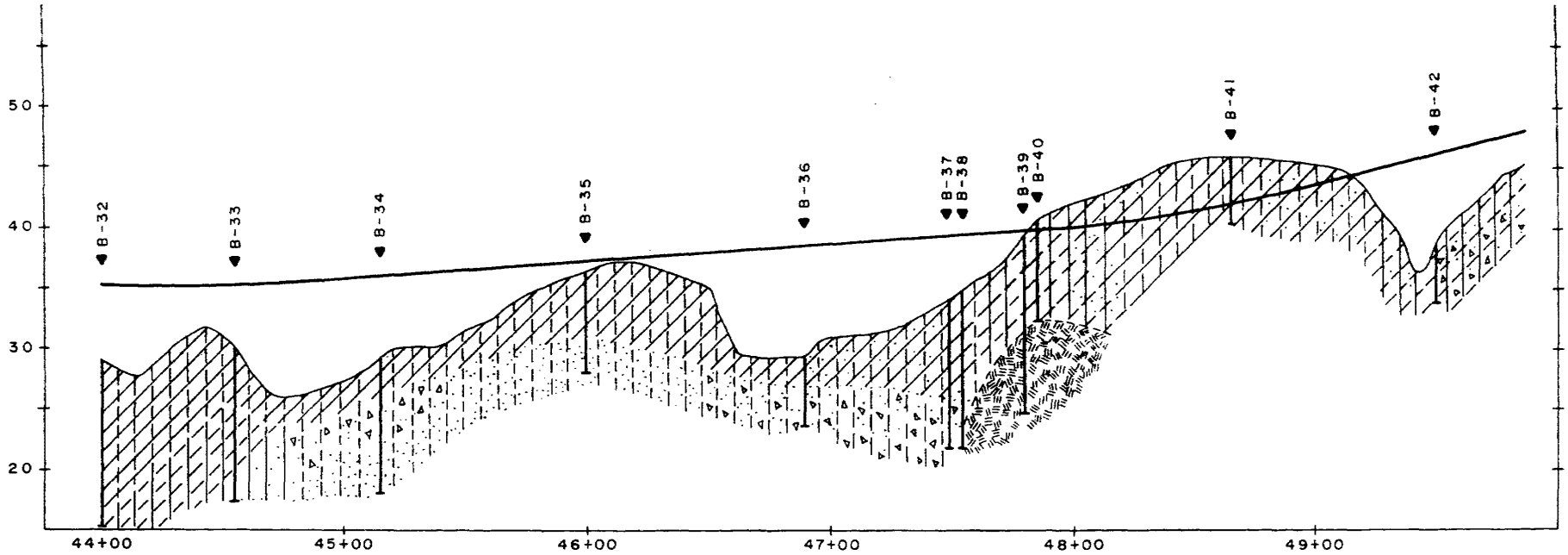
There are several soil classification systems for engineering purposes including the Unified Soil Classification System used by the U.S. Corps of Engineers and the U.S. Bureau of Reclamation, the FAA method used by the FAA for airport pavement design, and the AASHTO system which is widely used by highway engineers.

The AASHTO system, used by the Department, is based upon the observed field performance of soils under highway pavements and is described in AASHTO Specification M 145. The procedure classifies soils into seven groups based on particle-size distribution, liquid limit and plasticity index. The seven basic groups are further subdivided into twelve subgroups for more detailed classifications as shown in Table 12—1.

FIGURE 12-A

GEOLOGIC STRIP MAP





LEGEND

- SAND
- SILT
- SILTY
- GRAVEL
- CLAY
- CLAYEY
- WEATHERED ROCK OR ROCK FRAGMENTS
- SOLID ROCK

NOTE:
SEE BORING LOGS FOR MORE DETAILED DESCRIPTION OF SOILS AND ROCKS.

PORTION OF A SOIL PROFILE

FIGURE 12-8

Highly organic soils (peat or muck) may be classified on the basis of a visual inspection into an A–8 group not included in Table 12–1. These materials, composed primarily of partially decayed organic matter, are highly compressible and have low strength which makes them unsuitable for use in embankments and subgrade.

Evaluation of soils within each subgroup is further made by means of a group index value which is calculated from an empirical formula. A chart for graphically estimating the group index is included in AASHTO Specification M–145. The group index value of a soil is normally shown in parenthesis after its group classification. Group index values are useful in determining the relative quality of a soil material for use in embankments, subgrades and bases. Values range from O for good subgrade materials to over 20 for very poor materials.

12–04 SOIL CONSIDERATIONS IN DESIGN

The geophysical investigations previously described are made to define soil and rock conditions along the project so that adequate and economic solutions may be incorporated in the design. The ideal is to identify, evaluate and apply the proper solution to all soil conditions during the design stage so as to avoid, as much as possible, encountering unexpected problems during the construction stage when their solution is usually more difficult and expensive.

The following sections cover some of the soil related items that the highway designer and the soils specialists shouls be cognizant of and that should be resolved early in the development of the project plans.

12–04.01 EARTHWORK FACTORS

The highway alignment and grade line is established primarily on the basis of the applicable geometric design standards. Obtaining a balanced earthwork is a desirable secondary consideration which should be practiced provided geometric design criteria is not violated.

To complete the mass diagram and plan the earthwork movements the designer must have an estimate of the shrinkage or swell factors for excavated materials. Most soils decrease in volume when excavated and then placed in compacted fills. The shrinkage factor is the difference between the original soil volume in cut and the final volume in fill. On the other hand, rock usually increases in volume when excavated and then placed in the embankments because of the high percentage of voids; the difference is called the swell factor.

For earthwook calculations, the earthwork factor is used. This is the number by which the cut volume of a material must be multiplied to determine the embankment volume obtained. In general the earthwork factor for soils in Puerto Rico ranges from 0.70 to 0.90 while for rock it ranges from 1.00 to 1.20. However, for the same soil the earthwork factor is, as a rule, lower in value for a shallow fill than for a high fill. The designer should request the advice of the soils engineer on the earthwork factors for the various soils in the project area if these have not been included in the soils report.

12–04.02 CUTS

Because of our mountainous terrain, most rural projects in Puerto Rico, other than in the coastal plains, involve extensive cut excavation. Some of the most troublesome problems in highway construction and maintenance are encountered in cut slopes, particularly erosion and slides. Although all possible problems can not be anticipated, the soils report should include recommendations on the cut slopes that should be used for the various soils in the project and any special measures that should be incorporated in the design such as benching or serrated slopes and groundwater interception.

Locations involving sidehill cuts must be frequently used in mountainous terrain. On such locations, the direction of the inclination of the soil and rock strata should be observed and preference should be given, whenever feasible, to locating the highway where the cut will be such that any movement of the strata will tend to be into the hill rather than down the side towards the cut.

The combination of sidehill fill is generally troublesome, particularly on very steep terrain, and should be avoided to the extent possible. It is normally preferable to locate the entire roadway on the sidehill cut and avoid having it partially on a sidehill fill. Where sidehill cut and fill design must be used, benching of the natural ground should be employed to key the sidehill fill to a firm foundation and adequate drainage provisions incorporated in the design to prevent the accumulation of surface water and groundwater within the embankment.

Rock excavation is more difficult and expensive than soil excavation. However, there are some advantages to rock excavation that the designer should consider. Rock cut slopes can be steeper than soil slopes and thus rock cuts will normally require less right-of-way. In addition sound rock cuts will generally be more stable and less suceptible to erosion than soil slopes and the excavated rock may be used for the production of aggregates for the project. The design of rock cut slopes is dependent on the composition and structure of the rock which is very variable in Puerto Rico. Benches in rock cut slopes should be used only when necessary and designed according to the rock type and structural conditions. Therefore the advice of the soils engineers should be obtained for the design of the rock cut slopes and any special treatments that may be required if not included in the soils report. The use of presplitting excavation methods is very desirable but should not be specified without prior consultation with the Soils Engineering Division.

12—04.03 EMBANKMENTS

Embankment performance is associated with the stability and the deformation of both the embankment and the underlying foundations materials. Embankment failures fall into two general categories —failure within the embankment itself or failure due to poor foundation conditions. The first may be due to use of unsuitable fill materials, unsatisfactory construction methods or ineffective quality control procedures. The foundations failures are caused primarily by inadequate consideration of foundations soils, sidehill locations, cut-fill transitions and groundwater conditions.

The soil survey should provide information on which cut soils are inadequate for embankment construction and should be wasted, and which soils, although poor, may be used but requiring special treatment. It should also identify those locations where foundation problems should be expected and recommended corrective measures to avoid embankment failure.

One of the most frequent type of embankment failure is the settlement or distortion of the fill resulting from a shear failure or lateral displacement of soft foundation soils such as peats, muck and organic and inorganic silts and clays. The most common treatments used in improve soft foundation are the complete or partial removal of the unsuitable material when economically feasible. Another method is the consolidation of the soft soil layer. Consolidation can be obtained by preloading for a given length of time, if a greater shear strength is required in the same length of time or with a shorter waiting period a surcharge should be used. Sand draing may also used for this purpose and may be combined with a surcharge load.

The construction of embankments on soils of a low or poor shear strength require careful consideration. The initial inadequate shear strength of the foundation soil to carry the total embankment load will require a time-loading sequence of fill placement so as to progressively build up the soils shear strength. A toe berm should be considered in some cases to provide an additional stability during or after construction.

Excavation and replacement with a good material is the most satisfactory solution and usually the most economical when the depth of the unsuitable material does not extend more than 4 to 6 meters. The economical depth for a given site will depend on the soil type, groundwater condition and availability of replacement material. A cost comparison with other methods should be made in doubtful cases.

Consolidation in place of the poor foundation soil is a time-dependent process which requires waiting period between completion of the embankment and the construction of the pavement. The rate of settlement may be accelerated by applying a surcharge load which also helps in eliminating post-construction settlement. On certain soils the rate of settlement can be further accelerated by improving the drainage of the compressible layer by the use of sand blankets and vertical sand drains. These methods of solving settlement problems by consolidation procedures require detail laboratory testing and analysis of the soils and the design procedures and construction requirements should be developed in close coordination with the soils engineer.

12—04.04 GROUNDWATER CONTROL

Because of its erosive action and softening effects, the penetration of water into the subgrade is one of the principal causes of pavement failure. Surface waters can be satisfactorily handled through the design of adequate storm drainage systems (See Chapter II). The control of groundwater is just as important and should be given consideration during the preliminary and final design stages. Failure to provide for adequate handling of subsurface waters can prove to be disastrous and very costly in the long run.

Much less is normally known about the location of groundwaters than surface waters in the project area. However, the soils investigations should include the study of existing and potential groundwater conditions.

The soils engineer can provide valuable assistance in identifying potential problem areas and suggesting groundwater control measures.

Groundwater problems are usually encountered in cut sections, sidehill fills and cut-fill transitions. They can also develop at the low point in vertical curves, in sections with shallow ditches, on the low side of superelevated section, and/or roads underlaid with retentive subsoils.

Groundwater is normally controlled through the introduction of a subsurface drainage system. The basic purpose is to intercept and drain the groundwater away from critical areas. They are also used to intercept and lower the water table, and prevent the accumulation of groundwater in the subgrade under the pavement.

The most common subdrain systems consist of pervious blankets and/or perforated pipe underdrains. Whenever pipe underdrains are installed they must be surrounded by a pervious material which must also be capable of protecting the pipe from infiltration by the surrounding soil. When large quantities of ground water are involved, a continous pervious blanket may be more effective and economical than a pipe underdrain system.

The specific design of a subdrain systems may vary considerable as to cost and complexity depending on the topography, depth of waterbearing strata and amount of groundwater flow. The major problem is the identification of the specific problem sites and the severity of the groundwater conditions so that an effective and economical solution be designed prior to construction.

Once the grade line has been established a thorough review should be made of all locations where groundwater problems may be expected using the soil survey data and consulting with the soils engineer. The subsurface drainage system for each location should be individually

designed taking into consideration the type of soils, the location of the various strata, the presence of water in such strata and the direction of flow of the groundwater.

12–04.05 EROSION CONTROL

Cuts and fills with their exposure of bare ground present an erosion problem which can be quite serious when highly erodible soils are exposed in cuts and used in embankments.

Environmental and practical considerations require that erosion control measures be incorporated in the design for implementation during the construction phase which is normally the most critical stage for the development of erosion and pollution problems. The soils study should identify the highly erodible soils along the route location that warrant special attention by the designer.

The highway construction contracts include special provisions for temporary erosion control measures during construction aimed at protecting the project and preventing water pollution, sedimentation and ecologic damage to adjacent land and water bodies. However, much can be done by the designer to minimize erosion and related pollution if adequate consideration is given to this problem during the location and design stages.

Erosion control measures fall into two general categories —vegetative and mechanical. Vegetative refer to the seeding and planting to provide a protective cover of vegetation to the soil in place and slow down the water runoff. Vegetative measures are discussed in Chapter 14.

Mechanical erosion control measures are basically those aimed at controlling the surface water runoff, through other than vegetative measures, to minimize their damaging action. These measures normally contribute to the development of a vegetative cover.

Mechanical erosion control measures include:

1. The selection of a cut and fill slopes apropriate to the soil.

2. The use of independent highway alignment on divided highways to reduce the height of cuts and fills.

3. The use of benched slopes to control the velocity of an channelize the runoff.

4. The use of serrated cut slopes at suitable locations, usually sites containing rotten or fragmented rock.

5. The use of curbs or berms on high fills to collect runoff water and guide it into inlets or slope pipes.

6. Adequate design of the ditches, particularly in steep terrain, to insure the capacity to carry the maximum flow and control of the flow velocity.

7. Providing channel protection such as riprap, paving of ditches, etc.

8. The rounding of the tops of cut and fill slopes.

12–04.06 MECHANICAL EROSION CONTROL MEASURES

There are a variety of mechanical erosion control measures that can be designed and used to control surface runoff, and as a result minimize soil erosion. They are usually constructed of concrete, rock, masonry, prefabricated metal or wood. Among them are:

Graded Chanels — across a slope to intercept the water and lead it an outlet where it can be safely discharged.

Berms or Benches — May also be used in the manner as diversious to reduce slope length and divide the runoff volume.

Chutes Flumes — channels of concrete to control runoff downslope.

Check Dams — To reduces or prevent excessive erosion by reduction of velocities.

Diversions Dike — constructed at the top of cut or fill slopes; erosion check, to prevent the formation of rills and gullies.

Gabions — a multi-celled, rectangular wire mesh box, filled with rocks used for erosion control structure.

Sandbag Sediment Barrier — used at storm drain inlets, across minor swales and ditches.

Sectional Downdrain — conduct storm runoff from one elevation to another without erosion of slope.

Sedimentation Retention Basins — It is a structure detains runoff water carrying heavy loads of silt, sand or gravel. It is usually consists of an earth embankment and a perforated pipe spillway. A large part of the debris settles out and the water automatically drawns out the spillway. The structure should be designed to store the expected debris for the life of the structure. The basin created should be periodically cleaned of eroded material.

Energy Dissipators — Used to prevent water erosion at the outlet of the pipe.

Stone Lining — Stone lining with a gravel foundation may be used for large diversion channels. On projects where rock excavation is encountered, ledge fragments should be stockpile for use in lining channels, ditches, pipe outlets and constructing haul roads across streams.

12—04.07 FILTER MEDIA

Filter Berm — Gravel or crushed rock constructed across a graded right of way. The berm retain the sediment on site by retarding and filtering runoff.

Filter Inlet — Gravel or crushed rock constructed at storm sewer curb inlet structure. The rock retain sediment on site by retarding and filtering runoff before it enters storm sewer system.

Plastic Filter Fabrics — On steep slopes, inaccessible to construction equipment, it will be necessary to surface the slope with filter cloth and crushed stone or other suitable material.

Plastic filter sheets are used as a replacement for graded filter systems and filter blankets in conjuction with many hydraulics structures. Filter fabrics have been used also in the construction of subsurface drains beneath roadway shoulders; roads and parking areas over soft soils; and siltation-control fences along superhighways. In general the material is rolled out unto the prepared surface. When in place the succeeding layer of material, can be places on the filter fabric where more than one sheet is required, they should be lap jointed to ensure continous converage of the area to be protected.

12—05 SELECTED REFERENCES

There are innumerable textbooks and publications which cover the application of geology and soils engineering to highway works. The following are some selected AASHTO and TRB references which can be particularly helpful to the highway designer.

1. AASHTO
   a. Standard Specifications for Transportation Materials and Methods of Sampling and Testing. Volumes I and II. In particular — Specifications M-145, and Method of Sampling and Testing T-86.
   b. Manual of Foundation Investigations (1967).
2. Transportation Research Board — National Cooperative Highway Research Program

a. Synthesis of Highway Practice No. 8 — Construction of Embankments (1971).

b. Synthesis of Highway Practice No. 18 — Erosion Control on Highway Construction (1973).

c. Synthesis of Highway Practice No. 29 — Treatment of Soft Foundations for Embankments (1975).

d. Synthesis of Highway Practice No. 33 — Acquisition and Use of Geotechnical Information.

3. Transportation Research Board — Special Reports

a. Landslides Special Report 29

b. Soil Erosion Special Report 135

CHAPTER 13

UTILITIES

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UTILITIES

13—01 DEFINITION OF UTILITIES

The term "utility" means and includes all privately, publicly or cooperatively owned lines, facilities and systems for producing, transmitting or distributing communications, power, electricity, light, heat, gas, oil, crude products, water, steam, wastes, storm water not connected with highway drainage, and other similar commodities, including publicly owned fire and police signal systems and street lighting systems, which directly or indirectly serve the public or any part thereof. The term "utility" shall also mean the utility company or agency.

The major utilities in Puerto Rico are the following:

P.R. Water Resources Authority (PRWRA)
P.R. Aqueduct and Sewer Authority (PRASA)
P.R. Telephone Company (PRTC)
P.R. Communications Authority (PRCA)
Pipelines of Puerto Rico Inc. (PLPR)
San Juan Gas Company (SJGCO)

13—02 GENERAL POLICY

It is generally in the public interest to accommodate on the right-of-way of Commonwealth highways the facilities of those utilities which serve the public provided such use and occupancy of the highway rights-of-way does not interfere with the integrity, function, operational safety and maintenance of the highway. Such use shall not be in conflict with the provisions of Commonwealth and Federal laws and regulations.

The requirements of the Department of Transportation and Public Works are covered in the "Policy on the Accomodation of Utilities on Highways Rights-of-Way" of May 1973. The requirements on Federal-aid projects are covered in the FHWA Highway Program Manual (Vol. 6, Chap. 6, Sect. 3, Subsection 2). The designer of a highway project involving utility work should be familiar with and have access to these publications. The designer should also have available and be familiar with the following AASHTO publications:

—A Policy on the Accommodation of Utilities on Freeway Rights-of-Way (1969).

—A Guide for Accommodating Utilities on Highway Rights-of-Way (1969).

13—03 UTILITIES AND ROADSIDE SAFETY

Poles and certain other utility facilities constitute major roadside hazards, particularly on high-speed highways, and should be treated as such. The designer of a new or relocated utility facility should insure that the horizontal and vertical location of utility lines within a highway right-of-way conforms to the clear roadside policies applicable to the highway class and to the specific conditions for the highway section involved.

Since poles supporting overhead lines can not normally be designed with breakaway features, they should be located as far from the traveled way as feasible. When utility poles or other fixed utility facilities must intrude upon the designated clear roadside space, suitable protective barriers should be installed. The principles, guide warrants and standards covered in Chapter 8 of this manual shall be followed.

13—04 DESIGN PROCESS – UTILITY RELOCATIONS

Highway improvement projects, whether reconstruction or new construction, frequently requiere the relocation of existing utility facilities, particularly in urban areas. On some projects,

the utility relocation work may be minor but in other projects, such as expressways in large cities, the cost can run into the hundreds of thousands of dollars.

It is very important to identify during the early stages of the project the utility relocation work that must be performed in order that adequate provisions be made with the utilities concerned to plan this work and coordinate it with the construction schedule for the project. Failure to do so can result in substantial delays and, in some instances, increased project costs. Whenever feasible, any required utility relocation work should be performed in advance of awarding a construction contract for the highway project.

13—04.01 SURVEY PHASE

1. The highway project survey is made by the Surveying Division of the Photogrammetric Office or by a consultant. As part of the project survey, all known existing utility facilities shall be located and identified by the field parties.

2. As part of the survey phase, the responsible unit shall contact the various utilities to complete the data on types, sizes, etc. of the utility facilities located by the survey crew, and to determine the location, types and sizes of any other underground utility facilities that may exist within the survey area but were not readily apparent to the surveyors.

13—04.02 PRELIMINARY DESIGN PHASE

1. The existing utility data shall be plotted in the preliminary highway project plans. Underground utilities should be plotted in the cross sections and major utility crossings should be plotted in the profile. Standard symbols used by the Department for utility facilities are illustrated in Figures 13—A, 13—B and 13—C. For PLPR and SJGCO facilities use symbols similar to those in Figure 13—C but identified by the letter "F" or "G" respectively. Common abbreviations used on plans are included in Chapter 19.

2. Minor utility facilities generally have little effect on the geometric design. However, the designer shall consider major utility facilities as one of the controlling factors in the project design.

3. The design of the relocation of utility facilities should be initiated as soon as advance project plans have progressed to where the following is available:

a. Plan and profiles
b. Right-of-way limits
c. Location of major structures (bridges, culverts, retaining walls, etc.)
d. Proposed drainage facilities
e. Preliminary cross sections

4. When the design of the utility relocation is to be done in-house or by the utility, the advance detail plans shall be forwarded by the Project Manager to the Utilities and Lighting Office of the Highway Design Office. Since PRTC, PRCA, PLPR and SJGCO always design and construct the relocation of their own facilities, the advance highway plans are sent by the Utilities Office to them for action. In the case of PRASA and PRWRA, the relocation design may be done either in-house, by a consultant or by the respective utility as agreed upon for each specific project.

5. When the utility relocation design is to be performed by a consultant, he is responsible for coordinating his design effort, through the project manager, with the utility concerned. The consultant shall comply with the design standards of the respective utility as well as with the Department's policies, guides and standards.

6. In the case of utility designs, the utility is requested to check the plotted details of its existing facilities for accuracy and to mark on the plans their proposed relocation. The

relocation plan shall show facilities to remain, to be removed or abandoned, to be installed, and any provisional facilities. The marked plans are returned to the Utilities Office together with a preliminary estimate of cost except when the relocation work is to be included in the highway contract or is not eligible for payment by the Department.

7. In the case of in-house design, the Utilities Office coordinates with the utilities concerned and obtains their approval of the proposed relocation plans.

8. Consultant preliminary designs and estimates are submitted, through the Project Manager, to the Utilities Office. The submission shall show evidence of the utilities' approval of the proposed relocation plan.

9. The Utilities Office reviews all preliminary relocation plans and estimates for conformance with the Department's utility accommodation and payment policies. On Federal-aid projects, these preliminary utility relocation plans and estimates are sent by the Utilities Office to the FHWA Division Office for review and comments.

10. The preliminary plans phase is completed when agreement is reached between the Department and the respective utilities on the proposed relocation plans, how the construction will be accomplished (whether by the utility or the highway contractor) and the preliminary estimate of cost when applicable.

13—04.03 CONSTRUCTION PLANS PHASE

1. The existing facilities and proposed utility relocations, temporary and/or final, shall be plotted in the utility sheets of the contract plans (see chapter 19). The plans shall clearly indicate the capacity of the facilities and who will perform the various items of relocation work; when betterments are included, the extents of such betterments shall also be indicated. Reference shall be made as to the required vertical clearance between overhead lines and pavement; and pedestrian areas.

Major relocations of utilities shall be part of the construction phases of the project.

2. During the preparation of the final contract plans, the need for some revisions to the utility relocation plans may arise. In such cases, the Project Manager shall advise the Utilities Office so that the latter may coordinate necessary action with the utilities concerned.

3. For utility relocation work to be performed by the contractor, complete details must be included in the contract plans to clearly define the scope of the work to be accomplished. A detailed cost estimate of the relocation work is also prepared.

4. When the relocation work is to be performed by a utility, the highway project contract plans need only include the essential data on existing facilities and proposed relocations necessary for coordination of the highway construction with the utility work. However, the utility will prepare more detailed plans for its own use and for the necessary approval by, and agreement with, the Department. If payment by the Department is involved, the utility will also prepare and submit a detailed estimate of cost.

5. The final construction plans and estimate (if payment by the Department is involved) on all utility relocation work are subject to review and approval by the Utilities Office. When betterments are to be included in the contract plans their cost of installation shall be estimated separately and the Utilities Office shall obtain a written acceptance from the Agency concerned. Costs of betterments shall be reimbursed to the Highway Authority by the Agency concerned.

6. On Federal-aid projects the utility relocation plans are also subject to approval by the FHWA Division Office. If Federal funds participate in the relocation cost, the estimate is also subject to FHWA approval.

13—04.04 UTILITY AGREEMENTS

The necessary written agreement between each utility and the Department covering the relocation work are coordinated and processed by the Utilities Office after approval of the final relocation plans, estimates and other supporting documents.

STANDARD SYMBOLS — P.R.A.S.A. FACILITIES

W OR S — EXISTING PIPE LINE TO REMAIN (1)

W OR S — NEW PIPE LINE TO BE INSTALLED (1)

W OR S — EXISTING PIPE LINE TO BE REMOVED OR ABANDONED AS INDICATED (1)

W OR S — PROVISIONAL PIPE LINE TO BE INSTALLED (1)

PIPE LINE IN CASING (2)

VA — EXISTING VALVE TO REMAIN (3)

VA — EXISTING VALVE TO BE REMOVED OR ABANDONED AS INDICATED (3)

VA — NEW VALVE TO BE INSTALLED (3)

EXISTING AIR VENT TO REMAIN (3)

EXISTING AIR VENT TO BE REMOVED OR ABANDONED AS INDICATED (3)

NEW AIR VENT TO BE INSTALLED (3)

EXISTING BLOWOFF TO REMAIN (3)

EXISTING BLOWOFF TO BE REMOVED OR ABANDONED AS INDICATED (3)

NEW BLOWOFF TO BE INSTALLED (3)

MTR — EXISTING WATER METER TO REMAIN (3)

MTR — EXISTING WATER METER TO BE REMOVED (3)

MTR — NEW WATER METER TO BE INSTALLED (3)

RED — EXISTING REDUCER TO REMAIN

RED — EXISTING REDUCER TO BE REMOVED OR ABANDONED AS INDICATED

NEW REDUCER TO BE INSTALLED

SMH NO.__ EXISTING SANITARY MANHOLE TO REMAIN (4)

SMH NO.__ EXISTING SANITARY MANHOLE TO BE REMOVED (4)

SMH NO.__ NEW SANITARY MANHOLE (4)

NOTES:

(1) INDICATE WHETHER WATER (W) OR SANITARY (S) AND PIPE SIZE AND TYPE.

(2) SHOW CASING SIZE AND TYPE.

(3) INDICATE SIZE.

(4) IDENTIFY BY NUMBER.

FIGURE 13-A

STANDARD SYMBOLS – P.R.W.R.A. FACILITIES

- E ● EXISTING POLE TO REMAIN
- R ● EXISTING POLE TO BE REMOVED
- I ● NEW POLE TO BE INSTALLED
- GUY WIRE
- OVERHEAD GUY WIRE WITH STUB POLE
- E 4.16KV EXISTING AERIAL LINE TO REMAIN (1)
- R 4.16KV EXISTING AERIAL LINE TO BE REMOVED (1)
- I 4.16KV NEW AERIAL LINE TO BE INSTALLED (1)
- E U EXISTING UNDERGROUND LINE TO REMAIN (2)
- R U EXISTING UNDERGROUND LINE TO BE REMOVED (2)
- I U NEW UNDERGROUND LINE TO BE INSTALLED (2)
- EXISTING POLE MOUNTED TRANSFORMER (3)
- NEW POLE MOUNTED TRANSFORMER (3)
- EXISTING PAD MOUNTED TRANSFORMER (3)
- NEW PAD MOUNTED TRANSFORMER (3)
- E EXISTING SWITCHING UNIT TO REMAIN
- R EXISTING SWITCHING UNIT TO BE REMOVED
- I NEW SWITCHING UNIT TO BE INSTALLED
- E SB EXISTING SPLICING BOX TO REMAIN
- R SB EXISTING SPLICING BOX TO BE REMOVED
- I SB NEW SPLICING BOX TO BE INSTALLED
- E PB EXISTING PULL BOX TO REMAIN
- R PB EXISTING PULL BOX TO BE REMOVED
- I PB NEW PULL BOX TO BE INSTALLED
- E MH EXISTING MANHOLE TO REMAIN (4)
- R MH EXISTING MANHOLE TO BE REMOVED (4)
- I MH NEW MANHOLE TO BE INSTALLED (4)
- TRANSMISSION LINE METAL TOWER

NOTES:

(1) INDICATE VOLTAGE.
(2) INDICATE VOLTAGE AND CONDUIT DATA.
(3) INDICATE APPLICABLE DATA.
(4) IDENTIFY BY NUMBER.

FIGURE 13-B

STANDARD SYMBOLS – COMMUNICATION FACILITIES

P.R.T.C.[1]	P.R.C.A.[2]	
ET	EC	EXISTING POLE TO REMAIN
RT	RC	EXISTING POLE TO BE REMOVED
IT	IC	NEW POLE TO BE INSTALLED
T	C	GUY WIRE
		OVERHEAD GUY WIRE WITH STUB POLE
ET	EC	EXISTING AERIAL LINE TO REMAIN[3]
RT	RC	EXISTING AERIAL LINE TO BE REMOVED[3]
IT	IC	NEW AERIAL LINE TO BE INSTALLED[3]
EUT	EUC	EXISTING UNDERGROUND LINE TO REMAIN[4]
RUT	RUC	EXISTING UNDERGROUND LINE TO BE REMOVED[4]
IUT	IUC	NEW UNDERGROUND LINE TO BE INSTALLED[4]
ET MH	EC MH	EXISTING MANHOLE TO REMAIN[5]
RT MH	RC MH	EXISTING MANHOLE TO BE REMOVED[5]
IT MH	IC MH	NEW MANHOLE TO BE INSTALLED[5]
ET PB	EC SB	EXISTING SPLICING BOX TO REMAIN
RT SB	RC SB	EXISTING SPLICING BOX TO BE REMOVED
IT SB	IC SB	NEW SPLICING BOX TO BE INSTALLED
ET PB	EC PB	EXISTING PULL BOX TO REMAIN
RT PB	RC PB	EXISTING PULL BOX TO BE REMOVED
IT PB	IC PB	NEW PULL BOX TO BE INSTALLED
T	C	RISER

NOTES:

(1) P.R. TELEPHONE CO.
(2) P.R. COMMUNICATIONS AUTHORITY.
(3) PROVIDE CABLE AND TERMINAL DATA.
(4) PROVIDE CABLE, TERMINAL AND CONDUIT DATA.
(5) INDICATE MH NUMBER.

FIGURE 13-C

CHAPTER 14

LANDSCAPING

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DESIGN REFERENCES

1.—AASHTO (Formerly AASHO)

(Note: AASHTO publications are subject to updating and/or revisions changes in concepts and standards develope. Therefore, the designer should ascertain as to the latest edition of the following publications that may be in effect at the time of design).

a. A Guide for Highway Landscape and Environmental Design.—1970.

b. A Guide on Safety Rest Areas for the National System of Interstate and Defense Highway.—1968.

c. Guide for Selecting, Locating and Designing Traffic Barriers, 1977.

2.—U.S. Environmental Protection Agency

Guidelines for Erosion and Sediment Control Planning and Implementation.—1972

3.—Federal Highway Administration (FHWA)

Roadside Safety Design.—1975

4.—National Cooperative Highway Research Program

Report 158, Selection of Safe Roadside Cross Sections. NRC, 1975.

5.—Commonwealth of Puerto Rico, Department of Transportation and Public Works, Survey and Design Area.

Highway Design Manual.—1976.

6.—Commonwealth of Puerto Rico. Puerto Rico Highway Authority.

Standard specifications for Road and Bridge Construction.—1971

7.—Commonwealth of Puerto Rico.—Puerto Rico Water Resources Authority.—

"Siempre Adecuadamente"

8.—Albert L. Little Jr., Frank H. Wadsworth and José Marrero.—

"Arboles Comunes de Puerto Rico e Islas Vírgenes".—

CHAPTER 14

14.–01 GENERAL

The main purpose of this Chapter is to offer a landscape design guide to the highway landscape designers and to recommend a close cooperation between the landscape and highway design teams.

14.–02 INTEGRATION OF HIGHWAY AND LANDSCAPE DESIGNS

The integration of the principles of highway engineering and landscape design into design of the highways will assist greatly in producing a safe, economic and attractive facility.

Results of this integration in rural areas are the broad medians of varying width and wide areas between the highway slopes and the right of way limits, major contributions to a safe and attractive highway.

In urban areas adequate consideration must be given to the integration of highway engineering, city planning and landscape architecture because of the great impact on the area through which it passes, with special attention to the multiple use and joint development possibilities in areas over, under and adjacent to the highway.

14–03 SCOPE OF LANDSCAPE DESIGN

Highway landscape design should be considered at the earliest stages of corridor development and through all the design stages. Within the scope of landscape design are considerations for conservation of land and waterways areas, preservation of historical features, topography, existing and potencial land use, improved perceptual qualities and appearance, appropriate planting and reduced roadside maintenance requirements. All these are broad basic concepts, but there are minor design details to be considered as flattening of cut and embankment slopes and rounding cross sections for the purpose of preventing soil erosion. These minor design details help to mold the highway into the terrain, making it an harmonious part of the natural landscape and to minimize accident severity to vehicles leaving accidentally the roadway.

DESIGN GUIDE

14–04 LANDSCAPE ELEMENTS IN HIGHWAY DESIGN

14–04.01 CONSERVATION OF NATURAL FEATURES AND STRUCTURES

The natural features of the area should be preserved and used as elements of the highway landscape design in rural and urban areas. With a carefull selection of the alignment seashores, ponds, rivers, woodlands, croplands, rocky spots, interesting structures and vistas will be disturbed to a minimum. These features are an important element in highway design.

14–04.02 TOPOGRAPHY

The topography should be carefully studied because of its definite influence in the selected alignment. The highway should be placed where it fits in the natural contour of land, with the advantages of preservation of the natural features and environment, safety and less maintenance and construction costs.

14—04.03 ACTUAL AND POTENCIAL LAND USE

Sufficient land should be acquired with different purposes. Among them, to create a desirable and attractive environment, avoiding splitting of farms and residential developments. Changes in land use should be foreseen and sufficient land acquired for a future appropriate landscape development. The acquisition of remnats may provide areas for planting with different purposes and for the development of rest and recreation areas and overlooks.

14—05 LANDSCAPE AND GEOMETRIC DESIGN

Coordination of the common objectives between the highway design engineer and the landscape designer is of a great importance to the creation of a well integrated highway. This coordination should begin at the earliest phases of the selection of alternate routes and shall continue until the completion of the project. Highway design shares a number of common principles with landscape design and the landscape designer shall be familiar with the highway design principles.

From the standpoint of landscape design, basic elements of highway design are examined in this Section.

14—05.01 RIGHT OF WAY

The right of way width is influenced among others, by the following factors.

a) Desire to preserve the natural landscape of the area, existing structures and vistas, blending the higway with its environment.

b) Character and extent of the landscape treatment for a rural or urban situation.

c) Adequate width for a cross section fitting into the natural contour of land or a rounded cross section with appropriate slopes for planting or prevention of soil erosion.

d) Necessity of a complete separation of the highway and the adjacent areas.

e) Considerations given to the amenities of the highway as the development of rest and recreation areas and overlooks and its aesthetic effect upon the adjoining area.

f) Appropriate space for planting, based on the probable mature size of trees and other plant materials.

g) Utilization of highway right of way for multiple use-joint development projects.

14—05.02 ALIGNMENT AND PROFILE

In rural areas it is desirable to fit the highway gracefully into the natural contour of land. The independent roadway design permits a pleasing and flowing alignment and profile with medians of variable width offering the advantages of natural drainageways, reduction in construction and maintenance costs and preservation of the natural features. In urban areas the alignment and profile are generally dictated by the existing street pattern. In these areas the landscape design should be carefully studied leaving adequate space for the appropriate landscape development in accordance with the adjacent land values.

14—05.03 CROSS SECTION ELEMENTS AND GRADING

Once the cross section is selected according to the engineering requirements, shall have adequate space for landscape development, providing the planting clearances from the edge of the traffic lanes as stablished in the subsection 14.—05.07 in this Chapter.

The cross sections shown on Figures No. 14—A and 14—B of this Chapter are examples of the varieties of possibilities for landscape treatments for different conditions of alignment and profiles in urban and rural locations.

In urban areas additional elements such as bridge abutments, concrete mats, piers and retaining walls should receive an special architectural treatment. The whole section derserves a carefull study with rounded and warped grading, appropriate slopes and effective drainage and erosion control.

When necessary to stablish turf for erosion control the slopes shall be 3:1 or flatter, providing for economy in maintenance, on slopes steeper than 3:1 various groundcovers such as vines and shrubs may be used to prevent erosion. When earth embankments parallel channels, streams or shorelines it is necessary to provide protection against the water erosion. This could be accomplished using planting, riprapping or building different classes of walls. Every situation deserves a carefull study.

Existing vegetation and mounds between the shoreline and highway embankments should be saved as a natural protection against erosion. It is desirable to do adjustments to the highway alignment and not to change the stream channel course because of the increasing erosion effects in the area.

Contour grading plans should be used on every project, specially at intersections.

Cross sections of the highway should show the full width of right of way, paved areas, medians, shoulders, gutters, cut and fill slopes, border areas and frontage roads in all areas along the highway, to use them for the landscape design.

14—05.04 SIGHT DISTANCE

As stated in Section 3—02.01 of this Manual, stopping sight distance is the minimum sight distance required by a driver traveling at a given speed to bring his vehicle to a stop before reaching an object in his path. This distance is another control for planting along the highway. Care must be exercised that proposed landscaping do not result in stopping sight distance reduction.

14—05.05 SURFACE DRAINAGE

Drainageways deserve a careful study because of its vital function, safety and appearance in the entire landscape development. No planting, except sodding, should be done in drainageways and its surfaces should be treated with sodding or paving according with the conditions of the specific case. Flat slopes should be provided for safety, for ease of maintenance and for stablishment of vegetation. An interesting study of drainage appurtenances is shown on pages 45 to 64 of the publication "Roadside Safety Design" of the U.S. Departament of Transportation Federal Highway Administration, november 1975.

In urban areas paved ditches or paved gutters may be used, leading the water to drain inlets connected to the storm sewer system. All efforts should be done to prevent soil from entering the storm sewer system at the earliest construction stages.

Rounded and trapezoidal gutters and channels are generally used for drainage in rural areas. Their surfaces may be sodded or lined depending on the water volume and its velocity. Intercepting channels, ditches, dikes, swales or silting basins should be constructed to control erosion on them. All drainage systems should be as incospicuous as possible, and blended with the natural or proposed contour lines. Grading and drainage plans are useful to the landscape designer to selected the appropriate location of the plant materials. An example of a grading plan is shown on Figure No. 14—C.

14—05.06 EROSION AND SEDIMENT CONTROL

Planting at the beginning of the construction phase is an effective mean to avoid deterioration of slopes, to prevent siltation of highway drainageways, to prevent soil from entering the storm sewer systems, and to prevent pollution of lakes, rivers and other watercourses in the area.

Grass is planted as an effective mean of erosion control on 3:1 slopes or flatter. On steeper slopes shrubs, trees and vines planting is recommended because of the little maintenance required. Optimum vegetative stability requires slopes 4:1 or less.

A dense vegetation cover of grass, shrubs, vines or trees is very effective in preventing erosion on steep slopes, swales, and along drainageways and impounded waters. It is important to evaluate the vegetation on a proposed development site in terms of its benefit to erosion and sediment control. The vegetative cover along waterways and around impoundments serves as a soil stabilizer and as a filter for sedimentladen water flowing into water courses. Vegetation also disipates the erosive energy from falling raindrops, a most important contribution to sediment and erosion control.

14—05.07 PLANTING

Planting should be developed along the entire highway corridor with different purposes and according with the requirements of the highway design.

The planting plans should be developed in separate sheets. (1) They may be part of the general construction contract for some projects. For other projects it is desirable to have a separate landscape development contract. They should contain all the planting details, landscaping limits, and plants schedule. Figure No. 14—D contains some examples of planting details and Figure No. 14—E shows a plants schedule.

Areas that need special treatments such as natural growth to be preserved, planting for erosion control, selective thinning, clearing and grubbing, fertilizing or moving should be clearly indicated on the plan sheets.

The planting limits should be shown on the plan sheets using a thin broken line to make correct, faster an easier the staking-out process for planting. An example of a planting plan is shown on Figure No. 14—F.

From the Guide for Highway Landscape and Environmental Design is taken the following valuable information related to the planting purposes:

a. Screening for Headlight Glare

This can be of considerable value in certain areas depending on road alinement, ground forms, existing vegetation, and width of median separation. The screening of headlight glare between an urban highway and the immediately adjacent frontage road is often desirable. In some situations, materials other than plants may be appropriate. Where needed, planting should form a continuous screen and avoid intermittent glare. The method of controlling headlight glare should be determined at an early design stage.

b. Screening for Noise Abatement

The effectiveness of screen planting for noise abatement has not yet been definitely determined. It could depend upon many factors, such as: density of plant foliage, density of plantings, distance from traffic noise, slope of ground, direction of prevailing winds, and highway type and design. The visual obscuring of traffic by planting between the highway and adjacent areas may have a psychological effect of seeming to deminish highway noise. Research is being done on the subject.

c. Screening of Undersirable Views and Objects

This is commonly used and effective method of obscuring undersirable views seen from and toward the highways. In some cases, effective screening with plants will take a period of years to achieve but this should not prevent the accomplishment of such work. The sight lines from and toward the highway to the object to be screened should be studied. Occasionally, there will be an opportunity to utilize existing trees and other growth as the foundation of a screen planting. Action should be taken early in the design stage to take appropriate measures to protect the existing vegetation. In some instances, a year-round screening effect is desirable. Effective screening may be accomplished by using fencing or other structural materials. Whenever possible, consideration should be given to the removal of the objectionable development.

d. Planting for Traffic Indication

Functional planting can assit in making it evident to the motor vehicle operator that a change in alinement of the road is imminent or that the operator is approaching an exit or a bridge. Such plantings should be designed with consideration for traffic safety, inexpensive maintenance and ease of mowing.

e. Planting to Provide Shade

Trees and other plantings should be used to provide shade where desirable. Shade effectiveness should be analyzed carefully in consideration of offset distances and the angle at which shade is cast by the summer sun.

f. Planting to Control Sand Drift

Sand drift presents unusual problems specific to the individual site and my requiere special consideration.

g. Planting to Provide a Crash Barrier[1]

Dense shrub masses, by their slower decelerating effect, cause less damage and injury to car and driver than solid barriers. However, they may require 2 or 3 years to become firmly roted and well grown. In the median, multiple rows of dense shrubs are effective.

h. Offset Distances for Trees

The following descriptions may vary somewhat from State to State, according to a State's special experiences and safety regulations.

New plantings of trees whose trunk diameter at maturity will exceed 4 inches should not be made closer than 30 feet from the edge of the traveled way except in special circunstances. However, the 30-foot distance for vehicle recovery area is not to be considered a fixed single-control dimension. Variations in cross section design and traffic speed may increase or decrease this dimension. Shrubs and ground cover may be planted or be retained within the recovery area for safety and esthetic purposes. Existing trees may be retained (1) on the high or cut side of the roadway not in the likely path of an uncontrolled vehicle, (2) on the low or fill side if protected by a guardrail or not likely to be hazardous to an out-of-control vehicle, and (3) if important historically or esthetically and protected by a guardrail.

[1] When necessary to provide a crash barrier a careful study should be done to determine the effectiveness of dense planting in lieu of barrier or impact attenuators. In the Guide for Selecting, Locating and Designing Traffic Barrier "AASHTO 1977", the use of vegetative barriers is not included.

Minimum setbacks for newly planted trees with an ultimate trunk diameter of more than 4 inches should be as follows:

(1) 50 MPH or greater design speed[2]

a) Minimum setback from the edge of the traffic lane should be 30 feet unless one of the following reasons will allow for a lesser distance.

1. Cuts of 3 to 1 or steeper-10 feet behind the point of vertical intersection (P.V.I.) at the toe of the slope.

2. Where concrete barriers, walls, abutments, or other rigid obstructions are used-4′ behind the obstructions.

3. Where flexible guardrail (box-beam, W—beam, or cable) is used-6 to 20 feet behind the face of the guardaril, depending upon the type (See NCHRP Report 54, "Location, Selection and Maintenance of Guardrails and Median Barrier". HRB, 1968.)

4. Where there are barrier curbs near a traveled lane-6 feet behing the face of the curb; adjacent to a parking lane-no definite setback distance.

5. Were limited right-of-way or the necessity for planting would result in less clearance, all factors in the particular problem area should be weighed to decide if a special exception is warranted.

(2) 50 MPH or less design speed

Minimum setback from the edge of the traffic lane may be 25 feet unless one of the reasons set forth under (1) will allow for a lesser distance.

(3) On curves, adequate sight distance for the design speed of the highway must be maintained.

(4) Modification of the minimum setback may be required by special considerations. For example:

(a) Occasionally, special conditions may warrant planting slightly closer to the pavement in order to fulfill some limited specific function, but most functional planting should consist of low-growing shrubs below the line of sight.

(b) The charasteristics of the plant material used affect the amount of offset needed.

Some conditions may be unfavorable to plant growth in an urban area. Drainage conditions may be inadequate; there may be excess drainage or not enough. Air pollution is often serious, from the fumes of motors and from adjacent factories. Many plants, including most evergreens, cannot survive the polluted and dust-laden atmosphere of severe urban condition. The reflected heat from pavements and buildings further limits the use of many desirable plants. Only those plants which have proved themselves adaptable to the difficult growing conditions found in some urban situations should be used in such locations.

Good planting soil is one of the necessary requirements for successful plantings. Paving stones or bricks laid with open joints, or a metal or concrete grate may be used to keep pedestrian traffic from compacting the soil over the roots. Where practical, areas to be mowed may be topsoiled, graded, seeded, and mulched according to standard practices of the several States."

[2] The "1977 AASHTO GUIDE FOR SELECTING, LOCATING, AND DESIGNING TRAFFIC BARRIER" recommends minimum distances to obstables that differ from those recommended in this section. Please see figures IIIA-3, VII-C-1, VII-C-2, VII-C-3, VII-C-4, VII-C-5, and VII-C-6.

The clear distance to obstructions recommended in the Guide for Highway Landscape and Environmental Design should be compatible with the following publications:

1. This Design Manual.
2. Selection of Safe Roadside Cross Sections, NCHRP Report 158.
3. Guide for Selecting. Locating and Designing Traffic Barriers, AASHTO 1977.

The Puerto Rico Highway Authority Standard Specifications for Road and Bridge Construction cover all the subjects related to landscaping.

14–06 ADDITIONAL CONSIDERATIONS FOR HIGHWAY LANDSCAPE DESIGN AND MAINTENANCE

The location and spacing of the plants in the final design should be based on the probable mature size of the plants selected. The size of the plants to be used in the design should be in scale with the size of the areas to be planted and with the structures in the project, creating a balance among all the features in the landscape design.

If the selection of the plant materials is done among the species of plants existing in the area the new planting will help to blend the new facility with the natural landscape of the area. Other species may be used in special locations because of its aesthetic value and to avoid monotony in the design.

An useful aid in the selection of trees for different locations in Puerto Rico is the book "Arboles Comunes de Puerto Rico e Islas Virgenes".

When designing for planting in urban areas the selection of the plants to be used should be done considering the difficult growing conditions found in these areas, providing for then adequate planting spaces. A careful selection of the species of trees and their root growth habits or to develop special planting methods is necessary to avoid damages to sidewalks, street pavements and public utilities under and above the ground level.

Trees should not be planted where they interfere with the highway or street illumination.

The installation of aereal utilities structures should be avoided in areas such as scenic strips, overlocks, rest areas, recreation areas, the right of way of highways adjacent thereto, and the right of ways of sections of highways which pass through public parks and historic sites.

The surrounding environment and the type of highway have a definite influence in the design of bridges, retaining walls, planters and other structures to be used in the desigs of the complete highway and in the selection of the highway hardware which includes bridge railings, luminaries and traffic control signing.

Maintenance is a factor in determining the most effective and economical design for roadside grading, drainage, erosion control and planting appropriate to the local soil, climatic and other conditions.

The final location on the plans of the selected plants should be done providing appropriate space for the maneuvers of the mowing and trimming machines.

In Puerto Rico irrigation is not provided for the highway landscaping projects. Thirty inches annual precipitation in the dryest regions of the Southwest areas of the Island permits trees and shrubs planting, if they are selected among the species who have proved themselves adaptable to the growing conditions found in those areas.

Watering during the planting process and until the final acceptance of the job is asked for in our Standard Specifications under Construction Requirements.

Areas of mowing may be reduced by appropriate plantings. This is recommended on steep slopes, small curbed islands, narrow medians and narrow planting strips and some other locations where the mowing operations are difficult or dangerous for the operator of the equipment.

In these locations it is recommended to use vines and groundcovers.

To reduce maintenance costs is desirable to use plants that will grow to an ultimate size without requiring removal, topping or frequent prunning, those who are suitable for the planting requirements and adaptable to roadside conditions are selected.

Roadside project plans should be prepared for some projects showing: mowing limits, areas of naturalization, refertilization schedule, plant and turf reestablishment, utility locations and other management operations. These plans are useful to keep the design concepts, the outstanding vistas and the desired appearance of the Highway for many years. These plans may also be used, with some revisions, as maintenance plans.

14—07 CONSTRUCTION CONSIDERATIONS IN DESIGN

During the preliminary site evaluation the proximity of lakes, rivers, shorelines and other water courses should be evaluated in order to determine what deleterious effect, sedimentation could have on their ecological and phisical features. They are aesthetically valuable and should be protected against sediment damages.

With proper planning, borrow pits can be effectively utilized for stormwater retention and sediment collection during construction. Properly constructed, with sufficient area and capacity, it is desirable to preserve them for aesthetic and recreational benefits and for runoff control.

At the completion of the construction works the borrow areas, waste areas, haul roads and any other construction or erosion scar should not be visible from the highway. The affected areas should be revegetated, regraded or in any other way treated to blend them into the roadside landscape.

Suggested practices related to the location and treatment of borrow areas, waste areas and haul roads are:

a) Provide contour grading plans where feasible and warranted.
b) Provide adequate space to allow for the conservation of existing screening or permit the installation of screen planting.
c) Locate them so that the area will not be below the eye level or in exposed locations so that the screening is impossible.
d) Cover stumps logs and other litter in areas exposed to view from the highway.
e) Grade, plant, fertilize and mulch exposed borrow areas and waste areas.
f) Locate access or haul roads at right angles to the highway or against the angle of vision of the motorist.
g) Place fill around trees in a manner that will not injure or kill then (see Figures number 14-G and 14-H for suggested methods of trees protection)
h) Place waste material so that it will not interfere with surface drainage.
i) In certain situations, it may be advisable not to drain borrow pits in order to retain them as ponds or marshy areas.

14—08 SAFETY REST AREAS

Rest areas are integral elements of the highway and serve to provide motorists a greater measure of safety and comfort. These areas may have complete facilities including: access and exit ramps, parking areas for different vehicles, toilet buildings, drinking fountains, picnic tables

and benches, shelters, grills and or fireplaces, walks, information facilities, lighting and landscaped grounds. The necessary systems for water supply, sewage disposal, power supply, and adequate operacional and maintenance procedures may also be included. The rest area should be designed as safe, useful, and attractive as possible.

The sizes and locations of their sites, according to the facilities to be provided, should be selected early in the design stage. The right of way acquisition for rest areas should be made concurrently with highway right of way. An example of a rest area is shown on Figure number 14-I.

The 1968, AASHO publication, "A Guide on Safety Rest Areas for the National System of Interstate and Defense Highway" deals with all the subjects related to their design.

Some factors that influence the selection of the site from the standpoint of landscape development are: topography, passive environment, interesting natural features, groups of trees shading the area and outstanding vistas.

If replanting is necessary, the plant materials selected should help to emphasize the distinctive character of the area.

Walks and paths should be built to provide all weather access to the facilities in the site, preventing damages to the lawn and groundcover planted areas.

The design of walks, paths, and other facilities should be done following the guides for the design and construction of facilities for the handicapped.

In some instances, additional lands have been acquired for multiple use and joint development of facilities with public agencies other than the Department of Transportation and Public Works. Where this has been done, there are agreements relating the activities and responsibilities of the concerned agencies for the design, operation and maintenance costs. Parcels, remnants of parcels, and other areas of land may be acquired to provide recreational or other facilities of a limited nature within a rest area.

Rest areas should be included when preparing roadside maintenance plans.

14-09 SCENIC OVERLOOKS

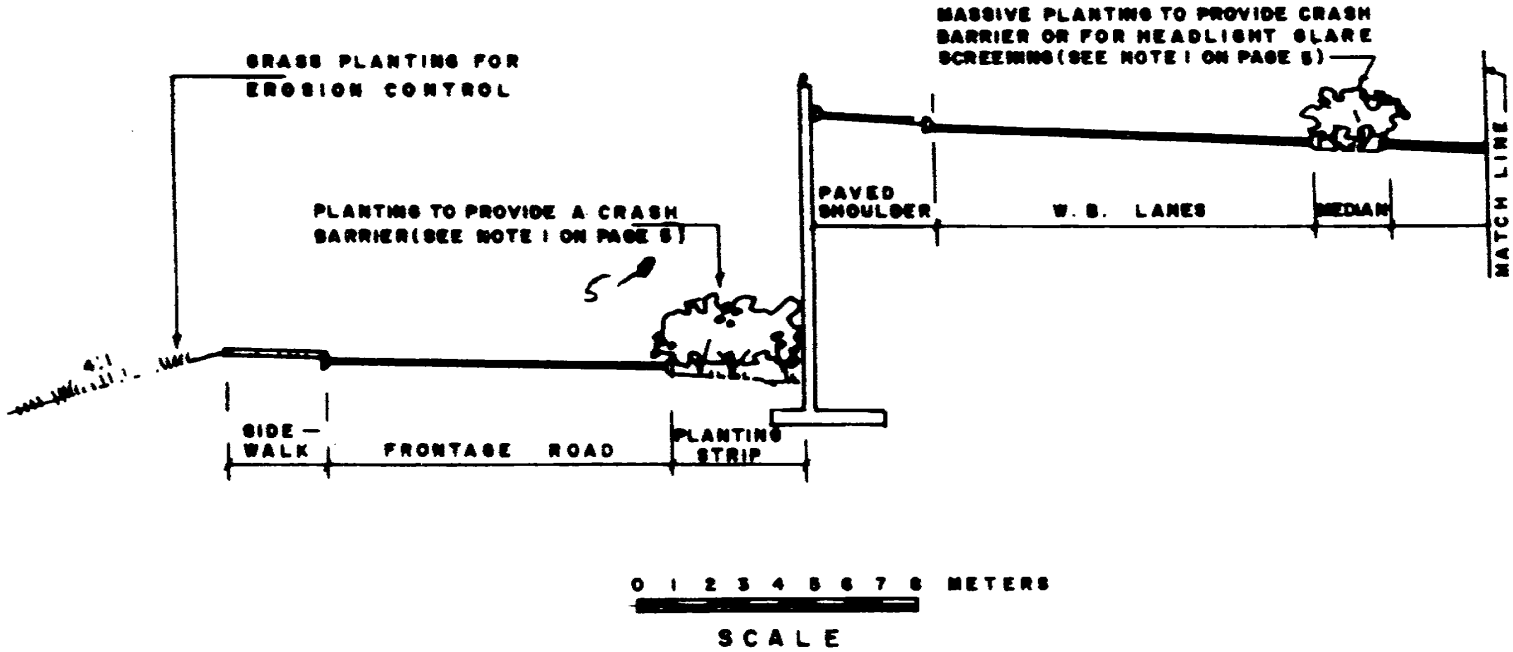
Are special areas, selected primarily to take advantage of a beautiful, spectacular or unique view.

The selection of the site should be done at an early design stage. The size of the site and the topography should determine the facilities to be provided. Adequate right of way acquisition for scenic overlooks should be made concurrently with the highway right of way to preserve and protect the view.

In some overlooks picnic tables, toilets, and drinking fountains may be included. Others provide only the parking spaces, paved ramps for entrance and exit, and the landscape development.

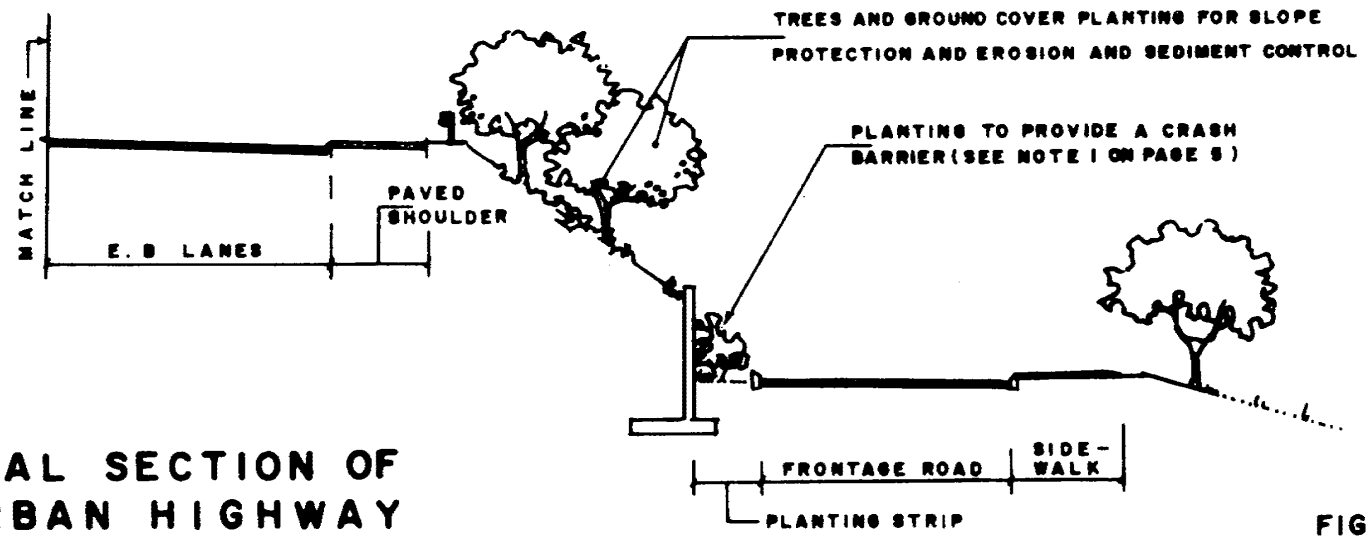
Areas from which photos may be taken should be provided. A plaque shall furnish information of the area viewed.

An example of an overlook is shown on Figure number 14-J.



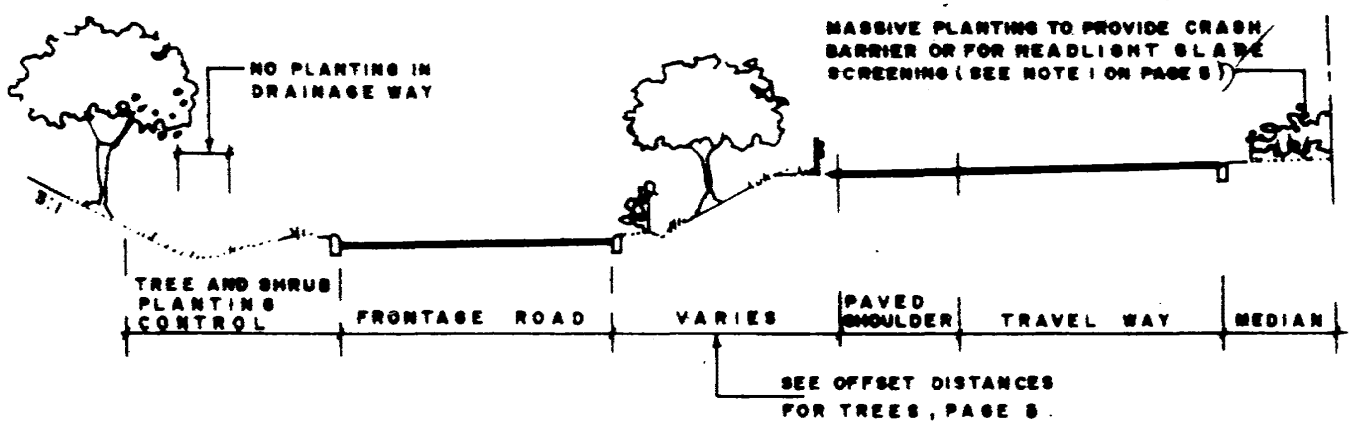
0 1 2 3 4 5 6 7 8 METERS

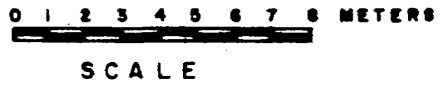
SCALE

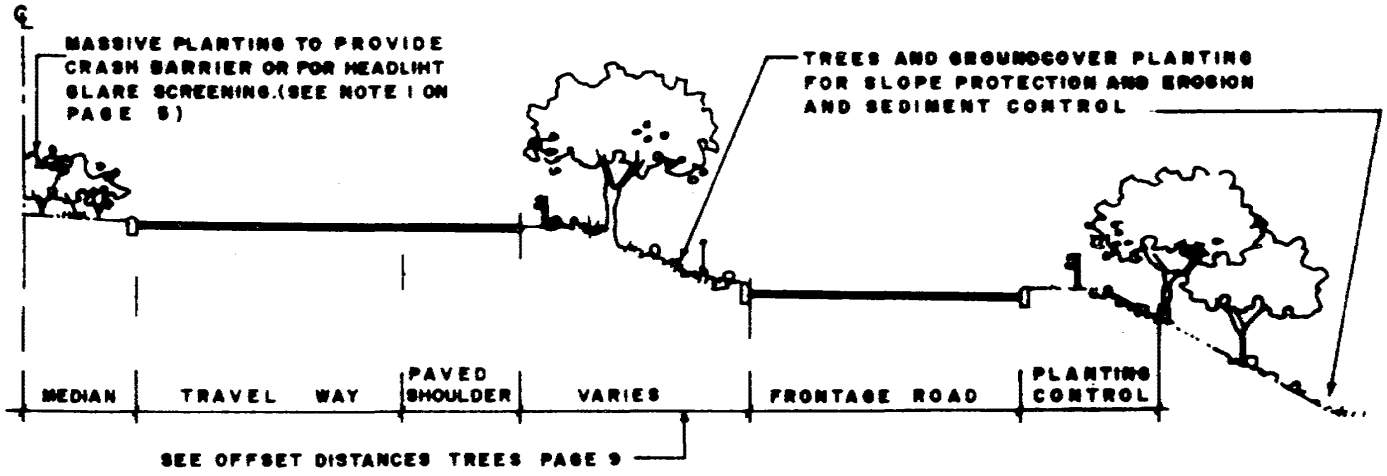


TYPICAL SECTION OF AN URBAN HIGHWAY

FIGURE 14-A

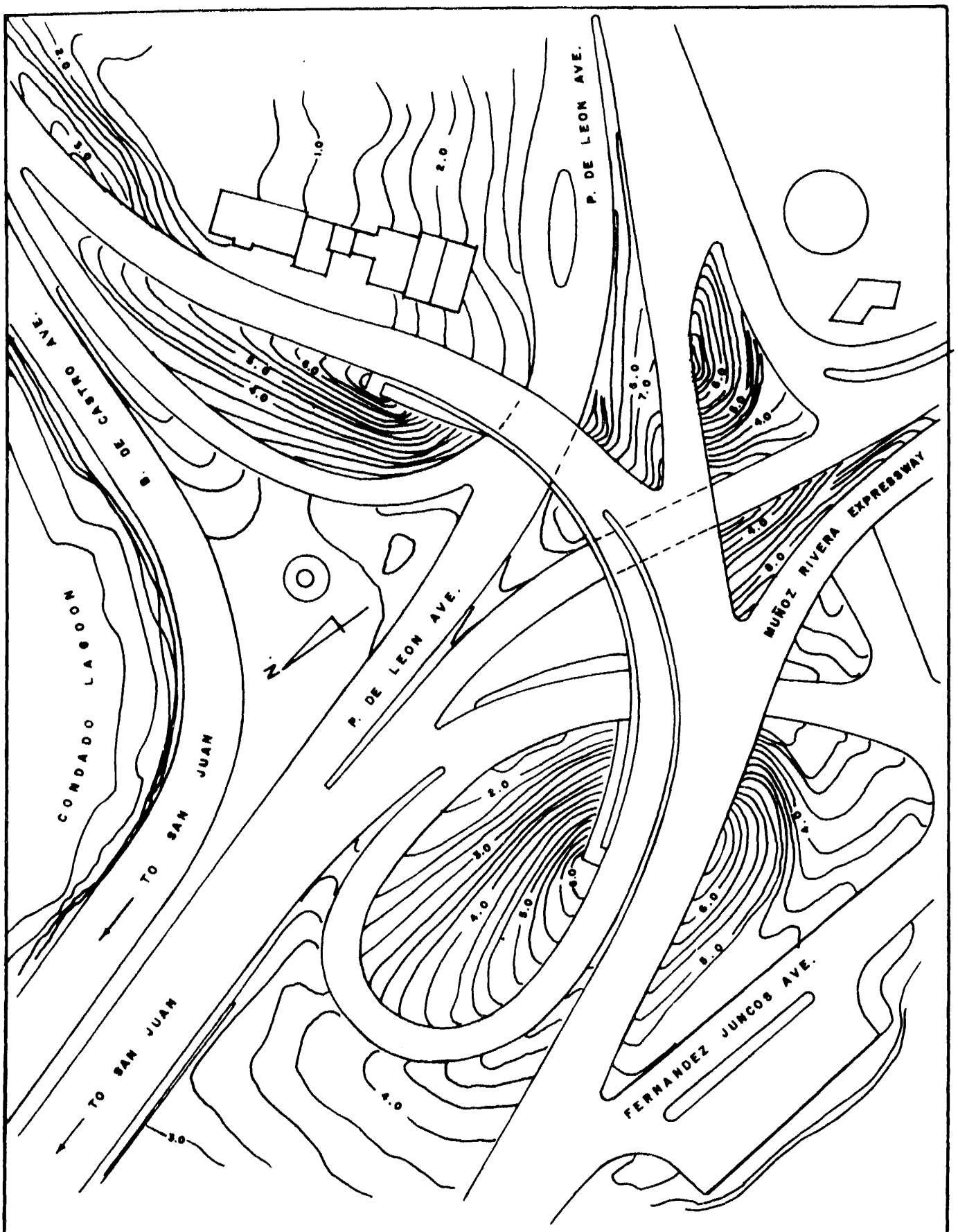






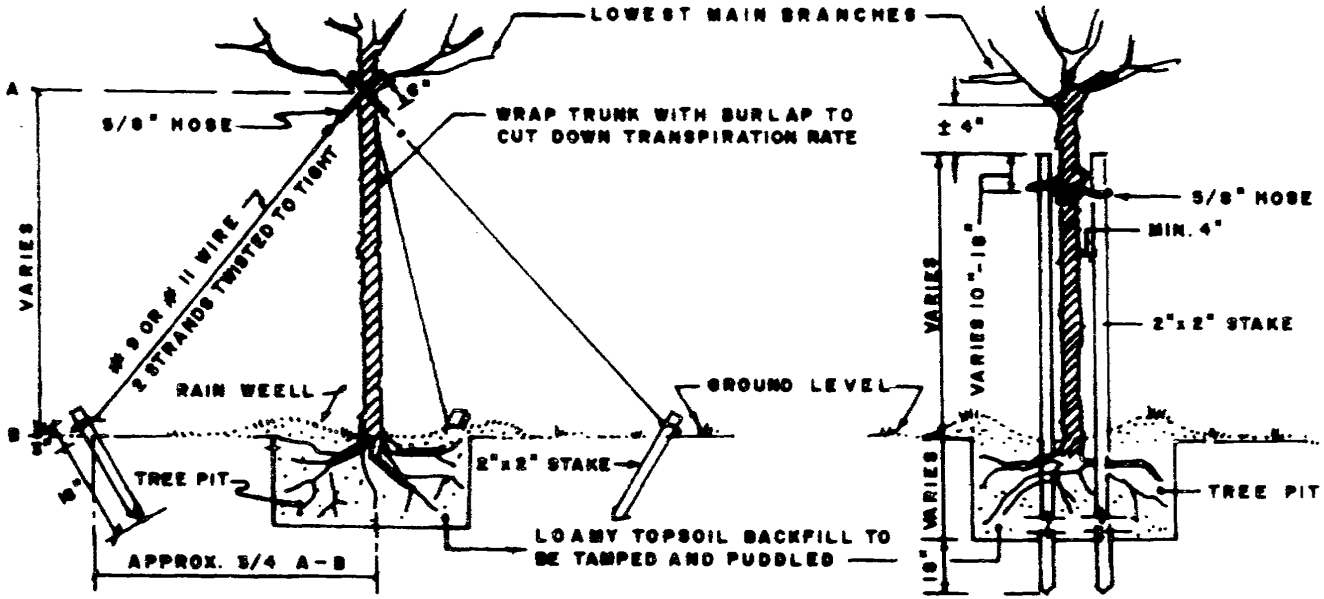
TYPICAL SECTION OF A RURAL HIGHWAY

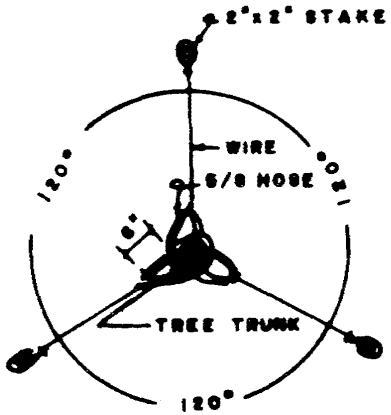
FIGURE 14-B



GRADING PLAN OF AN INTERCHANGE

FIGURE 14-C



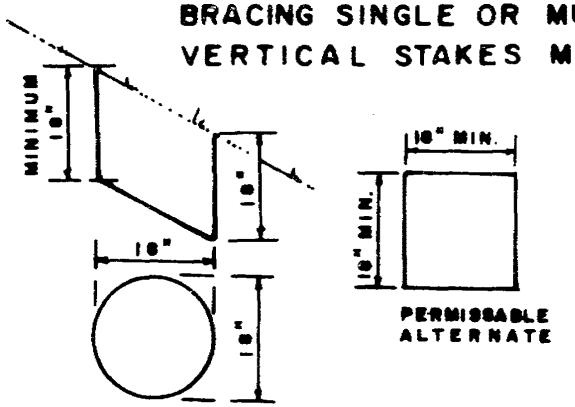


TREES LESS THAN 4" IN CALIPER

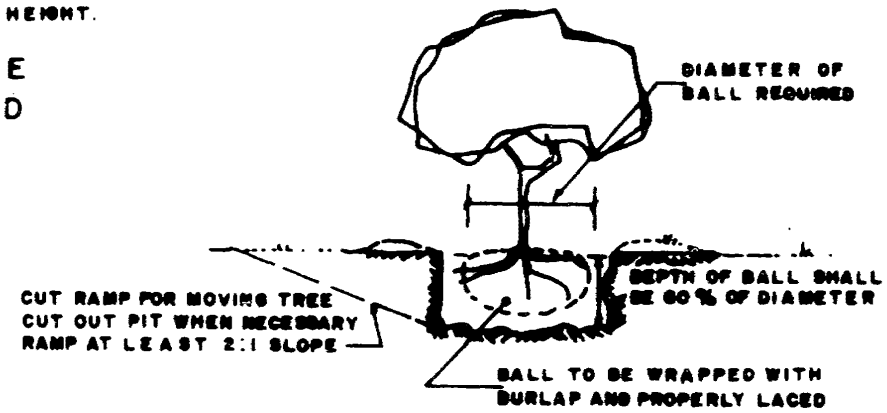
BRACING TRIPOD METHOD

USE SINGLE VERTICAL STAKE BRACING FOR TREES 2" CALIPER OR LESS AND OTHER TREES LESS THAN 8' IN HEIGHT; 2 OR 3 VERTICAL STAKES BRACING FOR TREES OVER 2" CALIPER AND OTHER TREES 8' OR MORE IN HEIGHT.

BRACING SINGLE OR MULTIPLE VERTICAL STAKES METHOD



POCKET HOLES ON SLOPE



SKETCH SHOWING METHOD OF DIGGING AND BALLING TREES

PLANTING DETAILS

FIGURE 14-D

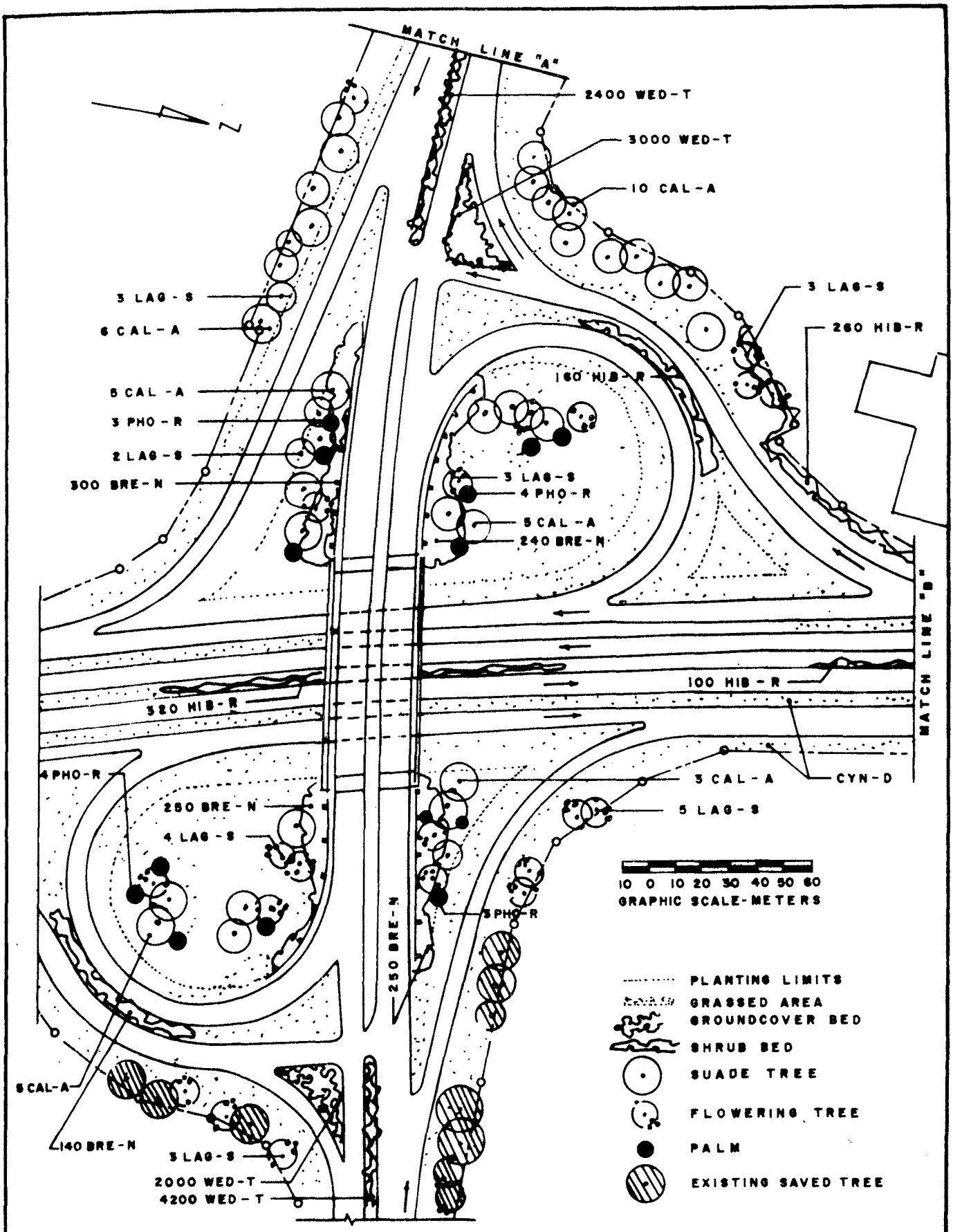
PLANTS SCHEDULE

SYMBOL	KEY	BOTANICAL NAME	COMMON NAME	QUANTITY	SPACING	SIZE	DELIVERY	REMARKS
	COC-U	COCCOLOBIS UVI-FERA	SEA GRAPE (UVA DE PLAYA)	255	4'-0" C/C	18"-24"	1 GAL. CAN	FOR PLANTING DETAILS SEE SHEET NO. 159.
	NER-O	NERIUM OLEANDER	OLEANDER (ALELI)	425	4'-0" C/C	18"-24"	1 GAL. CAN	
	BAU-G	BAUHINIA GALPINI	RED ORCHID (ORQUIDEA ROJA)	9	AS SHOWN ON PLAN	18"-24"	1 GAL. CAN	VINE BAUHINIA
	TAB-P	TABEBUIA PENTAPHYLLA	TRUMPET TREE (ROBLE ROSADO)	7	" " " "	8'-10'	B & B	
	ROY-B	ROYSTONEA BORINCANA	ROYAL PALM (PALMA REAL)	6	" " " "	8'-10'	B & B	TOTAL HEIGHT
	CYN-D	CYNODON DACTYLON	BERMUDA GRASS (GRAMA BERMUDA)	7700 SQ.FT.	—	—	BLOCKS	
TOP SOIL				80 C.M.				SEE DETAILS ON SHEETS 17 TO 19

TO BE INCLUDED IN THE PLANTING PLANS

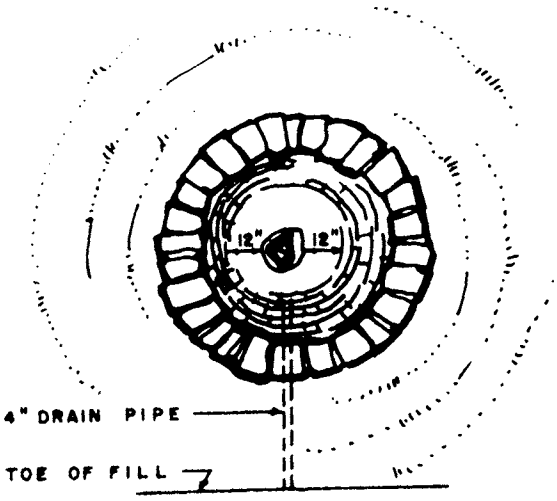
PLANTS SCHEDULE

FIGURE 14-E

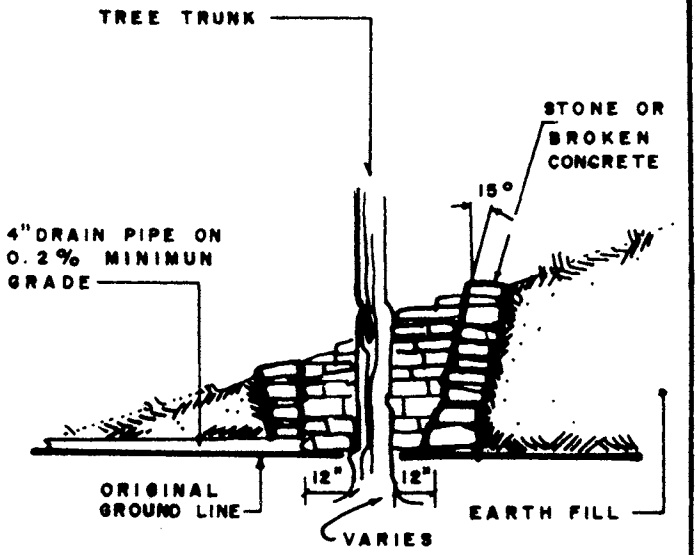


PORTION OF A PLANTING PLAN

FIGURE 14-F



PLAN



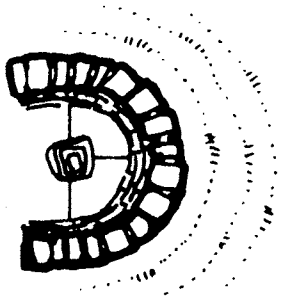
SECTION

NOTES:

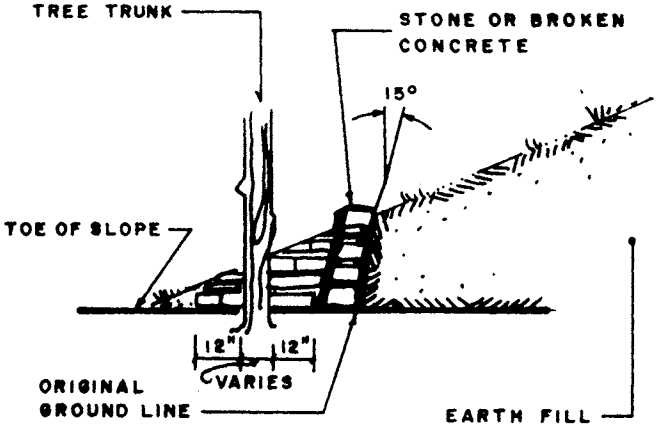
1 - HEIGHT OF WELL DEPENDENT ON SLOPE AND DEPTH OF FILL.

2 - DRAIN PIPE MAY BE OMITTED IF DISTANCE FROM TREE TO TOE OF SLOPE IS MORE THAN 20 FT. OR LESS THAN 5 FT.

3 - THE MINIMUM SIZE OF THE BROKEN CONCRETE OR RUBBLE STONE SHALL BE 4" IN THICKNESS AND 6" IN LENGTH AND WIDTH.



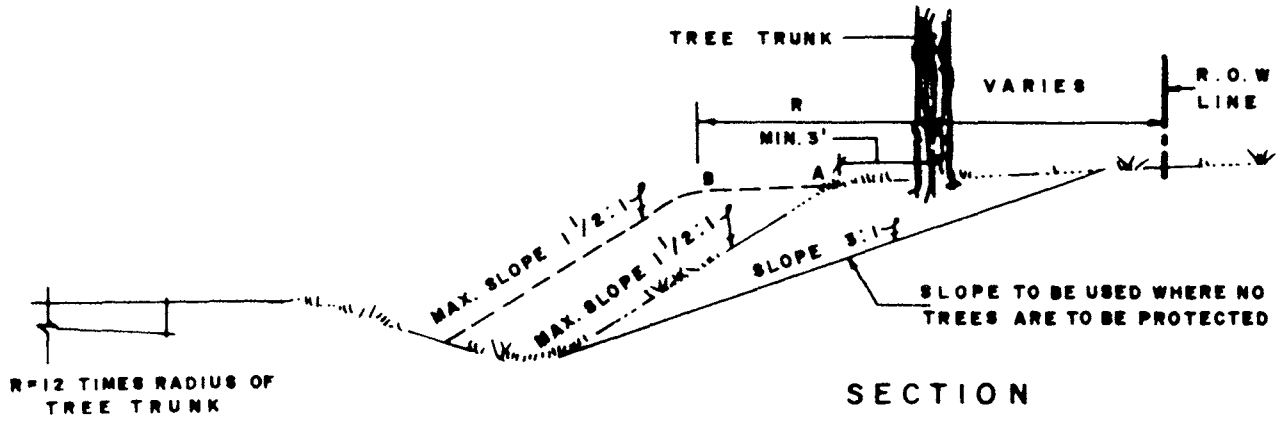
PLAN



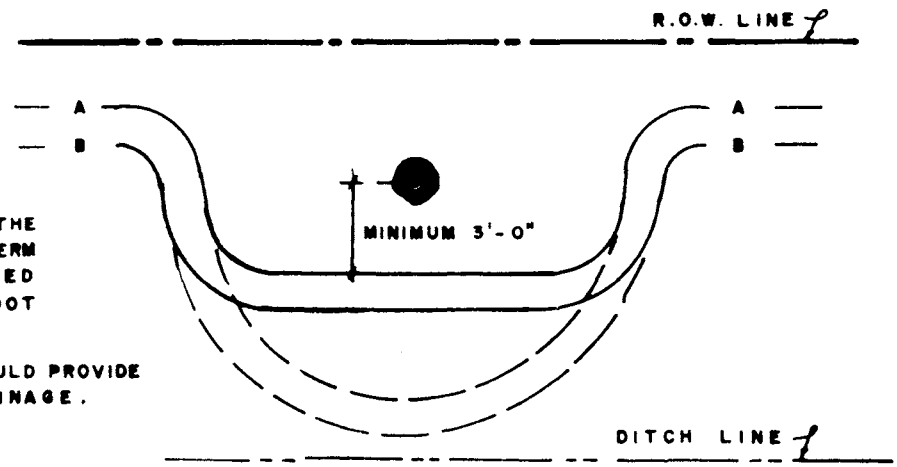
SECTION

TREE WELLS TO CONSERVE EXISTING TREES

FIGURE 14-G



SECTION



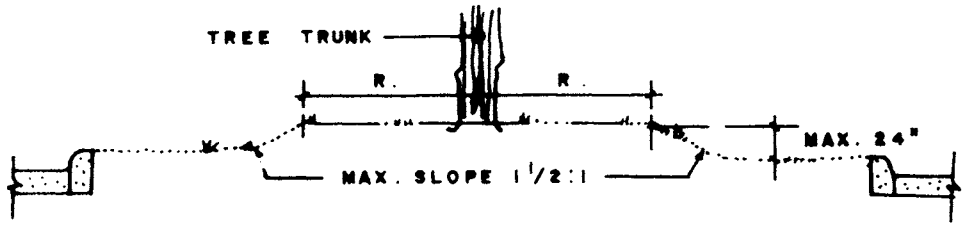
PLAN

NOTES:

1- THE BROKEN LINE SHOWS THE RECOMMENDED WIDTH OF BERM AND BACKSLOPE TO BE USED TO CONSERVE ADEQUATE ROOT SYSTEM.

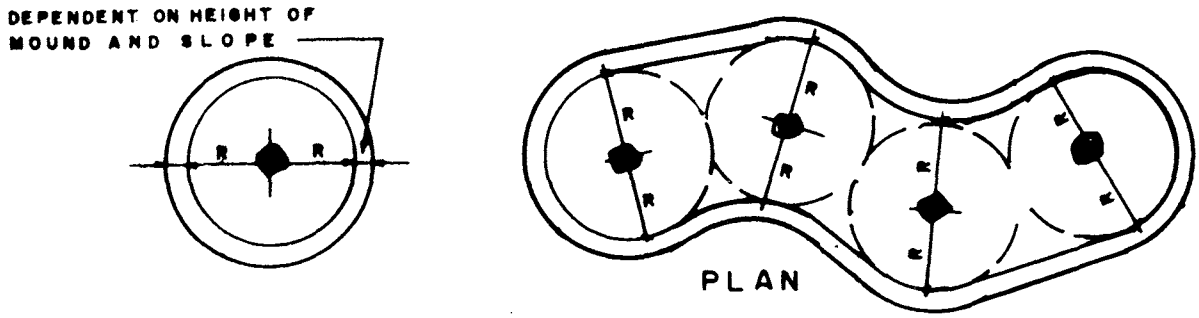
2- THE PROPOSED SLOPE SHOULD PROVIDE ADECUATE SPACE FOR DRAINAGE.

ROOT PRESERVATION IN BACKSLOPES



R = 12 TIMES RADIUS OF TREE TRUNK

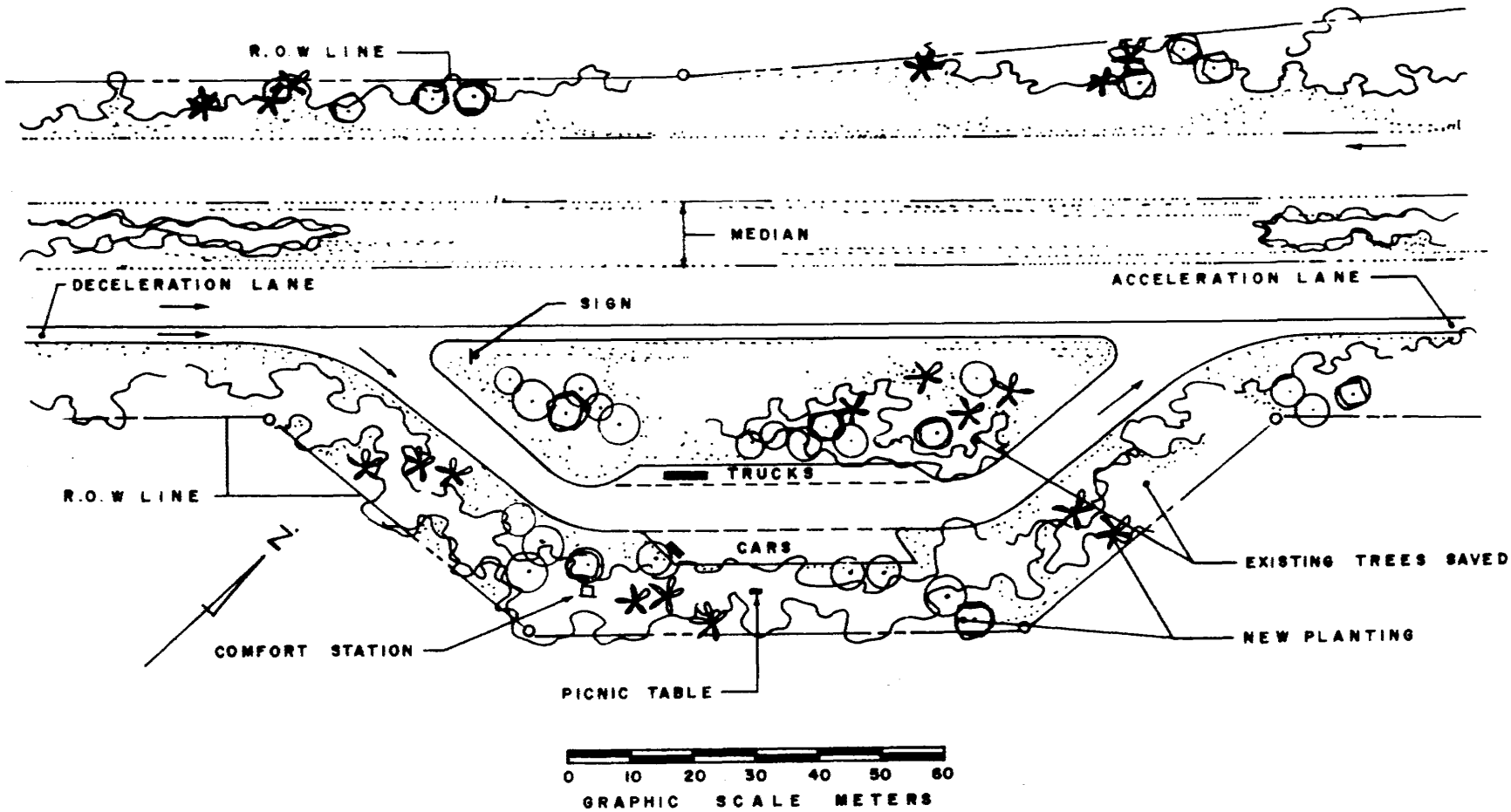
SECTION



PLAN

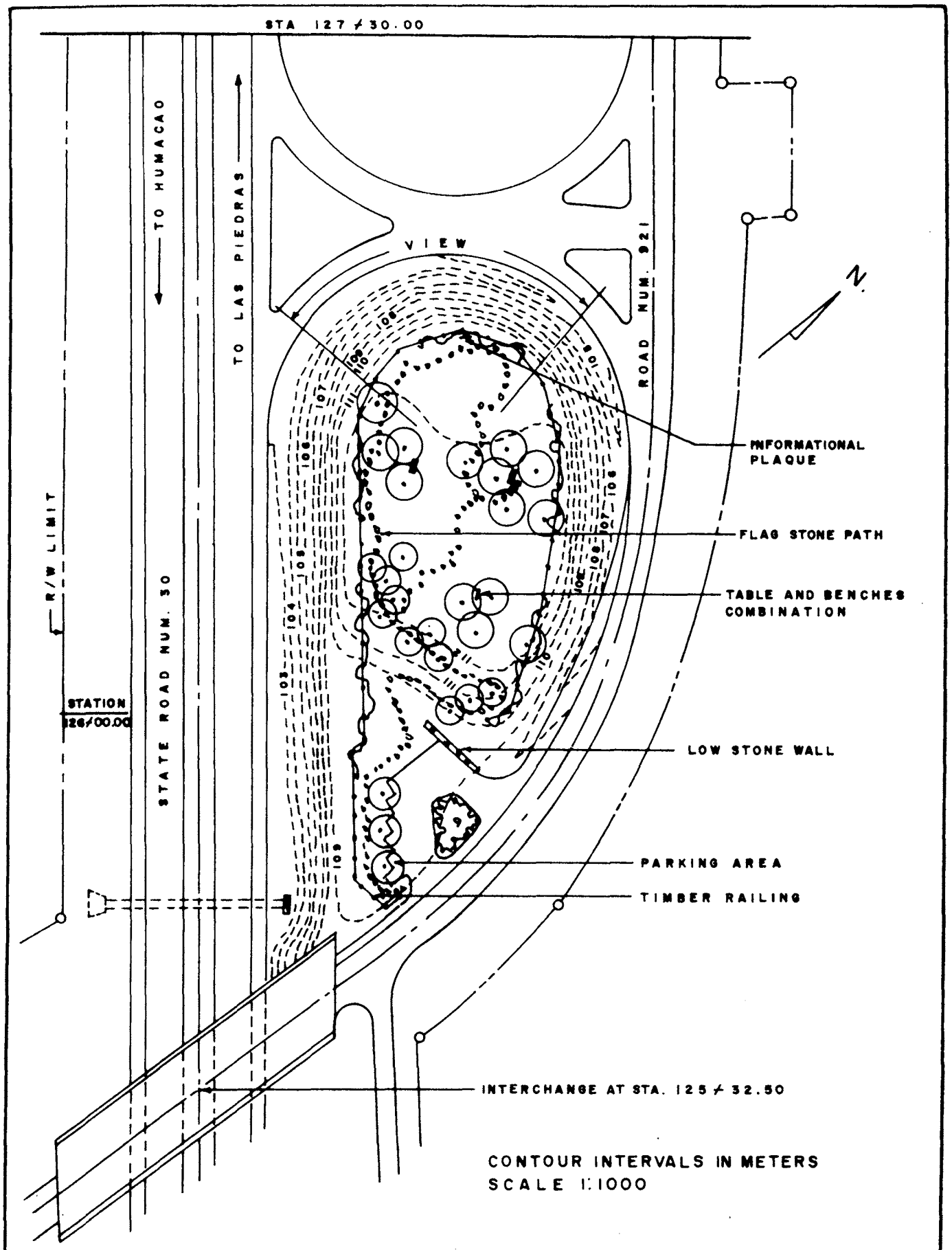
ROOT PRESERVATION

ROOT PRESERVATION SYSTEMS FIGURE 14-H



EXAMPLE OF SAFETY REST AREA

FIGURE 14-I



EXAMPLE OF SCENIC OVERLOOK

FIGURE 14-J

CHAPTER 15

PEDESTRIAN FACILITIES

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CHAPTER 15

PEDESTRIAN FACILITIES

15—01 GENERAL

This chapter provides guidance and details on the policies and standards concerning the provisions of pedestrian facilities in the various types of highways. It complements information appearing in Chapter 2 "Typical Sections" and Chapter 9 "Traffic Control Devices" of this Manual on facilities to be included parallel or transversally to the traveled way, in access controlled or non access controlled highways, both urban and rural.

The facilities described in this Chapter comprises shoulders, sidewalks, marked crosswalks, school zones, traffic signals, and elevated or underground facilities.

The designer of pedestrian facilities should take into consideration the overall impact, including the need of and measures to insure the proper use of the facility, on the surrounding area by the adequate planning of it. The appropiate facility, according to the need as determined by the corresponding study, should be selected. Adequate safety for preventing pedestrian accidents such as falls and collisions with fixed objects and crime prevention by having the proper illumination and visibility is to be provided in the overall planning and design of the facility. Its visual impact on the environment, or aesthetics of the project, especially when elevated pedestrian facilities are contemplated, is to be given appropiate consideration.

Consideration should also be given to the possibility that some sectors of the right of way of the road could be used for passive recreation. In those places benches, drinking fountains, proper illumination, shelters, signs as need and designed in accordance to the standards set in Puerto Rico's MUTCD, litter containers, etc., should be provided. These areas can be given scenic treatment or landscaping with grass, bushes, trees, flowering shrubs, etc.

In constructing these facilities, differently textured and or colored materials, including materials such as bituminous asphalt concrete, stainless steel, aluminum or wood could be used to enhance their appearance making them aesthetically more pleasing. The different colors could be given by the addition of pigments to the mixture used, by painting the surface or by using different colored aggregates.

15—01 PEDESTRIAN FACILITIES TERMINOLOGY

Pedestrian facilities are hereby defined and examples shown in figures 15—A, 15—B, 15—C, 15—D, 15—E, 15—F, 15—G and 15—H.

15—02.01 PAVED SHOULDERS

These are Paved portions of the roadway contiguous with the traveled way for accommodation of stopped vehicles for emergency use and for lateral support of the base and surface courses. In Puerto Rico, due to our densely populated condition, usually the shoulders of non-access or partial access controlled highways are used by pedestrians. Sometimes, this occurs also on full access controlled ones. (Fig. 15—A)

15—02.02 SIDEWALKS

These are paved portion of the right of way dedicated to the exclusive use of pedestrians. (Fig. 15—B)

15—02.03 WHEELCHAIR RAMPS

These are inclined planes at curbed sidewalks to facilitate access to them to the handicapped. (Fig. 15—C)

15-02.04 MARKED PEDESTRIAN CROSSWALKS

These are markings made with paint or other marking devices (raised pavement markers, etc.) on the pavement and used to indicate the pedestrians the point where they can cross the highway at grade and to warn the motorist, identified or not together with traffic signs, where pedestrian activity can be expected. They also help to establish the right of the pedestrians to be on the traveled way of the highway and the responsibility of drivers to yield them the right of way. (Fig. 15-D)

15-02.05 TRAFFIC SIGNALS

These are electro-mechanical, electronic, solid state, etc., devices used to assign the right of way to vehicles and/or pedestrians on the highway according to a fixed or variable program, usually through visible indications by means of electronically illuminated signal lenses, (Fig. 15—E). A hazard identification beacon, (Fig. 15—F), which is one or more sections of a standard traffic signal with a flashing circular yellow indication in each section, can be used to warn motorists of midblock crosswalks or other hazardous zones, as in school zones, etc. For additional information related to their use refer to Chapter IV of the Puerto Rico MUTCD.

15-02.06 PEDESTRIAN GRADE SEPARATIONS

These are structures or means to separate physically pedestrians from vehicular activity or traffic, and thus are usually the measures providing the most safety to pedestrians by eliminating vehicle-pedestrian conflicts. They can be elevated and underground or depressed facilities. (Fig. 15-G and 15-H).

15-03 CHARACTERISTICS OF PEDESTRIAN FACILITIES

15-03.01 PAVED SHOULDERS

Paved shoulders provide satisfactory protection for pedestrians or other users in need to utilize them, on all highways, by keeping those from walking parallel to traffic along the roadway. They are specially useful for this at night or when mud or other unsatisfactory conditions exist as on unpaved shoulders. To be effective in this usage they shall be properly delineated by pavement markings and signs, as needed.

15-03.02 SIDEWALKS

Sidewalks provide additional safety for pedestrians walking along rural or urban highways and streets by introducing or providing physical separation from the traveled way, usually by means of curbs. They are often used with planting strips from 1.25 to 2.50 meters wide that provide additional separation from traffic and also serve as a means of beautification for the facility.

Sidewalks can also be used in some cases together with barriers and fences to provide additional safety to pedestrian from vehicles intruding upon them and to keep pedestrians from the traveled way.

15—03.03 WHEELCHAIR RAMPS

Provide the handicapped access to the curbed sidewalk at established pedestrian crossings.

15—03.04 MARKED PEDESTRIAN CROSSINGS OR CROSSWALKS

Marked pedestrian crossings establish the right of way of pedestrians over vehicles when making use of them to cross a street or highway at places other than signalized intersections or when used together with pedestrian controlled signals.

At signalized intersections they serve to delineate the area of permitted pedestrian activity.

At locations other than intersections (i.e mid-block) and when used together with signs, they serve to warn motorists of places where pedestrian activity can be expected, including school crossings. The last can be of two types: school crossings only or school zones. Marked pedestrian crossings do not eliminate vehicle pedestrian conflicts.

15-03.05 SCHOOL ZONES AND SCHOOL CROSSINGS

School zones and school crossings are specials types of marked pedestrian crosswalks. (Fig. 15-1).

A school zone is that part of a highway or street directly in front of a school plus an additional distance to every side of a variable length in which a limited or low speed is established. It is so identified and indicated by signs and pavement markings. Its purpose is to give special protection to school children crossing the right of way or taking or leaving transportation at the curb.

A school crossing is a pedestrian crosswalk used by any number of school children when the school is located more than 100 meters from the street or highway.

15—03.06 TRAFFIC SIGNALS

Traffic signals generally provide adequate safety to pedestrian crossings at highways and streets, through their operation and control of traffic at intersections, mid-block or other locations where they are installed. Traffic signals, when not properly designed and installed, can cause vehicle traffic interruptions or delays and increase accident frequency (especially the rear-end type). At intersections, signals usually do not eliminate right and/or left turn vehicle interference unless a special pedestrian phase is provided.

Traffic signals can be pedestrian actuated, vehicle and pedestrian actuated and fixed time.

Pedestrian actuated signals shall be used only at locations between intersections or at other special sites. These and the other two types to be used at intersections or other locations, are to be determined by an engineering study, as established in the next section of this chapter and in the Puerto Rico MUTCD.

A flashing traffic signal or beacon is a warning device that can be used to call with more urgency the attention of drivers approaching a hazardous pedestrian crossing, for the protection of these.

15—03.07 PEDESTRIAN GRADE SEPARATIONS

Pedestrian grade separations provide maximum safety to pedestrians from traffic accidents. On full or partially access controlled highways, a facility of this type could offer the only legal means to pedestrians for traveling from one side of the road to the other. On the other hand, unless certain minimun conditions exist and necessary restrictions can effectively be imposed on pedestrians, the facility might be a less than desirable investment.

Pedestrian grade separations can be of two types: elevated or underground. Because of the high crime incidence in Puerto Rico, underground facilities are not too strongly recommended.

OVERCROSSINGS OR ELEVATED PEDESTRIAN FACILITIES (OVERPASSES)

A. ADVANTAGES:

1. Separate physically the pedestrian movement from vehicular movement, offering

pedestrians the maximum safety, thus increasing the efficiency and safety of the transportation system.

2. Improve at grade vehicular circulation by eliminating pedestrian caused vehicular delays.
3. Accidents will decrease, resulting from a reduction in conflicts.
4. Can be readily included in new highway construction or in existing ones.
5. Do not cause significant personal security problems to the pedestrian user.

B. DISADVANTAGES:

1. High construction cost.
2. Require change in grade, with the complementary inconveniences to the different classes of pedestrians, and their acceptance of it.
3. Can interfere adversely with adjacent properties and utilities.
4. Need the utilization of adequate controls to channelize and force pedestrians into using the facility.
5. Create potential danger for motorists, by possible falling objects, if not totally or adequately designed against this hazard.
6. May affect adversely the aesthetics of the city or the highway environment.

DEPRESSED OR UNDERGROUND PEDESTRIAN FACILITIES

A. ADVANTAGES:

1. Separate physically the pedestrian movement from vehicular movement, offering pedestrians the maximum safety from traffic accidents and thus increasing the offering and safety of the transportation system.
2. Provide built-in protection from the sun and inclement weather.
3. Improve at grade vehicular circulation by eliminating pedestrian-caused vehicular delays.
4. Accidents will decrease, resulting from a reduction in conflicts.
5. Can be readily included in new construction.
6. Maintain an unobstructed city-scape.
7. May interfere much less or not at all with adjacent properties.
8. The required grade separation may be much less than for an overpass.

B. DISADVANTAGES:

1. Extremely expensive and difficult to construct and can interfere greatly with underground utilities.
2. Present various and difficult security, ventilation, illumination, drainage, maintenance, vandalism, etc., problems, that must be adequately solved.
3. Require change in grade, with the complementary inconveniences to the different classes of pedestrians and their acceptance of it.
4. Need the utilization of adequate controls to channelize and force pedestrians into using the facility.

15-04 WARRANTS FOR THE PROVISION OF PEDESTRIAN FACILITIES

15-04.01 PAVED SHOULDERS

Paved shoulders should be provided, from the point of view of the pedestrian, where light (less than 20 per hour) pedestrian activity along rural and sub-urban uncontrolled or partially controlled access highways exists or is expected.

15-02.02 SIDEWALKS

Sidewalks should be provided along rural uncontrolled or partially controlled access highways in addition to paved shoulders, if possible, on one or both sides of the roadway, where a high pedestrian activity of more than 20 per hour exists or is to be expected according to the existing or proposed traffic generators considered during route planning. They shall be included in front of semi-urban areas, factories, schools and other developed sections.

In urban highways, sidewalks shall be provided as set forth in Chapter 2, Article 2-04.09 (2) and in this Chapter, Article 15—05.02. .

15-04.03 WHEELCHAIR RAMPS

As established in Section 228 of the Highway Safety Act of 1973 (CURBED RAMPS FOR THE HANDICAPPED) and set forth in EHPM 6-2-1-1 of January 11, 1977, wheelchair ramps are to be installed at all pedestrian of crosswalks on Federal-aid projects approved for construction after July 1, 1976, and, wherever feasible, on all such projects approved for construction prior to that time.

15-04.04 MARKED PEDESTRIAN CROSSWALKS

Marked pedestrian crosswalks are to be provided at all signalized traffic crossings. When determined necessary from a study of existing or new created hazardous or undesirable conflicts between pedestrians and turning vehicles, the marked pedestrian crosswalks at any one of the accesses or approaches to the intersection can be omitted or eliminated and, in urban areas, signs R9 (Peatón No Cruce Aquí) may be installed facing the traffic for which they are intended.

Marked pedestrian crosswalks should be provided at all other intersections where there is substantial conflict between vehicle and pedestrian movements. Also, at other appropiate points of pedestrian concentration, such as at loading islands, mid-block pedestrian crossings and/or where pedestrians could not otherwise recognize the proper place to cross. For additional information please refer to section 3B—15 of the Puerto Rico MUTCD.

15-04.05 SCHOOL ZONES AND SCHOOL CROSSINGS

A school zone is warranted in front of any school that is located adjacent to a street or highway.

A school crossing sign is intended for use at any marked pedestrian crossing, including those at signalized intersections, used by school children going to and from school. Only crossings adjacent to schools and those on established school children routes shall be signed.

15-04.06 PEDESTRIAN TRAFFIC SIGNALS

Traffic signals to be provided for the express purpose of serving the pedestrian are justified under warrants 3 (Minimun Pedestrian Volume) and 4 (School Crossing) and specification number 3 of Warrant 6 (Accident Experience) of the Puerto Rico MUTCD. Warrant 3 reads as follows:

"The Minumun Pedestrian Volume warrant is satisfied when, for each of any 8 hours of an average day, the following traffic volumes exist:

1. On the major street, 600 or more vehicles per hour enter the intersection (total of both approaches); or where there is a raised median island 4 feet or more in width, 1,000 or more vehicles per hour (total of both approaches) enter the intersection on the major street; and

2. During the same 8 hours as in paragraph (1) there are 150 or more pedestrians per hour on the highest volume crosswalk crossing the major street."

"When the 85th percentile speed of major-street traffic exceeds 40 miles per hour (65 Kms. per hour), or when the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the minimun pedestrian volume warrant is 70 percent of the requirements above (in recognition of differences in the nature and operational characteristics of traffic in urban and rural environments and smaller municipalities)."

"A signal installed under this warrant at an isolated intersection should be of the traffic actuated type with push buttons for pedestrians crossing the main street. If such a signal is installed at an intersection within a signal system, it should be equipped and operated with control devices which provide proper coordination."

"Signals installed according to this warrant shall be equipped with pedestrian indications conforming to requirements set forth in other section of this Manual (Puerto Rico MUTCD)."

"Signals may be installed at non-intersection locations (mid-block) provided the requirements of this warrant are met, and provided that the related crosswalk is not closer than 45 mts. to another established crosswalks. Curbside parking should be prohibited for 30 mts. in advance of, and 6 mts. beyond, the crosswalk. Phasing, coordination, and installation must conform to standards set forth in this Manual. Special attention should be given to the signal head placement and the signs and markings used at non-intersection locations to be sure drivers are aware of this special application."

Warrant 4 reads:

"A traffic control signal may be warranted at an established school crossing when a traffic engineering study of the frequency and adequacy of gaps in the vehicular traffic stream as related to the number and size of groups of school children at the school crossing shows that the number of adequate gaps in the traffic stream during the period when the children are using the crossing is less than the number of minutes in the same period (sec. 7A-3)."

"When traffic control signals are installed entirely under this warrant:

1. Pedestrian indications shall be provided at least for each crosswalk established as a school crossing.

2. At an intersection, the signal normally should be traffic-actuated. As a minimun, it should be semi-traffic-actuated, but full actuation with detectors on all approaches may be desirable. Intersection installation that can be fitted into progressive signal system may have pretimed control.

3. At non-intersection crossings, the signal should be pedestrian-actuated, parking and other obstructions to view should be prohibited for at least 30 mts. in advance of and 6 mts. beyond the crosswalk, and the installation should include suitable standard signs and pavement markings. Special police supervision and/or enforcement should be provided for a new non-intersection installation."

Warrant 6 reads:

"The Accident Experience warrant is satisfied when:

1. Adequate trial of less restrictive remedies with satisfactory observance and enforcement has failed to reduce the accident frequency; and
2. Five or more reported accidents, of types susceptible of correction by traffic signal control, have ocurred within a 12-month period, each accident involving personal injury or property damage to an apparent extent of $100 or more; and
3. There exists a volume of vehicular and pedestrian traffic not less than 80 percent of the requirements specified either in the minimun vehicular volume warrant, the interruption of continuous traffic warrant, or the minimun pedestrian volume warrant; and
4. The signal installation will not seriously disrupt progressive traffic flow.

Any traffic signal installed solely on the Accident Experience warrant should be semi-traffic-actuated (with control devices which provide proper coordination if installed at an intersection with a coordinate system) and normally should be fully traffic-actuated if installed at an isolated intersection."

A flashing traffic signal can be installed in conjunction with a marked pedestrian crossing at locations of limited sight distance.

15–04.07 ELEVATED AND UNDERGROUND PEDESTRIAN FACILITIES

The study of the need for the installation or construction of elevated or overhead and depressed or underground pedestrian crossings in new projects can be divided into two types:

A. Where pedestrian activity is not permitted or not possible, as in highways with full or partial control of access between intersections, or sites where, due to some conditions such as a center barrier, pedestrians are unable to cross.

Elevated or underground facilities (overpasses or underpasses) are to be provided to serve points of significant pedestrian trip generation or attraction as suggested and recommended in the study made by the New Jersey Department of Transportation, its Report No. 75-006-7712 "Pedestrian Grade Separation Locations—A Priority Ranking System" Volume I and II, December 1975.

The factors to consider are: 1) pedestrian trip generation, 2) distance to nearest crossing; and 3) a judgement factor which is in itself divided into: a) safety at alternate crossing; b) surplus trip generation; and c) uniqueness of location. Appropiate weights are given to these according to the procedures detailed in that report which shall be consulted and used in conjunction with this Manual for the justification of the construction of pedestrian grade separations.

As explained in the aforementioned report, a costs and benefits analysis is not used because of the many unknown or incomplete data that is needed and which can not be accurately obtained and, also, because of the excessive weight given to the cost of fatal and non-fatal pedestrian accidents which are variable ocurrences.

B. For locations where pedestrian activity is possible, the same study establishes the following parameters that are to be analyzed and weighted by the method established thereby: 1) pedestrian and vehicle volumes, 2) actual sight distance-desirable sight distance ratio or maximun green and yellow for pedestrians compared to the pedestrian crossing time needed; 3) school crossing; 4) distance to alternate crossing and type of protection at it; and 5) judgement.

15–05 DESIGN SPECIFICATIONS OF PEDESTRIAN FACILITIES

15–05.01 PAVED SHOULDERS

To provide safety to pedestrians on rural routes paved shoulders outside the right pavement edge should be at least 1.20 meters wide, depending on the type of highway, up to a maximun of 3.00 meters, clearly identified or delineated from the traveled way by a white border line 10 cms. wide (see Fig. 15—I). For additional details refer to the typical sections in Chapter 2.

15—05.02 SIDEWALKS

A. RURAL HIGHWAYS—When required, sidewalks should be a minimun of 1.25 meters wide with a planting strip of 1.25 meters. When necessary from pedestrian circulation and/or refuge, as in front of schools, industrial, commercial, etc., areas, the sidewalk could be a maximum of 2.50 meters wide and a planting strip of 1.50 meters. The whole width can also be paved, if needed by the existing or anticipated pedestrian density. As a basic safety concept, sidewalks in rural highways should be as far as possible from the traveled way.

B. URBAN HIGHWAYS AND STREETS—Depending on the typical section used for the design of the facility, in residential areas the minimun sidewalks width shall be 1.25 meters together with a planting strip of 1.25 meters. In front of schools or similar areas it may be wider, separated by a planting strip.

In commercial, industrial or similar areas, the sidewalk could be a minimun of 1.25 meters with a planting strip of 1.25 meters. Preferably the sidewalk should be 1.50 meters wide with a planting strip 1.50 meters wide. The whole width could also be paved as sidewalk depending on existing or anticipated pedestrian density.

For special highway sections (urban or rural), sidewalks of a minimun of 1.70 meters in width are required. For this, and additional information see Chapter 2 and the Regulation for the Control of Accesses to the Public Highways in Puerto Rico, promulgated by the Department.

15–05.03 WHEELCHAIR RAMPS

Wheelchair ramps shall have a maximun slope of 12:1. The minimun width shall be 1.00 meter. Included as a reference for their design is the one adopted by the Highways Authority and approved by the Federal Highway Administration. Figures 15—K and 15—L.

15—05.04 MARKED PEDESTRIAN CROSSWALKS

Pedestrian crosswalks can be marked using two parallel white lines from 15 centimeters wide up to 60 centimeters wide where the 85th percentile speed is over 60 KPH across the intersection approaches where they are to be marked, or at the point between intersections where the pedestrian crossing is to be established. The separation between lines or crosswalk width will range from a minimun of 1.80 meters to as wide as necessary (Figure 15—M). Pedestrian crosswalks can also be marked with white longitudinal lines at a 90° angle to the line of the crosswalk (Fig. 15—N). These lines should be approximately 60 centimeters wide and spaced 60 centimeters appart. When a marked crosswalk is to be provided at rural locations between intersections, traffic signs W11—2 (Cruce de Peatones) shall be installed as established in Section 2C—32, of the Puerto Rico MUTCD. The use of these signs is optional in urban conditions.

15—05.05 SCHOOL ZONES AND SCHOOL CROSSINGS

A school zone is established by painting a yellow line 30 cms. wide at a distance of fifty (50) meters from both sides of the entrance to a school adjacent to a street or highway. Sign

S5–1 ("Escuela, Velocidad Máxima 25, 6 AM — 6 PM") shall be installed on each approach (Fig. 15–O). Depending on conditions at the site, the speed limit at a school zone can vary from 10 MPH to 25 MPH. School advance Signs (S1–1) shall be installed in advance of established school zones in each direction of travel at not less than 90 mts. nor more than 120 mts.

A school crossing is established by using an S2–1 sign ("Cruce de Escolares") together with regular pedestrian crossing pavement markings. A School Advance sign S1–1 shall be used in advance of the School Crossing sign.

15–05.06 TRAFFIC SIGNALS

Traffic signals located or to be installed at intersections or other locations as determined by a study according to the warrants established in Section 15–04.05, or other warrants of the Puerto Rico MUTCD, shall be complemented with pedestrian signal indications under the conditions specified in Section 4D–3 of the Manual.

The basic combinations of pedestrian signal intervals with vehicular signal operations shall be as indicated on Section 4D–7 of the Manual.

The design requirements for the pedestrian indications and the detectors (push - button or other type) are set forth on Sections 4D–4, 4D–6 of the Manual. See Figure 15–P for details on pedestrian signal faces installation.

Traffic signal installations shall include appropiate pavement markings and the signs necessary for adequate pedestrian guide and control.

15–05.07 PEDESTRIAN GRADE SEPARATIONS

The design characteristics of pedestrian grade separations should include (See Figures 15–Q, 15–R):

A. For elevated pedestrian facilities or overpasses:

1. A minimun width of 2.13 meters (7 feet) for the stairs, ramps and super structure.
2. The use of ramps instead of stairs when available space permits. Their gradient shall be no more than 8.33%. When stairs are used, their gradient shall be no more than 64.3% and one or two intermediate landings of 2.13 meters (7 feet) in length shall be provided.
3. The maximun free span for the superstructure shall be 38.00 meters (135 feet).
4. The free height over the roadway shall be no less than 5.20 meters (17 feet and not over 6.40 meters (21 feet).
5. The superstructure shall be an enclosed or partially covered one to prevent objects to fall or to be thrown to the roadway below and to provide additional safety to pedestrians making use of it, especially children and old aged or handicapped citizens.
6. Illumination should be provided as determined by the location studied.

B. For underground pedestrian facilities or underpasses:

1. A minimun width of 2.13 meters (7 feet) for the stairs, ramps and underground structure with a minimun height of 2.44 meters (8 feet).
2. Ramps with an inclination of no more than 8.33% should be prefered over stairs, when possible. Stairs shall have an inclination of no more than 64.3% and one or two intermediate landings of 2.13 meters (7 feet) should be provided, if necessary.
3. Adequate illumination, ventilation, drainage and maintenance shall be provided. Measures should be taken or considered for the protection or physical security of

pedestrians (especially children, women, and old aged and handicapped citizens) and, also, for the prevention of vandalism.

4. Provision could be made for their closing at night or at other times deemed necessary.
5. Every effort should be made in the design of the facility to provide a continuous visual line or visibility for the pedestrian from one end of the facility to the other.

15–06 CONSTRUCTION PLANS

Pedestrian facilities construction plans and specifications are to be included in the project plans. Paved shoulders are to be presented in the construction and pavement marking sheets. Sidewalk details, including wheelchair ramps, shall appear in the construction plans. Marked pedestrian crossings and school zones shall appear in the pavement markings and signs plans. Traffic signals will appear on the plans as set forth in Chapter 9, Section 9—04.03 of this Manual. Elevated and or depressed facilities shall appear in the construction plans.

15–07 REFERENCES AND GUIDES

The following is a list of selected references and guides to be used in the selection and design of pedestrian facilities:

1. Puerto Rico Manual on Uniform Traffic Control Devices for Streets and Highways — Puerto Rico Department of Transportation and Public Works — 197__.
2. Transportation and Traffic Engineering Handbook — Institute of Traffic Engineers, 1976
3. Traffic Control Devices Handbook — Federal Highway Administration, 1975
4. Standard Highway Signs — Federal Highway Signs — Federal Highway Administration, 1972
5. Manual of Traffic Engineering Studies — Institute of Traffic Engineers, 4th Edition
6. A Manual for Planning Pedestrian Facilities — Federal Highway Administration — 1974
7. Regulation for the Control of Accesses to Public Highways in Puerto Rico — Puerto Rico Department of Transportation and Public Works, — 1976
8. Pedestrian Grade Separation Locations — A priority Ranking System — Volume I and II — New Jersey Department of Transportation — 1975

SHOULDER IN TYPICAL SECTION

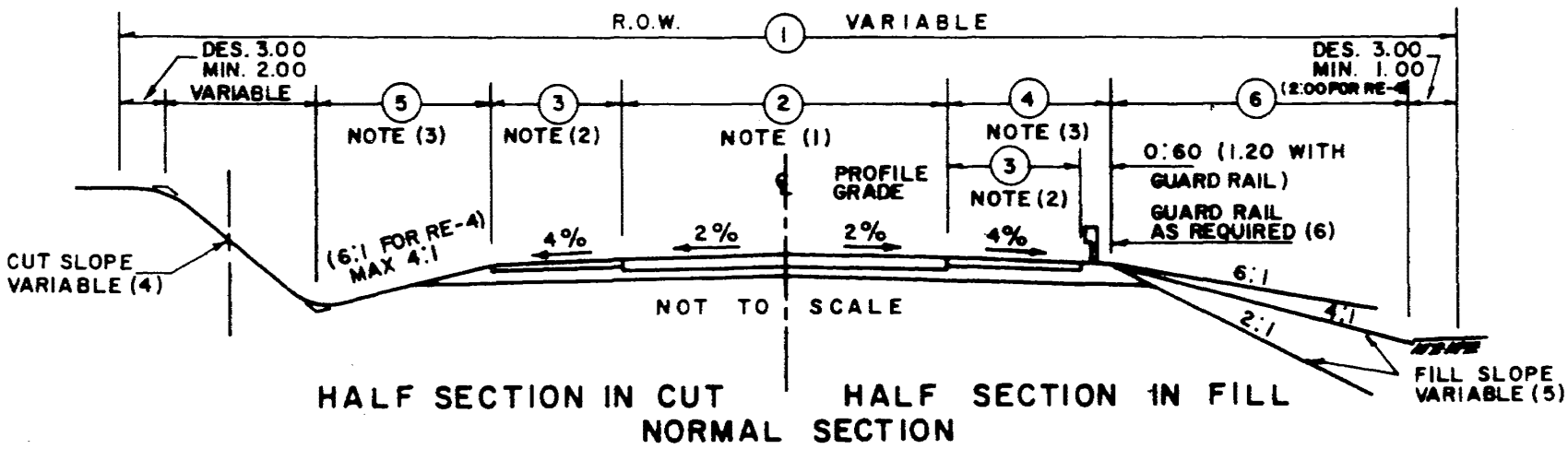


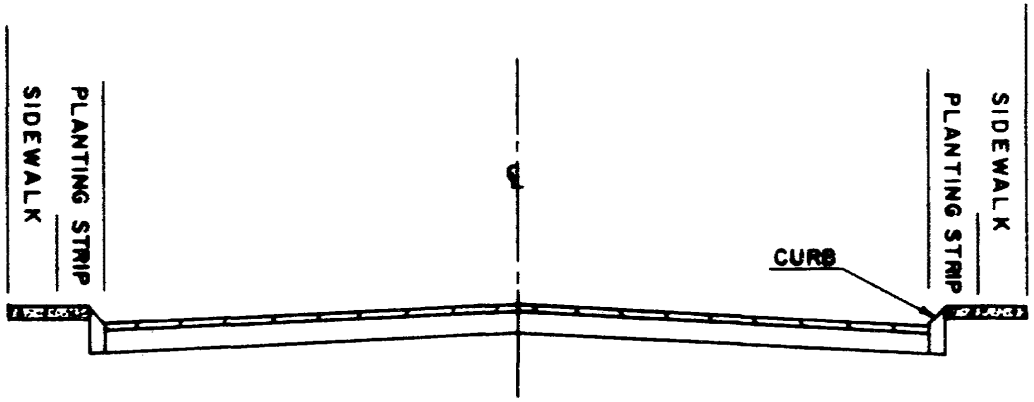
FIG. 15-A

NOTES:

(1) THE ELEMENTS OF THE PAVEMENT STRUCTURE ARE TO BE DETERMINED FOR EACH PROJECT, SEE CHAPTER
(2) MAY BE REDUCED IN MOUNTAINOUS TERRAIN, SEE TABLE 1-12
(3) FOR VARIATIONS SEE FIG. 2-H.
(4) FOR TYPICAL CUT SECTIONS SEE FIG. 2-J.
(5) FOR TYPICAL FILL SECTIONS SEE FIG. 2-K
(6) FOR WARRANTS FOR GUARD RAIL SEE CHAPTER 8.

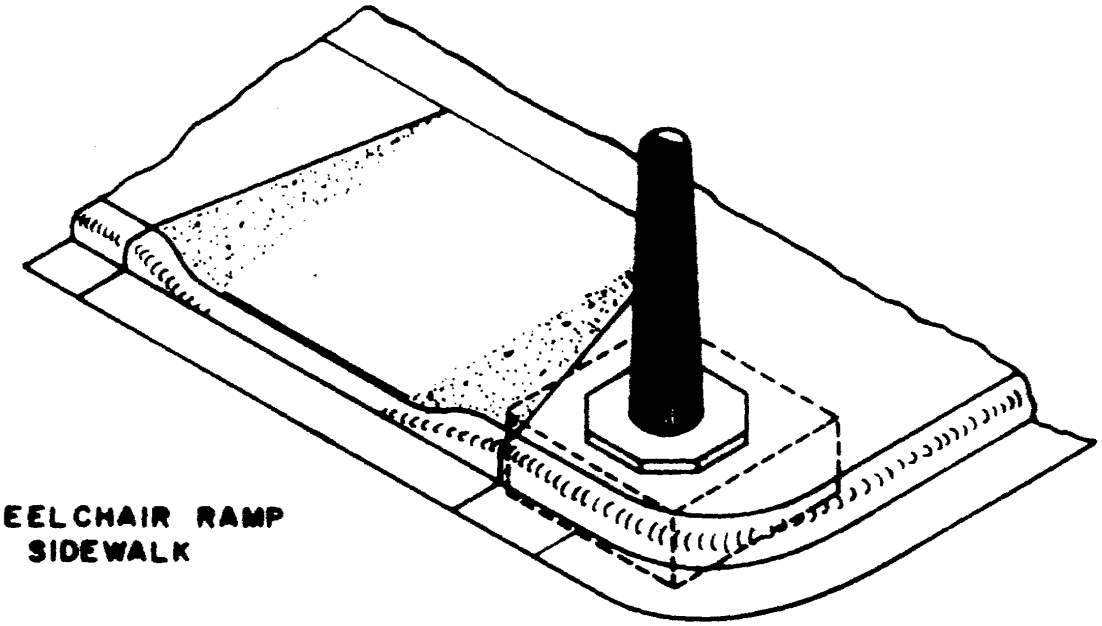
SECTION ELEMENTS

		R-6	R-7	R-8	RE-4
1	MIN. R.O.W.	30.00	22.00	20.00	30.00
2	NORMAL PAVEMENTS	7.30	6.70	6.10	7.30
3	SURFACED SHOULDER	3.00	2.40	1.00	3.00
4	SHOULDER ON FILL	3.60	3.00	2.40	3.60
5	NORMAL INSLOPE	4.00	3.00	3.00	6.00
6	MIN. FILL SLOPE	4.00	3.00	3.00	5.00

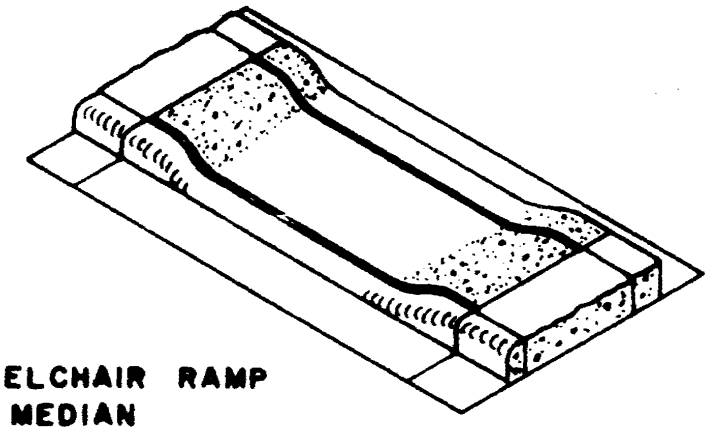


SIDEWALK WITH PLANTING
ON LOCAL STREET-RESIDENTIAL U-10

FIG. 15-B

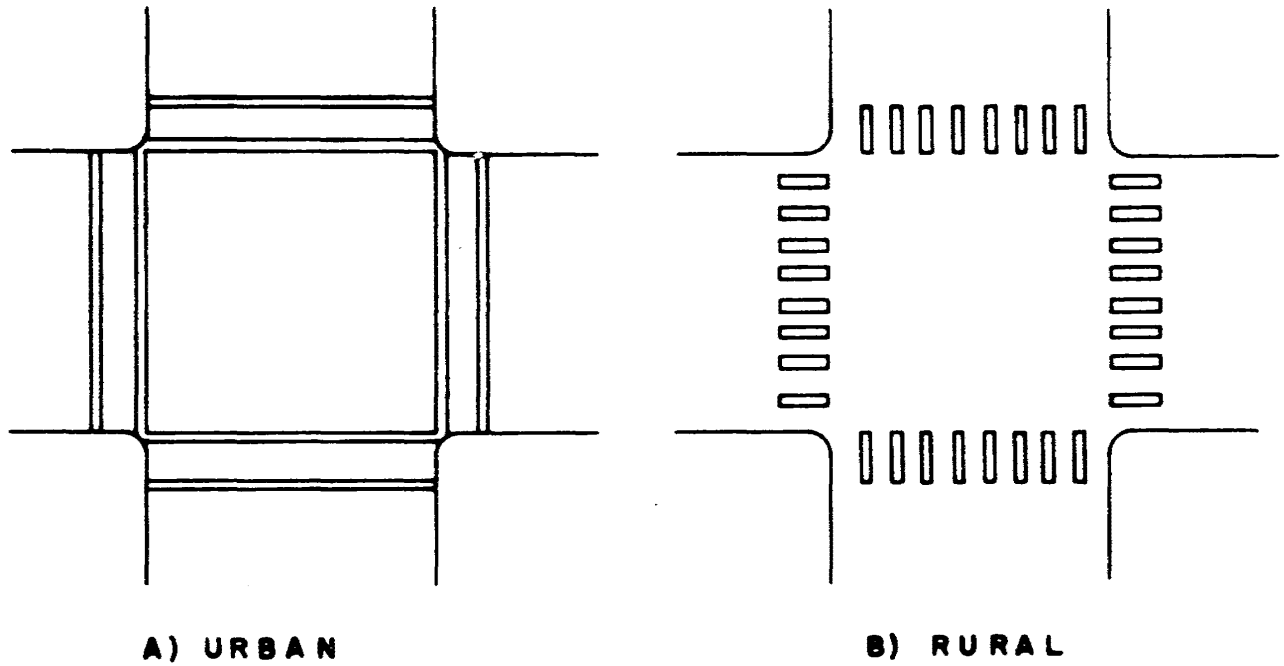


(A) WHEELCHAIR RAMP
ON SIDEWALK



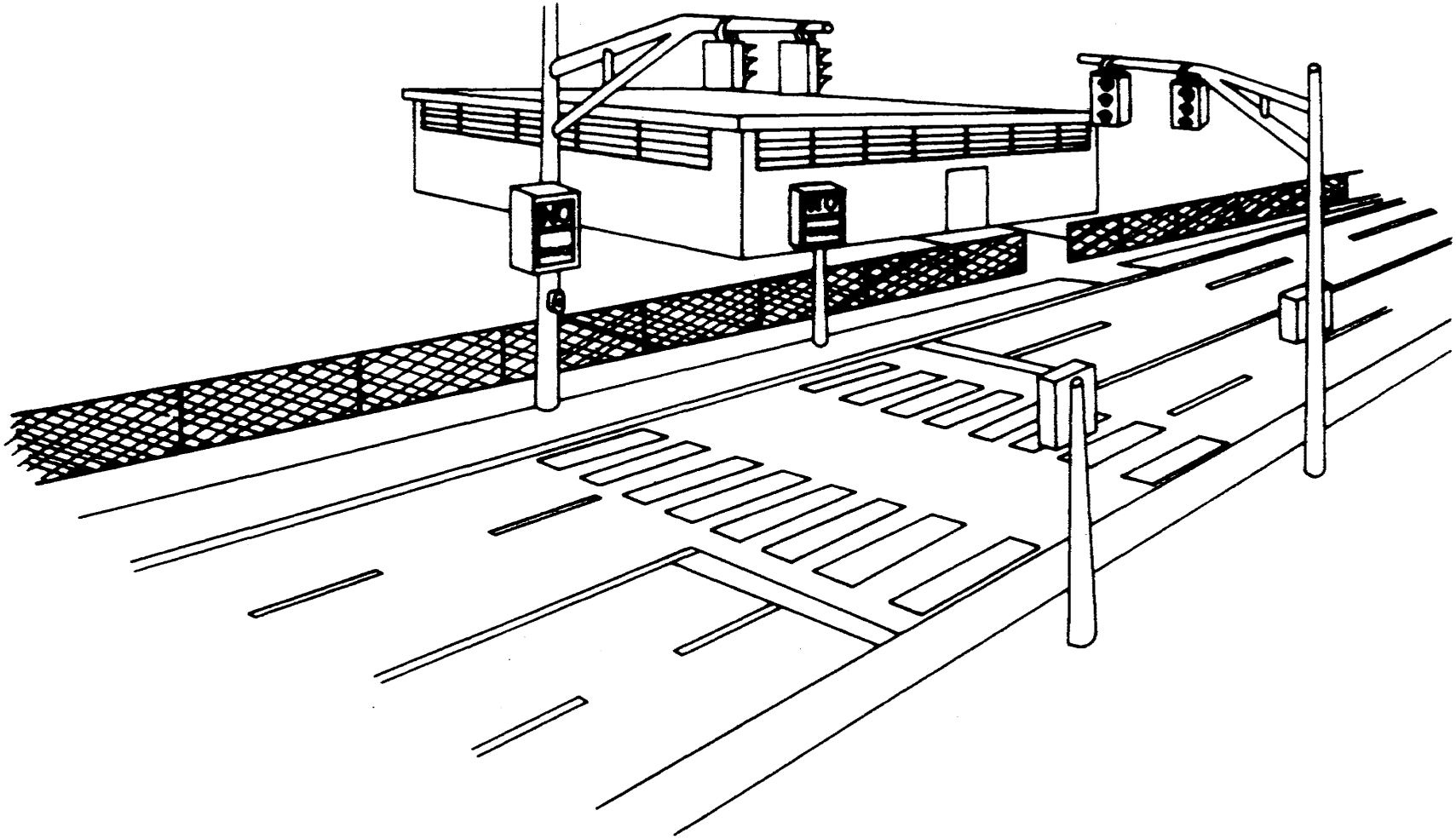
(B) WHEELCHAIR RAMP
ON MEDIAN

WHEELCHAIR RAMPS
FIG. 15-C



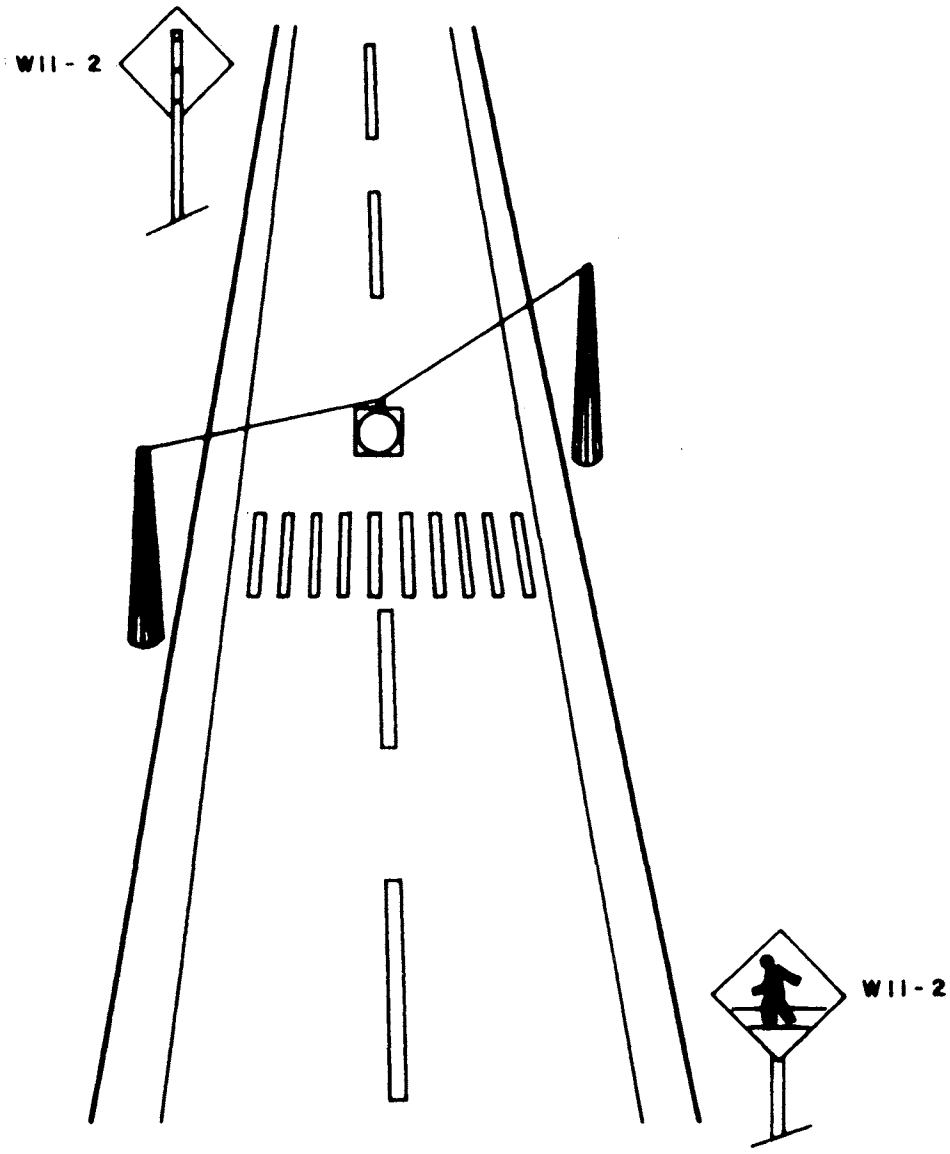
TYPICAL CROSSWALK MARKING

FIG. 15-D



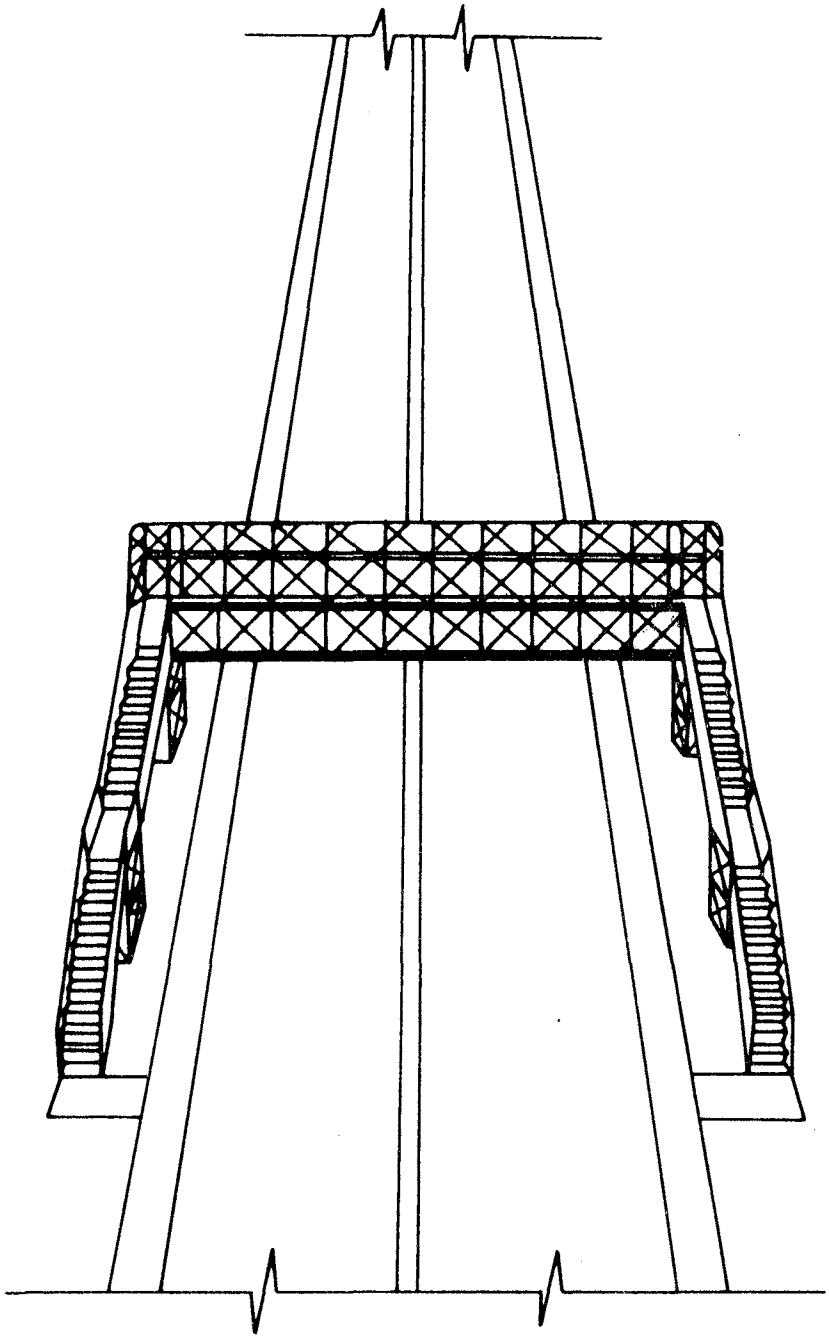
PEDESTRIAN SIGNAL INSTALLATION

FIG. 15-E



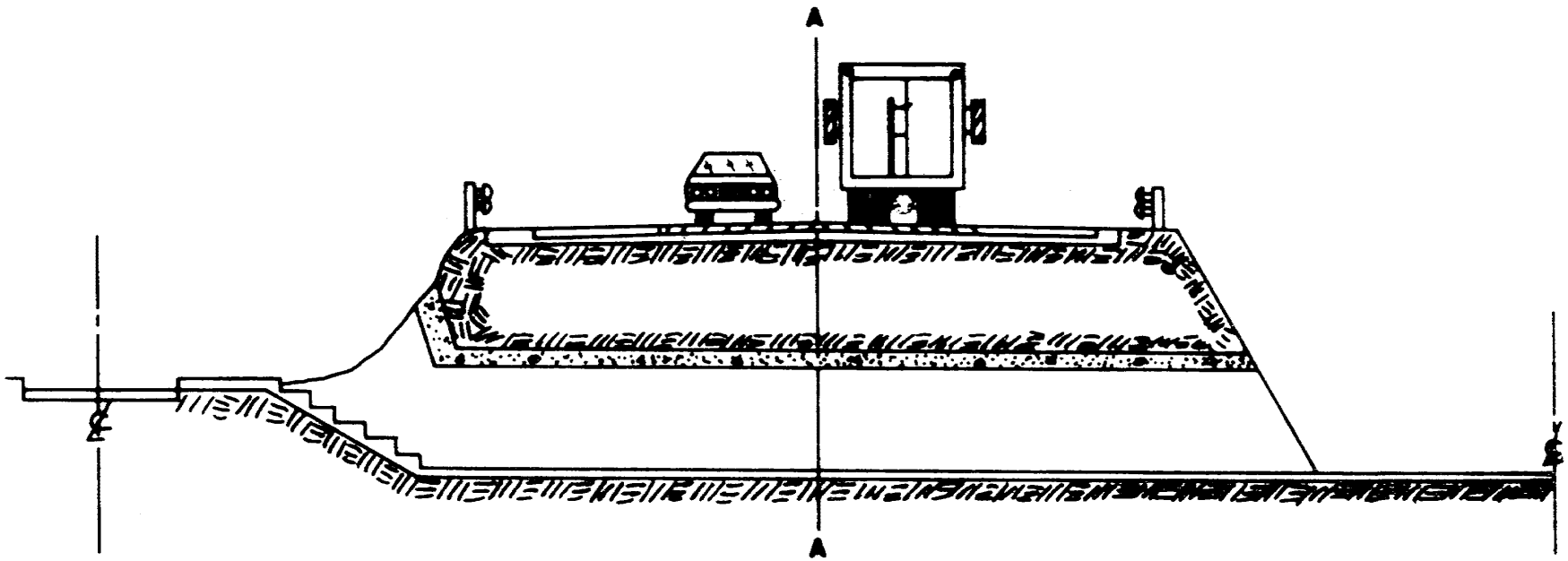
HAZARD IDENTIFICATION BEACON

FIG. 15-F



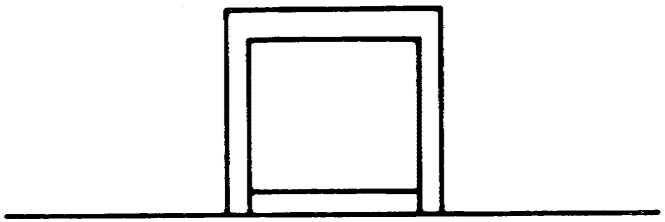
ELEVATED PEDESTRIAN CROSSING

FIG. 15-G

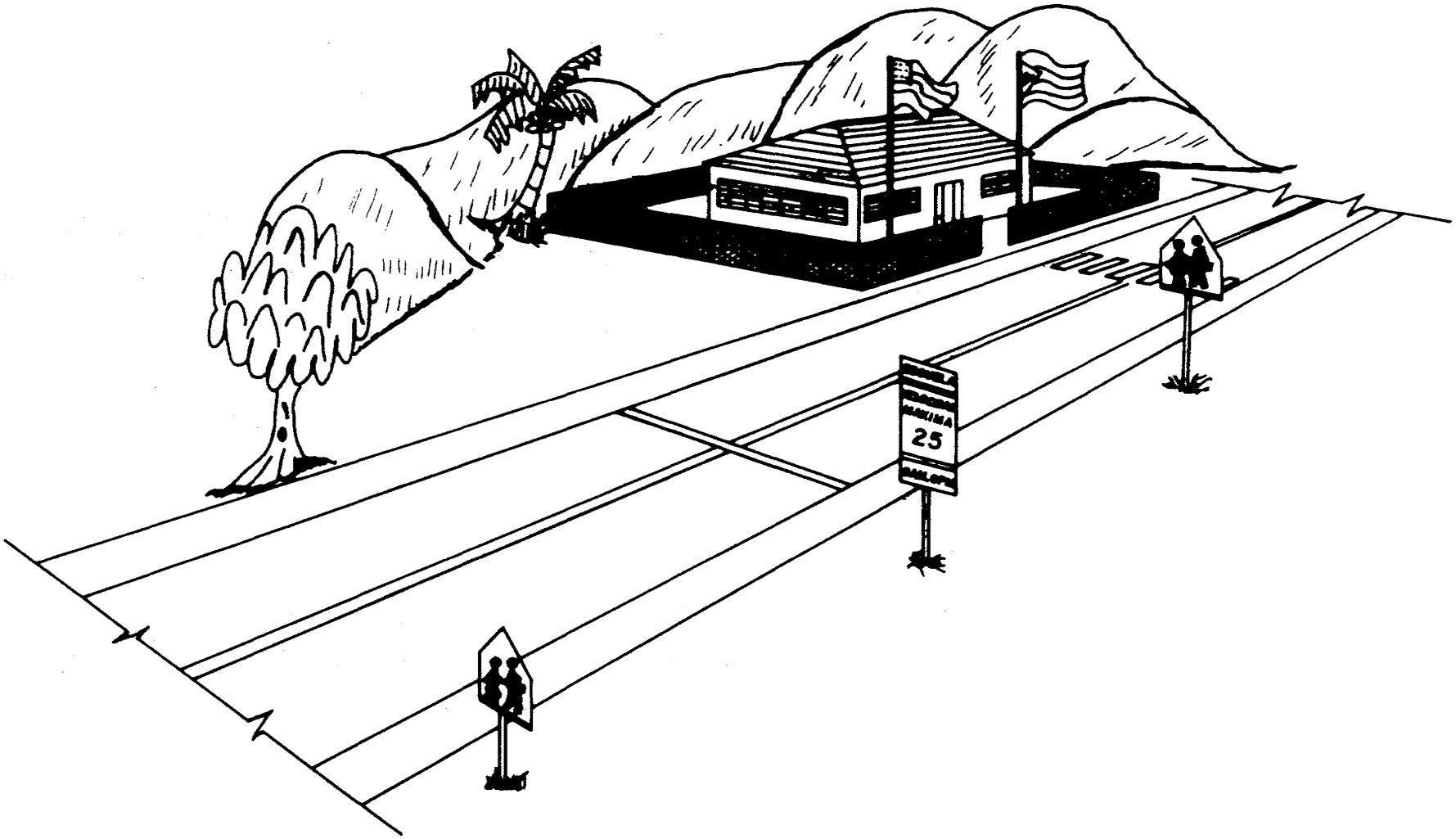


UNDERGROUND PEDESTRIAN CROSSING

FIG. 15-H



SECTION A - A



SCHOOL ZONE

FIG.- 15 - 1

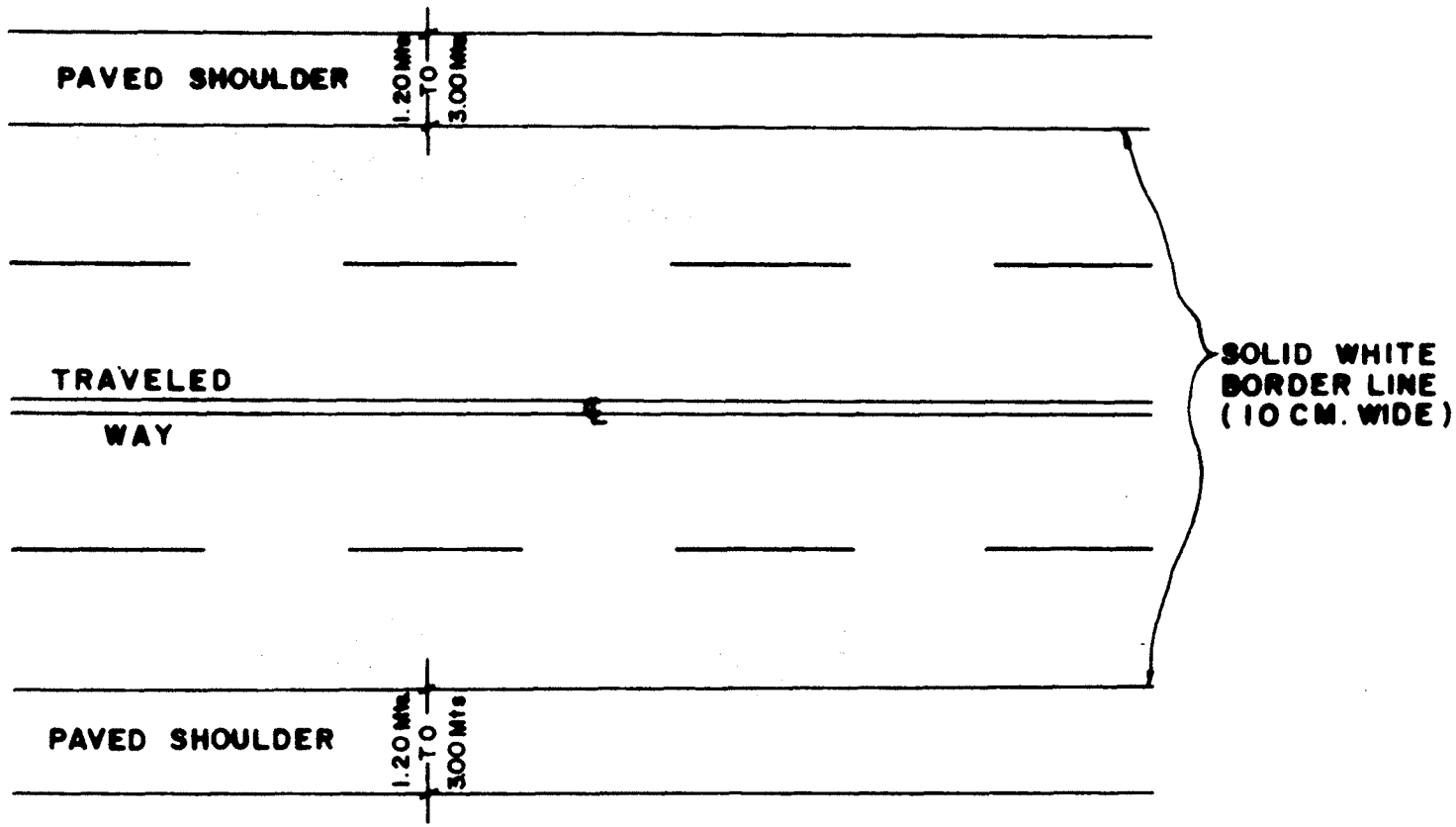
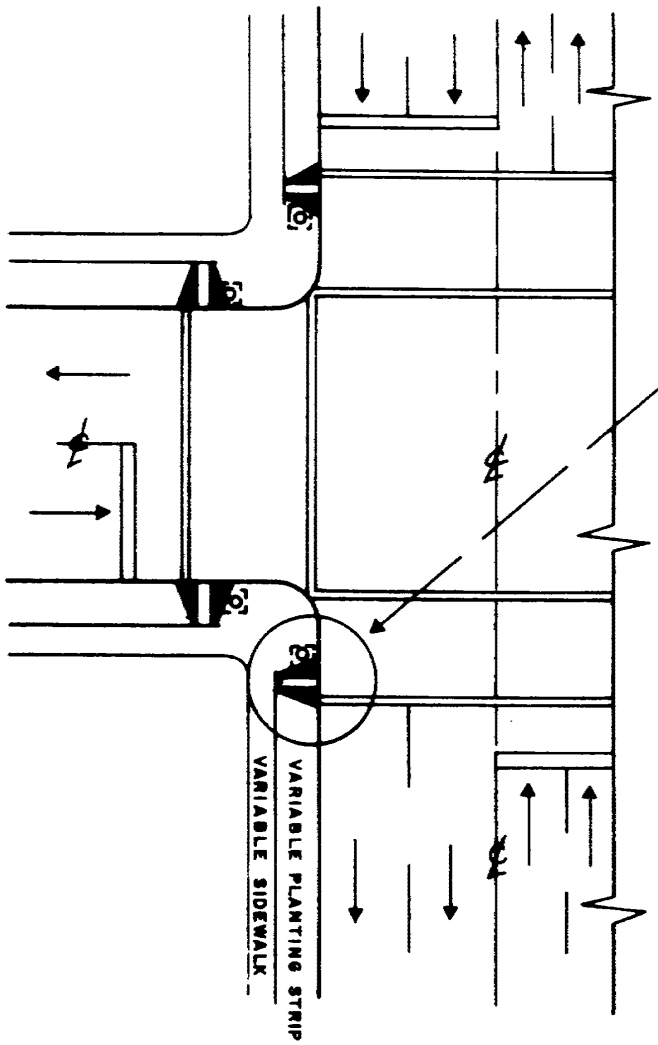
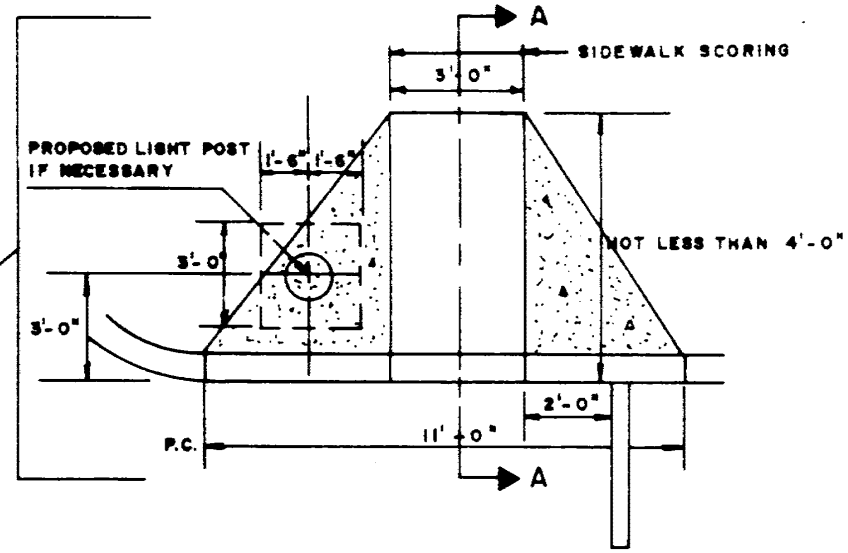
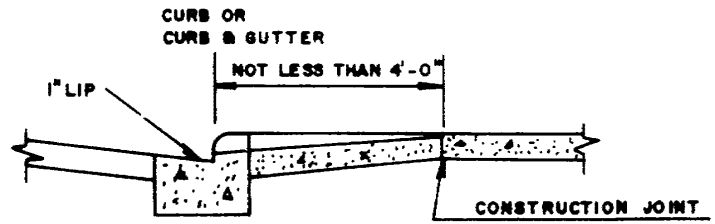


FIG. 15-J

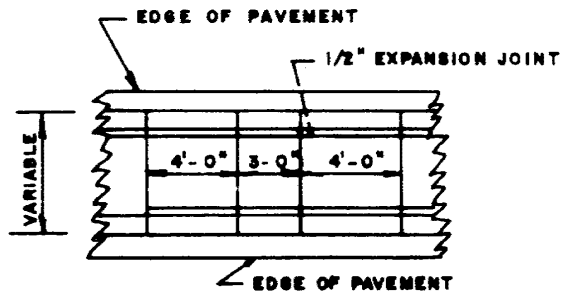
PAVED SHOULDER MARKINGS

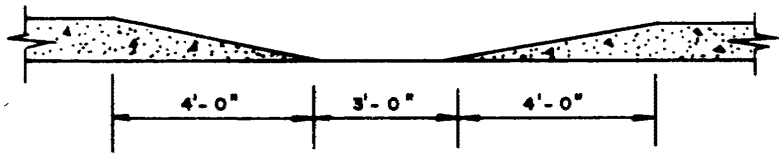






SECTION A-A



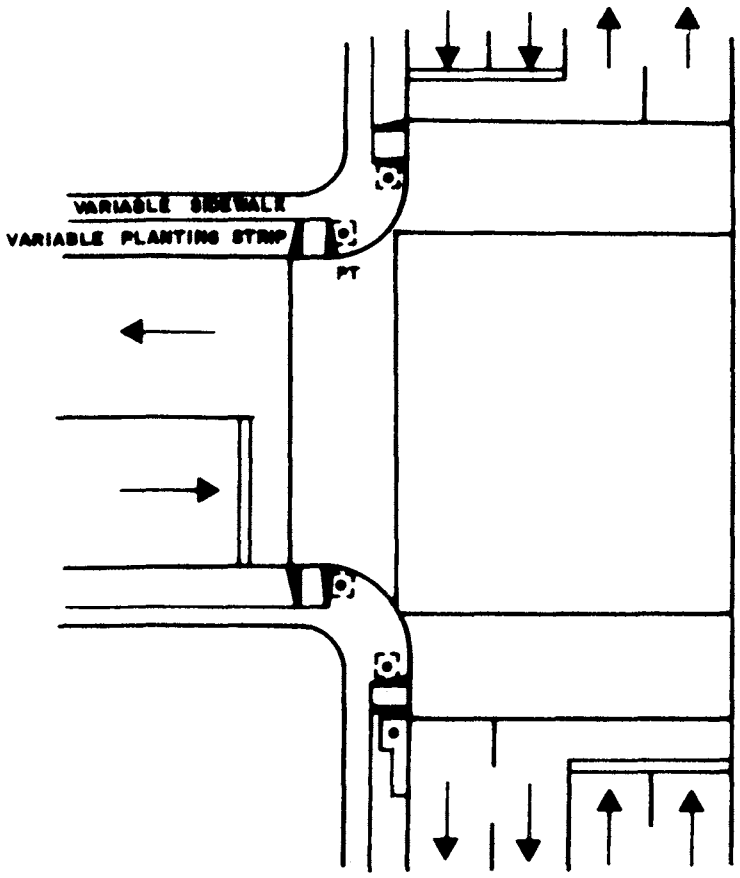


CONSTRUCTION DETAILS
FOR WHEELCHAIR RAMPS

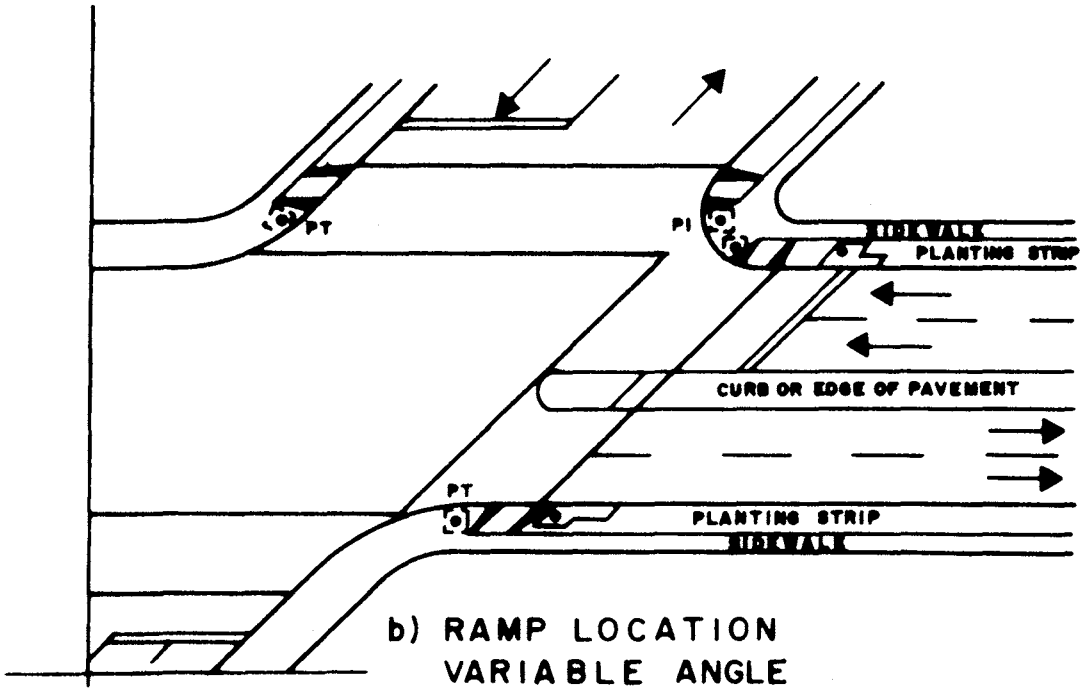
FIG.-15-K

WHEELCHAIR RAMPS

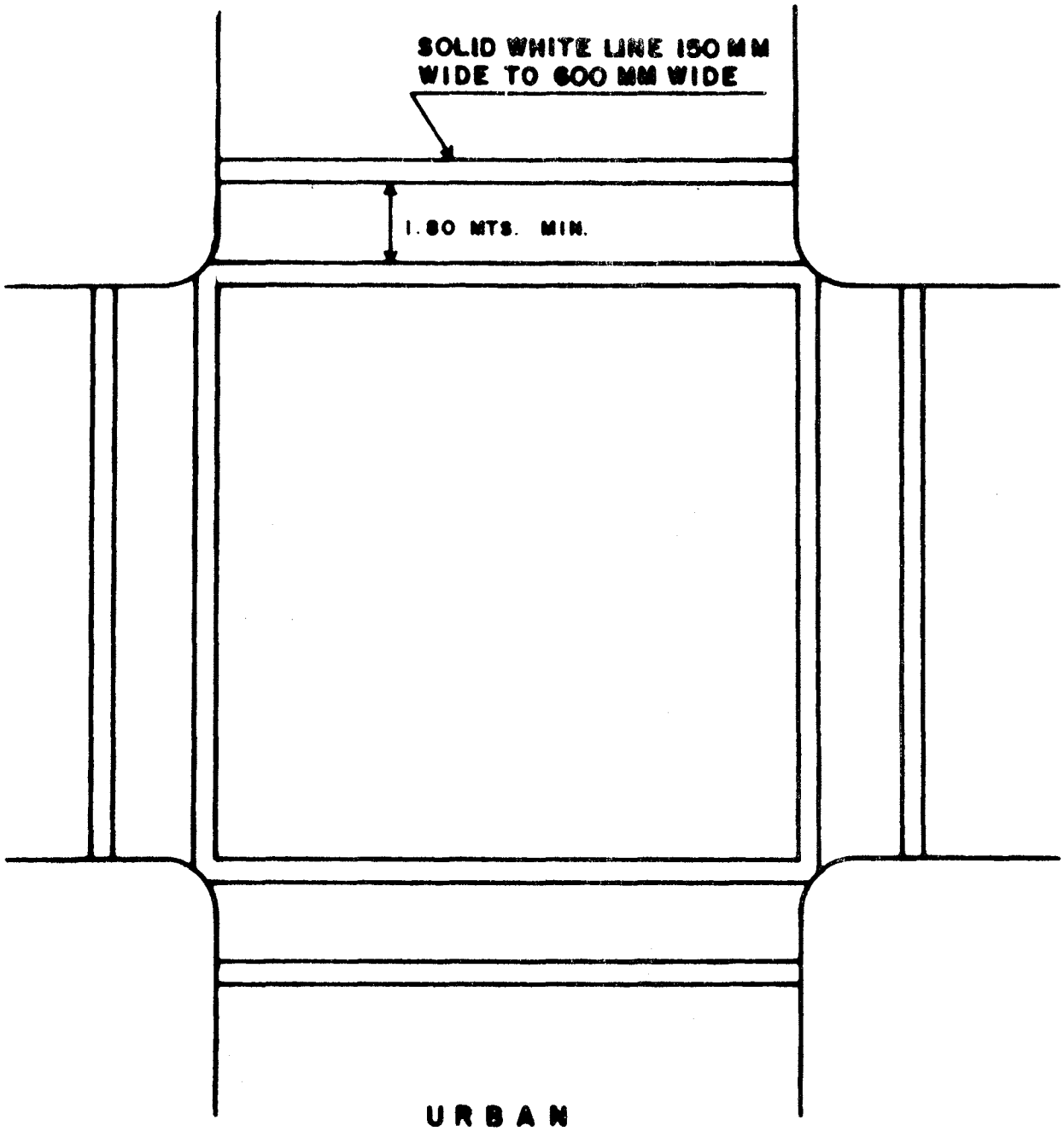
FIG. 15-L



a) RAMP LOCATION
RIGHT ANGLE INTERSECTION

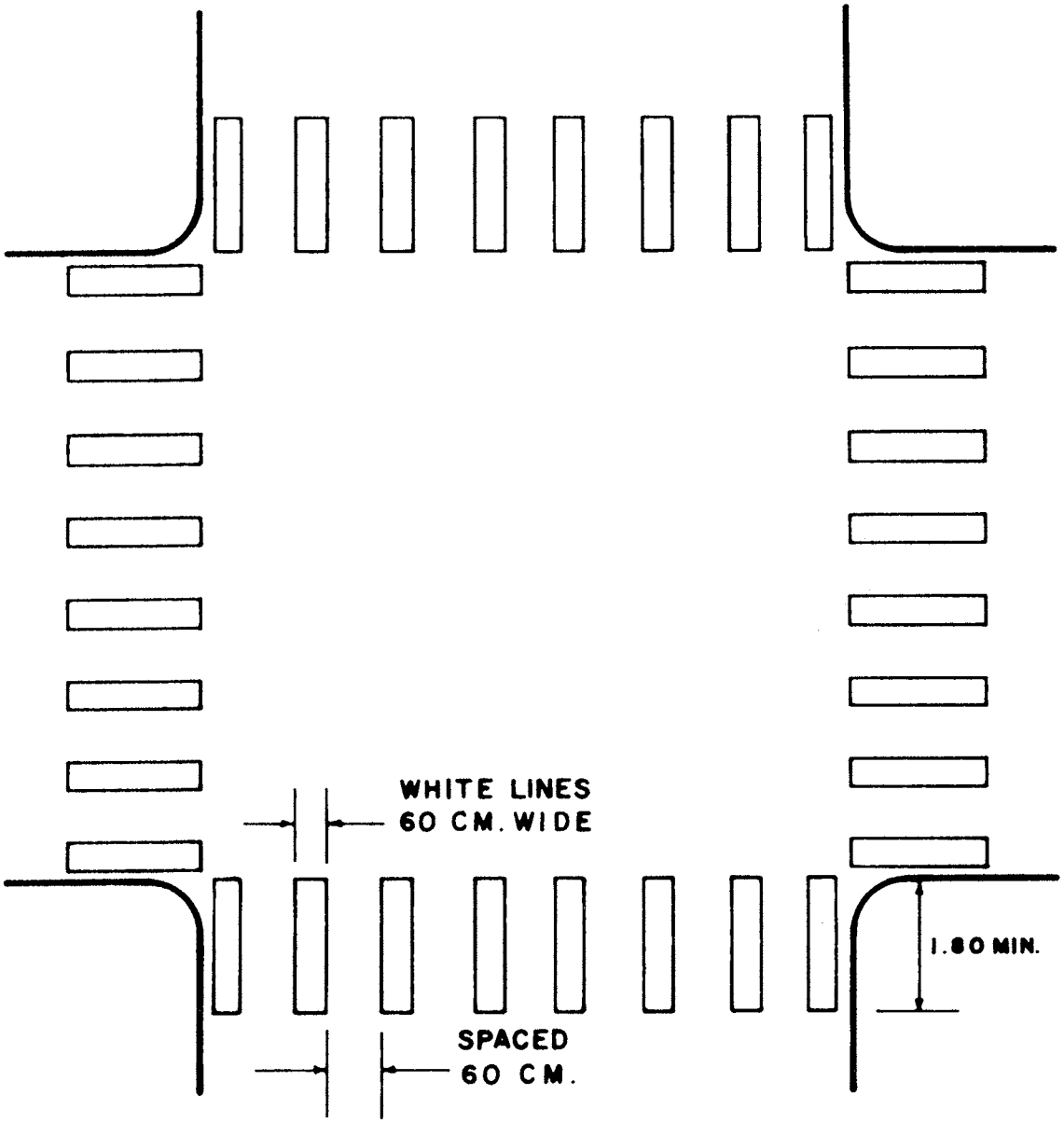


b) RAMP LOCATION
VARIABLE ANGLE



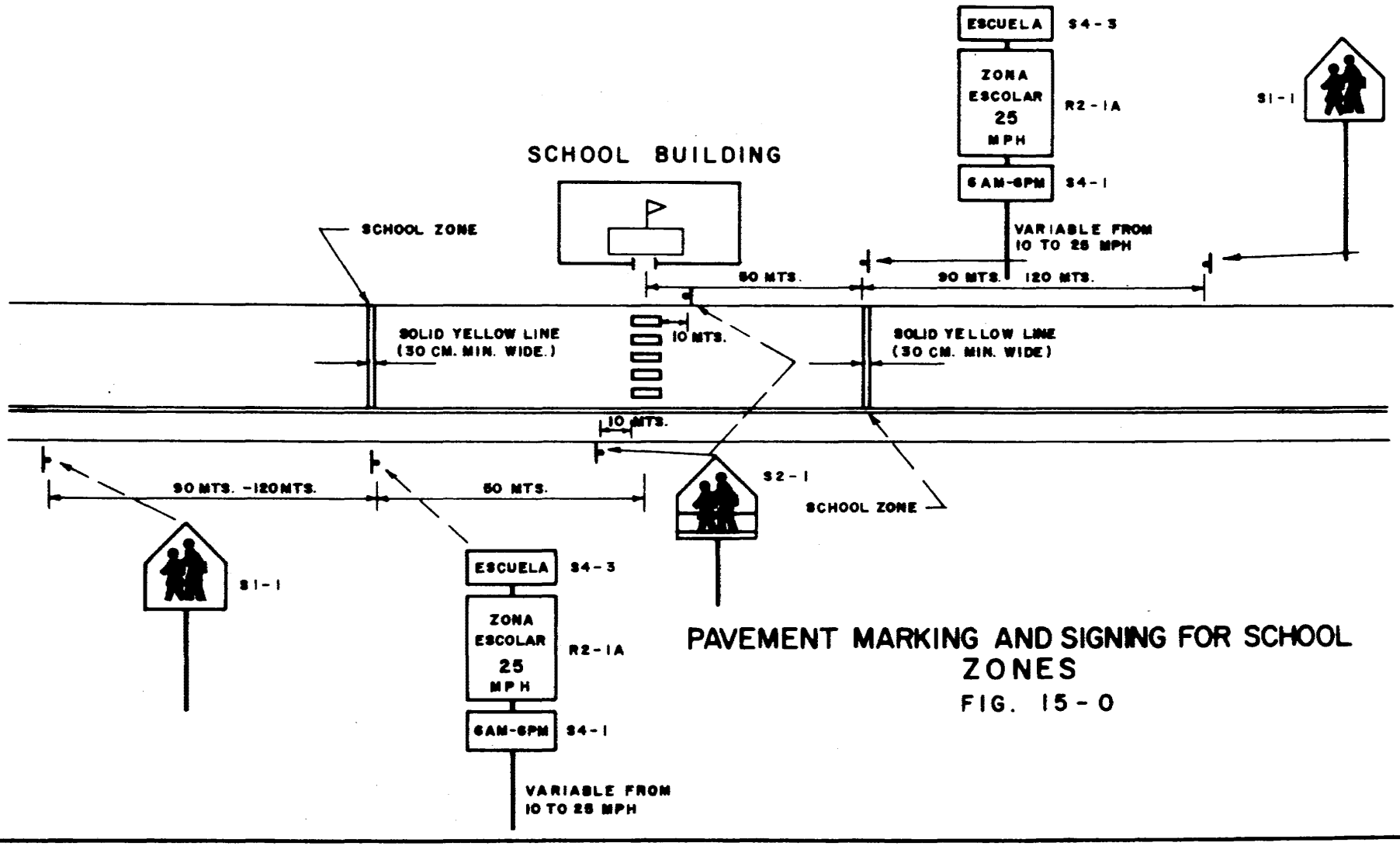
URBAN
STANDARD CROSSWALK
MARKING

FIG.15-M



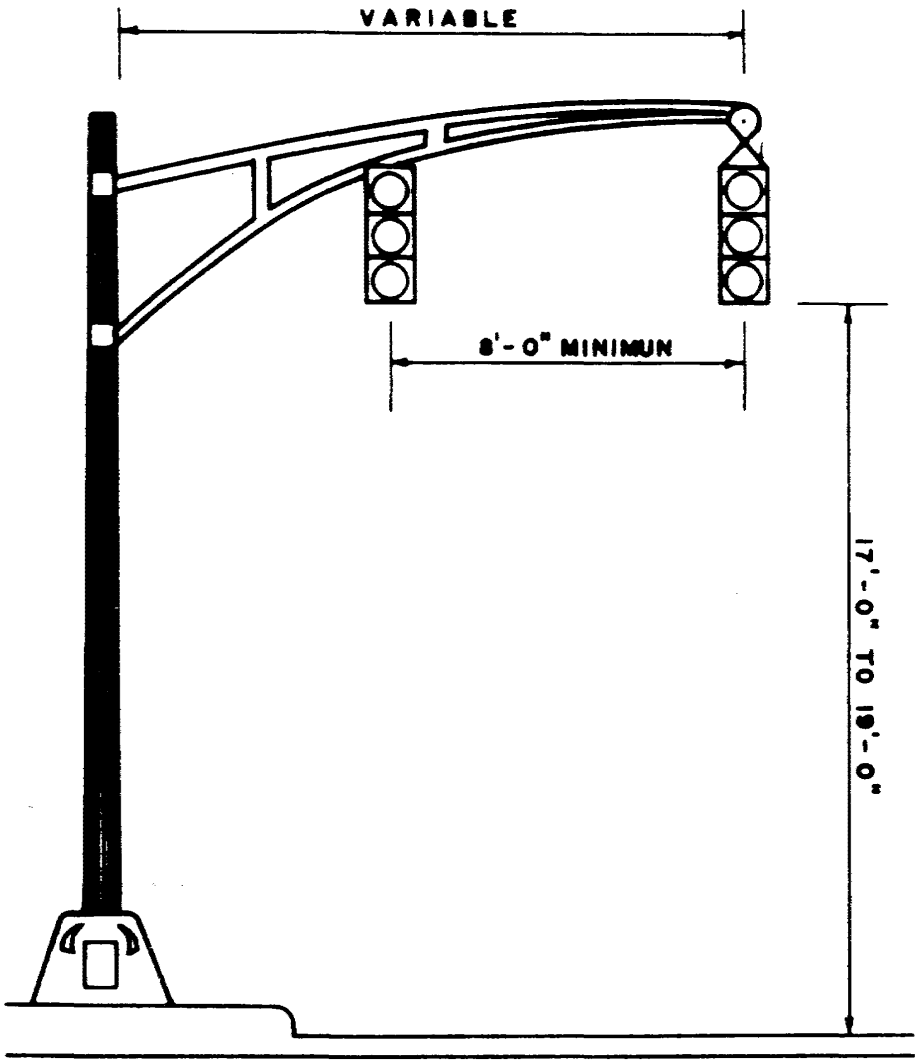
RURAL CROSSWALK MARKING WITH LONGITUDINAL LINES FOR ADDED VISIBILITY

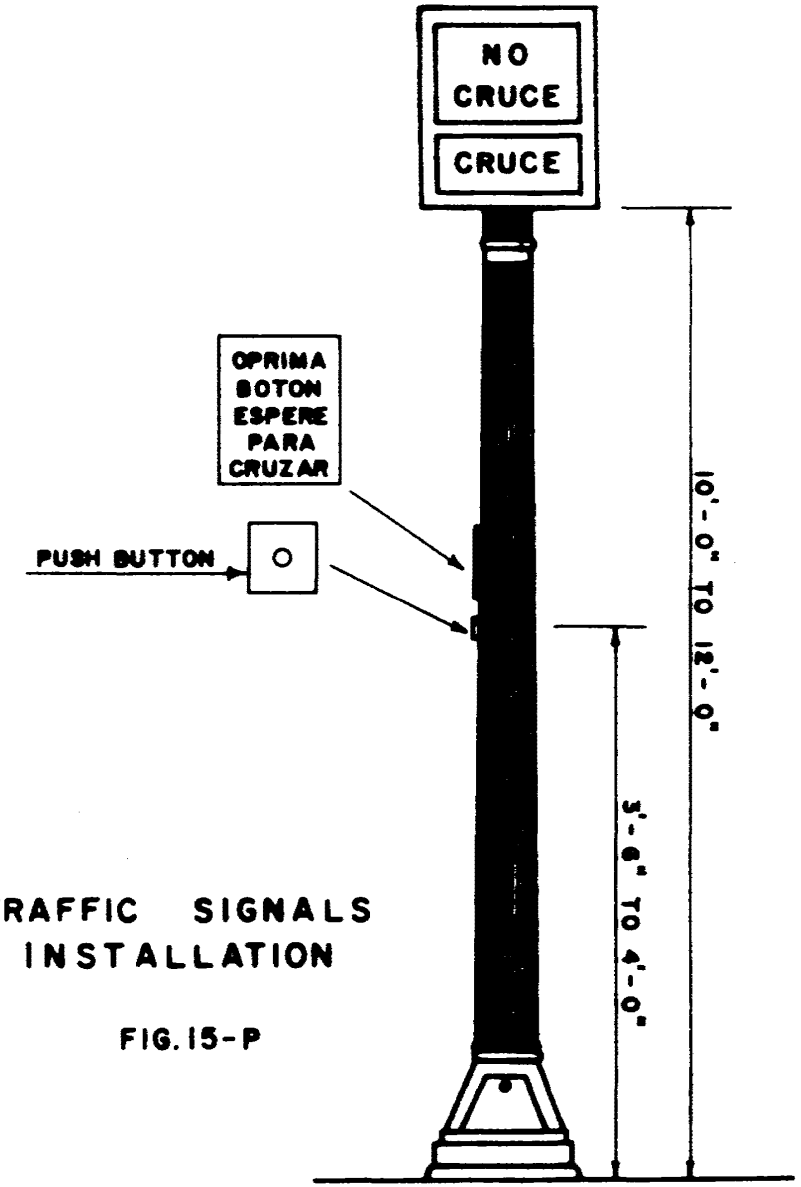
FIG. 15-N



PAVEMENT MARKING AND SIGNING FOR SCHOOL ZONES

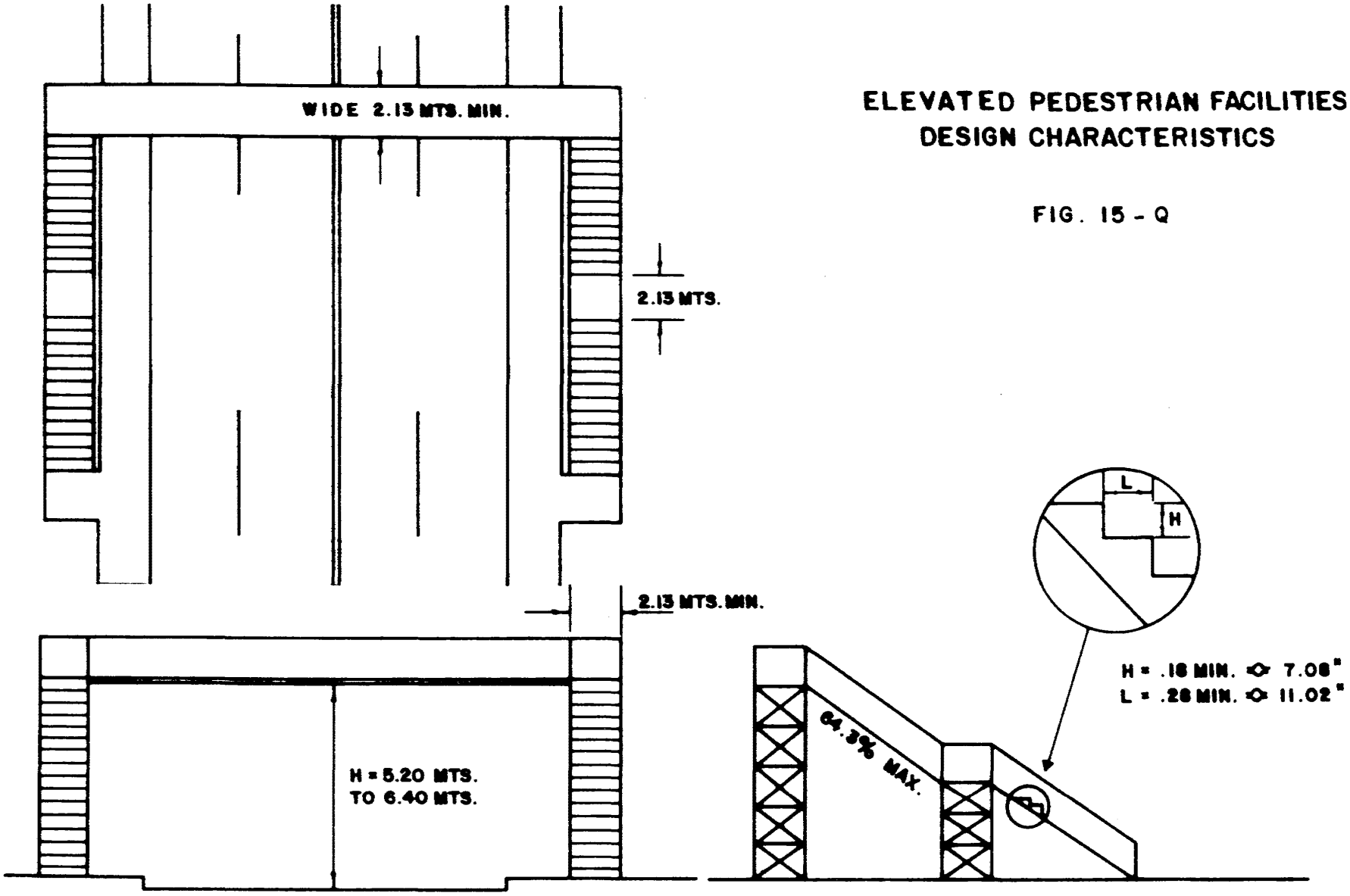
FIG. 15-0





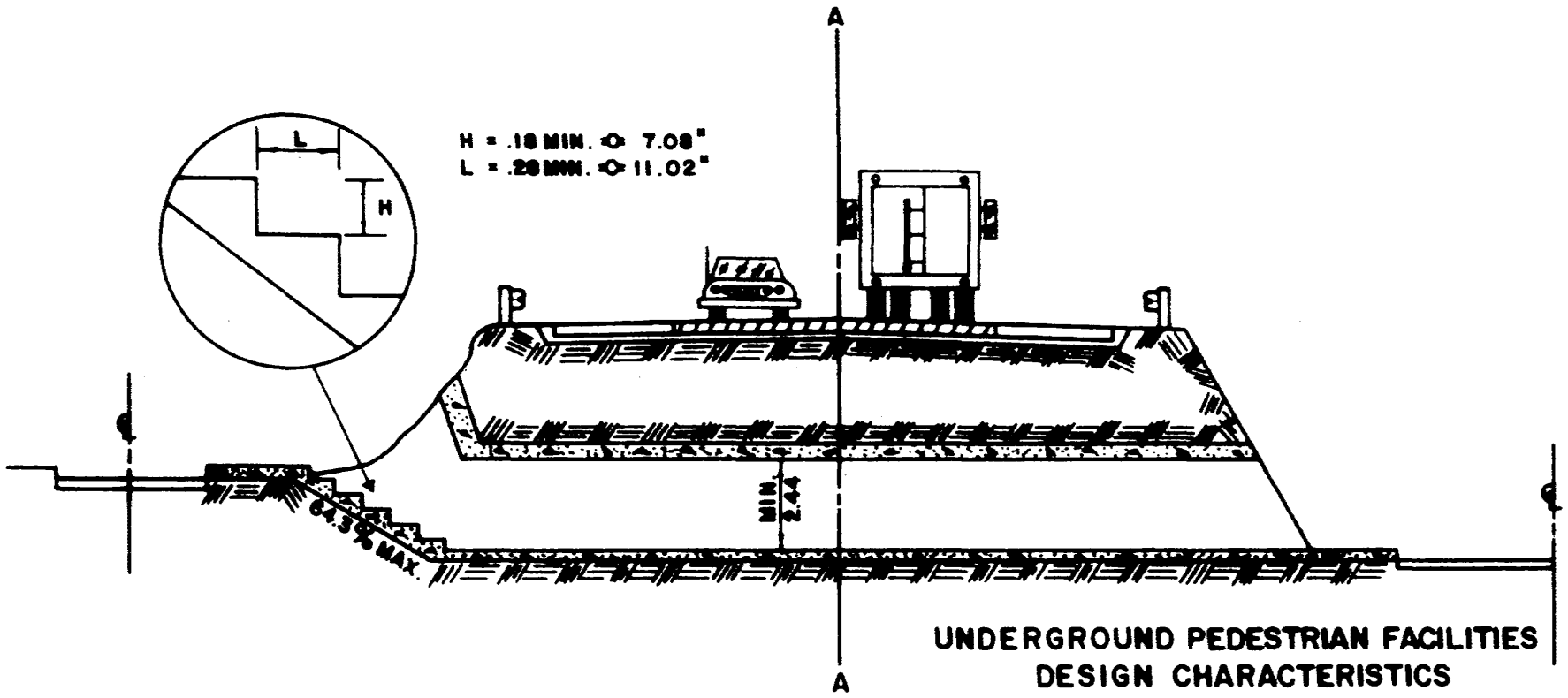
TRAFFIC SIGNALS INSTALLATION

FIG. 15-P



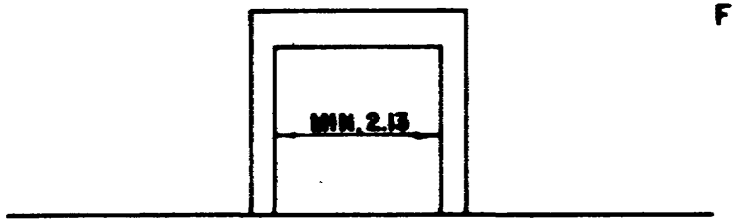
ELEVATED PEDESTRIAN FACILITIES
DESIGN CHARACTERISTICS

FIG. 15 - Q



UNDERGROUND PEDESTRIAN FACILITIES
DESIGN CHARACTERISTICS

FIG. 15 - R



SECCION A-A

CHAPTER 16

PART A -- FIELD SURVEY DATA

PART B -- PHOTOGRAMMETRY

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16-2	Gauning Table Illustration for Deflection Angles	10
16-3	Route Location Notes	15
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PART B – PHOTOGRAMMETRY

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16–15	Final Design	27

CHAPTER 16

FIELD SURVEY DATA

16–01 GENERAL

The field survey data is obtained by the Field Survey Bureau. This Office performs the necessary field work by means of field parties. All the field information should be obtained from control points or establishing a base line that normally is the center line of the future highway. The field information consist basically in the location of structures, utilities, waterways and property boundaries, profile and cross sections of the center line.

All measurement are obtained using the metric system with a 30 meter metalic tape and the instrument most used is the "Transit".

All the field information is recorded in field notebooks which are send together with the field drawings to the Design Bureau.

The selection of alignment and the extend to which it may be chosen to fit the ground economically, depends on the geometric design standards adopted for the construction. These standards, in turn depend on the amount and type of transportation usage expected.

Standards may range from the criteria for widths, curvature, grades and sight distances sufficient to accommodate sparse rural traffic at moderate speeds, to those criteria necessary for large volumes of heavy traffic at high speeds.

With the classification of service established and the appropiate standards of alignment fixed thereby, ordinarily the combination of tangents and horizontal curvature is sought that will best fit the surface of the ground within theimit of the criteria.

This chapter will cover detailed information about the field procedures to be perform in working a project mentioned as follows: Reconnaissance, Control Surveys, Monumentation, Location Survey and others.

16–02 RECONNAISSANCE SURVEY

Reconnaissance Survey is the process of evaluating the feasibility of one or more possible routes for a highway between specific points, which may be many kilometers apart.

Service requirements of the termini and intermediate points are determined in advance by traffic studies. Consistent with proper service selection of an approximate route involves consideration of roadway design standards, topography, geology and land use.

Good reconnaissance can be the largest single money-saving phase in the construction of a new road.

16–02.01 STUDY OF AVAILABLE DATA

Reconnaissance begins with a "paper study" (topographic map) of an area 30% to 50% as wide as the distance between the termini. Ridges, water courses and land use are examined first. Low points or passes in the ridges, become potential fixed points in the location, as do stream-crossing sites that afford suitable topography for approaches. Thickly settled areas, as well as swamps and other ground unsuited to economical construction, should be avoided. Utility-relocation problems should be anticipated. Photographs, also, suplement the map, to a greater or lesser extended depending on its quality.

16-02.02 FIELD INSPECTION

Next, cognizant of the questions generated by the map study, the reconnaissance Engineer goes to the field. The best way to get a first look at key points and intervening alignments is to fly over them. Much of the engineers aerial-visual data will be sufficient to accomplish his appraisal of the terrain. The engineer then can restrict his ground study to considerations of unusual topographic features, hydrology, the nature of some manmade works and subsurface conditions.

The engineer should utilize all available survey control as the reconnaissance is executed. Bench marks, triangulation and traverse points may be tied to points that will be distinguishable in aerial photographs.

16-03 CONTROL SURVEYS

The purpose of the primary control survey shall be to provide permanent monuments with accurate horizontal and vertical coordinates throughout the entire length of the project. These points shall be used as control for all other surveys connected with the project.

The primary control survey shall be performed prior to other surveys and prior to the beginning of construction on the project.

The primary control survey shall be a closed survey or tied at each end and at such intermediate points as may be available, to one of the following:

a. USC & GS Control point.
b. Other primary control survey point.
c. Other survey point of known accuracy at least equal to that specified for the primary control survey itself.

Methods, procedures and equipment used for primary horizontal and vertical control survey shall be sufficiently precise to insure second order accuracy. If a survey fails to conform to second order standards prior to adjustment, a re-survey shall be made.

The survey shall be adjusted by an approved method prior to computing coordinates, bearings or distances.

All level lines, loops or nets shall be adjusted prior to computing elevations of points on the survey.

Elevations of all points shall be based on the Mean Sea Level Datum and all subsequent level surveys shall be adjusted to the primary vertical control survey.

16-04 MONUMENTATION

The monumentation of control survey points is an important part of a highway project. A monument is a fixed object on the ground, whether natural or artificial, serving as a permanent mark of the survey. Thousands of dollars in surveying work are lost annually because surveys were not properly monumented or the monuments were subsequently destroyed. A control survey monument should posses stability, positive identity and protection against destruction.

The variety in monuments depends on the type of survey, the local terrain conditions and the requirement of the survey project.

In highway engineering practice there are three types of monuments: standard tablets set in concrete, survey caps and marks placed in existing structures. References for each of the above described monuments should be made in the field either to permanent natural objects or

to additional points set nearby. A witness post to each monuments should be placed above the ground and it serve as a warning to construction and maintenance personnel.

16- 05 LOCATION SURVEY

The location survey fixes the proposed highway's center line on the ground and includes the procurement of field data necessary for design and the acquisition of right of way. In a normal location survey, the alignment determined by the reconnaissance survey is staked out and a sufficient number of selected points on the center line are referenced so that it can be re-established when necessary.

The staked base line is used as a reference line for profile, cross sections, topography, the location of existing property lines and utilities and other information that will be needed.

16-05.01 STAKING CENTER LINE

The center line established on the ground shall follow as closely as practical the final line projected on the preliminary survey map conforming to the mayor and minor control points and the alignment prescribed. Minor alterations and adjustments are permissible and desirable in best fitting the line to the terrain during the staking-out process.

Center line tangents are established on the ground, the intersection of each pair of adjacent tangents is determined and the deflection angle from the back tangent to the forward is measured and checked for approximate agreement with the angle previously obtained in projecting the final line on the preliminary survey map. The measured deflection angles and the degrees of curve specified in the preliminary design are used to compute the data necessary for running the curves as the staking of the center line progresses. Where the intersection of tangents is inaccessible, the usual methods for determining the deflection angle are used.

The location surveys must be referenced to the State Plane Coordinate System so that the final line can be established on the ground by using the coordinates of P.I.'s and the azimuths of tangent together with ties to the control points. With reasonable care, third-order accuracy should be obtainable.

Center line stakes are placed at intervals of not more than 20 meter and where there is any significant change in the slope of the ground and should be alined in with a transit. Stationing is carried forward continuously through curves and tangents with provision for station equations if and where they occur. All points of curvature, points of tangency and points at discrete intervals on long tangents should be carefully referenced to permit easy relocation of the line during all phases of construction.

16-05.02 LEVELS

Location survey bench marks should be established as many as necessary to provide them at a maximum spacing of 300 meters along the alignment of the highway and at a distance from the center line sufficient to insure against disturbance during construction operations. In addition, at least one bench mark should be established within a reasonable distance (30 to 50 meters) of each proposed structure. The elevation and a complete description of each bench mark should be recorded.

Profile levels are taken along the center line to obtain the elevation of the ground at each station and at all intermediate points where there is any significant change in the slope of the ground, in order to obtain a profile truly representative of the ground. For the design of adequate transition grades for connecting with existing roads or proposed improvements, the profile should extend at least 200 meters beyond the beginning and end points of the projects.

When conventional ground methods are used in taking the profile, checks should be made on each bench mark as it is reached along the line with a permissible tolerance of 0.005 meter.

16 05.03 CROSS SECTIONS

Cross section should be taken at each station of the center line. Each cross section should be alined carefully at right angles to the center line and should extend far enough on both sides of the center line to provide adequate ground-surface information for the designer and for quantity computations.

Cross sections on flat terrain shall be taken using a level instrument and on rough terrain could be use a 3 meter long wooden board with a small carpenter level attached and shall be properly recorded in field books as a permanent record.

16- 05.04 UTILITIES

The nature and location of all utilities within the area of the proposed improvement should be determined and recorded both above and below the ground surface. These will include the mayor utilities in Puerto Rico that are the following:

P.R. Water Resources Authority	(PRWRA)
P.R. Aqueduct and Sewer Authority	(PRASA)
P.R. Telephone Company	(PRTC)
P.R. Communications Authority	(PRCA)
Pipelines of Puerto Rico Inc.	(PLPR)
San Juan Gas Company	(SJGCO)

Complete information on utilities is important so that provision can be made for their rearrangement or relocation where necessary. The responsible unit shall contact the various utilities to complete the data on types, sizes, etc. of the utility facilities located by the survey crew and to determine the location, types and sizes of any other underground utility facilities that may exist within the survey area but were not readily apparent to the surveyors.

16-05.05 PROPERTY LINES

The position of all property corners, property lines, fences, buildings and other improvements must be accurately determined and recorded. This information provides the basis for determining right-of-way requirements, for writing deed descriptions, for appraisal and for negotiating for right-of-way acquisition or easements.

The names of all property owners where right-of-way acquisition or easement may be involved should also be obtained.

All property lines should be referenced to stations on the center line.

16—05.06 INTERSECTING ROADS

The direction of all intersecting roads, with respect to the staked center line, should be measured and recorded. In addition profiles and cross sections of the intersecting roads should be taken for some distance on both sides of the center line of the project.

Where an intersection or a grade separation is anticipated, a special survey (topography) of the area is made for the detailed studies necessary for design and plan preparation.

16- 05.07 DITCHES AND STREAMS

Ditches and streams within the area of the improvement should be carefully located with respect to the staked center line. In addition, stream-bed profiles should be taken for some

distance up and down the stream; from 50 meters to 100 meters on ditches or small streams may be adequate, whereas for larger streams a more extensive profile is necessary. Also cross sections of the stream should be taken to provide information for use by the designer in making hydraulic studies.

Detailed information should be obtained for existing culverts or bridges including the type, size, number of openings or spans, elevation of culvert flow lines or stream-bed elevation under the bridge and high-water elevations. Also, the first structures up and down stream should be recorded since this information is important to the design engineer.

At any creek or river crossing along the staked center line where a large culvert or bridge may be needed, a special survey (topography) of the area is made to provide the detailed information needed for the design and preparation of plans.

16--06 DRAINAGE SURVEY

The application of hydraulic formulas in drainage structures design requires consideration of the following physical characteristics of the drainage area:

(a) The size of the area in acres
(b) The path of the stream bed or channel
(c) The slope of the stream bed or profile
(d) The average slope of the land within the drainage area
(e) The use of the land
(f) Topographical conditions

Generally, the surveys do not require a great amount of detail, but must be comprehensive enough so the above factors can be determined.

16--06.01 SIZE OF DRAINAGE AREA

All drainage area which are crossed by the survey line shall be taken from topographical maps. If these are not available, all areas will be run by stadia method. Areas will be classified as to the nature of the terrain, (flat, very flat and steep). The source of drainage area shall be indicated.

16--06.02 DRAINAGE PATH

Survey the horizontal alignment of the existing stream bed by running angle base line for a convenient distance left and right of survey center line, then measure from base line to center of stream bed at all angle points. A well-drawn sketch should show the stream alignment.

16--06.03 STREAM PROFILE

Information to establish the stream profile can be taken simultaneously or by a separate operation from the stream alignment. Shots shall be taken at every points where there is a change in the slope of the stream bed.

16--06.04 TOPOGRAPHICAL CONDITIONS

Record any topographical features, natural or man made, within the drainage area that would affect the run off. Record any high water marks observed and exact location taken. Also record any pertinent information relative to the area and date as obtained from persons familiar with the area. Recommendations should be made by the Supervisor if a particular placement of culvert seems desirable. Is a skewed structure is recommended give the skew angle. If a channel change seems necessary, run the centerline of the proposed channel change and take necessary cross sections to cover the new location and the old channel, so that proper location for necessary channel blocks can be determined.

16--07 FORMULAS

16--07.01 SIMPLE CIRCULAR CURVE

Simple circular curves elements are obtained by using the trigonometric tables of M.J. Gaunin for the lay out of curves for roads, railroads, and channels.

If the angle of the tangents and the radious are known, it will be information enough to calculate the length of the curve and to establish the points T, T' and M on the ground (PC, MC, PT.)

According to Figure 16--A, the elements of a simple curve are:

Tangent = ST = ST' = R tang $\Delta/2$

External = MS = OS-OM = R sec $\Delta/2$-R = R (Sec $\Delta/2$-1)

1/2 Length = 1/2L = Length of Arc TM = $\frac{\pi R \Delta/2}{180} = \frac{R(\pi \Delta/2}{180}$

L = Length of ARC TMT' = $\frac{2R(\pi \Delta/2)}{180}$

Examples:

Known: semiangle at center ($\Delta/2$) = 28 -° 32' — 30"

Radius (R) = 800 Mts.

When $\Delta/2 < 45°$, superior headings of the table are used.

Curve elements for a radius of one (1) meter will be found on Table 16—1. All curve elements obtained are multiplied by 800 except for the length of the curve that should be multiplied twice the radius.

Results

T	=	(0.543898)	R	=	(.543898)	(800)	=	435.118	Mts.
E	=	(1.138343-1)	R	=	(.138343)	(800)	=	110.674	Mts.
L	=	(.498146)	2R	=	(.498146)	(1600)	=	797.034	Mts.

When $\Delta/2 > 45°$, inferior headings of the table are used.

All cases developed are based in the theory involved in Figure 16-A. Every time that two of the elements are known, the others can be obtained.

16—07.02 DEFLECTION ANGLES

The table most used in staking the center line is the "Gaunin Table" (Principles of Tables Construction).

Having obtained the elements, the curve can be laid out on its P. C., M. C. and P. T.

If detailed monumentation is necessary to specify intermediate stationing, the curve has to be deflectioned as needed.

GAUNIN TABLE ILLUSTRATION FOR CURVE ELEMENTS

TABLE 16–1

Angulo de las tan gentes	Semi-ángulo al centro en segundos	Semi-ángulo al centro en grados, minutos y segundos	Seno Semi-cuerda Abscisa sobre la tangente	Seno-Verso Flecha Ordenada sobre la tangente	Tangente	Secante	Desarrollo del arco del semi-ángulo al centro
60′	102.600	30′ ″	0.477 159	0.121 183	0.542 956	1.137 893	0.497 419
59	102.630	30.30″	0.477 287	0.121 252	0.543 144	1.137 983	0.497 564
58	102.660	31. ″	0.477 414	0.121 322	0.543 332	1.138 075	0.497 710
57	102.690	31.30	0.477 542	0.121 391	0.543 521	1.138 163	0.497 855
56	102.720	32. ″	0.477 670	0.121 461	0.543 709	1.138 253	0.498 001
55	102.750	32.30	0.477 798	0.121 530	0.543 898	1.138 543	0.498 146
54	102.780	33. ″	0.477 925	0.121 600	0.544 086	1.138 433	0.498 292
53	102.810	33.30	0.478 053	0.121 669	0.544 275	1.138 523	0.498 437
52	102.840	34. ″	0.478 181	0.121 739	0.544 463	1.138 613	0.498 582
51	102.870	34.30	0.478 309	0.121 808	0.544 652	1.138 704	0.498 728
50	102.900	35. ″	0.478 436	0.121 878	0.544 840	1.138 794	0.498 873
49	102.930	35.30	0.478 564	0.121 947	0.545 029	1.138 884	0.499 019
48	102.960	36. ″	0.478 692	0.122 017	0.545 218	1.138 974	0.499 164
47	102.990	36.30	0.478 820	0.122 087	0.545 406	1.139 065	0.499 310
46	103.020	37. ″	0.478 947	0.122 156	0.545 595	1.139 155	0.499 455
45	103.050	37.30	0.479 075	0.122 226	0.545 784	1.139 245	0.499 600
44	103.080	38. ″	0.479 203	0.122 296	0.545 975	1.139 336	0.499 746
43	103.110	38.30	0.479 330	0.122 365	0.546 161	1.139 426	0.499 891
42	103.140	39. ″	0.479 458	0.122 435	0.516 350	1.139 517	0.500 037
41	103.170	39.30	0.479 586	0.122 505	0.546 539	1.139 608	0.500 182
40	103.200	40. ″	0.479 713	0.122 575	0.546 728	1.139 698	0.500 528
39	103.230	40.30	0.479 841	0.122 644	0.546 917	1.139 789	0.500 473
38	103.260	41. ″	0.479 968	0.122 714	0.547 106	1.139 879	0.500 619
37	103.290	41.30	0.480 096	0.122 784	0.547 295	1.139 970	0.500 764
36	103.320	42. ″	0.480 225	0.122 854	0.547 484	1.140 061	0.500 909
35	103.350	42.30	0.480 351	0.122 924	0.547 673	1.140 152	0.501 055
34	103.380	43. ″	0.480 479	0.122 994	0.547 862	1.140 242	0.501 200
33	103.410	43.30	0.480 606	0.123 063	0.548 051	1.140 353	0.501 346
32	103.440	44. ″	0.480 734	0.123 133	0.548 240	1.140 424	0.501 491
31	103.470	44.30	0.480 861	0.123 203	0.548 430	1.140 515	0.501 637
30	103.500	45. ″	0.480 989	0.123 273	0.548 619	1.140 606	0.501 782
29	103.530	45.30	0.481 116	0.123 343	0.548 808	1.140 697	0.501 928
28	103.560	46. ″	0.481 244	0.123 413	0.548 997	1.140 788	0.502 073
27	103.590	46.30	0.481 371	0.123 483	0.549 187	1.140 879	0.502 218
26	103 620	47. ″	0.481 499	0.123 553	0.549 376	1.140 971	0.502 364
25	103.650	47.30	0.481 626	0.123 623	0.549 565	1.141 062	0.502 509
24	103.680	48. ″	0.481 754	0.123 693	0.549 755	1.141 153	0.502 655
23	103.710	48.30	0.481 881	0.123 763	0.549 944	1.141 244	0.502 800
22	103.740	49. ″	0.482 009	0.123 834	0.550 133	1.141 336	0.502 946
21	103.770	49.30	0.482 136	0.123 904	0.550 323	1.141 427	0.503 091
20	103.800	50. ″	0.482 263	0.123 974	0.550 512	1.141 518	0.503 237
19	103.830	50.30	0.482 391	0.124 044	0.550 702	1.141 610	0.503 382
18	103.860	51. ″	0.482 518	0.124 114	0.550 892	1.141 701	0.503 527
17	103.890	51.30	0.482 646	0.124 184	0.551 081	1.141 793	0.503 673
16	103.920	52. ″	0.482 773	0.124 255	0.551 271	1.141 884	0.503 818
15	103.950	52.30	0.482 900	0.124 325	0.551 461	1.141 976	0.503 964
14	103.980	53. ″	0.483 028	0.124 395	0.551 650	1.142 067	0.504 109
13	104.010	53.30	0.483 155	0.124 465	0.551 840	1.142 159	0.504 255
12	104.040	54. ″	0.483 282	0.124 536	0.552 030	1.142 251	0.504 400
11	104.070	54.30	0.483 410	0.124 606	0.552 220	1.142 342	0.504 546
10	104.100	55. ″	0.483 537	0.124 676	0.552 409	1.142 434	0.504 691
9	104.130	55.30	0.483 664	0.124 746	0.552 599	1.142 526	0.504 836
8	104.160	56. ″	0.483 792	0.124 817	0.552 789	1.142 618	0.504 982
7	104.190	56.30	0.483 919	0.124 887	0.552 979	1.142 710	0.505 127
6	104.220	57. ″	0.484 046	0.124 958	0.553 169	1.142 802	0.505 273
5	104.250	57.30	0.484 173	0.125 028	0.553 359	1.142 894	0.505 418
4	104.280	58. ″	0.484 501	0.125 098	0.553 549	1.142 986	0.505 564
3	104.310	58.30	0.484 428	0.125 169	0.553 739	1.143 078	0.505 709
2	104.340	59. ″	0.484 555	0.125 239	0.553 929	1.143 170	0.505 855
1′	104.370	59.30″	0.484 682	0.125 310	0.554 119	1.143 262	0.506 000
122*	104.400	60. ″	0.484 810	0.125 380	0.554 309	1.143 354	0.506 145
Angulo al centro	Semi-angulo de las tangentes: en segundos	Semi-angulo de las tangentes: en grados, minutos y segundos	Coseno	Coseno-verso	Cotangente	Cosecante	Complemento del arco

61°

SIMPLE CIRCULAR CURVE

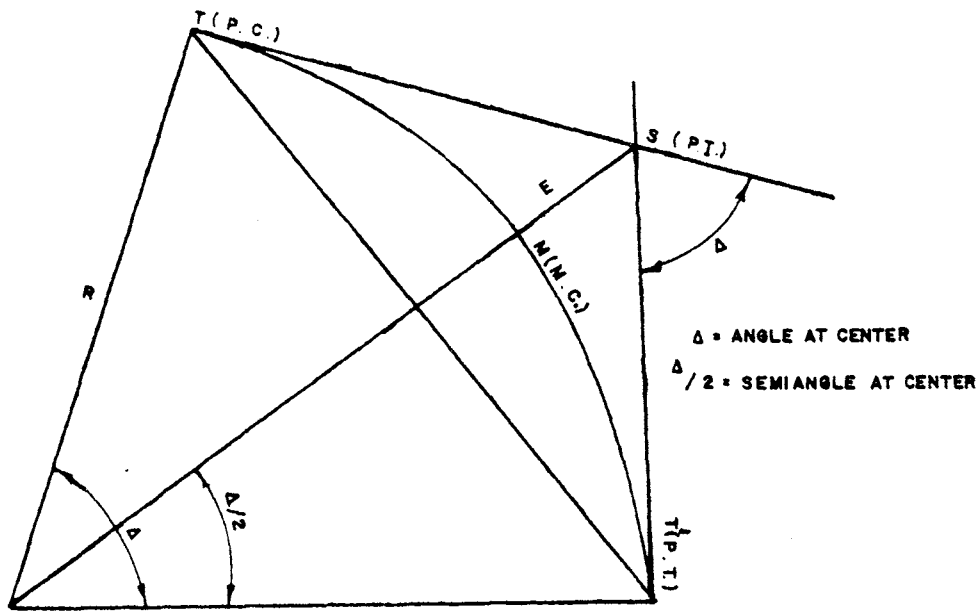


FIGURE 16-A

To obtain the values of the deflection angles, Table 16—2 from the Gauning book is used. This table gives values of the angles in function of the arcs. The corresponding angle at center for the curve of the radius given on the heading.

Remembering that from Figure 16—A, we obtained.

$$L = 2R \quad \frac{(\pi \ \Delta/2)}{180}$$

where : L = total length of arc

R = Radius

$\Delta/2$ = Semiangle at center = total deflection angle from P.C. to P.T.

So, if we want to obtain the deflection angle for any section of arc in the curve (L), it is necessary to refer to Table 16—2 with radius = 2R (according to formula above). Then the angle obtained in the Table 16—2, corresponds to the angle $\Delta/2$ when the formula is solved. For examples of this case, refer to Figure 16—B.

Examples:

a) Known: R = 450 Mts.

L = 653.43 Mts.

Using Table 16—2 for R = 900

	Partial Arc.		Deflection Angle
	600		38°— 11′ — 49.8708″
	50		3°— 10′ — 59.1559″
	3		— 11′ — 27.5494″
	.40		1′ — 31.6632″
	.03		6.3755″
L =	600.43	$\Delta/2$ =	41°— 35′ — 54.6148″

b) For a specific point at 217.54 Mts. from the P.C.

	Partial Arc (Mts.)		Deflection Angle
	200		12°— 43′ — 56.6236″
	10		38′ — 11.8312″
	7		26′ — 44.2818″
	.50		1′ — 54.5816″
	.04		09.1673″
L =	217.54	$\Delta/2$ =	13°— 50′ — 56.4855″

GAUNIN TABLE ILUSTRATION FOR DEFLECTION ANGLES

TABLE 16–2

"ARC" ARCOS	R = 600 1m = 343′ 774.677.078.494	R = 700 1m = 294′ 664.008.924.423	R = 800 1m = 257′ 831.007.808.870	R = 900 7m = 229′ 183.118.052.329	R = 1.000 1m = 206′ 264.806.247.096	ARCOS
m.						
0.01	0°00′03′4377	0°00′02′9466	0°00′02′5783	0°00′02′2918	0°00′02′0626	0.01
0.02	0.00.06.8755	0.00.05.8933	0.00.05.1565	0.00.04.5837	0.00.04.1253	0.02
0.03	0.00.10.3132	0.00.08.8399	0.00.07.7349	0.00.06.8755	0.00.06.1879	0.03
0.04	0.00.13.7510	0.00.11.7866	0.00.10.3132	0.00.09.1673	0.00.08.2506	0.04
0.05	0.00.17.1887	0.00.14.7332	0.00.12.8910	0.00.11.4592	0.00.10.3132	0.05
0.06	0.00.20.6265	0.00.17.6792	0.00.15.4699	0.00.13.7510	0.00.12.3759	0.06
0.07	0.00.24.0642	0.00.20.6265	0.00.18.0482	0.00.16.0428	0.00.14.4385	0.07
0.08	0.00.27.5020	0.00.23.5731	0.00.20.6265	0.00.18.3346	0.00.16.5012	0.08
0.09	0.00.30.9397	0.00.26.5198	0.00.23.2048	0.00.20.6265	0.00.18.5638	0.09
0.10	0.00.34.3775	0.00.29.4664	0.00.25.7831	0.00.22.9183	0.00.20.6265	0.10
0.20	0.01.08.7549	0.00.58.9328	0.00.51.5662	0.00.45.8366	0.00.41.2530	0.20
0.30	0.01.43.1324	0.01.28.3992	0.01.17.3493	0.01.08.7549	0.01.01.8794	0.30
0.40	0.02.17.5099	0.01.57.8656	0.01.43.1324	0.01.31.6632	0.01.22.5059	0.40
0.50	0.02.51.8873	0.02.27.3320	0.02.08.9155	0.01.54.5816	0.01.43.1324	0.50
0.60	0.03.26.2648	0.02.56.7984	0.02.34.6986	0.02.17.4999	0.02.03.7589	0.60
0.70	0.04.00.6423	0.03.26.2648	0.03.00.4817	0.02.40.4182	0.02.24.3854	0.70
0.80	0.04.35.0197	0.03.55.7312	0.03.26.2648	0.03.03.3365	0.02.45.0118	0.80
0.90	0.05.09.3272	0.04.25.1976	0.03.52.0479	0.03.26.2648	0.03.05.6383	0.90
1	0.05.43.7747	0.04.54.6640	0.04.17.8310	0.03.49.1831	0.03.26.2643	1
2	0.11.27.5494	0.09.49.3280	0.08.35.6620	0.07.38.3662	0.06.52.5296	2
3	0.17.11.3240	0.14.43.9920	0.12.53.4930	0.11.27.5494	0.10.18.7944	3
4	0.22.55.0987	0.19.38.6560	0.17.11.3240	0.15.16.7325	0.13.45.0592	4
5	0.28.38.8734	0.24.33.3200	0.21.29.1550	0.19.05.9156	0.17.11.3240	5
6	0.34.22.6481	0.29.27.9841	0.25.46.9860	0.22.55.0987	0.20.37.5888	6
7	0.40.06.4227	0.34.22.6481	0.30.04.8171	0.26.44.2818	0.24.03.8536	7
8	0.45.50.1974	0.39.17.3121	0.34.22.6481	0.30.33.4649	0.27.30.1184	8
9	0.51.33.9721	0.44.11.9761	0.38.40.4791	0.34.22.6481	0.30.56.3833	9
10	0.57.17.7468	0.49.06.6401	0.42.58.3101	0.38.11.8312	0.34.22.6481	10
20	1.54.35.4935	1.38.13.2802	1.25.56.6202	1.16.23.6624	1.08.45.2961	20
30	2.51.53.2403	2.27.19.9203	2.08.54.9302	1.54.35.4935	1.43.07.9442	30
40	3.49.10.9871	3.16.26.5604	2.51.53.2403	2.32.47.3247	2.17.30.5922	40
50	4.46.28.7339	4.05.33.2004	3.34.51.5504	3.10.59.1559	2.51.53.2403	50
60	5.43.46.4806	4.54.39.8405	4.17.49.8605	3.49.10.9871	3.26.15.8884	60
70	6.41.04.2274	5.43.46.4806	5.00.48.1705	4.27.22.8183	4.00.38.5364	70
80	7.38.21.9742	6.32.53.1207	5.43.46.4806	5.05.34.6494	4.35.01.1845	80
90	8.35.39.7209	7.21.59.7608	6.26.44.7907	5.43.46.4806	5.09.23.8326	90
100	9.32.57.4677	8.11.06.4009	7.09.43.1003	6.21.58.3118	5.43.46.4806	100
200	19.05.54.9354	16.22.12.8018	14.19.26.2016	12.43.56.6236	11.27.32.9612	200
300	28.38.52.4031	24.33.19.2027	21.29.09.3023	19.05.54.9354	17.11.19.4419	300
400	38.11.49.8708	32.44.25.6036	28.38.52.4031	25.27.53.2472	22.55.05.9225	400
500	47.44.47.3385	40.55.32.0045	35.48.35.5039	31.49.51.5590	28.38.52.4031	500
600	57.17.44.8062	49.06.38.4054	42.58.18.6047	38.11.49.8708	34.22.38.8837	600
700	66.50.42.2740	57.17.44.8062	50.08.01.7055	44.33.48.1826	40.06.25.3644	700
800	76.23.39.7417	65.28.51.2071	57.17.44.8062	50.55.46.4944	45.50.11.8450	800
900	85.56.37.2094	73.39.57.6080	64.27.27.9070	57.17.44.8062	51.33.58.3256	900
1.000	95.29.34.6771	81.51.04.0089	71.37.11.0078	63.39.43.1181	57.17.44.8062	1.000

DEFLECTION ANGLES

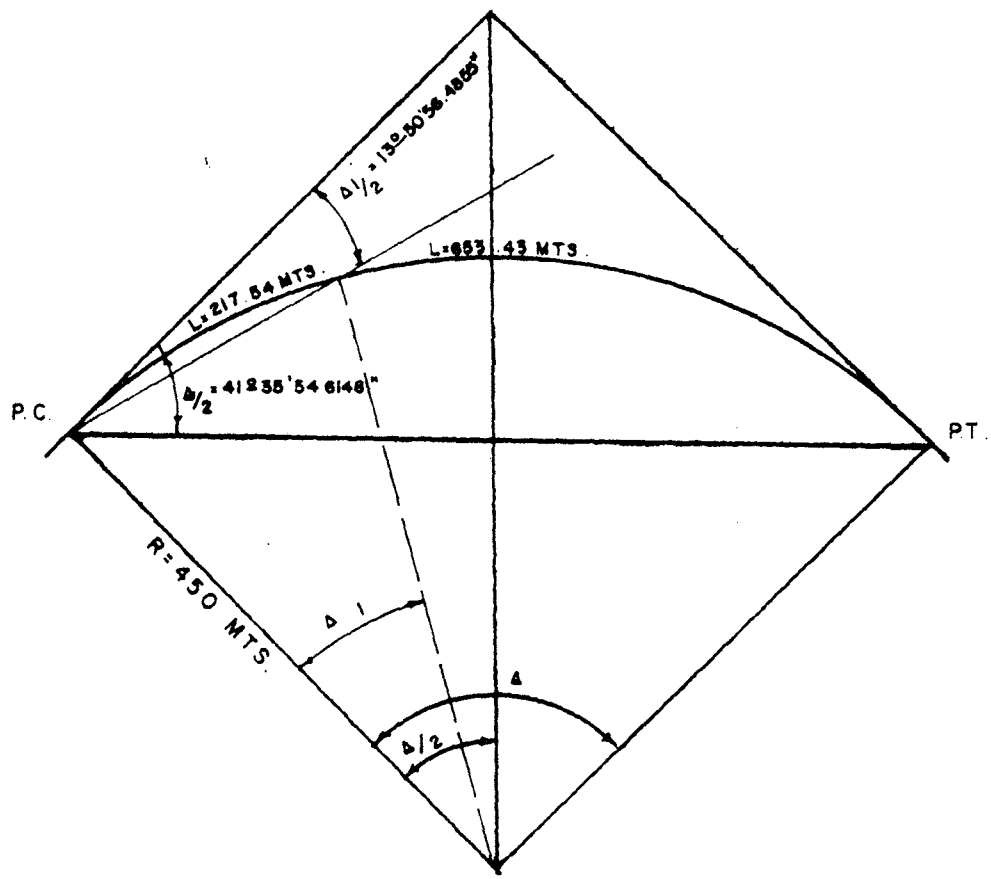
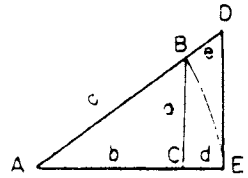


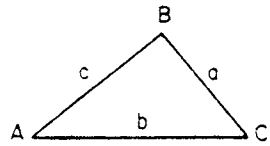
FIGURE 16-B

16.07-03

TRIGONOMETRIC FORMULAS



Right Triangle



Oblique Triangle

RIGHT TRIANGLES

$\sin A = \frac{a}{c} = \cos B$ $\qquad$ $\sec A = \frac{c}{b} = \operatorname{cosec} B$

$\cos A = \frac{b}{c} = \sin B$ $\qquad$ $\operatorname{cosec} A = \frac{c}{a} = \sec B$

$\tan A = \frac{a}{b} = \cot B$ $\qquad$ $\operatorname{vers} A = \frac{c-b}{c} = \frac{d}{c} = 1 - \cos A$

$\cot A = \frac{b}{a} = \tan B$ $\qquad$ $\operatorname{exsec} A = \frac{e}{c} = \sec A - 1$

$a = c \sin A = c \cos B = b \tan A = b \cot B = \sqrt{c^2 - b^2}$

$b = c \cos A = c \sin B = a \cot A = a \tan B = \sqrt{c^2 - a^2}$

$c = \sqrt{a^2 + b^2}$ $\qquad$ $d = c \operatorname{vers} A$ $\qquad$ $e = c \operatorname{exsec} A$

OBLIQUE TRIANGLES: $A + B + C = 180°$ $s = \frac{1}{2}(a + b + c)$

Given	Sought	Formulas
A, B, a	b, c	$b = \frac{a}{\sin A} \cdot \sin B \quad c = \frac{a}{\sin A} \cdot \sin (A + B)$
A, a, b	B, c	$\sin B = \frac{\sin A}{a} \cdot b \quad c = \frac{a}{\sin A} \cdot \sin C$
C, a, b	A, c, B	$\tan A = \frac{a \sin C}{b - a \cos C} \quad c = \frac{a \sin C}{\sin A} \quad b > a$
C, b, a	B, c, A	$\tan B = \frac{b \sin C}{a - b \cos C} \quad c = \frac{b \sin C}{\sin B} \quad a > b$
A, b, c	a	$a^2 = b^2 + c^2 - 2bc \cos A$
B, a, c	b	$b^2 = a^2 + c^2 - 2ac \cos B$
G, a, b	c	$c^2 = a^2 + b^2 - 2ab \cos C$
a, b, c	A, B, C	$\sin^2 \frac{1}{2} A = \frac{s-b}{b} \cdot \frac{s-c}{c}$
		$\sin^2 \frac{1}{2} B = \frac{s-a}{a} \cdot \frac{s-c}{c}$
		$\sin^2 \frac{1}{2} C = \frac{s-a}{a} \cdot \frac{s-b}{b}$
a, b, c	A, B, C	$\cos A = \frac{b^2 + c^2 - a^2}{2bc}$
		$\cos B = \frac{a^2 + c^2 - b^2}{2ac}$
		$\cos C = \frac{a^2 + b^2 - c^2}{2ab}$

16-07.04 AREA AND VOLUME FORMULAS

AREA OF:

Trapezoid: 1/2 (Sum of parallel sides) X (perpendicular height)

Circle: πr^2, Where r = radius, π = 3.1416

Ellipse: πab = 3.1416 X Long diameter X short diameter

Parabola: Base X $\frac{2}{3}$ Perpendicular height

Sector of Circle: Arc X 1/2 radius = 1/2 r^2 X Central Angle (in radians) = 0.0087266 r^2 X Central Angle (in degrees)

Segment of Circle: $\frac{r^2}{2}\left(\frac{r\,\phi}{180} - \sin\phi\right)$ where ϕ is Central Angle in degrees

Triangle: 1/2 base X height

Rectangle: base x height

VOLUME OF:

Prism or Cylinder: Area of base X the perpendicular height = (A X h)

Pyramid or Cone: 1/3 (Area of base X height) = 1/3 (A X h)

Frustum of Pyramid or Cone: Sum of end Areas, A_1 and A_2, Plus the Square root of their products X 1/3 Perpendicular height $h = (A_1 + A_2 + \sqrt{(A_1 \times A_2)})\frac{h}{3}$

Sphere: $\frac{4}{3}\pi r^3$ = 4.1888 radius^3

Rectangle: Area base X height

16–08 MISCELLANEOUS

Electronic Computer Programs for Highway Surveys

ICES COGO is a computer system designer to aid engineers and surveyors in the solution of geometric problems. The user of ICES COGO describes his problem to the computer programs of the COGO systems using a language and conventions which are made natural for the engineer solving a geometric problem, rather than being tailored to the computer.

Open and closed traverses curve elements and areas are checked by this system.

ROUTE LOCATION NOTES

STA.	PARTIAL DIST	TOTAL DIST	VERTEX	CURVE ELEMENTS	OBS BEARING	CALC BEARING
2 + 54 42	12 24	254 42				
2 + 42 18	13 17	242 18				
2 + 29 01	15 00	229 01				
2 + 14 01	16 93	214 01				
PT.1+97 08	11 00	197 08		A=127° 50"		
1 + 86 08	7 21	186 08		R= 40 00		
MC.1+78 87	6 21	178 87	V-3-R	T= 19 58	S 44° 15" W	S-44° 10" W
1 + 72 66	8 00	172 66		E= 4 54		
1 + 64 66	4 00	164 66		L=36 42		
PC 1+60 66	5.65	160 66				
1 + 55 01	7 00	155 01				
1 + 48 01	8 81	148 01				
PT.1+39 20	9 00	139 20		A=155°00"		
1 + 30 20	7 36	130 20		R= 75 00		
MC 1+22 84	6 36	122 84	V-2-L	T= 16 63	S-7° 45" E	S- 8° 00" E
1 + 16 48	10 00	116 48		E= 1 82		
PC 1+06 48	11 47	106 48		L=32 72		
0 + 95 01	14 43	95 01				
PT 0+80 58	10 00	80 58		A=116° 30"		
0 + 70 58	6 63	70 58		R=30 00		
MC0.+63 95	3 47	63 95	V-1-R	T= 18 56	S-17° 00" W	S-17° 00" W
0 + 60 48	13 15	60 48		E= 5 28		
PC.0+47 33	7 33	47 33		L=33 25		
0 + 40 00	20 00	40 00	0 51 +	38 00		
0 + 20 00	20 00	20 00	0 51 +	23 00		
0 + 00 00	0 51 + 00	00 OF PAVED ROAD				

OBSERVATIONS

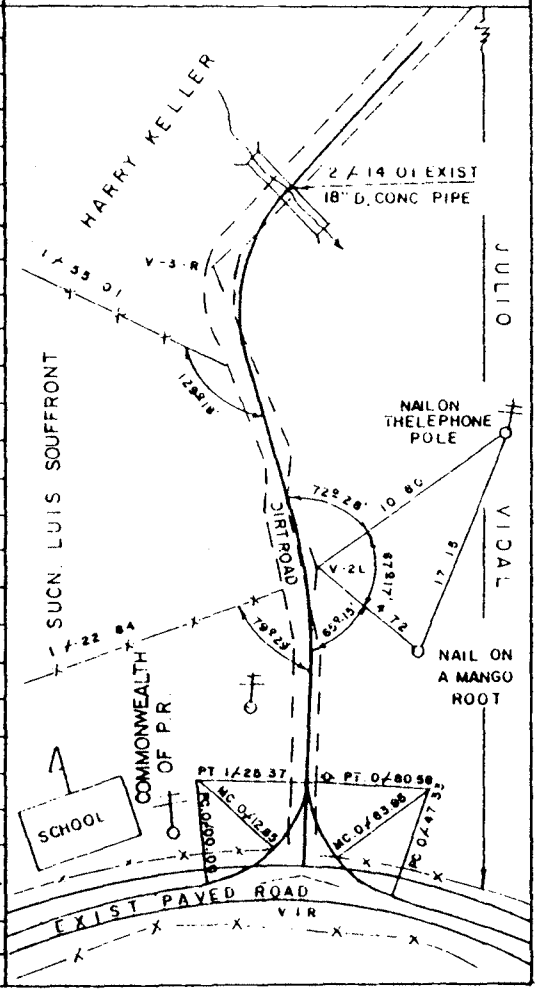


FIGURE 16 - 3

LEVELING NOTES

STA.	BACK SIGHT (+)	H - I	FORE SIGHT (−)	T. P. S.	ELEV. (MTS.)
BM # 10	3.168	335.769			332.601
0+00.00			1.75		334.019
0+20.00			1.81		333.959
T.P. # 1	3.768	339.465		0.072	335.697
0+30.00			3.09		336.375
0+40.00			3.03		336.435
0+55.00			2.75		336.715
T P. # 2	3.234	342.597			339.323
0+65.00			2.98		339.617
0+80.00			2.45		340.147
1+00.00			2.43		340.149
T.P. # 3	2.657	345.020		0.234	342.363
1+10.00			3.65		341.370
1+25.00			2.98		342.040
1+35.00			2.02		343.000
BM # 1				1.058	343.962

LEVELING CHECK

BM. # 1	1.058	345.020			343.942
T.P. # 1	0.198	342.020		2.657	342.363
T.P. # 2	0.156	339.479		3.238	339.323
T.P. # 3	0.067	335.766		3.780	335.699
BM. #10	.			3.162	332.604

332.601
332.604

ERROR OF CLOSURE = .003 MT.

TABLE 16-4

SURVEY LINE CROSS SECTIONS

PARTIAL DIST.	DIFF. IN ELEV.		TOTAL DIST.	TOTAL DIFF. IN ELEV.	OBS.		PARTIAL DIST.	DIFF. IN ELEV.		TOTAL DIST.	TOTAL DIFF. IN ELEV.	OBS.
		000	+ 20.00					ELEV.	333.	959		
3 0	+0 30		-03·0	+00·30			1·0	-0·60		01.0	-00·60	
3·0	+0 25		-06 0	+00·55			1 5	-0·20		02·0	-00·89	
3·0	+0·33		-09·0	+00·88			1·5	-0 90		04·0	-01·70	XXXX
3 0	+0 40		-12·0	+01·28			4·0	-0 80		08·0	-02·50	
3·0	+1·10		-15·0	+02·38			3·0	-1·10		11·0	-03·60	
3·0	+0·92		-18·0	+03·30	XXXX		3 0	-1·40		14·0	-05·00	
3·0	+0·30		-21·0	+03·60			3·0	-0·10		17·0	-04·90	
3·0	+0·20		-24·0	+03·80			3·0	-0·20		20·0	-05·10	
3·0	+0·20		-27·0	+04·00			3·0	-0·15		23 0	-04·95	
3·0	+0·10		-30·0	+04·10			3·0	-0·60		26·0	-05·55	
							3·0	-0·50		29·0	-06·05	
				IMPORTANT			COLUMNS					

Notes:

1- All cross sections information must be filled like the illustrated form.

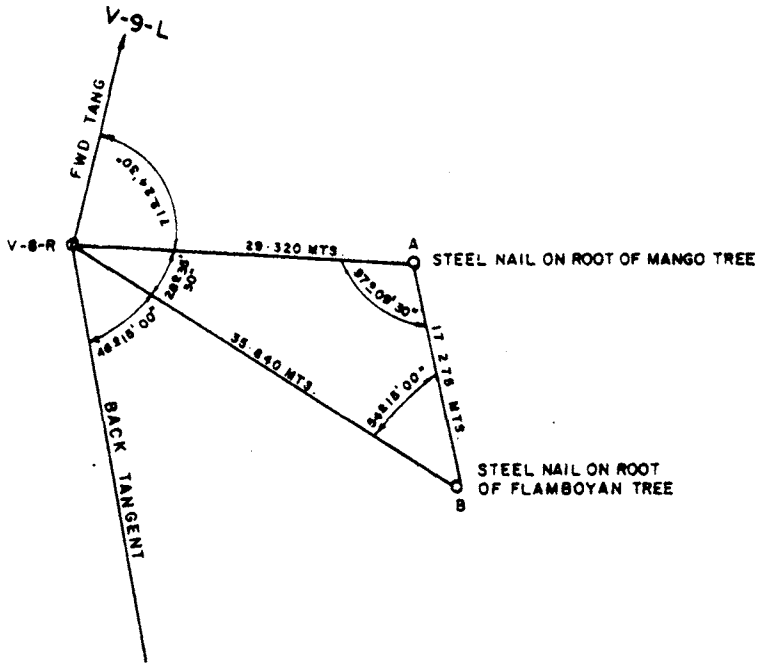
2- The indicated columns should have the correct number of digits, the decimal point, and the corresponding sign in the difference in elevation columns.

3- The reason for the specific details mentioned on 1 and 2 is that the information is going to be punched in IBM cards directly from the field book. Then it will be processed by the computer.

TABLE 16-5

SURVEY REFERENCE POINTS

THIS TYPE OF REFERENCE IS THE MOST COMMONLY USED



THIS TYPE OF REFERENCE IS ALSO ACCEPTED

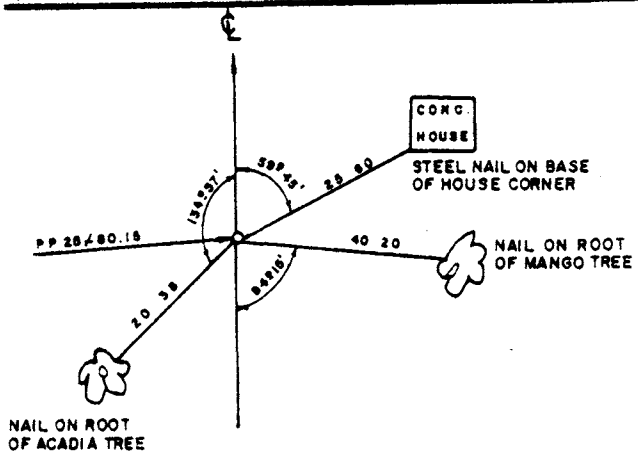
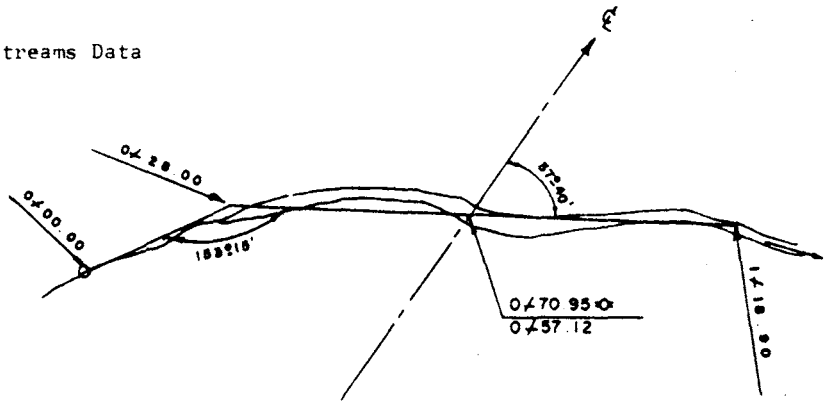


FIGURE 16-C

DRAINAGE SURVEY

1. Streams Data



Beside the ground plan, a profile and cross sections of the stream are drawn to be used in the design.

2. Bridge Replacement

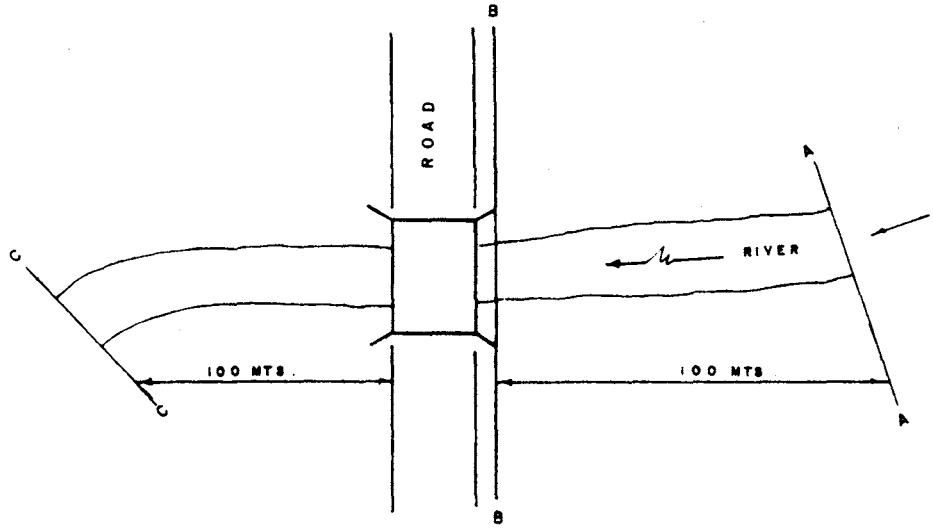
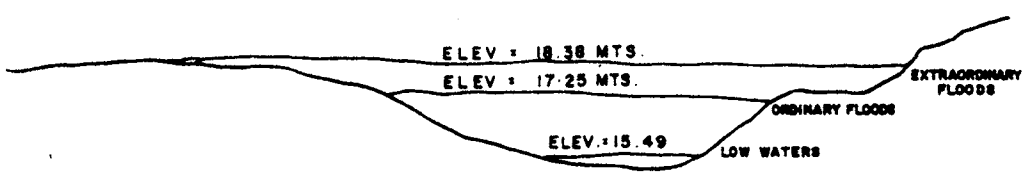


FIGURE 16-D

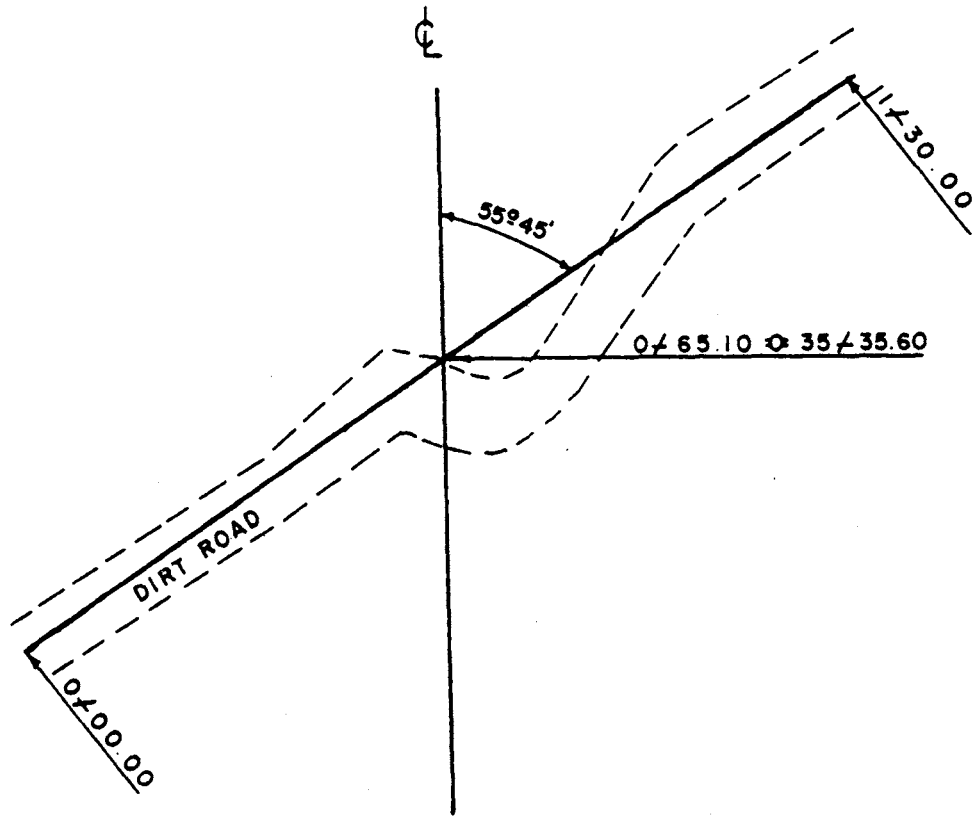
For bridge replacement, a topography is necessary. The size of the topography is determined after a joint field trip between the structural engineer in charged of the bridge design and the Survey Office Personnel.

Three cross sections are necessary to show the river or stream bed and slope in the vicinity of the bridge location. Section B - B must show the water marks. See example:

SECTION B-B



ACCESS DETAILS

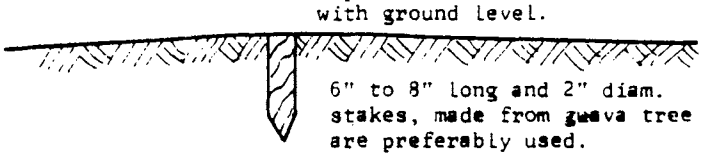


Beside the ground plan, a profile and cross sections of the access are drawn to be used in the design.

FIGURE 16-E

TYPES OF STAKES

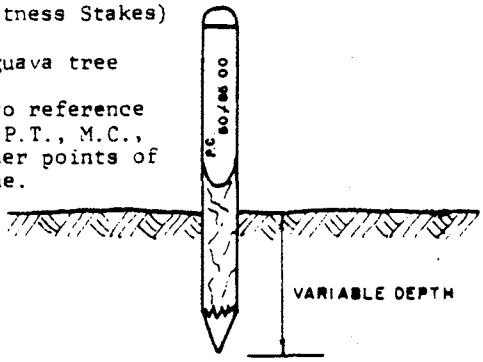
1- AT GRADE STAKES (Center line stakes)



2- REFERENCE STAKES (Witness Stakes)

18" long - made from guava tree

This stakes are used to reference points such as P. C., P.T., M.C., P.P., P.I. and all other points of the highway center line.



3- BENCH MARKS

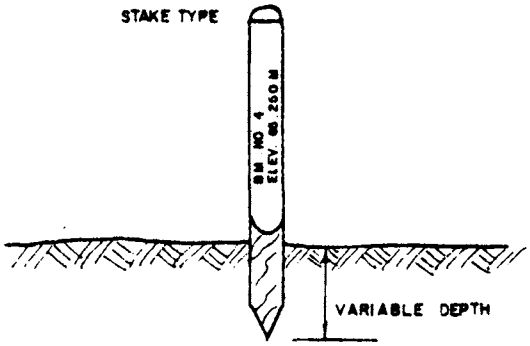


FIGURE 16-F

CONVENTIONAL SIGNS

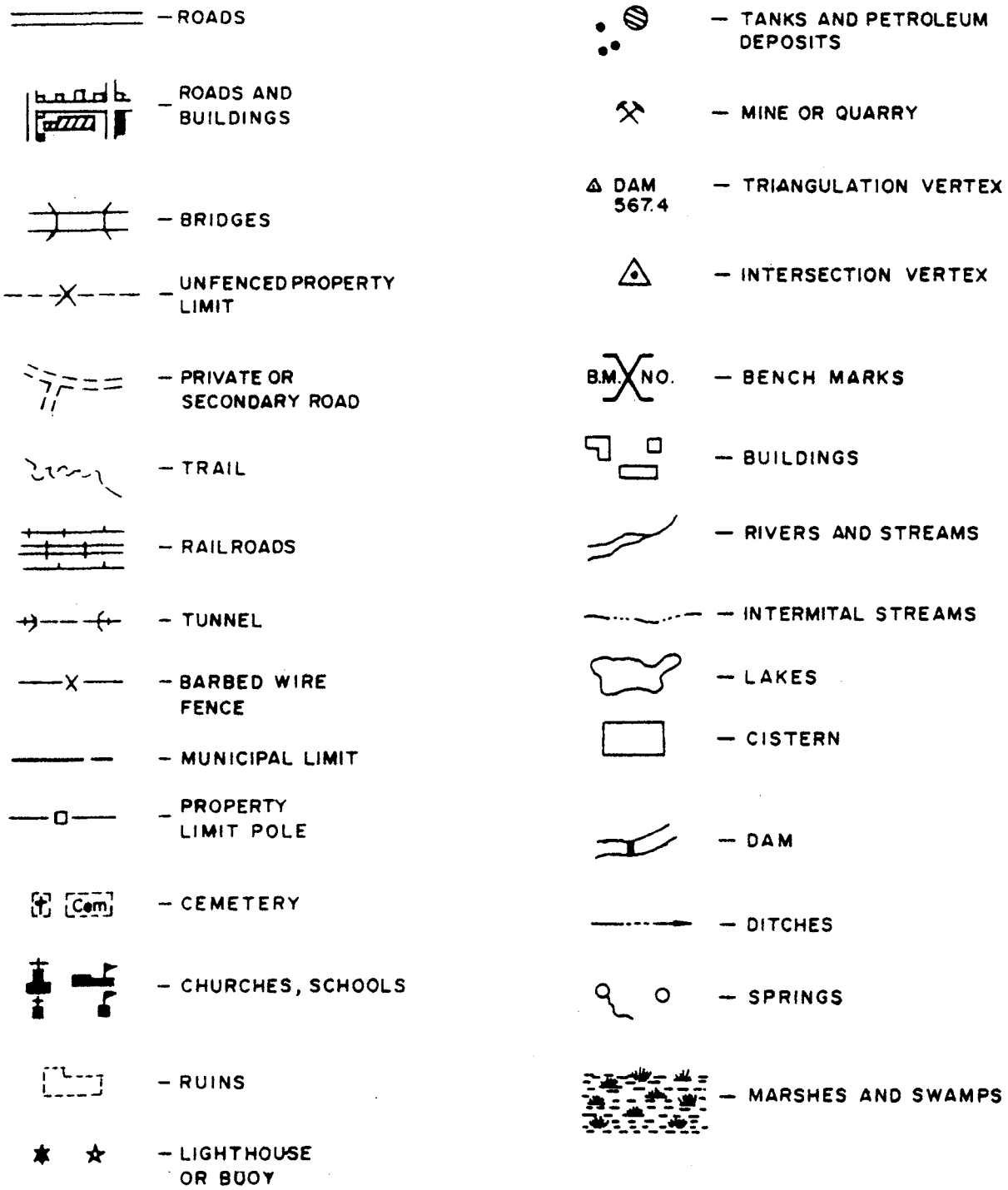


FIGURE 16-G

UTILITIES SYMBOLS

PUERTO RICO
AQUEDUCT AND SEWER AUTHORITY
(PRASA)

- W 8" W — AQUEDUCT
- LINE PIPE
- WATER METER
- MANHOLE (A)
- VA — VALVE
- AIR VENT
- red — REDUCER
- SHUT OFF VALVE

PUERTO RICO
WATER RESOURCES AUTHORITY
(PRWRA)

- ELECTRICITY POLE
- E — EXISTING AERIAL LINE
- EU — EXISTING UNDERGROUND LINE
- ELECTRICITY POLE MOUNTED TRANSFORMER
- PAD MOUNTED TRANSFORMER
- SWITCHING UNIT
- EWR MH — MANHOLE

PUERTO RICO TELEPHONE COMPANY
(PRTC)

- TELEPHONE POLE
- ET — EXISTING AERIAL TELEPHONE LINE
- EUT — EXISTING UNDERGROUND TELEPHONE LINE
- ET MH — MANHOLE

PUERTO RICO
COMMUNICATION AUTHORITY
(PRCA)

- C — COMMUNICATION POLE
- EC — EXISTING AERIAL COMMUNICATION LINE
- EUC — EXISTING UNDERGROUND COMMUNICATION LINE
- EC MH — MANHOLE

FIGURE 16-H

Application of Photogrammetric Methods to the Different Stages of Highway Design

16–12 INTRODUCTION

The development of the technique of highway design during recent decades has implied that the requirements on the information regarding the topography and geology of the terrain have increased. One of the reasons is the introduction of more advanced elements of road alignment. Another is the fact that the requirements on the fitting of the road into the surrounding terrain or landscape from the points of view of environments, of aesthetics and traffic safety have increased.

The process of highway design can generally be divided into three different stages, namely Route Location, Preliminary Design and Final Design. This division is, from the point of view of photogrammetry, a practical division as there is a relation between each of the different design stages and the requirements of the geometrical accuracy of the terrain information for that stage. In the first two stages interest is concentrated upon requirements on less accurate topographic information over wide areas. While in the final stage accurate detailed information is required over limited areas. The requirements of geological-geotechnical information follow the same principles in the design process.

16–13 ROUTE LOCATION

The main considerations of the highway network of the single road are defined in this stage. Therefore a preliminary fitting of the requirements of the forecasted traffic to the topographical and geological conditions of the terrain is needed in order to optimize the total cost function. The actual cost function is principally divided into construction cost and cost of vehicle operation. These two cost functions are correlated with the alignment of the road in the terrain.

One of the main tasks of the analysis of the terrain in the location stage is to delimit areas, that because of their geological conditions are evidently unsuitable for highway construction. Areas, where geotechnical problems may play a determining influence upon the construction cost are also of interest. The geological-geotechnical photointerpretation therefore is an important aid in this design stage.

A summation of the delimitations of terrain areas that are complicated from point of view of highway construction gives an indication of the location of possible terrain corridors.

Aerial photographs from flying heights between 5,000′ and 10,000′ are generally used for the photogrammetric study of the terrain. Photo interpretation studies of these photographs ordinarily give a satisfactory survey of the loading capacity and other geological-geotechnical parameters of the terrain from the road construction point of view. Airphoto-interpretation may be very valuable for the choice of the route for a road and for information of soil conditions and materials, areas of poor drainage, marshy areas, landslides and unstable ground, mining subsidence, swallow holes, and rock outcrops. Man-made features of interest include any changes since the last map revision, e.g. new roads of buildings, demolition of buildings, extensions to quarries and gravel-pits, removal or changes in field boundaries, pipelines and movement of mining spoil heaps.

The application of airphoto-interpretation relate mainly to the route location and preliminary stages of Highway Design.

Investigation of possible alignments of different fundamental centerlines can be made photogrammetrically. The Kelsh Plotter may be mentioned as an instrument suitable for

producing and efficient and convenient overall view of the entire photogrammetric model or set of models including preliminary measurements of the longitudinal profiles along the fundamental alternative centerlines.

Complete horizontal and vertical control for the different photogrammetric models is generally not required. And arbitrarily located baseline, measured in the field can by satisfactory for the scaling of the model. Vertical control can be achieved by simple measurements, barometric, etc, if is is not already available.

The control points for the evaluation of the models can also be achieved by aerial triangulation. This method is mainly used when the result of the evaluation consists of a map with contours. The scale of the map is generally 1:10, 000 to 1:2, 000 and the contour interval 5m or 2m. Second order photogrammetric equipments as Kelsh Plotter are mainly used for the mapping.

16--14 PRELIMINARY DESIGN

The first part of this design stage consists of a systematization and actualization of the result from the route location stage concerning the actual terrain corridor. The result of the design work of this stage is a centerline, analized in such detail, that it is ready for setting out in the terrain. This means that the actual alternative centerlines within the terrain corridor are investigated concerning their preliminary horizontal and vertical alignment, so that their cost functions, construction and vehicle operations, can be analized together with their effects upon the development of the community. Therefore, in this design stage the requirements on a survey over wideareas within the terrain corridors must be combined with requirements on geometrical quality of the terrain data, that are adapted to the real needs.

Aereal photographs from 5,000′ to 10,000′ flying heights are generally used in the preliminary design stage, depending on the information requirements. These image scales are more related to the requirements on an overall view of wide areas than to the requirements of geometric accuracy. Experience has up to now, shown that these photographs, evaluated in suitable equipment, using a suitable technique, give an acceptable compromise between an overall view and geometrical accuracy.

The terrain corridors generally have a long and narrow form and planimetric control points can thus be arranged in the form of a traverse through the corridor. The traverse points are signalized before the photography. The advantage of terrestrially measured control points compared to photogrammetrically triangulated control points consists of the possibilities of using the control points as both reference and control points for the staking out of the centerline in the terrain.

The required vertical control is procured in a conventional way using levelling, trigonometric or phototrigonometric height measurement, depending on topography and vegetation.

It can thus be stated that the recent development in the field of aerial triangulation means a good step forward in improving the practical application of photogrammetry to highway design, as the combination of geodetic methods and photogrammetric triangulation can be organized in a more efficient way than before for the horizontal and particularly and for the vertical control.

The detail maps are generally made at the scale of 1:2, 000 and the contour interval is 1m or 2m depending on the topography. The maps are made in a conventional photogrammetric way but as the flying height for the photographs mainly is estimated by a compromise between the requirements on good topographic information over the entire terrain corridor for the evaluation of alternatives and the requirements of geometrical accuracy for the detail mapping; great attention must be paid to the geometrical quality of the photographs and of the evaluation equipments.

16—15 FINAL DESIGN

In the first step an analysis is made concerning the method of procuring the detailed terrain information that is needed for the final design of the body of the road, hereinafter reffered to as the roadbody, along the centerline, that is determined in the previous stage. Terrain topographic data can be obtained by terrestrial or by photogrammetric methods or by a combination of the two methods. The choice of methods generally depends on the ground vegetation, the size of the project and the topography of the terrain. A traverse with a side-length of approx. 200 m is record noted, marked and signalized along the centerline before the photography in order to serve as planimetric control for the photogrammetric evaluation. The traverse points are located in such a way that they can also be used as control points for the setting out of the centerline. Terrain details, identified in the photographs after the photography, are mainly used for the vertical control.

The aerial photographs are taken from a flying height of 1250′ to 2500′.

The evaluation of the photographs consists of measurements of longitudinal and transverse profiles and of preparing detail maps at the scale of 1:500 to 1:1000 with contours at an interval of 0.5 to 1m. The maps are used for the final design of interchanges, bridges etc.

The photogrammetric measurements of longitudinal and transverse profiles, the model coordinates, are automatically registered on punch cards by a registering device, connected to the evalutation equipment. The model coordinates are first transformed into the ground system of coordinates and then into the system of the centerline before they are shown in the form o longitudinal and transverse profiles. The computer programs generally allow the insertion of terrestrial measurement in cases, where gaps occur due to vegetation etc.

Ordinarily the topographic data must also be complemented by geological-geotechnical data from borings, etc, as the design of the roadbody also depends on soil conditions.

CHAPTER 17

ENVIRONMENTAL CONSIDERATIONS

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CHAPTER 17

17–01 ENVIRONMENTAL IMPACT STATEMENT

The National Environmental Policy Act (NEPA) of 1969 (P. L. 91-190) established a broad national policy to promote efforts to improve the relationship between man and his environment.

The NEPA further requires that all policies, regulations and public laws of the United States and Puerto Rico shall be interpreted and administered in accordance with those policies and goals.

Section 101(a) of the NEPA clearly states these policies and goals and declares that it is the continuing policy of the Federal Government, in cooperation with State and local governments as well as concerned public and private organizations, to use all practicable means to create and maintain environmental conditions under which present and future generations can exist in productive harmony with nature.

The NEPA also established the Council on Environmental Quality with the authority to prepare and issue guidelines for the implementation of Section 102(2) (c). This section requires that " . . . all agencies of the Federal Government must include in every recomendation or report on proposals for legislation and other major Federal actions, significantly affecting the quality of the human environment, a detailed statement by the responsible official on:

1. The environmental impact of the proposed action,
2. Any adverse environmental effects which can not be avoided should the proposal be implemented,
3. Alternatives to the proposed action,
4. The relationship between local short-term uses of man's environment and the maintenance and enhancement of long term productivity,
5. Any irreversible and irretrievable commitment of resources which would be involved if the proposed action is implemented".

In actions where the location studies reveals no feasible and prudent alternative to avoid the use of land from a publicly owned park, recreation area, wildlife and waterfowl refuge or any land from a historic site, a 4(f) statement will be prepared and included in the Environmental Document. The 4(f) statement supports the determination in which the action will include all possible planning to minimize harm. Reference should be made to FHPM 7-7-2 Part 20.

Guidelines have been established for carrying out the intent of these requirements and these guidelines have been adopted by the Department not only in the preparation of Environmental Impact Statement, but also in the general environmental evaluation of all projects (see FHPM 7-7-2, Section 1653(f) of 49 United States Code, Section 470(f) of the United States Code, and Section 309 of the Clean Air Act of 1970; September 7, 1972).

The type of Environmental Impact Statement required for a project will be determined by the Environmental Studies Office in conjuction with the Federal Highway Administration.

17–02 METHODS OF ENVIRONMENTAL EVALUATION, GENERAL CHECKLIST

The first step in the preparation of the environmental evaluation of any highway project is the recognition of the protection and enhancement of the environment that is of increasing importance and must be fully considered.

The Environmental Studies Office in coordination with government and private organizations is responsible for preparing all phases of the Environmental Impact Statement and

4(f) Statement when required. It is of particular importance that the designer will make full use of any environmental comments received from the Environmental Studies Office during the review of the Design Reports.

The following non-exclusive list of "Social, Economic and Environmental Effects", represents many of the factors to be considered as interrelated in the environmental evaluation:

1. Conservation and preservation of Natural, Ecological and Scenic Resources
2. Displacement and Relocation of Individuals and Families
3. Regional and Community growth
4. Commnunity Cohesion
5. Public Facilities Service
6. Air and Water Quality
7. Noise Pollution
8. Aesthetics and Other Values

These topics on the above list are investigated and reported upon by the Environmental Studies Office.

17–02.01 CONSULTED AGENCIES BY THE ENVIRONMENTAL STUDIES OFFICE FOR THE PREPARATION OF AN ENVIRONMENTAL DOCUMENT

Puerto Rico Planning Board
G.P.O. Box 9447
Santurce, Puerto Rico 00908

Puerto Rico Acqueducts and Sewers Authority
G. P. O. Box 7066
Santurce, Puerto Rico 00916

Environmental Quality Board
G. P. O. Box 11488
Santurce, Puerto Rico 00910

Department of Housing
G. P. O. Box 20591
Río Piedras, Puerto Rico 00928

Public Parks and Recreation Administration
G. P. O. Box 3207
San Juan, Puerto Rico 00910

Department of Commerce
G. P. O. Box 4275
San Juan, Puerto Rico 00905

Department of Education
G. P. O. Box 795
Hato Rey, Puerto Rico 00919

Puerto Rico Water Resources Authority
G. P. O. Box 4267
San Juan, Puerto Rico 00936

Department of Health
G. P. O. Box 9942
Santurce, Puerto Rico 00908

Department of Natural Resources
G. P. O. Box 5887
Puerta de Tierra, Puerto Rico 00906

Institute of Puerto Rican Culture
G. P. O. Box 4184
San Juan, Puerto Rico 00905

Puerto Rico Economic Development Administration
G. P. O. Box 10163
Santurce, Puerto Rico 00908

MUNICIPALITIES IN WHICH PROPOSED PROJECT IS LOCATED

U. S. Department of the Interior
Office of the Secretary
Southeast Region, 148 Cain Street, N. E.
Atlanta, Georgia 30303

Environmental Protection Agency
Regional Office II
Federal Building
26 Federal Plaza
New York, New York 10007

U. S. Department of Health, Education and Welfare
Region II, 26 Federal Plaza
New York, New York 10007

U. S. Department of Agriculture
Soil Conservation Service
Caribbean Area
G. P. O. Box 4868
San Juan, Puerto Rico 00936

U. S. Department of Housing
and Urban Development
Commonwealth Area Office
G. P. O. Box 3869
San Juan, Puerto Rico 00936

U. S. Coast Guard Commander
7th Coast Guard District
Federal Room – 1012
51 SW, 1st Avenue
Miami, Florida 33130

U. S. Army Corps of Engineers
San Juan Area Office
400 Fernández Juncos Avenue
San Juan, Puerto Rico 00901

17–02.02 DATA SOURCES

In addition to the U. S. G. S. Topographic Survey maps and aerial photographic coverage, soil maps, land use map inventories, zoning maps, master plans, historic site inventories, regional growth projections and geologic maps should be used during the preparation of the Environmental Evaluation.

The Design Area shall have a copy of each Environmental Impact Statement and its disposition so that recommendation for measures to minimize possible environmental damage can be included in the plans and specifications.

From the above data, the Design Area designer should assemble a check list of the environmental factors considered. With the list available, the designer is then prepared to make a field inspection of the project.

The importance of the field inspection can not be over-estimated for it is at this point that the designer will be able to expand or reduce his environmental checklist. A number of basic decisions will be the product of these field trips.

Following the on-site inspection of the project the designer should seek the expert opinion of specialists such as planner, environmental engineers, soil engineers and landscape architects within the Department as well as representatives of state agencies on various environmental factors in the review of the project.

In addition to providing basic data, agencies contracted during the Environmental Evaluation can also provide the designer with the preliminary data to find the techniques and procedures related to solving the expected problems.

17—03 ENVIRONMENTAL FACTORS

For the purpose of this Chapter, natural and physical environmental factors include air, water, land and wildlife, while the social factors include recreational needs, aesthetics, noise and the preservation of historic and prehistoric sites.

The evaluation and identification of the impacts of air, noise and water, the economic and social environmental factors, such as "economic activity, employment, public health and safety, residential and neighborhood characteristics and location, religious institutions, properties values, housing replacement, education and displacement of families and business" is developed by the Environmental Studies Office in consultation with other offices inside the Department and other agencies as well.

17—03.01 PHYSICAL ENVIRONMENTAL FACTORS

The visual impact to the physical environment related to a highway project should be of a major concern to the environmentalist and the designer. The designer in rural areas must make every effort to preserve the existing natural environment with the objective of creating an attractive highway. In the urban areas there may be a natural environment to preserve or enhance. In this situation the designer should provide enough right of way on which to do the landscape development necessary to improve the physical environment.

A. Air Factors

A highway project can contribute to air pollution during and after the construction. The designer may obtain general information through the Air Quality Division (Office of Environmental Studies). At a local level the Environmental Quality Board should be contacted for broad guidelines and specifications with regard to air pollution abatement as covered under clearing and grubbing (non burning disposal techniques). Demolition contracts in urban and suburban areas require special consideration. The designer should also be aware of air pollution abatement references within the general specifications.

Every highway project individually considered, as well as the overall transportation plan shall be consistent with the State Implementation Plan. The SIP is to specify the plan of action for achieving the Act's (Clean Air Act of Puerto Rico) objectives, i.e., reduction in emissions levels requisite for meeting the National Ambient Air Quality Standards (NAAQS) and the prevention of excessive increases in emissions in the future in order that the NAAQS be maintained and that significant deterioration of air quality be prevented. In addition, in the SIP, a plan of action is established requiring an strategy to provide for incremental reduction in transportation system emissions as expeditiously as practicable. This strategy can include (where serious problems with air quality exists) transportation control measures and highway design criteria for the reduction of motor vehicle emissions. In order that every project be consistent with the SIP, it must form part of the established strategy or meet the basic objectives of the plan. The consistency determination must be part of the air quality study prepared for each individual project in the Environmental Impact Statement.

Several guidelines are currently available relating highway design to vehicle emission pollution. However, as new information becomes available, the Division of Air Quality Studies may be consulted for additional data and criteria.

Air pollution may be intensified by unpredictable metereological events such as temperature inversions, turbulences inhomogenity of the atmosphere or non-characteristic wind patterns and criteria (peak hours) traffic condition. In general, air pollution due to vehicle emissions can be reduced by avoiding steep grades, conditions requiring acceleration and deceleration, and highway segments having poor air circulation (in which a channelization effect is created) due to man made and/or topographical features alongside it, particularly in urban and suburban areas. Unfortunatelly for the air quality those highway segments offer a solution to noise pollution, therefore, this problem should be studied concurrently. Air pollution projections and suggested study techniques may be found in the following written material:

1. Highway Air Quality Manual
   USDOT, FHWA
2. California Line Source Mathematical
   Mathematical Model — User's Manual
3. Fundamentals of Air Quality
   Department of Transportation
   Federal Highway Administration
   Washington, D. C. 205590
4. "Workshop of Atmospheric Dispersion Estimates"
   U. S. Public Health Service Publications
   999-AP-26 avail. BTIS
5. Clean Air Act for Puerto Rico
   Commonwealth Evironmental Quality Board

B. **Water Factors**

A highway project can contribute to water pollution in a number of ways both during and after construction.

Pollutants such as plasticisers, lead, lubricants and fuels are readily identified as potential pollutions factors. However, since pollutants are defined as many natural or man-produced substances that are detrimental to a waterway, one of the major pollutants is from soil erosion. The designer must be aware of the content and use of all the Department specifications to control soil erosion, stream conservation, water pollution abatement, solid waste disposal, restoration of disturbed areas and temporary water pollution control.

The use of construction timetables in conjunction with the use of erosion control specification remains in an absolute necessity although the effects of water pollution can be minimized through the recognition of these problems during design.

Identification of easily erodible soils, predictable internal and surface drainage patterns, stream channel characteristics and local geologic features are necessary in the environmental evaluation.

During construction, the rapid stabilization of disturbed areas through revegetation is of primary importance. Both temporary and final soil erosion control must be considered by the designer (Reference should be made to FHPM 6-7-3). However, it should be noted that the excess fertilizer run off from seeded areas may increase phosphate in adjacent waterways to the point of becoming a pollutant.

The range of water related factors involved in any project may include alteration of streams marshes and other wet lands, boating on navigable streams water supplies, potential floodings conditions and possible alteration of water tables.

The effect of overloading existing combined sewer systems which might result in untreated sewage by-passing treatment plants should also be investigated.

In addition to the Water Quality Division (Office of Environmental Studies), the designer should consult with the local offices of the U.S. Soil Conservation Service. This organization can be particularly helpful in the design of sedimentation basins (The designer should also be familiar with the **Guidelines for Erosion and Sedimentation Control Planning and Implementation**, prepared by the Office of Research and Monitoring, U. S. Environmental Protection Agency, Washington, D. C. 20460 and **Suggestions for Temporary Erosion and Siltation Control Measures** prepared by the U. S. Department of Transportation Federal Highway Administration).

The standard method of soil stabilization such as seeding, sodding and mulching, together with the use of jute mesh and other erosion control mats or netting are all helpful.

In certain areas of highly erodible soil or highway hydraulic gradients, the use of these common revegetational procedures may not be sufficient to permit stabilization. In these cases, granular fill slope protection, subsurface drainage or retaining structures should be considered with the aid of the Division of Soil Engineering.

The proper design of drainageways must provide for anticipated design flow together with adequate protection of the terrain and low maintenance characteristics.

Special care must be exercised in the design of energy dissipators so as to prevent additional erosion problems.

If the project must encroach upon natural waterways or impoundments, a special effort must be made to design all works in a manner which will lessen the impact on these areas.

Special consideration must be given to the methods of crossing live steams by construction equipment, together with the specifications of materiales when such temporary crossings are necessary.

Stream relocations must be designed with full knowledge of the conditions which are conducive to erosion as well as those protective procedures available to eliminate or alleviate this problem.

Natural impoundments or other bodies of water with erodible banks require stabilization through the use of vegetation or slope protection techniques due to wave action, although in many cases the problem is not as critical as with moving water.

Wetlands, due to their high environmental value should be avoided wherever possible. Highway projects bisecting wetland areas often cause problems due to disturbance of the ground water table by the highway fill. If such situations arises, heavy fills without adequate cross drainage structures should be avoided. Minor elevation changes of ground water create ecological problems which may result in the death of mature vegetation adjacent to the highway. This problem may be alleviated through the use of equalizing culverts.

With regard to the final deposition of water collected on a project, particular attention should be given to the final discharge so that physical damage to adjacent properties is avoided and the resultant water is as free of pollutants as possible.

The office of Soil Engineering should be consulted in matter relating to drainageway design, bank and channel protective linning design and roadside drainage channel design. Also, the designer should be familiar with the following literature:

1. Excerpts from the Michigan Department of State
   Highways and Transportation
   Program for Soil Erosion and Sedimentation Control
   As prepared for the Water Resources Commission Under
   Act 347 P. A. 1972

FOR

Designation as an Authorized Agency State Highway Commission

2. Shore Protection Guidelines
   Department of the Army
   Corps of Engineers
   Washington, D. C.
3. Standards and Specifications for Soil Erosion and Sedimentation Control in Developing Areas
   U. S. Department of Agriculture Soil Conservation Service
4. Puerto Rico Highway Authority
   Standard Interim Specifications for Road and Bridge Construction 1971 Issue

C. Land Use Factors

Land use as it relates to ecological value, productivity and economic value should be a basic factor in the environmental evaluation of a highway project.

Valuable agricultural lands such as prime and unique farm lands are recognized as a diminishing resource and should be so identified and avoided if possible. Prime farmlands are those ,whose value derives from their general advantage as cropland due to soil and water conditions. Unique farmlands are those who derives from their particular advantages for growing specialty crops.

Efforts should be made to assure that these agricultural lands are not irreversibly converted to other uses unless other public interest overside the importance of preservation or otherwise outweigh the environmental benefits derived from their protection. These benefits stem from the capacity of such agricultural land to produce relatively more food with less erosion and with lower demand of fertilizer, energy and other resources. In addition, the preservation of agricultural land in general provides the benefits of open space, protection of scenery, wildlife habitat and in some cases controls on urban sprawl.

The United States Department of Agricultural as well as the United States Soil Conservation Service personnel should be consulted in order to obtain assistance in identifying these agricultural lands before the preparation of the environmental impact statement. Reference should be made to paragraph 101(b) (4) of the National Environmental Policy Act as interpreted by the Council of Environmental Quality in their August 30, 1976 memorandum.

Wetlands constitute a land use category which require a great deal of careful consideration by the designer in order to avoid major negative environmental impacts.

Marshes (fresh, salt and estuarine), swamps and bogs are all wetlands which are valued for ground water recharge basins, wildlife refuges and open space. These areas are recognized as producing high quantities of food basic to the ecological "food chain" as well as being the headwaters of many watersheds. Due to their low human occupancy, they are often regarded as logical areas for highway development. However, they are rated high on the environmental scale and should be competely avoided wherever possible.

Other detrimental effects on wetlands and water impoundments are discussed under Water Factors.

The social use of land is directly related to its environmental value. Therefore, land with a potential for needed open space or recreation must be considered in relation to the highway project impacts.

The designer should obtain copies of local "master plans", and use them together with expertise of local planning boards in order to evaluate project alternates with regard to long range planning.

Woodland areas may have more than commercial timber value. With increasing demand for convenient recreation areas, the designer should consider multiple use values of woodlands as well as the aesthetic impact of the project on such areas. The designer should consult the Department of Natural Resources and also be familiar with the Master Plan for the Commonwealth Forests of Puerto Rico.

The construction demands for selected granular material and other earth fill often requires large volumes of borrow, which in turn can result in the alteration of sizeable acreages of valuable land. In such instances, the environmental impact of a highway can extend far beyond the limiting right of way. The designer must therefore consider the economic as well as the physical environmental aspects of such an action with regard to long-term impact on a non-renewable natural resource.

In instances where the designer must encroach on areas of high environmental value, conservation techniques designed to ameliorate the environmental impact should be sought from the appropriate local agencies.

Borrow pits and waste areas often contribute to a major impact in the environment. While it is usually impossible for the designer to know where the contractor will establish these areas, he should participate in the review of plans submitted by the contractor during the construction. Such controls should be covered in the environmental commitments of the environmental evaluation. At the time of review, the designer should contact the local municipalities to make certain that the Department's recommendations do not conflict with local ordinance or solid waste managements plans.

On ocassion, borrow or spoil areas may be within the construction limits. In these cases, the designer should carry out the detailed design as part of the prime contract.

In some cases, the preservation of a unique natural area or cultural site may be carried out through the use of minor adjustments in line and grade. Where geometrics permit, such a design change may prove to be both an economic and environmentally sound approach to the problem.

D. Wildlife Factors

The continuing reduction of the habitat of many froms of wildlife is reflected in the public concern for a highway environmental impact. This impact can range from the obstruction of the trout spawning movement through a culvert to small ground water table changes which can contribute to major ecological impact on large wetland areas.

An inspection to the area within a project site will be done in an earlier stage of the preparation of the environmental evaluation. This inspection will be done by the Environmental Studies Office in coordination with the Department of Natural Resources. This measure is undertaken in order to avoid, as much as possible, the negative effect of a highway corridor upon endangered flora and/or fauna.

In the event that the highway corridor cannot avoid the area where the endangered flora and/or fauna is located, the designer will coordinate with the Department of Natural Resources personnel in order to use appropiate abatement measures to prevent negative impacts upon this area.

On occasion, the designer will be faced with unique natural areas which because of unusual ecological conditions, support a rare plant or animal community. Such areas, upon expert evaluation, should be avoided for highway construction if at all possible.

In any evaluation of environmental impact on wildlife, the designer should make full use of the Department of Natural Resources personnel.

Special consideration must be given to the treatment of wetlands and water courses as wildlife areas. Stream channel alterations should be carefully considered to avoid the

destruction of fish habitats. The designer should consider the possibility of recreating situable fish habitats as part of a project involving stream relocation with assistance from the Department of Natural Resources.

In some cases, established wildlife territories and life patterns may require construction adaptations, such as modified culverts for fish spawning streams. Both aquatic and upland wildlife areas may require special considerations during design and in construction details. Full use of the consultation of professional wildlife management personnel will provide the designer with the criteria necessary to meet habitat requirements.

It should be kept in mind that some controlled access rural highways with wide right of way can be designed to provide wildlife habitats for the preservation of existing unusual or common species of plants and animals, providing their presence does not constitute a safety hazard to the traveling public.

Wildlife crossings are not considered in the design of highways in Puerto Rico. They are not necessary because wild animals such as rats mangoos, frogs and lizards, which are our common species do not require highway crossings. There is no way to control their pass across the road. Also, their presence will not affect the safety of the users.

Specialized publications, such as the Wildlife Habitat Improvement Handbook, Forest Service, U. S. Department of Agriculture, FSH 2609-11, 1969 or Fish Versus Culverts, Technical Report ETR-7700-5, Forest Service, U. S. Department of Agriculture, 1970 may be of aid to the designer.

In some cases, areas of excavation for borrow, after thorough investigation, might be developed as wetlands or wildlife ponds within the right of way.

E. Auditory Factors

Noise evaluation techniques and criteria as they apply to highway are still in the development stage.

As yet noise standards are tentative, (see FHPM 7-7-3) and additional research of the physiological effects of various types of noise is needed. (See Highway Noise, A Design Guide for Highway Engineers, C.G. Gordon, et. al., Highway Research Board Report 174, 1971).

The designer should make contact with the Noise Division under the Office of Environmental Studies in addition to any specialized information in order to acquire the most recent guidelines and applicable controls.

The following are considered noise abatement measures: barriers, heavy vegetation, regulation of truck traffic and the modification of highway horizontal and vertical alignments. In many cases, vegetation has been psychologically successful, but has failed as a physical noise abatement measure. There are highways that have a considerable amount of sensitive receptors along them and also have a large volume of truck traffic using them. In those cases, one attenuation measure could be the restriction of truck traffic along the highway during certain hours of the day.

Barriers include earth berms, walls, hills, etc. They affect sound propagation and creates an "acoustic shadow tone". Barriers have been constructed of a variety of materials and in three basic shapes: earth berms, free-standing walls, and combination berm-walls. Evaluation of these barriers has pointed out several crucial features of noise barriers.

1) The transmitted noise must be 10 dB less than the diffracted noise.
2) The barriers cannot have cracks in them.
3) The barriers must be high enough to break the line-of-sight between the observer and source and long enough to prevent noise leaks around the ends.

The use of depressed sections, berms and other physical barriers should be considered in heavily populated areas. However, the designer shall remember that the alignment and grade of a highway is an important factor to be considered to avoid air pollution.

In general, noise control must be considered from both the viewpoint of the adjacent property owner and the motorist. Noise levels will be of prime design consideration in the areas involving hospital, schools and residential areas.

Other publications which will aid the designer in projecting potential noise levels within the adjacent environment include:

1. Fundamentals and abatement of Highway Traffic Noise
   Report No. FHWA-HH-HEV-73-7976-1
   U. S. Department of Transportation
   Federal Highway Administration
   National Highway Institute
2. Effect of Highway Landscape
   Development on Nearby Property,
   John H. Brinton, et. al, Highway
   Research Board Report
   No. 75, 1969
3. Highway Noise, Measurement, Simulation
   and Mixed Recreations, William J. Galloway,
   et. al., Highway Research Board Report
   No. 78, 1969
4. FHWA-PD-7658
   Noise Barrier Design Hand Book
   U. S. Departament of Trnasportation
   Federal Highway Administration

In general, while techniques for predicting noise levels and evaluating existing noise abatement barriers are being developed, the designer will find little with regard to the best methods of noise abatement. The designer should use noise abatement techniques such as changes in horizontal and vertical alignment; acquisition of additional right of way or modified grading to try to avoid increasing existing community sound levels rather than attempting to correct it by barriers after basic design is set.

In addition to Highway Noise, a Design Guide for Highway Engineers, (HRB Report No. 117), the designer should consult other Noise Assessment Guidelines, for details on approaches to highway noise analysis. In developing a noise report it is necessary to obtain actual meter readings of existing noise levels.

The designer without background in acoustical engineering will find an excellent basic introduction in Fundamentals and Abatement of Highway Traffic Noise, Bolt Beranek and Newman, Inc.

F. Visual Factors

The aesthetic quality of the finished highway is discussed or refered to in various places in the Design Manual. However, it should be noted that the visual portions of the highway as well as the offscape views always constitute an environmental impact. Careful consideration of these factors during the environmental impact investigation will prevent the necessity of expensive and sometimes ineffective "cosmetic" treatments in the later development phases.

The highway is viewed both from the adjacent property as well as from the highway itself. Because of this fact, the designer must consider, from both viewpoints, such diverse elements as; the general land forms created by the construction, structures, vegetation, roadside views, street furniture and other appurtenances.

Special consideration should be given to highway directional signs. While such signs are a necessary adjunct to the highway and are tightly controlled by standards, they should not be permitted to create visual "clutter", which can, in itself, be a safety hazard.

G. **Construction Factors to Consider During Design**

Temporary environmental effects are significant in some cases. The designer should fully evaluate the effects that construction activities will have on maintenance and protection of traffic, local fire, police, utility services, water, noise and air pollution, etc.; and to prepare plans and specifications that will minimize disruption.

17–03.02 SOCIAL ENVIRONMENTAL FACTORS

In addition to the relatively easily identifiable physical environmental factors, the designer must also take into consideration the impact of the proposed highway on the social environment which may be changed or modified by the project.

Regional and community growth characteristics as reflected by planning projections, must be evaluated.

The effect of the project on the following shall be taken into consideration: public facilities and services, including community protection and emergency services as well as health, education and religious facilities.

Each community possess specific characteristics involving life patterns and economic activity. The designer must consider the effect of the project on these characteristics. The impact of the highway on property values, economic activity and displacement of businesses and people are an integral part of the environmental evaluation. (See FHPM 7-7-5)

In addition to the social environmental effects noted above, the development of cultural resources, recreational facilities and open space are prime areas of concern to the designer and are discussed in detail as follows:

A. **Cultural Factors**

Culture, for the purpose of this Chapter, is defined as any physical developments, remains or identifiable sites associated with a particular period of man's social or material development.

It includes historic buildings, structures, landmarks and archeological sites. Paleontological and geological sites must also be considered.

Even though there is no legislation in Puerto Rico for protecting land marks, consultation will be made to the Institute of Puerto Rican Culture by the office of Environmental Studies during the preparation of an environmental document. This measure is undertaken in order to preverve such sites. Actually there is one site in Puerto Rico on the National Registry of National Landmarks but there are 26 potential sites.

In order to preserve or salvage segments of our cultural environment, it is necessary to identify and evaluate areas or sites of prehistoric or historic importance at an early stage of the environmental study.

Information related with cultural background, archeological findings and any activity related with our history and culture are carried through the Institute of Puerto Rican Culture (State Historic Preservation Officer). The Institute should be consulted in the early stages of the environmental investigation and design in order to avoid damages on historical or archeological places. If any non registered archological findings appear in any stage of construction, the Institute should be notified. A note on this effect should be included to the contract documents of the project.

A number of localities, within the past few years, have collected, and in some cases, published information on surviving examples of buildings having architectural or historic merit.

In many cases, the Institute of Puerto Rican Culture can advise the designer if such publications or manuscripts are available for the area under study.

Examination of the National Register of Historic Places should be carried out at an early stage of the environmental investigation. The National Register is constantly being enlarged by addition of new entries. Historic places are frequently added after the processing of the Draft Environmental Impact Statement. The advisory Council procedures require FHWA and the State Historic Preservation Officer to apply the National Register Criteria to all possible historic sites within the project's area of potential environment impact, at the earliest stage of planning or consideration of the proposed undertaking; therefore potential entries should have been recognized before the preparation of the draft Environmental Impact Statement.

If the Department of Transportation and Public Works before the preparation of an Environmental Impact Statement determines that it is questionable whether a property meets the Nation Register criteria, FHWA shall request, in writing, an opinion from the Secretary of the Interior, Attention: The Keeper of the National Register, National Park Service Washington D. C. 20240, with respect to the property's eligibility for the inclusion in the National Register.

If during construction an archological finding appears the designer might consider a slight modification of alignment which would leave the historical site outside of the construction limits, thus preserving the site. In instances where the designer cannot avoid such a site by adjusting the alignment or grade, special efforts should be made to reduce the highway impact.

While a highway may physically bypass areas of high cultural value, the proximity of the project may still require design modifications due to visual or sound problems. The use of "buffers" consisting of natural barriers or the establishment of artificial berms or structures may be considered as part of the design.

In some cases, such a buffer may be created by modification of line and grade so as to form a barrier with an existing land form or other physical obstruction. Further guidelines relating to Historic Preservation may be found in FHPM 7-7-2.

B. **Recreational Factors**

The possible expansion or creation of new recreation areas is not a direct function of this Department. However, the environmental impact of the highway on existing recreational facilities is an important factor within the environmental investigation.

The publication, "Park and Recreational Facilities, Their Consideration as an Environmental Factor Influencing the Location and Design of a Highway", (U.S. Department of Transportation, Federal Highway Administration, Office of Environmental Policy, Environmental Development Division) in 1971, provides guidelines for inventory data required for objective evaluation, major classification of park types and suggested design criteria to be considered, including noise abatement control. This data imput is necessary, not only from the viewpoint of overall environmental evaluation, but also as part of the 4(f) review statement required when a highway project affects conservation land. These lands are further defined as "public parks, recreation areas, wildlife and waterfowl refuges and historic sites". (See FHPM 7-7-2). The purpose of the 4(f) Statement is to document the considerations and alternatives studied for the determination that there are no feasible and prudent alternatives to the use of such lands. It also includes all possible planning to minimize harm.

During the evaluation of the environmental impact on recreation lands, the designer should make full use of local and regional personnel of the Parks and Recreation Administration.

The signifance of "conservation lands", as defined above, must be evaluated by the agency responsible for the "conservation lands". Such significance must consider social needs for the activity provided, their general contribution to the needs of the community and their accessibility.

In cases where recreational areas cannot be avoided and a Section 4(f) review is required, the designer must developed detailed plans to minimize highway impact. This may involve a monetary settlement with the agency or governmental unit involved as well as the replacement of recreational facilities.

C. **Open Space Factors**

Open space, for the purpose of this Chapter, is defined as urban, suburban or rural lands which because of physical or economic factors have remained in an essentially undeveloped condition. The highway may have a positive or a negative impact on such low intensity land use areas. The designer should consider undeveloped open space as an opportunity to further the preservation of such lands rather than as a limiting design factor. The demand for future areas of open space is more difficult to evaluate without the aid of projections of such land use demands by local municipalities and regional planning agencies. The Puerto Rico Planning Board may aid in directing the designer to existing and projected land use studies. The designer should consider the preservation of such open space only with the cooperation of regional and local agencies able to provide advance planning data and guidelines.

In some cases, open space will be created through land severances. The designer should take advantage or these situations by the retention or acquisition of "land-locked" parcels if a desirable pattern of open space will result or if the land is suitable for appropriate landscape development.

CHAPTER 18

ROUTE AND PROJECT PLANNING

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GENERAL DESCRIPTION OF ROUTE AND PROJECT PLANNING

18—01 GENERAL

This chapter describes some steps of the organization to be utilized and the responsibilities assigned in regional studies (system planning), corridor studies, and route location.

18—02 REGIONAL STUDIES (System Planning)

System planning studies are carried out to develop long-range, area wide plans for overall transportation systems, all modes inclusive.

The System Planning Studies are: 1) the Urban Transportation Studies, 2) the Highway Classification and Needs Studies, 3) Small Urban Areas Studies.

These three documents constitute the factual highway master plan. All highway facilities must be analyzed and studied following the concepts and priority criteria under the applicable study. For example, if the project is located within a metropolitan boundary the respective urban transportation study is the principal planning guide and tool followed by the Highway Classification and Needs Study and possibly by any pertinent special project.

1. Urban Transportation Studies

The Metropolitan Planning Organization (MPO) is the organization designated by the Governor as being responsible for carrying out the provisions of section 134 of title 23 of US Code related to highway planning in urban areas of more than 50,000 population and capable of meeting the requirements of Section 1602, 1603 and 1604 of title 49 of US Code related to Urban Mass Transportation Planning.

The MPO is responsible for, but not limited to the following activities:

a. In cooperation with publicly owned operators of mass transportation services carry out the urban transportation planning process specified in paragraph 12 of Volume 4, Chapter 4, Section 2 of the Federal-Aid Highway Program Manual (FHPM).

b. Develop the prospectus and the UPWP.

c. Development of a transportation plan consisting of a Transportation System Management Element and a long-range element.

d. Review the Transportation Plan annually to confirm its validity and its consistency with current Transportation and Land Use conditions.

e. Development of a transportation improvement program including an annual element, as described in Volume 4, Chapter 4, Section 6 of the FHPM. This program must be consistent with the Transportation Plan developed under paragraph 10 of Volume 4, Chapter 4, Section 6 of the FHPM.

f. Coordinate the Urban Transportation Planning Process with all other related state and Federal Agencies.

g. Is the recipient of FHWA, UMTA and FAA planning funds.

h. Negotiate all contracts and agreements deemed necessary and convenient in order to achieve the plans and programs.

i. Enter into contracts with the A—95 clearinghouse agency, other state agencies and municipal authorities to carry out selected elements of the Planning Process.

The Transportation Planning Studies start with the setting of goals and objectives which include the economic, environmental and social aspects and transportation needs of communities or regions.

Travel, social, economic and environmental information is collected through personal interviews in the community under study and by using census or any other reliable source of information in collaboration with the Puerto Rico Planning Board, DTPW and other government agencies, civic organizations, institutions and public interest groups.

The analysis of this data serves as the basis for forecasts and plans for land use development from which the travel estimates are then made. To fit this future travel, alternative networks are developed, including all possible modes of transportation. Extensive social and economic analysis consultation is required leading to a selection of the recommended transportation plan. The recommended plan, then is presented to the citizens in informal meetings and citizens points of view and opinions are evaluated. The resulting plan then is endorsed by the MPO and adopted by the Planning Board that undertake public hearings before it is submitted to the Governor for approval. Projects for different modes will be entrusted by the Secretary of Transportation and Public Works to the pertinent government agency attached to the Department for implementation.

2. Highway Classification and Needs Study (H.C.N.S.)

This document constitutes the long-range Master Plan for all highways in Puerto Rico.

In general terms, highway needs studies are undertaken to determine the funds necessary to construct new roads and streets, to maintain and improve existing facilities, and to administer highway programs for several time periods into the future. It is an integral part of the planning-programming process.

To develop highway travel forecasts, close coordination is maintained with the Planning Board, Municipal Governments and the Urban Transportation Studies to obtain socio-economic, traffic and land use data which enables to estimate travel patterns that are in line with local and island-wide development policies.

The results of the study provide information about the deficiencies and needed improvements and costs of the functional highway system devised for the future. This provides, in conjuction with the needs indicators that aid in establishing priorities, for an orderly and sound planning program.

3. Small Urban Area Studies

In urban area communities with a population ranging from 5,000 to 50,000, system planning is accomplished in a detail commesurate to the level of importance and general development of the area.

These studies, resulting in the preparation of Urban Master Plans, are made by the Puerto Rico Planning Board following the current methodology and procedures for urban planning. An inventory is done of the existing physical, social, economic and environmental elements and a 20-year projection is made of the relevant elements — population, employment, land use, growth rate and transportation needs.

These documents are subject to review by the DTPW and other Commonwealth and Federal related agencies prior to and after public hearings before they are approved by the Governor after which they become the guide for the development of the infrastructure which are the legally binding regulations.

18—03 THE FIVE-YEAR PRIORITY CONSTRUCTION PROGRAM

Annually the Programming and Control Office of the Planning Area of the DTPW prepares an updated 5-year priority construction program.

Almost all of the individual projects selected to be included in the 5-year program are from the projected road network in the Master Plan as described before. The priority criteria for the

inclusion of projects in the 5-Year Program are: a) traffic needs, b) highway users costs, c) completion of circuits, d) service to important centers of activity, e) economic evaluation and, f) overall public interest which includes social and environmental considerations.

The 5-Year Program in brief, identifies each project, describes its length and location, indicates the estimated costs and origin of funding, indicates the estimated dates for the start and completion of the project and estimates the year by year investment.

After the 5-Year Program is approved by the Planning Board, the Secretary of the DTPW will authorize to proceed with the processing of the Program. At this stage the specific projects within the 5-Year Program are identified and scheduled for processing in the next step, the Corridor Location Stage.

18—04 CORRIDOR LOCATION

18.04—01 NATURE OF STUDIES

The Corridor Location Studies are generally undertaken during the Regional Studies (System Planning). When a corridor resulting from these studies becomes part of the Master Plan for Highway and/or an Urban Master Plan the corridor location phase is considered completed and projected processing continues to the next phase: route location. The recommended corridor does not represent a specific location, but only a variable width band through which the highway may be placed. For a project not evaluated under systems planning, the corridor location study will be the initial planning phase.

18.04—02 WORK DESCRIPTION

In executing the identification of the corridor, the Traffic Analysis Office has the responsibility to prepare the preliminary engineering of all the alternatives involved. To carry out this activity, a general reconnaissance of the terrain is made by means of topographic maps, geological maps, flood control maps, existing and proposed road networks, aerial photographs and previous road location studies in the area.

The limits of the strip of terrain to be studied is defined using the information obtained during the reconnaissance and evident environmental issues that are identified. A field data collection program is referred for execution to the Data Collection Office. This program may include mechanical traffic volume counts, turning movement counts at intersections, vehicle classification counts, and origin and destination surveys.

Simultaneously with the field traffic data collection, the social, economic and environmental appraisal studies are undertaken. To prepare these studies it is necessary to make direct contact with pertinent State and Federal Agencies to gather the necessary information. This is done by personal interviews, letters and telephone calls.

Throughout the duration of the location studies stage there is continous feedback information between the studies team and interested persons and parties and the public in general. This is done through the personal interviews during the studies and more formally through the Citizens Committee which will be organized to permit interaction with the study team and the Technical and Policy Committees.

18.04—03 WORK ASSIGNMENT

The principal work load and compliance with FHPM-7-7-1 requirements in E.S.E. corridor location studies are assigned in the following manner:

The preliminary engineering, socio-economic and environmental studies are assigned to the Traffic Analysis Office and the Multidisciplinary Team. Once the preliminary engineering

studies are undertaken and corridor alternatives selected, the Multidisciplinary Team in a series of meetings will evaluate their socio-economic and environmental effects.

Once the corridor has been identified, selected, and included in the 5—Year Program, the FHWA processing starts.

18.05 ROUTE LOCATION STUDIES

18.05-01 ALTERNATE ROUTES SELECTION

After the corridor has been finally selected by the Puerto Rico Highway Authority, and approved by FHWA, the Design Area starts route location and selection studies.

The following information is made available by the Planning Area to the Design Area for the selection of the alternate routes to be studied, including a no-build alternative.

1. Limitations derived from socio-economic and environmental studies.
2. Recommendations of local, state and federal agencies.
3. Recommendations of the citizenship.
4. Limitations imposed by the topography and the geology of the area.

Limitations imposed by the ROW compelling considerations will also be submitted by the ROW Area to the Design Area.

The selection of the alternate routes is made jointly by the Design Area and the Interdisciplinary Team, composed of a group of specialized technicians of different disciplines such as: engineering, planning, geology, biology, sociology, economics and environmental sciences.

18.05—02 ADVANCE PRELIMINARY ENGINEERING ON ALTERNATE ROUTES

A traffic analysis is made from the information submitted by the Data Collection Office. Computerized techniques are used in some stages of this analysis. Programs as "Origin--Destination Survey" and "Speed and Delay" are commonly used. Based on this analysis, estimates are made of the existing current and future traffic.

1. The highway typical cross section is selected based on the traffic capacity analysis.
2. A horizontal alignment is established, considering intersection with existing and projected highways.

   The necessary data for selected cross section is obtained using U.S. Geological Survey Maps.
3. At this stage, with the cross sections data, a profile of the terrain is produced and the vertical alignment is established. A rough design of the alternates is made using the computer facilities. The Roadway Analysis and Design System (ROADS) and Coordinate Geometry (COGO) subsystems of the Integrated Civil Engineering System (ICES) program are used to obtain the earthwork, slope, stake, etc., for the typical road cross section and alignment.
4. Vertical and horizontal alignment of the different alternates are used for the performance of related studies, such as: soil studies, hydrological studies, and the preliminary design of required structures.
5. Vertical and horizontal alignment of the different alternates are sent to the Property Acquisition and Administration Area for the determination of the right of way costs.
6. Cost and time estimates of the design and construction phases of each one of the alternates are determined.

Where applicable, the rough design of each alternate is submitted to the U. S. Coast Guard, and the U. S. Corps of Engineers.

A rough draft of each alternate including the estimated time and cost of design and construction is submitted to the Economic and Statistical Research Office and to the O. E. S. for more detailed socio-economic and environmental evaluations.

18.05—03 SOCIO-ECONOMIC AND ENVIRONMENTAL STUDIES

1. Socio-Economic Studies

A through review and updating is done of the socio-economic elements considered and studied during the corridor location studies, as presumably impacted by each of the alternatives including the no-build.

2. Environmental Studies

A detailed analysis is made of the impact of each alternative on the following factors: noise impact, air pollution, water pollution, wildlife and vegetation, solid waste disposition, historic or archeological sites and visual and aesthetic impact.

18.05—04 ALTERNATE ROUTES EVALUATION

After having considered the engineering, socio-economic, environmental factors and the recommendations of the Coast Guard and Corps of Engineers (where required), the Design Area jointly with the Multidisciplinary Team evaluates the different alternatives (including the no-build) to insure that the E.S.E. factors are throughly considered and weighted.

The comparison base of this evaluation is the no-build alternative against which all other alternatives will be compared to determine the environmental and socio-economic impact of each alternate route.

18.05—05 ALTERNATE ROUTES STUDY REPORT

After the evaluation of each alternative, including the no-build, and considering the engineering, social, economic and environmental studies, the alternate Routes Report is prepared.

This report will address the following items:

1. General description of the area—includes land use pattern, location, tax bases, etc.
2. Geology and hidrology—includes general information about the characteristic composition and hidrological features of the area affected by the alternatives.
3. Soils—includes an evaluation of the soils affected by the alternatives, its use and its adequacy for foundations throughout the length of the proposed lines.
4. Existing roads in the area—includes general information about the roads to be substituted by the alternatives, and on the roads affected by it.
5. Traffic capability studies of the proposed routes—the determination of the traffic carrying ability of a roadway, which is influenced by its width, lateral obstructions, grades, percentage of trucks and buses, sight distance, service volume and capacity rates and required level of service.
6. Design—includes the criteria for the design of this primary facility and its appurtenances base on the latest standards, findings, recommendations and specifications.
7. Aesthetics—discusses the aspect of integrating the highway to be constructed with the environment.

8. Description of preliminary routes—it discusses the preliminary investigations, the adaptation and combinations of portions of plans and profiles of different alternates from which the final alternates are selected. All must satisfy the basic requirements of the geometric design criteria established for the project.

9. Unit prices—presents the unit prices which are to be basis for the development of the cost estimates.

10. Construction cost estimates of recommended route—comparative cost estimates of the recommended lines.

11. Road user benefit analysis—it includes the quantifiable benefits to the road users, such as: reduced vehicle operating costs, savings in time, increased comfort and convenience and most important reduction of overall accident rates.

    To arrive at the computed benefit ratios, use is made of the existing facility as the "comparison base". A second benefit ratio analysis is made, where the different alternatives are compared to the recommended line.

12. Impact of improvement on the economy of the area—includes an analysis of the effects of the new facility to individuals and to the economic development of the area.

13. Impact of improvement on the environment—includes an analysis of the effects of the new facility to the community, to vegetation, water bodies, littoral view, fish, wildlife refuges, etc.

14. Availability of construction materials—includes information about the necessary materials for the construction of the facility, its abundance and its nearness to the construction site.

15. Bibliography

To allow for public participation and to keep the affected citizenry posted on the development of the project, a copy of the Alternate Routes Study Report will be sent to the president of the Citizens Committee, and to all interested members, who should provoke a special meeting to discuss the contents of the report and submit their comments and recommendations heretofore. Representatives of the O.E.S. Multidisciplinary Team and Design Area should attend this meeting.

18.05-06 ROUTE SELECTION

It is conducted after the following:

a) Draft Environmental Impact Statement
b) Public Hearing

After the Multidisciplinary Team selects a route, a final EIS or a Negative Declaration is prepared for the recommended alternative. Final approval to the EIS by the FHWA constitutes the location approval of the project.

CHAPTER 19

PLANS, SPECIFICATIONS AND ESTIMATES

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CHAPTER 19

PLANS, SPECIFICATIONS AND ESTIMATES

19—01 INTRODUCTION

The highway construction plans, specifications and estimate (P.S. & E.) include all the necessary design information and details to construct a proposed project. They are to be prepared in such a manner that they can be clearly interpreted by the engineers, technicians and contractors responsible for the project construction. The plans should be carefully checked for errors and omissions which may lead to misunderstandings or misinterpretations and which in turn, may result in faulty construction and/or claims against the Highway Authority.

The right-of-way plans provide necessary information and details on the properties to be acquired by the Highway Authority so that the construction of the project may be undertaken.

This chapter includes instructions on the preparation of construction plans, right-of-way plans, specifications, estimates and the contract book.

19—02 CONSTRUCTION PLANS

The construction plans are the end result of the design process which show the location, character and dimensions of the work to be performed under the project, either by contract or force account. Construction plans include working drawings which are supplemental design sheets that a contractor is required to submit such as shop drawings, erection plans, falsework plans, framework plans, cofferdam plans, etc. However, details on the preparation of working drawings are not included in these instructions.

19—02.01 GENERAL

The final tracings of the construction plans shall be on tracing cloth, mylar or approved equal material. All drafting should be in black ink. Pencil work, although not encouraged, will be accepted provided high quality draftmanship and good uniform density of lines is attained, and provided that the final drawing is transferred to a reproducible mylar sheet in order to have a more permanent tracing. Pencil and ink in combination on the same sheet is not acceptable. The Title Sheet must be fully drafted in ink. Mylar film shall be no less than 0.003" in thickness and be matte on both sides.

The use of pressure sensitive appliques for shading, symbols, lettering, titles, standard notes, etc., and the use of typewriting (Pica or Vari Type), preferably capital letters, are also allowed provided the final drawing is transferred to a reproducible mylar. Appliques should be of the heat resistant type to prevent slipping in the reproducing process and must be applied to the face of the plan sheet to insure full reproduction.

Plans must be drafted to insure good legibility when reduced by photographic process (Xerox or otherwise) for half-size prints and when microfilmed for permanent recording. Emphasis is given to proper density of line work, adequate lettering size and proper arrangement of notes, dimensions, etc. Minimum height of lettering will be 1/8 inch or No. 120 in the standard template but may be 3/32 inch or No. 100 template if capital letters are used. Minimum pen size will be No. 0. Running dimension lines, note arrows, etc. through notes or figures must be avoided.

Figure 19—A shows the standard plan sheet of the Highway Authority. All plan tracings will be 36" wide by 22" high. Border lines will be placed on all sheets so as to provide a 2 inch margin at the left edge and 1/2 inch margin on each of the remaining three edges.

Each sheet will have a project identification block in the upper right hand corner. This block is illustrated on Figure 19—A. The Federal-aid project number will be left blank until it is furnished by the Design Area. The A.C. Project Code No., Municipality, Highway No. and Fiscal Year will be available prior to the final design stage. The Island space will always be P.R. The Sheet No. and Total Sheets are discussed under Section 19—02.04.

Each sheet, except the Title Sheet, will also have a title block along the bottom border. This is illustrated on Figure 19—A. The following remarks apply to this title block:

1. Agency and Design Unit Identification — this will always show Puerto Rico Highway Authority on the top line. For in-house designs it will show Design Area on the second line and either Highway Design Office or Structural Design Office on the bottom line. For designs prepared by consultants, the consulting firm will be identified on the second line below Puerto Rico Highway Authority.

2. Project Title and Location — this will normally be the highway number and the beginning and end station for the project. In many instances, such as an urban route, bridge, interchange or municipal road, the project will also have a name identification.

3. Revisions — the date and a very concise summary of the revision made will be shown. It should be noted that this refers to revisions made to plans subsequent to approval by the Executive Director. Revisions made during the development of the construction plans are a part of the design process and need not be documented in the final construction plans.

4. Scale — the scale or scales of the information shown on each plan sheet will be indicated. Where drawings at various scales are included on the same sheet then "As Shown" will be entered in this block and the applicable scale shown under each drawing. In addition to the numerical scale, all plan sheets will carry a graphic scale for use on reduced size plans. This graphic scale should be included in this scale portion of the title block or under the numerical scale where more than one scale is used on a plan sheet.

5. Sheet Title — the information depicted in the plan sheet will be identified as for example: Typical Section; Plan and Profile, Sta._____to Sta._____; Drainage Plan; Structure at Sta._____; Abutments; Cross Sections, etc.

6. Sheet Group and Number — this is discussed under Section 19—02.04.

Certain plan sheets require blocks to document other agency approvals such as lighting and utility relocations. These are discussed subsequently in this chapter under the discussion of the respective plan sheets.

19—02.02 STANDARD SYMBOLS AND ABBREVIATIONS

Figure 19—B illustrates the more common standard symbols to be used on large scale plans (1:2000 or larger scale). On small scale drawings such as the location map on the title sheet, standard mapping symbols should be used.

Table 19—1 includes abbreviations for common terms used on highway plans. For terms not included in this table, accepted standard abbreviations may be used.

Standard symbols and abbreviations for specialized items found in lighting designs, subsurface explorations and utility work are included in Chapters 10, 12 and 13 respectively.

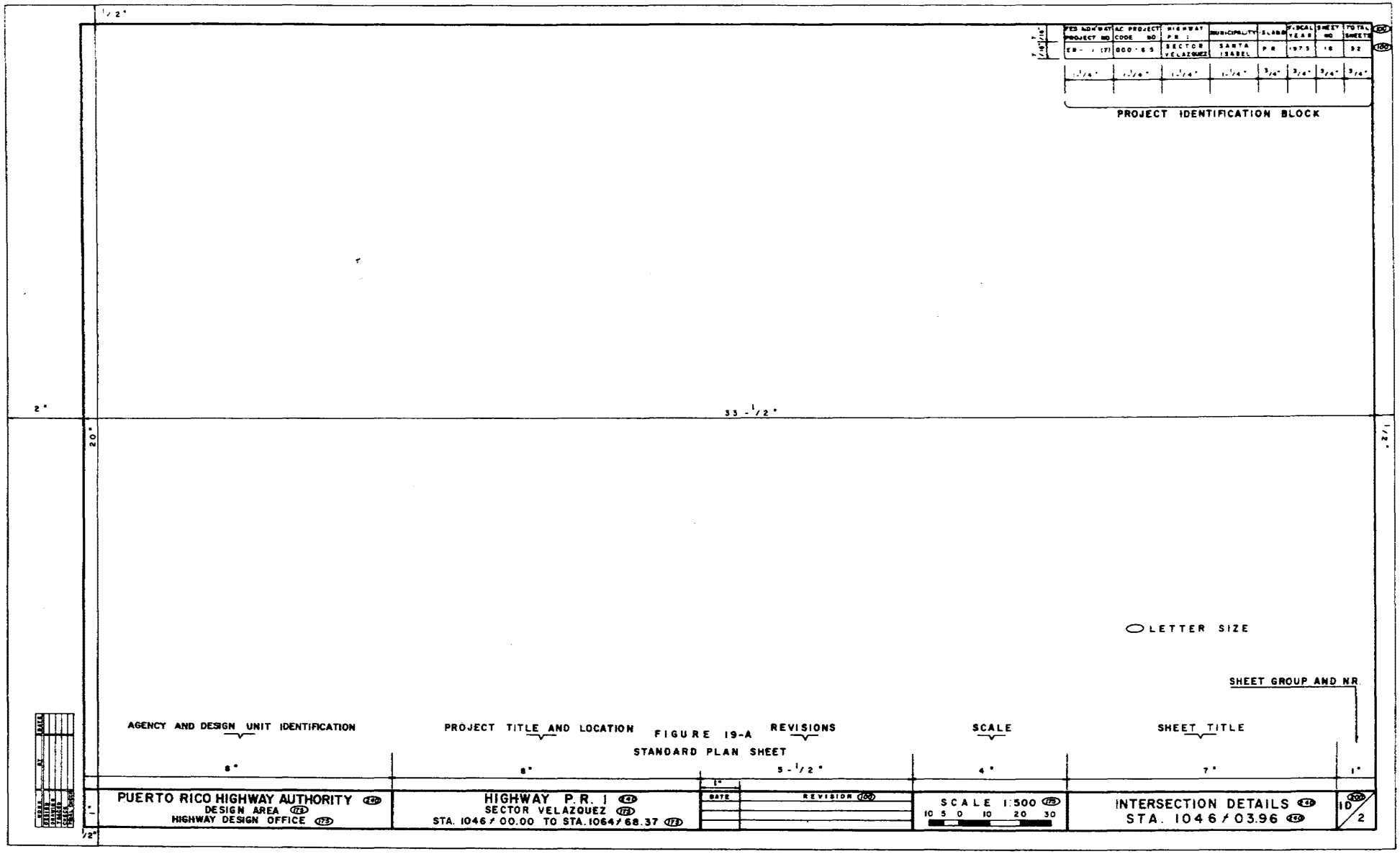


FIGURE 19-A
STANDARD PLAN SHEET

TABLE 19–1

ABBREVIATIONS

ABUT.	Abutment
AGG.	Aggregate
AH.	Ahead
AL.	Aluminum
ASB.	Asbestos
ASPH.	Asphalt
BK.	Back
B.L.	Base Line
B.W.F.	Barbed Wire Fence
B.V.	Bearing Value
B & S	Bell and Spigot
B.M.	Bench Mark
BIT. CONC.	Bituminous Concrete
B.C.C.M.P.	Bituminous Coated Corrugated Metal Pipe
BLDG.	Building
C.I.	Cast Iron
C.I.P.	Cast Iron Pipe
C.B.	Catch Basin
C.L.	Center Line
C. TO C.	Center To Center
CTD.	Coated
COL.	Column
COM.	Communications
CONC.	Concrete
C.O.A.	Control Of Access
COORD.	Coordinates
C.M.	Corrugated Metal
C.M.P.	Corrugated Metal Pipe
CU.M.	Cubic Meter
CULV.	Culvert
CS	Curve to Spiral
C.	Cut
DEG.	Degree
DIA.	Diameter
DIM.	Dimension
DWG.	Drawing
DWY.	Driveway
ELEV.	Elevation
E. TO E.	End To End
ENGR.	Engineer
EST.	Estimate
Exc.	Excavation
EXIST.	Existing
E.G.	Existing Ground
EXP.	Expansion
EXT.	External
E	External Distance
E.H.W.	Extreme High Water
F. To F.	Face To Face
FA	Federal Aid
FAP	Federal Aid Primary
FAS	Federal Aid Secondary
F.	Fill
F.L.	Flow Line
FWD.	Forward
G.I.	Galvanized Iron
G.	Gas
G.V.	Gas Valve
GRAV.	Gravel
GRD.	Ground
H.W.	High Water
HOR.	Horizontal
HYD.	Hydrant
INV.	Invert
I.E.	Invert Elevation
J.B.	Junction Box
LT.	Left
L	Length of Curve
L.P.	Light Pole
M.B.	Mail Box
M.L.	Main Line
M.H.	Manhole
MAX.	Maximun
M.H.W.	Mean High Water
M.S.L.	Mean Sea Level
MIN.	Minimun
MON.	Monument
O.C.	On Centers
O.D.	Outside Diameter
O. TO O.	Outside To Outside
PVMT.	Pavement
PCC	Point of Compound Curvature
PC	Point of Curvature
PI	Point of Intersection
PRC	Point of Reverse Curve
PT	Point of Tangency
P.C.C.	Portland Cement Concrete
PWR.	Power
P.P.	Power Pole
P.L.	Property Line
PROP.	Proposed
P.G.	Proposed Grade
P.V.I.	Point of Vertical Intersection
R	Radius of Curvature
RR.	Railroad
R.C.P.	Reinforced Concrete Pipe

RET.	Retaining
RT.	Right
R.O.W.	Right Of Way
RD.	Road
RDWAY.	Roadway
SAN.S	Sanitary Sewer
S.M.H.	Sanitary Sewer Manhole
SHDR.	Shoulder
SW.	Sidewalk
SC	Spiral to Curve
ST	Spiral to Tangent
SQ.M.	Square Meter
STA.	Station
S.S.	Storm Sewer
STR.	Structure
S.G.	Subgrade
S.L.	Survey Line
T	Tangent Distance of Curve
TS	Tangent to Spiral
TEL	Telephone
T.P.	Telephone Pole
T.E.	Top Elevation
T.G.	Top of Grate
UG.	Underground
V.C.	Vertical Curve
VERT.	Vertical
W.M.	Water Main
W.MTR.	Water Meter
W.V.	Water Valve
W.W.	Wing Wall
W.M.F.	Wire Mesh Fence
W.I.	Wrought Iron

19—02.03 ORDER OF PLAN SHEETS

In order to obtain uniformity of presentation, the completed construction plan sheets shall be assembled in the following order:

1— Title Sheet
2— Index Sheet
3— General Notes and Legend
4— Typical Sections
5— Summary of Quantities
6— Table of Structures
7— Construction Schedule and Maintenance of Traffic
8— Index Plan
9— Miscellaneous Tables
10— Roadway Soil Survey and Special Construction Details
11— Plan and Profile
12— Details of Intersections and Interchanges
13— Drainage Plans
14— Pipe Culverts and Miscellaneous Drainage Details
15— Miscellaneous Construction Details
16— Utility Plans

17 Lighting Plans
18 Signining, Pavement Markings and Signals
19 Landscaping and Roadside development
20 Structures

a. Bridges
b. Culverts (other than pipes)
c. Retaining Walls (other than standard)

21 Standard Models
22 Cross Sections
23 Mass Diagram

Many projects will, of course, not require all of the above plan sheets. In addition, on the smaller projects some of the listed drawings may be combined provided the basic sequence is maintained. For example, for most projects, the schedule of drawings included in the title sheet will provide an adequate index. Similarly, on small projects the general notes and legend may be placed in the typical section sheets and the summary of quantities and table of structures may fit in one sheet.

Plan and profiles for each road section should be on the same sheet whenever possible but in many instances it will be necessary to place the plan and profile on separate sheets in order to maintain the required scale and clarity of details.

The basic principle is to make efficient use of the plan sheet drawing space without cluttering the sheets to maintain the total number of sheets in the construction plans set at a reasonable minimum.

Since on complex projects various construction items are shown on separate sheets, such as utility relocations and lighting, a careful check should be made of the final construction plans to insure that no conflicts will arise even though this should have been previously taken care of during the design process.

19–02.04 NUMBERING OF PLAN SHEETS

The project identification block on the upper right hand corner of each plan sheet provides space to indicate the sheet number and the total sheets in the construction plans set. The sheets are to be numbered consecutively when the final tracings are assembled. The assignment and inking of these numbers, and entering them in the schedule of drawings or index, should be held until the review of the tracings has been completed and they are ready for submission to the Director of the Design Area. The use of sheet numbers with a suffix letter caused by last minute additions of plan sheets should be avoided. Similarly, omission of sheet numbers should be avoided but, if necessary, then the index should identify the plan sheet numbers omitted. The total sheets number must reflect the true total of plan sheets in the set.

During the design process it is customary to assign interim plan sheet numbers but these should be entered in pencil until the final number is assigned.

Since the design of the various categories of work in the project and the final tracings may be developed by separate sections and specialists, the title block provides for a separate numbering system for these plan sheet categories. This numbering system provides a letter prefix to identify the category and a number to identify the sheet within each group. This number is entered in the space provided at the lower right corner of the sheet in the title block. The following is a listing of the letter prefix for the various categories normally used:

GR – includes the general information sheets such as the index sheet, general notes and legend, typical sections, summary of quantities, table of structures, construction schedule and maintenance of traffic, index plan, and miscellaneous tables.

STANDARD SYMBOLS

FEATURE	SYMBOL		REMARKS
	PROPOSED	EXISTING	
CENTER LINE			IDENTIFY
SURVEY MONUMENT			IDENTIFY
SPOT ELEVATION		134.25	DECIMAL POINT AT SPOT ELEV.
BENCH MARK		B.M. № 3	IDENTIFY
HORIZONTAL P. I.		V-3	IDENTIFY
NORTH ARROW			TRUE
NORTH ARROW			MAGNETIC
CONTOUR LINES	90	90	
PAVEMENT			IDENTIFY ROAD
SIDEWALK	SW	SW	IDENTIFY
CURB			IDENTIFY
GUARD RAIL			IDENTIFY TYPE
BARRIER			IDENTIFY TYPE
BARRICADE			IDENTIFY
RETAINING WALL			IDENTIFY TYPE
CONC. PARAPETS			
FENCE (a)			IDENTIFY TYPE
PROPERTY LINE (a)		PL	
R.O.W LINE & MON. (a)			IDENTIFY IF C.O.A.
ACCESS CONTROL			IDENTIFY LIMITS
TOP OF CUT	T.O.C.	T.O.C.	
TOE OF SLOPE	T.O.S.	T.O.S.	

(a) WHEN MORE THAN ONE (1) LINE COINCIDE, THEY SHOULD BE IDENTIFY AS APPLICABLE.

FIGURE 19-B (1)

STANDARD SYMBOLS

FEATURE	SYMBOL		REMARKS
	PROPOSED	EXISTING	
PIPES			IDENTIFY SIZE TYPE & FLOW
HEADWALLS	or or	or or	AS PER TYPE
MANHOLE			IDENTIFY
INLETS			IDENTIFY AS PER TYPE
WATER COURSE			IDENTIFY
DITCH			
PAVED DITCH			IDENTIFY
LAKE OR POND			IDENTIFY
SWAMP			IDENTIFY IF REQ.
WOODS		W	IDENTIFY IF REQ.
TREES			IDENTIFY IF REQ.
EDGE OF WOODS			IDENTIFY IF REQ.
HEDGE			IDENTIFY IF REQ.
RIP RAP			IDENTIFY
RIP RAP PAVING			IDENTIFY
ROCK			IDENTIFY
BUILDING			IDENTIFY TYPE, ETC
FOUNDATION			IDENTIFY
BLDG. TO DEMOLISH		dem	IDENTIFY
SIGNS, GROUND, MTD.			
SIGNS OVERHEAD			
PROP. SIGN IDENT.	2 10		UPPER - CODE LOWER - LOCATION

FIGURE 19-B (2)

SS — Soil survey and special construction details.
PP — Plan and profile sheets.
ID — Details of intersection and interchanges.
DR — Drainage plans including pipe culverts and other drainage details.
MCD— Miscellaneous construction details.
UT — Utility plans.
LT — Highway lighting plans.
TS — Signing, pavement marking and traffic signals.
RD — Landscaping and roadside development.
BR — Bridge plans. If there is more than one bridge size structure in the project, each bridge may be separately identified in the prefix; e.g., BR—1, BR—2, etc.
CV — Culvert size structures, other than pipes. As in the case of bridges, each such structure may be separately identified in the prefix.
RW — Retaining walls.
CS — Cross sections.
MD — Mass diagram.

19—02.05 TITLE SHEET

The format of the title sheet is illustrated on Figure 19—C. It will include the information described below. The numbers refer to the location numbers shown on Figure 19—C.

1. Schedule of Drawings — on small projects the index of plan sheets is shown here. On large complex projects with a considerable number of plans and construction details a separate index sheet is provided. In the latter cases indicate: "See Sheet No. 2 for Index of Plan Sheets".

2. Standard Note — include in all projects the following note: "All work on this project shall be performed and all materials shall be in strict accordance with the Interim Standard Specifications and General Provisions approved by the Puerto Rico Highway Authority on August 6, 1971 and subsequent amendments in effect at the time of bidding, with these plans and with all special provisions and instructions included in the Contract Book".

3. Site location Map — a small scale of Puerto Rico showing the general location of the project site.

4. Design Designation — show as follows:

Control of Access	=	(Full, partial or none)
ADT 19_____	=	(Average daily traffic-current)
ADT 19_____	=	(ADT — design year)
DHV	=	(Design hourly volume)
D	=	(Directional distribution)
T	=	(Percent trucks in DHV)
V	=	(Design speed)

5. Project Location Map — for rural projects, a 1:20,000 scale map covering sufficient area to show the complete project and its relation to roads, urban areas, rivers, creeks and other important features within its vicinity. This map may be traced from the 1:20,000 USGS quadrangles for Puerto Rico. For urban projects, a larger scale map should be used to show the adjacent street system and other important features. The project should be identified by a heavy line and the following information shown:

a— Stations of beginning and end of project and limits of work.
b— Any equations in the stationing.
c— Location and stations of all bridge size structures.
d— On Federal-aid projects, the FA project number and that of any adjacent FA projects.
e— Numbers of all numbered routes.
f— North arrow and scale.

PES HIGHWAY PROJECT NO.	A.C. PROJECT CODE NO.	HIGHWAY P.R.	SHEET NO.	FISCAL YEAR	SHEET NO.	TOTAL SHEETS

(1)

SCHEDULE OF DRAWINGS

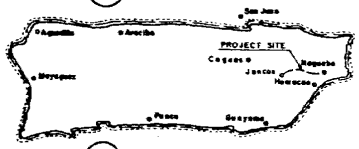
SHEET NO. DESCRIPTION

(2)

NOTE:

ALL WORK ON THIS PROJECT SHALL BE PERFORMED AND ALL MATERIALS SHALL BE IN STRICT ACCORDANCE WITH THE INTERIM STANDARD SPECIFICATIONS AND GENERAL PROVISIONS APPROVED BY THE PUERTO RICO HIGHWAY AUTHORITY ON AUGUST 6, 1971 AND SUBSEQUENT AMENDMENTS IN EFFECT AT THE TIME OF BIDDING, WITH THESE PLANS AND WITH ALL SPECIAL PROVISIONS AND INSTRUCTIONS INCLUDED IN THE CONTRACT BOOK.

(3)



(4)

DESIGN DESIGNATION

CONTROL OF ACCESS	= FULL
ADT 1979	= 4,300
ADT 1999	= 8,500
DHV	= 1,300
D	= 50 %
T	= 12 %
V	= 60 M.P.H

(5)

SCALE 1:20,000

(6)

TOTAL LENGTH OF PROJECT = 3.9700 Km. ⟷ 2.4670 Mi.

NET LENGTH OF ROADWAY = 3.9200 Km. ⟷ 2.4359 Mi.

NET LENGTH BRIDGE NO.___ = 0.0500 Km. ⟷ 0.0311 Mi.

(7)

A.C. CODE NUMBER 001042

HIGHWAY P.R. 31

JUNCOS — NAGUABO

STA. 14.00 / 50.00 TO STA. 1440 / 20.00

MUNICIPALITY OF JUNCOS

(8)

(9)

COMMONWEALTH OF PUERTO RICO

DEPARTMENT OF TRANSPORTATION AND PUBLIC WORKS

HIGHWAY AUTHORITY

DESIGN AREA

(10)

COMMONWEALTH OF PUERTO RICO

HIGHWAY AUTHORITY

(11)

SUBMITTED

DIRECTOR FOR DESIGN AREA — DATE

RECOMMENDED

DEPUTY EXECUTIVE DIRECTOR — DATE

APPROVED

EXECUTIVE DIRECTOR — DATE

(12)

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

APPROVED

DIVISION ADMINISTRATOR — DATE

(13)

PREPARED BY

LIC. NO.

FIGURE 19-C
SAMPLE TITLE SHEET
19-10

COMMONWEALTH OF PUERTO RICO
DEPARTMENT OF TRANSPORTATION AND PUBLIC WORKS
HIGHWAY AUTHORITY
DESIGN AREA

CONSTRUCTION COST ESTIMATE

Project Title:	Sabana Grande-Yauco	Highway:	PR—2
A.C. Project Code:	00269	Date:	June 23, 1974
Municipality:	Sabana Grande	District:	Mayagüez
Stationing:	314 + 50.00 to 349 + 52.00		
Total Length:	3.502 Kms. = 2.177 Miles		

UNIT I ROADWAY

Length: 3.214 Kms. = 1.997 Miles

Roadway:	Four Lanes divided		
Pavement Width:	14.60 M.	Median:	6.00 M
Shoulders:	3.00 M. paved		
Pavement Structure:	0.22 M. Plain concrete slab on 0.13 M. crushed stone or crushed gravel base.		

Item No.	Spec. No.	Approx. Quantity	Unit	Class of Work	Unit Price	Amount
1	150	L.S.	L.S.	Survey and Stake-out	L.S.	100,000.00
2	151	L.S.	L.S.	Mobilization	L.S.	255,000.00
3	201	46	Cda.	Clearing and Grubbing	300.00	13,800.00
4	202	L.S.	L.S.	Removal of Structures and Obstructions	L.S.	5,000.00
5	202	28	EA	Removal of Existing Traffic Signs and Posts	50.00	1,400.00
6	203	545,300	CuM	Unclassified Excavation	2.65	1,445,045.00
7	203	100,000	LnFt	Presplitting Drill Holes	1.45	145,000.00
8	203	33,665	CuM	Borrow	2.25	75,746.25
etc.						

Continues on Figue 19—D (2)

SAMPLE CONSTRUCTION COST ESTIMATE
FIGURE 19—D (1)

UNIT II — BRIDGE AT STATION 318 + 94.46

Length: 0.188 Kms. = 0.117 Miles
Roadway Width: 27.80 M. = 91.21 Feet

Item No.	Spec. No.	Approx. Quantity	Unit	Class of Work	Unit Price	Amount
9	206	765	CuM	Unclassified Excavation for Structures	10.00	7,650.00
17	601	1939	CuM	Class A Concrete	100.00	193,900.00
etc.						

UNIT V — TRAFFIC SIGNS

Item No.	Spec. No.	Approx. Quantity	Unit	Class of Work	Unit Price	Amount
48	613	9	EA	Traffic Signs Assemblies Code Nos: 1, 23, 24, 25	425.00	3,825.00
49	613	2	EA	Traffic Signs Assemblies Code No. 2	220.00	440.00
etc.						

UNIT VI -- RELOCATION OF P.R.A.S.A. FACILITIES

Item No.	Spec. No.	Approx. Quantity	Unit	Class of Work	Unit Price	Amount
84	620	L.S.	L.S.	Relocation of P.R.A.S.A. facilities	5,000.00	5,000.00

SUMMARY

Unit No.	Description	Length Kms.	Length Miles	Estimated Cost
I	Roadway	3.314	1.997	$3,256,456.01
II	Bridge at Sta. 318 + 94.46	0.188	0.117	881,442.53
III	Overpass at Sta. 332 + 80.00	0.038	0.024	171,158.89
IV	Pedestrian Overpass, Sta. 328 + 00.00	(0.046)	(0.029)	20,795.23
V	Traffic Signs	—	—	25,705.00
VI	Relocation of P.R.A.S.A. facilities	—	—	5,000.00
etc.				
TOTALS		3.502	2.177	$4,416,871.91

SAMPLE CONSTRUCTION COST ESTIMATE

FIGURE 19—D (2)

FEDERAL AID PROJECT NO: — U-1-1 (33),
"INTERSECTION OF LOMAS VERDES AND HIGHWAY PR-1"
MUNICIPALITY OF SAN JUAN, PUERTO RICO (CONT.)

Revised: — October 24, 1974
March 13, 1975

SEPARATE ESTIMATES

(1) Participating-Electric Line (Type Code PRWRA-Y060 ---------- $16,310.00
(2) Non-Participating-Telephone Line (Type Code Com. Auth.-Y060 ---------- $17,161.44

WITHIN URBAN AREA — SUMMARY

Force Account Or Contract	Type Code	Width (Feet)	Total Estimate Cost	Total Estimate F.A. Part. Cost	F.A. Funds Requested	F.A. Funds Recom-mended	Length (Miles)
C	6202	VAR	$ 833,039.46	$ 833,039.46	$ 583,127.62		(0.441
C	X078	47.9	738,418.56	738,418.56	516,892.99		(0.048)
C	Y030	—	59,812.50	59,812.50	41,868.75		—
C	Y002	—	17,715.50	17,715.50	12,400.85		—
C	Y031	—	14,027.20	14,027.20	9,819.04		—
F.A.	Y050	—	17,161.44				—
F.A.	Y060	—	16,310.00	16,310.00	11,417.00		—
TOTALS			$1,696,484.66	$1,679,323.22	$1,175,526.25		

TOTAL CONSTRUCTION COST ---------- $1,696,484.66
ENGINEER'S CONTRACT ESTIMATE ---------- $1,511,830.20

Estimated Construction time 400 Calendar Days.

San Juan, Puerto Rico

_____, 19 __

SUBMITTED:—

_____

Director for Design Area

RECOMMENDED:—

_____

Execute Director
Highway Authority

APPROVED:—

_____

Secretary
Transportation and Public Works

Sample Federal — Aid Funding tabulation

Figure 19—D (3)

COMMONWEALTH OF PUERTO RICO
DEPARTMENT OF TRANSPORTATION AND PUBLIC WORKS
HIGHWAY AUTHORITY
DESIGN AREA

ESTIMATES AND SPECIFICATIONS OFFICE

CONTRACT TIME ESTIMATE

Project Title: _____ Municipality: _____

A.C. Project Code: _____ Date: _____

Total Length (Kms.): _____ Estimator: _____

I. ITEMS OF WORK:

No.	Description	Quantity	Rate of Work	Partial Days	Total Days

II. TOTAL WORKING DAYS (t): _____

III. TOTAL CONSTRUCTION TIME (T = Kt) = _____ by _____ = _____

IV. TIME FOR LABORATORY TESTING OF MATERIALS: _____

V. TIME FOR OTHER FACTORS:

a. _____

b. _____

c. _____

d. _____

VI. TOTAL CALENDAR DAYS: _____

USE _____ CALENDAR DAYS

(Note: For "K" factors see separate table)

FIGURE 19–E

6. Project Length Data -- show the total length of project in kilometers and miles on the top line. Show below that the net length of roadway and the length of each bridge which is measured along the center line of the project; the sum of all these should equal the total length. All length should be shown to four decimal places.

Any bridges included in the project construction which overpass the main line should also be shown but the length enclosed in parenthesis to indicate that they are not part of the total project length.

When the contract includes more than one project show the above information for each.

7—Project Title Block -- show the A.C. code number, the FA project number if applicable, the project title, the section from Sta._____to Sta._____, and the municipalities where it is located.

8—Project Identification Block -- See Section 19—02.04.

9—Agency Title -- Show Commonwealth of Puerto Rico, Department of Transportation and Public Works, Highway Authority, Design Area.

10—Highway Authority Logo.

11—H.A. Signature Block -- provides space for the signature and date as follows:
Submitted--Director for Design Area
Recommended—Deputy Executive Director
Approved—Executive Director

12—FHWA Signature Block — This is for Federal-aid projects only and provides for the approval signature and date by the FHWA Division Administrator.

13—Consultants Signature Block — This is for use only on projects designed by consultants and will show the firm's title and the name, signature, and license number of the engineer(s) submitting the plans.

19—02.06 INDEX SHEET

A complete index to plan sheets must be provided indicating the general categories of details shown on each sheet or group of sheets which should correspond to that used in the individual sheet title block as for example: Sheet 15— Plan and Profile, Sta. 2+50.00 to 9+50.00; Sheets 54-57 Reinforcement Schedules, Structure at Sta. 4+32.50. As previously indicated, this index sheet may be omitted for small projects if the index can be adquately shown on the Title Sheet.

19—02.07 GENERAL NOTES AND LEGEND

General Notes will include only those general project notes and instructions which are not otherwise covered in the contract book and which are needed for the proper interpretation of the plans. Examples are: "All dimensions are in meters unless otherwide specified"; "All elevations are in meters and referenced to mean sea level".

The legend shall include all general symbols and abbreviations used on the plans except that the legend for special symbols and abbreviations used on items such as highway lighting, soil survey data and utility relocation work may be included in the plan sheets covering these work categories.

On small projects this sheet may be omitted if the general notes and legend can be shown in the typical section sheets.

19–02.08 TYPICAL SECTIONS

This group of plan sheets will show the typical sections for the main roadway, ramps, frontage roads (also called service or marginal roads), cross roads and other auxiliary roadways except for temporary detours which shall be included in the plan sheets covering maintenance of traffic.

The typical sections shall be drawn to any suitable scale of sufficient size to show all necessary details; normally 1:50 or 1:100 is used. The vertical dimensions are usually distorted to a larger scale than the horizontal dimensions to facilitate clarity of details.

The typical sections shall show:

1—Composition and dimensions of the pavement and shoulder structures.
2—Pavement and shoulder cross slopes and method of banking (superelevation table).
3—Point of application of plan grade, specially when other than centerline of pavement.
4—Location and details of curbs, curb and gutters, and sidewalks.
5—Location of guardrails, barriers, light standards and fences.
6—ROW limits.
7—Typical cut and fill slopes for various heights.
8—Medians, ditch sections and slope rounding.
9—Construction and/or survey centerline.

Where variations in the pavement structure for the same typical sections are proposed because of special soil conditions, these variations may be covered by a tabulation indicating the limiting stations to which they apply.

When more than one typical section is required, the station limits shall be noted below each. When three or more typical sections are required on the main line, an alphabetical code should be assigned to each section and the limits of its application shown on the plan and profile sheets. Typical sections will not be included for transition sections, these are shown in the detail sheets of the areas affected. Full sections must be drawn for each typical section required, half sections placed side by side to save space will not be accepted. When variable dimensions are shown, the limits of application must be indicated.

The typical section for improvements which are being developed by stage construction shall indicate by dashed lines the proposed ultimate development.

Typical sections are covered in detail in Chapter 2.

19–02.09 SUMMARY OF QUANTITIES

The summary of quantities tabulation is prepared to summarize all pay items necessary to construct the project. Roadway and bridge quantities, in addition to the total, are shown separately for each pay item. The following are the headings and explanation of each column in the summary:

1—Item No. – As it will appear in the Proposal Schedule.
2—Item – Class of work as covered by the specification.
3—Unit – unit of measurement and payment.
4—Roadway Quantity.
5—Bridge Quantity—total for all bridges.
6—Total Quantity.

19–02.10 TABLE OF STRUCTURES

The Table of Structures complements the Summary of Quantities by presenting in tabular form the location and distribution of the various pay items used on structures throughout the

FED. ROAD WAY PROJECT NO.	AC PROJECT CODE NO.	HIGHWAY P.R.	MUNICIPALITY	ISLAND	FISCAL YEAR	SHEET NO.	TOTAL SHEETS
				P.R.	19		

ITEM NO.	ITEM	UNIT	ROADWAY	BRIDGE	TOTAL

ITEM NO.	ITEM	UNIT	ROADWAY	BRIDGE	TOTAL

FIGURE 19-F
SAMPLE QUANTITY SUMMARY SHEET

PUERTO RICO HIGHWAY AUTHORITY DESIGN AREA HIGHWAY DESIGN OFFICE	HIGHWAY P.R.	DATE	REVISION	QUANTITY SUMMARY

project. It facilitates the checking of plans and helps the contractor and resident engineer to quickly locate the item in the field. It also aids in the determination of the final quantities used in the project.

The basic tabulation includes all the structures which have several pay items such as bridges, culverts, retaining walls, storm sewers, etc. The headings of the columns in this tabulation should include:

- Number, to identify the structure and line.
- Type of Structure, to provide brief description.
- Location, to show stations and side.
- Plan Location, to show the plan sheet number(s) where structure is detailed.
- Standard Model, to show which, if any, apply.
- Pay Items, a separate column for each applicable pay item so that quantities for each structure may be shown. The specification number and the unit of measurement should be indicated in the headings.
- Remarks, to provide for any pertinent remark needed to clarify the items.

Separate subtotals should be shown for all roadway and all bridge items and a total for each item. These subtotals and totals should agree with the totals shown in the summary of quantities for the respective items.

Structures and appurtances that include only one or two pay items such as guard rails, barriers, paved ditches, sidewalks, fencing, curbs, gutters, underdrains, driveways, slope paving, etc. may be included in the above basic tabulation or may be covered by a separate tabulation for each in order to save plan space. These tabulations will show the locations and length for each section or item.

19—02.11 CONSTRUCTION SCHEDULE AND MAINTENANCE OF TRAFFIC

These plan sheets will show by drawings and written description the suggested schedule of construction by phases or stages and the necessary provisions for maintaining traffic flow during the construction period. They will include typical sections, plan, profiles, cross sections and other necessary details for temporary roadways and detours; and details on temporary barricades, signing, signals and markings.

19—02.12 INDEX PLAN

The Index Plan is a small scale plan or schematic layout of the whole project, or sections of the project, showing the distribution and interrelation of the large scale detail plan sheets. It is used only on complex projects to facilitate the location of plan sheets for specific project sections.

The index plan is specially advantageous for large interchanges to show the area of the interchange covered by each of the large scale detail sheets. In lieu of an index plan, it will be satisfactory to include a small key map on each sheet of the large scale plans of the interchange showing the relation of the particular plan sheet to the other plan sheets covering the interchange area.

19—02.13 MISCELLANEOUS TABLES

These sheets will include tabulations and diagrams of important data not shown elsewhere on the plans. They will cover such items as:

- Survey line control stations locations, ties, elevations and coordinates.
- Road alignment data for the main line and auxiliary lines to include elements, stations, bearing, distance, coordinates, curve data (A,R,T,E,L) and spiral data.
- Bench Mark data to include location, elevations and description for each.

FED. AID HWY PROJECT NO	A.C. PROJECT CODE NO	HIGHWAY P.R.	MUNICIPALITY	ISLAND	FISCAL YEAR	SHEET NO	TOTAL SHEETS
				P. R.	19		

	TYPE OF STRUCTURE	STATION	MODEL	NO	REMARKS
1				1	
2				2	
3				3	
4				4	
5				5	
6				6	
7				7	
8				8	
9				9	
10				10	
11				11	
12				12	
13				13	
14				14	
15				15	
16				16	
17				17	
18				18	
19				19	
20				20	
21				21	
22				22	
23				23	
24				24	
25				25	
26				26	
27				27	
28				28	
29				29	
30				30	
31				31	
32				32	
33				33	
34				34	
35				35	
36				36	
37				37	
38				38	
39				39	
40				40	
41				41	
42				42	
43				43	
44				44	
45				45	
46				46	
47				47	
48				48	
49				49	
50				50	
51				51	
52				52	
53				53	
54				54	
55				55	
56				56	
57				57	
58				58	
59				59	
60				60	
61				61	

FIGURE 19-6
SAMPLE TABLE OF STRUCTURE (ESTIMATE)

DATE	BY

PUERTO RICO HIGHWAY AUTHORITY DESIGN AREA HIGHWAY DESIGN OFFICE	HIGHWAY P. R.	DATE	REVISION	TABLE OF STRUCTURES (ESTIMATE).

FED. AID HIGHWAY PROJECT NO.	A.C. PROJECT CODE NO.	HIGHWAY P.R.	MUNICIPALITY	ISLAND P.R.	FISCAL YEAR 19	SHEET NO.	TOTAL SHEETS

PLAN

PROFILE

FIGURE 19-H
SAMPLE PLAN & PROFILE SHEET

PUERTO RICO HIGHWAY AUTHORITY DESIGN AREA HIGHWAY DESIGN OFFICE	HIGHWAY P.R.	DATE / REVISION	SCALE	

- Disposal of buildings to include location and description, and identify whether removal by others, demolition by others, or demolition by contractor.
- Earthwork Summary — to show excavation available from main roadway and from other construction features, excavation of unsuitable material, shrinkage and/or swell factors estimated, embankment, waste, borrow, overhaul, topsoil stripping and topsoil needed.

On small projects these sheets may be omitted by including these tables in the plan and profile sheets.

19—02.14 ROADWAY SOIL SURVEY AND SPECIAL CONSTRUCTION DETAILS

Includes a plan of the complete roadway at a suitable scale showing the location of all borings and details of any special roadway construction methods required due to the existing soil conditions together with any necessary explanatory notes. These special construction methods include such cases as removal of unsuitable soils, stabilization of subgrade by use of surcharge or sand drains and surcharge, presplitting for rock cuts, etc.

In addition, the log of each boring will be included to show all data obtained with appropriate explanatory notes.

Chapter 12, SOILS, elaborates on subsurface explanations, and soils considerations in design.

19—02.15 PLAN AND PROFILES

General roadway plans and profiles should be prepared on standard metric plan-profile sheets whenever possible but in many instances they have to be drawn on separate sheets in order to maintain an adequate scale. Standard metric plan-profile sheets have the top half blank for the plan portion and the bottom portion contains a grid with the vertical lines spaced at one centimeter and the horizontal lines at one millimeter.

The scale to be used for plan and profile sheets should be adequate to show all necessary details as governed by the topography to be shown and the complexity of the work. Standard scales for rural projects are 1:1,000 horizontally and 1:200 vertically in the profile. For urban projects the standard scales are 1:500 horizontally and 1:100 vertically in the profile. At times it is necessary or advantageous to use larger scale than these or when a large amount of existing topography and details to be shown require more space. Generally, the 5 to 1 ratio of horizontal to vertical scale should be maintained.

When drawn on the same sheet the plan and profile should be so oriented that the profile stationing is directly below the plan stationing to the extent possible. Plan and profile data should be shown for approximately 200 meters beyond the beginning and ending stations to insure connection to contiguous sections at the proper horizontal and vertical alignment.

1. The roadway plan portion shall include the following:

a. The survey line and the construction centerlines which, whenever practical, should be coincident. When these two are not coincident, their relationship shall be indicated. Show all stationing reading from left to right. Normally, at a 1:1,000 scale, an average of seven 100M. stations per sheet may be shown. Identify each full station.

b. Identify the stationing of the project beginning and ending, limits of approach work, equations, curve and spiral control points (PC, PI, PT, TS, SC, CS, ST), intersecting roads, ROW control points, location of culverts, limits of bridges, location of miscellaneous structures and appurtenances (retaining walls, guardrails, median barriers, fences, etc.), indicate the slope limits and other key features included in the proposed construction.

c. Show ties and stationing of auxiliary construction control lines.

d. Show the 200 M. corner points for the Puerto Rico coordinate system. Unless included in other plan sheets, show the coordinates for the project beginning and ending stations, the P.I.'s, and other important controlling features on the line.

e. Include a north arrow on each plan sheet. Indicate the bearings for all tangents.

f. Show all existing topography and culture affecting the proposed construction particularly roads, streets, driveways, streams, lakes, swamps, wooded areas, bridges, culverts, building, sidewalks, curbs, storm sewers, inlets, manholes, retaining walls, fences, utilities (both underground and otherwise), railroads, and any other obstruction or encroachment within the right-of-way or adjacent thereto if influencing the project and/or the possibilities of becoming a safety hazard.

g. Indicate the disposition of all existing buildings, bridges, culverts, and other structures; whether to remain, to be removed by others, to be demolished by contractor or other action. Also identify any existing sections of pavement to remain or to be obliterated.

h. Show the right-of-way and control-of-access lines, and the location of ROW markers or monuments. Identify the stationing of all ROW and COA lines control points.

i. Unless shown on separate utility plan sheets, indicate the disposition of all existing utilities in such detail as needed to cover the scope of work to be performed.

j. Show the location and stationing of kilometer and hectometer posts to be installed and the location of all proposed driveways.

k. Identify the limits of clearing and grubbing.

l. If the miscellaneous tables group covered in Section 19—02.13 is not included in the plan set, then the data indicated in that section shall be shown at appropriate places in the plan sheets.

m. It is desirable to include on each plan sheet a tabulation summarizing the total quantities for each pay item of work shown on that sheet other than earthwork and bridge structures. A column for later insertion of as-built quantities should be provided. Such tabulations facilitate the preparation and review of the estimate and are helpful to the construction personnel.

n. On Federal-aid projects where existing bridges located adjacent to or within the project limits are to remain in place without change, the following data shall be indicated adjacent to each such structure: location (stationing), type, span lengths, overall length, roadway width, vertical clearance, horizontal clearance and estimated design capacity.

o. Also, on Federal-aid projects, a general plan or layout shall be shown for contiguous highways and bridges to be constructed without Federal participation. The layout shall be sufficient to show the location of the work in relation to the project including such details as span length and clearances, alignment, grade and other information needed to establish their relationship to the project.

2. The profile portion shall conform to and include the following:

a. Select a vertical elevation datum with due regard to the extremes of elevation which will occur on each sheet so that the profile will not crowd either the lower or upper limits of the profile strip. The elevation datum is to be indicated on both the right and left sides of the sheet. All elevations will be in meters carried to two decimal places.

b. Show the profiles of the existing ground surface and the finished grade using a light solid line for the ground surface and a heavier line for the finished grade. The finished grade profile shall represent the trace of the vertical plane intersecting the top of the wearing course usually along the center line of the roadway; however, when not along the centerline its location shall be shown. The finished grade profile may be for the base course, subgrade or temporary surface on stage construction projects. A notation shall be included to indicate what the finished grade line profile represents. The point to which the finished grade line profile is applied shall also be shown in the typical sections.

c. Show along the bottom, the stationing identifying vertical alignment control stations and all other stations for which ground and/or finished grade elevations are given. Stations equations and exceptions shall be indicated.

d. Show immediately above the stationing the ground surface elevations. Include all stations for which cross sections are available.

e. Show the finished grade elevation at each control point on the vertical alignment (PC, PI, PT), at the beginning and end of the project, at the beginning and end of each bridge, and deck type culvert, and at the beginning and ending station of each sheet. Also show length of vertical curves and low points in assymetrical sags.

f. Show the percentage of tangent gradient (+ or -) and the length of vertical curves on the grade profile. The length dimension is placed above the grade line for sag vertical curves and below the grade line for crest vertical curves.

g. It is desirable to show earthwork quantities (excavation, fill, borrow, overhaul) and balance point locations below the profiles, immediataly above the stationing and ground surface elevations.

h. Show the location and size of all bridges and culverts. For each pipe culvert indicate the invert elevation below the grade line. Show the high water elevation and date for each stream crossing requiring a bridge size structure.

i. Show by dotted lines and light cross-hatching the location and depth of any unsuitable material to be removed and replaced.

j. Show any special side ditches with the percentage gradient and the stations and elevation at the beginning and ending and at any change in gradient.

k. Where benching of deep cuts is required show the profile of each bench by light dashed lines and identify.

l. The profiles of all side and cross roads are required when a change in grade in involved. These may be shown as insets in the plan and profile sheets unless they are detailed in separate sheets.

19—02.16 DETAILS OF INTERSECTIONS AND INTERCHANGES

All items of construction which can not be satisfactorily detailed on the plan and profile sheets shall be shown on separate detail sheets. This applies specially to channelized intersections-at-grade and interchanges.

The detail sheets for intersections-at-grade and interchanges are generally prepared at a scale of 1:500 horizontally and 1:100 vertically for profiles. However, larger scales may be required on project sections with a multitude of details such as for complex urban projects.

The group of sheets detailing each intersection-at-grade and interchange will be placed in the project plan set in the same sequence as they are located along the project centerline.

1. Intersections-at-grade — The large scale plan layouts and profiles for intersections-at-grade will include essentially the same information as would be shown on the basic plan and profile sheets with the following exceptions and additions:

a. Existing topography is usually not plotted if it is covered elsewhere on the plans unless it is pertinent to the design.

b. Show all necessary horizontal control data and stationing for all auxiliary lines; curb radii; pavement and shoulder dimensions; details of channelization; location of curbs, gutters, sidewalks, guard rails, barriers, curb ramps, and other applicable items.

c. Details of channelizing islands, ramp terminals, noses and other critical features are usually drawn as insets at a larger scale to adequately show all controlling dimensions and transitions.

d. Include profiles for all auxiliary lines not previously included in the plan and profile sheets.

e. Include cross sections for intersecting roadways other than the main line.

f. Show pavement elevations and, if necessary, a grading plan for the intersection area. Spacing of the pavement elevation points must be indicated and ties to the stationing given.

g. Show location of all inlets and manholes. If a separate group of drainage plans is not included, then show all drainage structures, storm sewer lines, ditches, channels, etc.

2. Interchanges — Large scale interchange layouts are prepared in a manner similar to that described above for intersections-at-grade modified as follows:

a. Since the layout of an interchange will usually cover more than one plan sheet, a key or index plan should be included as described in Section 19—02.12.

b. A grading plan for the interchange area is required. This will show the existing and the proposed final contours in addition to the proposed pavement elevations. The contour interval should be no more than one meter but may be less if required by the Highway Design Office.

c. Special cross sections for the earthwork computations through the interchange area may be required. In such cases a layout showing the location of the cross sections will be provided and the cross sections included in the interchange plans group. The main line cross sections group will then show an exception with an appropriate note.

Chapters 4 and 5 cover design principles, procedures and details for intersections-at-grade and interchanges respectively.

19—02.17 DRAINAGE PLANS

On small rural projects the drainage layout can usually be shown on the plan and profile sheets. However, for the larger and more complex rural projects, and for urban projects, it is normally necessary to include a separate group of drainage plan layout sheets to adequately show all necessary details.

Drainage plans are normally prepared at a 1:1,000 scale for rural projects and 1:500 for urban projects and interchange areas.

The drainage layout plans will show and identify the stationing of all drainage structures on the mainline roadway, cross roads, intersections and interchanges, and auxiliary roadways. These will include all bridges, culverts, storm sewers, catch basins, inlets, manholes, side drains, side ditches, underdrains, open channels, etc. The types, sizes, length and direction of flow will be indicated.

The existing drainage courses will be shown and all proposed ditches, channels and channel relocations indicated. Include profiles and cross sections for channels which are not detailed elsewhere. Channel details in connection with pipes, bridges and culverts (other than pipes) are normally included with the plans for these structures. See Sections 19—02.18 and 19—02.24.

All controlling elevations will be shown including top and invert elevations for all manholes and inlets.

For interchange projects the drainage plan layout shall be prepared on the basic interchange layout which shows the final grading contours and pavement elevations.

Any proposed rip rap, curbs, gutters, concrete paving and channel lining will be indicated.

For closed storm sewer systems it is desirable to provide a number identification for each manhole and inlet, and to include a tabulation that will show for each connecting segment the location (from-to), the type and size of pipe, the gradient and the length.

19–02.18 PIPE CULVERTS AND MISCELLANEOUS DRAINAGE DETAILS

This group of plan sheets complements the drainage layout sheets.

For each pipe culvert include a roadway cross section (usually at a scale of 1:200) showing the location and profile of the pipe, the size and type, the length, the type of end treatment (headwall type, rip rap, etc.) the controlling elevations, and the method of bedding and backfilling. Show also any appurtenant structures such as manholes, catch basins and junction chambers.

Under the drawing for each pipe show the drainage area served, the pipe area required and the pipe area provided.

When channel work is required in connection with the pipe, include a profile and cross sections of the channel work.

For closed storm sewer systems include profiles of all segments showing ground and grade profiles, manholes, inlets, pipe types and sizes, length, gradient, discharge points, and controlling elevations.

This plan sheets group will also include all necessary details and dimensioning of any miscellaneous drainage structures (not covered by standard models or otherwise detailed on other plan sheets) such as concrete paving or stone revetment for channels, stilling basins, junction chambers, and special designs for headwalls, inlets, manholes and other drainage appurtenances.

19–02.19 MISCELLANEOUS CONSTRUCTION DETAILS

This group of plan sheets will show details of miscellaneous features not covered by standard models and not otherwise to be included in another plan group. It will include details on such items as pavement and median transitions, road relocations, special guard rails or barriers, tractor crossings, railroad crossings, driveways, pedestrian sidewalk curb ramps, automobile entrances, field office and laboratories, P.C. concrete pavement joint details, impact attenuators and other special safety features.

19–02.20 UTILITY PLANS

Chapter 13 covers the policies and procedures for utility work and the construction plans requirements.

Since the plans for utility relocation work require the approval of the respective utilities affected, or are designed by the utility itself, a separate set of plans should be prepared for each.

The plans for each utility are normally drawn on the basic roadway plan layout and show all the existing facilities, existing temporary and permanent relocations, facilities items to remain, items to be abandoned, items to be relocated, new facilities to be constructed and the capacities of the facilities. In addition, details necessary to define the scope of the work to be performed will be included. The plan sheets shall have a blank space, 6" x 6", on the lower right corner immediately above the sheet title block to provide for the approval stamp of the utility. The legend of symbols and abbreviations used will be shown on the first sheet. In case of a joint ownership of poles this should be clearly indicated.

Utility relocation work may be performed by the respective utility or may be included in the project contract for performance by the contractor. When the work is to be included in the contract all necessary plans, profiles and construction details to estimate the work and control the construction must be provided. A tabulation of quantities by items is desirable even though the work may be paid as a lump sum item.

On Federal-aid projects, if Federal funds are to be applied to any utility work, the plans must conform to the requirements of the Federal Highway Administration included in the FA Highway Program Manual, Book I, Volume 1, Chapter 4, Section 3.

19—02.21 LIGHTING PLANS

For projects to be provided with highway lighting a separate group of plan sheets will be included to show this work.

Chapter 10 covers in detail the policies and procedures for the design of highway lighting and the contract plan requirements.

The proposed lighting system is normally drawn on the basic roadway plan layout. The plans will show the location of all lighting fixtures, cable conduits, circuits, power centers and other appurtenances. In addition all necessary details not covered by standard models will be shown including wiring diagrams and applicable notes.

The lighting design criteria for the project will be shown on the lower left corner of the first lighting sheet. The legend of symbols and abbreviations used will also be shown at an appropriate location on the first sheet. A 6" x 6" space will be left blank on the lower right corner of each sheet, immediately above the title block, to provide for the approval stamp of the P. R. Water Resources Authority.

A tabulation summarizing the quantities of the various pay items shall also be included.

Each plan sheet shall show the name and license number, and carry the signature, of the electrical engineer responsible for the design of the lighting system.

19—02.22 SIGNING, PAVEMENT MARKINGS AND SIGNALS

Chapter 9 covers the Highway Authority's design criteria, policies and procedures on traffic control devices, namely: signing, pavement markings and signals.

The proposed traffic control devices for a project are normally included in a separate group of plan sheets. Their location is shown on a layout plan of the roadway. For small simple projects they may be shown on the basic plan and profile sheets.

The signs are shown and identified by appropriate symbols (See Figure 19—B) and the station location given for each. It is also desirable to indicate the minimum distance from the edge of shoulder or the curb line to the left edge of the sign plate for ground mounted signs. A note should clearly indicate the definition of this lateral distance, if shown.

A tabulation shall be included on a separate sheet (s) showing for each type of sign used the code number, location number, legend illustration, letter or symbol sizes, size of plate (s), type identification number as per signs manual, colors (background and characters), type of mounting, and total number of each type sign.

For standard signs, the symbol or letter sizes column can make reference to the signs manual. Destination signs and any special signs will each be detailed showing the letter sizes and series, plate dimensions and spacing dimensions.

The type of mounting for ground mounted signs will indicate number of posts and make reference to the applicable standard model or detail sheet. For overhead signs, a general layout of the supporting structure must be shown.

For pavement markings, detail blowups shall be included to cover markings at intersections, ramp terminals, pavement transitions and other special conditions. Identify colors, materials and widths of lines. Include a tabulation summarizing quantities of the various types of pavement markings.

If traffic signals are included in the contract, complete design and installation details must be shown on the plans.

19—02.23 LANDSCAPING AND ROADSIDE DEVELOPMENT

For projects including only erosion control items and minimum landscaping such as topsoil

and sodding or seeding, the required information for this work may be shown on other plan sheets (typical sections, layout plans, grading plans, etc.) However, it is important that the location and limits of such work be clearly identified and all necessary information be provided by notes as required by the specifications (See Standard Specifications 627 and 628) and any special provisions.

Where more extensive landscaping and roadside development features are to be included, then a separate group of plan sheets for this work shall be prepared to detail all the necessary information. This will be the case when the project includes such features as extensive tree planting, scenic overlooks, rest areas, safety parking areas or roadside parks.

Chapter 14 covers policies and criteria on landscaping.

19--02.24 STRUCTURES

This group of plan sheets will include bridges (total span of 6.1 meters or more), culverts (less than 6.1 M. span) other than pipe culverts, and retaining walls. Pipe culverts are included in the drainage plans group.

The plans for each structure should be placed in this group in the same sequence as they are located along the project center line.

1. Bridges - Chapter 6 covers bridge design criteria, procedures and construction plan requirements. In general, the set of plans for each bridge shall include the following:

a. A site plan at a suitable scale (1:200 to 1:500) showing the existing topography including contour lines, the project base lines and stationing of control points, existing roads and structures (identify if to remain or demolish), bench mark data, north arrow, and the location of proposed structure with controlling stations and elevations. For waterway crossings show borders and flow line and any channel work required.

b. For waterway crossings include on the site plan or a separate sheet the following hydraulic data:

1) Hydraulic section at the upstream side of the structure. Indicate slopes and Manning coefficients (n) used for analysis.
2) Drainage area, design discharge (Q) and year frequency.
3) Channel area required and provided.
4) Channel slope and wetted perimeter.
5) Velocity and water elevation for design Q, backwater elevation.

c. Design data to include design loading, applicable AASHTO standard specification (specify year), wind and earthquake loads, classes and grades of materials and design stresses (concrete, structural and reinforcing steel), soil bearing capacity, pile types and bearing capacity, and any other notes pertinent to the structural design criteria.

d. Large scale (1:400 or larger) plan an elevation views of the structure showing all pertinent details, dimensions and elevation. Include all important vertical and horizontal clearances, location of joints, high and normal water elevations for stream crossings, profiles, horizontal and vertical alignment control data, and span lengths.

e. Location plan and log of each sounding and boring. Also any pertinent notes and recommendations resulting from the geophysical investigation.

f. Plan of foundations showing base line, alignment of abutments and piers, and dimensions and elevations of footings (top and bottom). Where piles are called for, show their location, types, sizes, lengths, details, and note driving criteria and negative friction. Also identify proposed test piles. Show any special requirements such as the use of caissons, sheet piling, etc. It is desirable to show the existing contour lines on the foundation plan.

g. Show typical section(s) of the superstructure with all essential details and dimensions.

h. Include large scale detailed drawings of abutments, piers and wingwalls, showing plan, elevation and sectional views fully dimensioned.

i. Include large scale details of girders, beams, deck, diaphragms, slab seats, bearings, railings, parapets, joints, drains and other items of the superstructure.

j. Show framing details, camber and pouring diagrams as may be required.

k. Detail other applicable miscellaneous items such as approach slabs, guard rail connections, slope paving, drainage, identification plate, etc.

l. Include reinforcement bars lists and bar bending diagrams. Also a summary of quantities for each structure.

m. For waterway crossings include details of any channel work showing alignment, cross sections, slope protection, spur dikes, etc.

n. Throughout the plans include all notes and references to specifications essential to clarify the scope of the work.

2. Culverts and Retaining Walls — The plans for each culvert size structure and retaining wall shall show all of the above information and details as may be applicable and essential to completeness.

19—02.25 STANDARD MODELS

Include in this group copy of each approved Highway Authority Standard Model plan that is applicable to the project. See Section 19—07 for listing of current standard models available.

19—02.26 CROSS SECTIONS

The cross sections for the main line roadway and other main roads (if not shown on previous sheets) will be included in this group.

Although earthwork computations are generally performed by electric computer processing from data obtained by either field surveys or photogrammetric methods supplemented by field surveys, it is the practice of the Highway Authority to plot and include cross sections in the construction plans set.

Cross sections are normally shown at even 20—meter intervals with intermediate cross sections included to show significant changes in the existing ground surface and permit accurate determination of earthwork quantities or to show the relationship between the proposed roadway section and the existing conditions.

Cross sections for the beginning and end of construction must be included and, if available, for at least 50 meters beyond each end of the project. The cross sections should preferably be plotted on printed metric cross section sheets. The sections shall be plotted consecutively from the bottom of the sheet upward and separated sufficiently to avoid interference. The standard scale is 1:200 which should be used whenever practical; however, a larger scale may be desirable in some instances.

Each cross section shall extend at least 2 meters beyond the ROW line on each side. The ground line shall be shown by a light solid line and the proposed template by a heavier solid line.

Cross sections shall show the following information:

1. Existing ground line.
2. Proposed template to subgrade elevation.
3. The right-of-way limits on each side.
4. The station location of each section.
5. Ground elevation, subgrade elevation and depth of cut or height of fill at the centerline, all in meters to two decimal places.

6. Special ditches with invert elevations.
7. The side slopes shall be labelled on the first and last cross section on each sheet and at each change in slope.
8. On the right side of each section show the cut (C) and fill (F) areas for the roadway template. Show the cut areas for special side ditches separately.
9. Along the right side of each series of cross sections show the distance in meters from section to section.
10. Any structures or ROW encroachments.
11. Any existing pavement, sidewalk, curbs, etc.
12. Unless detailed elsewhere on the plans, a cross section shall be plotted at each side road connection and entrance to an adjacent property to be constructed.
13. Whenever a cross section coincides with the location of a pipe culvert, the latter shall be shown.
14. Indicate the beginning and end station of each bridge and deck type culvert to note the exceptions in the cross sections sequence.
15. Show depth and width of any excavation of unsuitable material.

19—02.27 MASS DIAGRAM

The mass diagram is developed to obtain the most economical distribution of the earth work. It is not normally included in the contract plans but is prepared primarily for the benefit of the designer, reviewer, approving officials and construction personnel.

A mass diagram shall be prepared for each project in olving earthwork except such projects such as single interchanges the nature of which would make a mass diagram meaningless.

19—03 RIGHT-OF-WAY PLANS

The right-of-way or land acquisition plans, similar to the construction plans, are developed in two stages — the preliminary plans and the final plans.

19—03.01 PRELIMINARY RIGHT-OF-WAY PLANS

The preliminary ROW plans provide basic data essential to the processing of the project through the environmental impact evaluation and public hearing processes. However, since the Property Acquisition and Management Area of the Highway Authority has to perform certain field investigations and activities that are time consuming, it is essential that these preliminary ROW plans be available as early as possible during the development of the project.

The preliminary ROW plans shall be prepared in the same standard size sheet (22" x 36") as the construction plans and shall have similar project identification and sheet title blocks as described in Section 19—02.01.

The preliminary ROW plans are normally prepared on the basic plan layout of the project. Usual scales are 1:1,000 for rural projects and 1:500 for urban projects. The plans shall show as a minimum the base line (s) and stationing; construction limits; existing roads, buildings, structures and other pertinent topographical features within and in the vicinity; existing and proposed ROW limits referenced to base line; control-of-access lines and limits if applicable; points of access; cut and fill slope limits if available; property lines; parcel numbers and property owners.

The parcels to be acquired, either fully or partially shall be delineated and buildings and other improvements affected identified. Each sheet shall contain a tabulation showing for each parcel affected the number, owner and a preliminary estimate of the total parcel area, area to be acquired and remainder area. The ownership of record shall subsequently be ascertained by the Property Acquisition and Management Area through field investigations and title search.

19—03.02 FINAL RIGHT-OF-WAY PLANS

The final right-of-way plans are a basic component of the official legal documents required to complete the acquisition of the properties necessary for the construction of the project. Since the property acquisition can be a lengthy process requiring title certifications, appraisals, negotiations, relocation assistance and filing of condemnation documents, it is essential that the final ROW plans be completed as soon as the project construction features have been defined. They normally can and should be completed in advance of the final construction plans.

The final ROW plans shall conform to the drafting requirements specified in Sections 19—02.01 and 19—02.02. The sheets shall be numbered as for construction plans (Section 19—02.04) with the letter prefix ROW used in the appropiate space in the sheet title block.

The final ROW plans set shall include a title sheet, location and parcel plans, parcel summary tables and parcel description tables.

19—03.03 RIGHT-OF-WAY TITLE SHEET

The format of the ROW title sheet is the same as for the final construction plans, illustrated on Figure 19—C, with the following modifications:

1. The standard note, Item (2), and the design designation, Item (4), are omitted.
2. Item (6) will show the title "LAND ACQUISITION PLAN" and below the total project length only.

19—03.04 LOCATION AND PARCEL PLANS

The location and parcel plans are prepared on a plan layout of the project at a 1:1,000 scale for rural projects and 1:500 scale for urban projects. Larger scales may be required for complex acquisitions where considerable detail need be shown.

The plans shall show the base line, stationing, and controlling geometric alignment data. All existing roads, driveways, fences, buildings, structures, water courses, ponds, and other pertinent existing and proposed features affecting the value of the ROW shall be shown and identified. For projects involving earthwork, the proposed limits of cut and fill slopes shall be indicated.

The plans shall also show the existing property lines and proposed right-of-way and control-of-access lines with ties to the centerline and stationing. All buildings, structures and improvements affected shall be identified and their disposition noted.

Each parcel to be acquired shall be clearly defined in the plans. For urban projects the total parcel affected shall be shown even though only a partial taking may be involved. For partial takings in rural projects, the full parcel shall also be shown if the taking affects the value of the remainder. In such cases large parcels may be shown by smaller scale inserts in the plan sheets. Each parcel shall be identified by a number as furnished by the Highway Authority.

All proposed driveways and access provisions shall be indicated and all work to be performed in mitigation of property damages shall be shown.

For parcels involving easement rights, whether temporary or permanent, rather than fee title, the same information shall be shown and the type of taking identified. Similarly, adjacent properties which may suffer damages by reason of the construction, even though no acquisition is involved, shall be identified.

19—03.05 PARCEL SUMMARIES

Include tabulations showing for each parcel:

1. Parcel identification number.

2. Name of owner of record.
3. Area in square meters, and also in "cuerdas" for rural parcels, of:
   a. Total parcel.
   b. Area to be acquired.
   c. Remainder, if any.
4. Remarks -- indicate here type of taking if other than fee title, access status of remainder if a consideration, and any other item pertinent to value.

The parcel summary tables should preferably be included in the plan sheets showing the respective parcels but may be shown on separate sheets if necessary.

19--03.06 PARCEL DESCRIPTIONS

For each parcel to be acquired show the parcel description in tabular form to include the parcel number and owner, the identifying number of each boundary point, the coordinates of each point, distance and bearing from point to point, and the total area to be acquired in square meters and also in cuerdas for rural parcels.

19--04 SPECIFICATIONS

Specifications is a general term applied to all directions, provisions and requirements pertaining to the performance of the work. The specifications together with the plans and estimate provide all necessary instructions for the completion of the work contemplated under a project as conceived by the designer.

19--04.01 STANDARD SPECIFICATIONS

The standard specifications cover all provisions and covenants applicable to all highway improvement contracts as well as provisions relating to construction methods, equipment, materials, measurement and payment for individual construction items. The standard specifications are intended for general application and repetitive use.

The current standard specifications of the Highway Authority are included in the "Interim Standard Specifications for Road and Bridge Construction" which were originally issued in 1971. Although some revisions have been made since the original publication, these interim standard specifications have been under review by the Authority's Specifications Committee prior to printing in book form. Until such time as the printed book is issued, the interim standard specifications applicable to each project are being included in the project contract book.

The standard specifications of the Highway Authority are arranged into four groups as follows:

1. **General Provisions** -- included in Section 100. These cover all the general requirements applicable to all contracts. No changes can be made in the General Provisions without the prior approval of the Secretary of Transportation and Public Works.
2. **Special Items** -- included in Sections 150 and 151. These cover the items of Survey and Stake-out, and Mobilization.
3. **Construction Details** — these are covered in the section series 200 to 600 inclusive and include individual specifications for each work item. These specifications are normally written following a standard format of five major parts which include description, materials, construction requirements, method of measurement and basis of payment.
4. **Materials** -- included in the 700 series. These cover the requirements for materials used under the various work items included in Group 3, Construction Details.

The standard specifications make frequent reference to specifications issued by other organizations, such as the American Association of State Highway and Transportation Officials (AASHTO) and the American Society for Testing and Materials (ASTM), particularly as to materials requirements and methods of sampling and testing. The General Provisions provide that where these references are made, the latest issue of such specifications will apply.

19—04.02 SUPPLEMENTAL SPECIFICATIONS

Supplemental Specifications are additions and revisions to the Standard Specifications which are approved subsequent to the issuance of the printed book. They are intended for general application as standard to cover additional items no included in the approved book or substantial changes in items that are included.

Since the Highway Authority has not as yet given final approval and issued in printed book form its standard specifications, no supplemental specifications are being used. Changes and additions to the interim standard specifications are being included as special provisions in each individual project as may be applicable.

19—04.03 SPECIAL PROVISIONS AND INSTRUCTIONS

Special Provisions cover additions or revisions to the standard specifications applicable to an individual project. In addition, any special requirements, regulations or directions pertaining to a particular project which are included in the Contract Book under Instructions to Bidders are considered as special provisions. The designer should remember that in the interpretation of the contract documents, the special provisions prevail over both the standard specifications and the plans.

The Estimates and Specifications Office of the Design Area inserts in the Contract Book special provisions and instructions to bidders pertaining to the contract which are currently in general use (See 19.06). The designer should submit with the project plans and estimate any other special provisions and instructions applicable to the particular project which it is proposed to have included in the Contract Book.

The following general guides apply to the preparation and submission of special provisions and instructions:

1. The use of special provisions should be held to a minimum. They should be submitted only after it has been determined that construction under the standard specifications will not achieve the desired result or is less economical.

2. Special provisions and instructions should not be used for items which can be adequately explained in the project plans through appropriate details and notes. However, any proposed pay item not covered by a standard specification requires a special provision.

3. Special provisions which provide for new items of work not covered by the standard specifications shall be written following the same general wording and five part format of the standard specifications to include (1) description of work, (2) materials, (3) construction requirements, (4) method of measurement, and (5) basis of payment. It is best to use a similar standard specification as a guide substituting the desired wording. In particular the measurement and payment parts should be worded as in similar standard specifications. Finally, they should be written keeping in mind their possible use in other projects and eventual adoption as a standard specification.

4. Special provisions which are used to modify a standard specification need only include the changes necessary to accomplish the desired result. However, when a portion of a paragraph is voided or modified, the complete revised paragraph should be inserted.

5. Prior to drafting a proposed special provision for a new work item, the designer should consult with the Specifications and Estimates Office where several such special provisions developed for other projects are on file.

6. Direct reference to proprietary specifications of national, regional or local trade associations shall be avoided. They may be permitted under special conditions such as for experimental features or when a satisfactory specification cannot be developed by the Department or obtained from organizations maintained for the specific purpose of developing specifications requirements based on laboratory test or other performance requirements. When the use of such proprietary specifications becomes essential, then the complete text or such parts as are applicable should be incorporated in full.

7. The use of manufacturers trade names should be avoided whenever a workable specification can be developed without them to assure opportunity for competition among equivalent materials, equipment and methods. If a satisfactory specification can not be developed and the use of trade names becomes necessary then the following rules apply:

a. If there are three or more acceptable trade names available, use at least three such names and the phrase "or approved equal".

b. If there are less than three acceptable trade names, use all available names and the phrase "or approved equal".

8. When a specification provides for furnishing a material or product for which it is a customary trade practice to give a warranty or guaranty, then the specification should include a provision requiring the contractor to obtain, and assign to the Highway Authority such warranties or guarantees.

9. The special provision for items which involve the furhishing and/or installation of electrical and/or mechanical equipment must include the following clause:

"All manufacturers' warranties or guarantees on electrical and mechanical equipment, materials or products purchased for use in the project which are consistent with those provided as customary trade practice, must be obtained by the Contractor and, upon acceptance of the project, the Contractor shall assign such warranties or guarantees to the Highway Authority."

In addition, at the discretion of the Highway Authority, the following clause may be required:

"The Contractor shall warrant the satisfactory in-service operation of the electrical and mechanical equipment, materials and products for a period of **(not to exceed six months)** following the project acceptance."

Prior to acceptance of the contract a delayed acceptance period of up to 90 days will be considered for plastic pavement marking materials, rest area building, weigh stations and other special materials and facilities.

Guaranty or warranty clauses for materials other than electrical and mechanical equipment will be acceptable subject to the following conditions:

1. The State insists on including a warranty or guaranty clause in the contract in lieu of delayed acceptance period.
2. The bid proposal must contain two items, one with or without the delayed acceptance period and the other with the full warranty.
3. The material and workmanship specifications for both items must be identical.
4. Regardless of the bid item selected by the State, Federal Participation will be limited to the lesser of the two bids.
5. Subsequently should it be determined that realistic bids are not being submitted to reasonably reflect the added cost of providing the guaranty, the dual bidding arrangement will not longer acceptable.

The above dual bidding arrangement is acceptable for plastic pavement markings, rest area building weigh station and other special material and facilities.

10. On federal-aid projects, any item of work which provides for salvaging of materials for delivery to the Commonwealth requires that salvage credit be given to the Federal participation. Therefore, in FA projects its is normally better to have the salvaged material reused in the project or turned over to the contractor in which case the value of the salvaged material should be reflected in his bid. The advantages accruing to the Commonwealth must be supported by written analysis in those instances where its is desired to retain salvaged materials.

19—04.04 SPECIFICATION – DATA REQUIREMENTS ON PLANS

The designer must include on the plans all data necessary for estimating the quantity of each pay item applicable to the project contract. The following listing summarizes certain special data required by the current Interim Standard Specifications in use by the Highway Authority.

ITEM NO.	TITLE AND REQUIREMENTS
150	SURVEY AND STAKE—OUT No special requirements. Lump sum item.
151	MOBILIZATION No special requirements. Lump sum item.
201	CLEARING AND GRUBBING 1. Limits must be shown when paid by cuerda. 2. Individual trees and stumps by sizes must be identified when a pay item for Cutting and Removing Trees and/or Removing Stumps is included. 3. Vegetation to remain must be identified.
202	REMOVAL OF STRUCTURES AND OBSTRUCTIONS 1. Identify all structures to remain or to be removed by others. 2. Identify any material to be salvaged. 3. Identify any structure to be dismatled, match-marked and stored. 4. When payment other than lump sum is specified, identify limits.
203	EXCAVATION AND EMBANKMENT 1. Identify location and limits of removal of unsuitable materials, if any. 2. Identify the location and limits of any materials, such as loamy topsoil, which may require more than one handling. 3. Identify location and limits of rock and/or muck excavation when included as a separate pay item. 4. Identify the location and limits of where borrow material is to be used when a pay item for borrow excavation is included. 5. Identify the location and limits of where presplitting blasting operations will be used where a pay item for this is included.
205	OVERHAUL 1. Where included as a pay item, show location and limits on mass diagram.
206	UNCLASSIFIED EXCAVATION FOR STRUCTURES 1. Identify location and details of cofferdams and cribs where a separate lump sum pay item is provided for these.
207	FOUNDATION FILL 1. Identify type and class required when different from specification requirements.
208	ALIGNMENT STAKES, PIEZOMETERS, AND SETTLEMENT GAGES FOR EMBANKMENT CONTROL 1. Show location of each unit and details on plans.

209 STONE OR GRAVEL SHEATHING

1. Identify whether crushed stone, crushed gravel or stone will be used.
2. Identify location and limits.

304 CRUSHED GRAVEL OR CRUSHED STONE BASE COURSE

1. Identify whether crushed gravel or crushed stone will be used and the class and grading called for.

307 LIME TREATED SUBGRADE OR BASE COURSE

1. Identify the location, limits and depth of subgrade or base course to be treated.
2. Indicate the percentage rate of lime application by weight of dry soil.

401 HOT PLANT MIX BITUMINOUS PAVEMENT

1. Identify all types of mixes to be used by courses showing necessary dimensions and details.
2. Specify whenever a course of any particular type mix is to be placed in more than one layer.

409 BITUMINOUS SEAL COAT

1. Specify type and grade of bituminous material if other than 85-100 asphalt cement.
2. Specify type and grading of cover coat material.

410 BITUMINOUS SURFACE TREATMENT

1. Specify type, grade and rate of application of bituminous material for each course.
2. Specify type, grading and rate of application of cover coat and blotter materials for each course.

501 PORTLAND CEMENT CONCRETE PAVEMENT

1. Identify location and thickness.
2. Detail joints on plans including dowels, tie bars and other joint material.
3. If pavement is to be reinforced, show details of reinforcement.

601 STRUCTURAL CONCRETE

1. Identify location of each class including rubble concrete.
2. Specify where air entrained concrete, if any, will be used.
3. Specify type of surface finish is other than normal specification requirement.
4. Locate and dimension any pneumatically applied mortar to be placed.

602 REINFORCING STEEL

1. Identify structures for which shop drawings are required to be submitted by contractor.

603 PIPE CULVERTS AND STORM DRAINS

1. Identify the type, class and size of each conduit.
2. Specify the bedding requirements when other than Class C.
3. Specify type and material of joints.
4. Specify where strutting is required.
5. Specify where imperfect trench method (A or B) of backfilling is required.
6. Detail any special end sections.

604 MANHOLES, INLETS AND CATCH BASINS

1. Identify each standard type used.
2. Detail any special types.
3. Specify manholes by height groups.

605 UNDERDRAINS

1. Locate and detail on plans. Specify type, class and size.

606 GUARD RAIL

1. Identify location for each type.
2. Detail when other than standard, including post details.
3. Locate and specify end anchorages.

607 FENCES

1. Identify location for each type.
2. Detail when other than standard.
3. Specify each gate location and detail when not standard.
4. Specify location of all grounding connections.

608 SIDEWALKS

1. All locations, types and dimensions will be shown on plans.
2. For hot plant mix bituminous sidewalks the type mix and courses must be specified.
3. Specify location, details and filler material for any expansion joints required.
4. Reinforcing, if required, will be shown and detailed.

609 CURBING

1. Identify locations for each type.
2. Show details when other than standard.
3. Specify location and details of any base layer required.
4. Specify location of expansion joints and joint filler material.

611 FIELD OFFICE AND LABORATORY

1. Specify type or types required.

612 ELECTRIC HIGHWAY ILLUMINATION

1. Location and complete details of all fixtures and appurtenances will be shown.

613 TRAFFIC SIGNS

1. Location and complete details of all types and classes used will be shown.

614 CRIBBING

1. Location and complete details will be shown.

615 PILING

1. Identify location, size and bearing capacity or penetration required for each type pile.
2. Identify test piles and length of each.
3. Show details of each type pile to be used.
4. Show estimated lengths.

616 STEEL STRUCTURES

1. Complete details will be included on plans with specific materials to be used.

617 TIMBER STRUCTURES

1. Complete details will be shown on the plans including species, grade and treatment of timber, and all other materials to be used.

618 PAVEMENT MARKINGS

1. Identify location of each type and color.
2. Detail all special markings at intersections, etc.

619 RAILINGS

1. Complete details and location will be shown on plans.

620 RELOCATION OF UTILITIES

1. Identify work to be performed by the contractor and that to be done by the utility.

2. Identify material to be salvaged by the contractor and turned over to the utility at a specified location.
3. For relocations to be performed by the contractor complete details will be included.

621 MARKER

1. Show location of all right-of-way markers, kilometer and hectometer posts, and Federal-aid markers.

622 IDENTIFICATION WOOD SIGNS (NOT NECESSARY IN FHWA PROJECTS)

1. Specify legend for each project.
2. Show locations.

623 STONE REVETMENT FOR SLOPE PROTECTION

1. Identify location and dimensions
2. Specify type of stone and filter material.

624 VERTICAL SAND DRAINS

1. Identify locations.
2. Detail depth and section of working blanket; size, depth and spacing of sand drains.

625 REINFORCED CONCRETE PIPE CAISSONS

1. Detail location, classes and sizes, and reinforcement on the plans.

626 REINFORCED CONCRETE PRESSURE PIPE

1. Show all details on plans.

627 TURF ESTABLISHMENT

1. Identify all areas and limits to be seeded.
2. Identify all areas and depth of loamy topsoil. Show separately areas where loamy topsoil is to be obtained from project stockpiles and paid under Spec. 203 and those areas where it is to be obtained from other sources and paid under Spec. 627.
3. Specify the depth of cultivation by areas prior to seeding.
4. Indicate any ground limestone, fertilizer and mulch required specifying locations and rates of application.
5. Specify rates of application of seeding.
6. Specify locations and rate of application of insecticide if required.
7. Identify all areas where special terrain stabilization after seeding is required.

628 PLACING SOD AND PLANTING TREES, SHRUBS AND VINES

1. Identify all areas to be sodded and type of grass to be used.
2. Same as 627-2 above.
3. Identify location, type, specie and size of each tree, shrub or vine to be planted.
4. Specify any limestone, fertilizer and/or mulch required.

650 GROUTED STONE OR CONCRETE SLOPE PAVING

1. Indicate locations and details on plans.
2. Indicate if either grouted stone or concrete paving is specifically required at any location.

651 CONCRETE PARAPETS

1. Indicate locations and details on plans.

652 EPOXY BOND COAT

1. Identify where required.

660 NAME PLATES

1. Show complete details on plans including location, forms, dimensions, inscription and material.

Where supplemental and/or special provisions are to be included in the contract book to cover special items, the designer will insure that the plans show all necessary information required to measure and pay for such items.

19—04.05 LISTING OF SPECIFICATIONS AND SPECIAL PROVISIONS

The designer shall submit with the plans and estimate a listing of all the standard specifications applicable to the project and a draft of all the special provisions and instructions proposed to cover all the work items to be included in the contract.

In listing the applicable standard specifications, it must be ascertained that specifications complementary to the ones covering pay items are also included. For example, standard specifications 407 (Bituminous Tack Coat) and 408 (Bituminous Prime Coat) are not direct pay items but complement standard specification 401 (Hot Plant Mix Bituminous Pavement). Similarly, the use of standard specification 401 requires the inclusion of materials specifications 702 (Bituminous Materials), 703 (Aggregates), 705 (Joint Materials) and 712 (Miscellaneous Materials), to fully cover the requirements of the work item. In addition, all special provisions proposed for use in the project must be checked to ascertain that any complementary standard specifications are included in the listing.

There may also be instances when minor work is required by a note on the plans and a specifications is referred to, for materials or construction requirements. Such specification must be listed for inclusion in the contract book if not already appearing as a pay item or complementary specification.

Table 19-2 shows a listing of the standard specifications covering construction details and the corresponding complementary specification which are referred to in the work item.

TABLE 19-2

CORRELATION BETWEEN STANDARD SPECIFICATIONS

CONSTRUCTION DETAILS SPECIFICATIONS	COMPLEMENTARY SPECIFICATIONS
201 — Clearing and Grubbing	203, 713
202 — Removal of Structures and Obstructions	201, 203
203 — Excavation and Embarkment	201,202
205 — Overhaul	—
206 — Unclassified Excavation for Structures	201, 207, 601, 603
207 — Foundation Fill	206, 703
208 — Aligment Stakes, Piezometers and Settlement Gages for Embarkment Control	617
209 — Stone or Gravel Sheathing	703
304 — Crushed Gravel or Crushed Stone Base Course	703
307 — Lime Treated Subgrade or Base Course	712
401 — Hot Plant Mix Bituminous Pavement	407, 408, 702, 703, 705, 712
407 — Bituminous Tack Coat	702
408 — Bituminous Prime Coat	702, 703
409 — Bituminous Seal Coat	702, 703
410 — Bituminous Surface Treatment	408, 409, 702, 703
501 — Portland Cement Concrete Pavement	701, 703, 705, 709, 711, 712
601 — Structural Concrete	501, 701, 703, 705, 709, 711, 712
602 — Reinforcing Steel	709
603 — Pipe Culverts and Storm Drains	206, 705, 706, 707
604 — Manholes, Inlets and Catch Basins	206, 601, 705, 709, 712
605 — Underdrains	703, 706, 707
606 — Guard Rails	710
607 — Fences	601, 710
608 — Sidewalks	401, 601, 703, 705, 709
609 — Curbing	401, 601, 703, 705, 712
611 — Field Office and Laboratory	—
612 — Electric Highway Illumination	206, 601, 602, 616, 714
613 — Traffic Signs	206, 601, 602, 612, 703, 709, 714, 715
614 — Cribbing	203, 601, 715
615 — Piling	601, 616, 708
616 — Steel Structures	708, 712, 715
617 — Timber Structures	616, 708, 715
618 — Pavement Markings	712
619 — Railings	601, 602, 612, 703, 709, 714
620 — Relocation of Utilities	206, 601, 709
621 — Marker	206, 601, 602, 613
622 — Identification Wood Signs	601, 617
623 — Stone Revetment for Slope Protection	201, 206, 712
624 — Vertical Sand Drains	201, 203
625 — Reinforced Concrete Pipe Caissons	206, 601, 602, 706, 709
626 — Reinforced Concrete Pressure Pipe	206, 603
627 — Turf Establishment	203, 713
628 — Placing Sod and Planting Trees, Shrubs and Vines	203, 713
650 — Grouted Stone or Concrete Slope Paving	601, 701, 703
651 — Concrete Parapets	601, 701, 703, 709, 712
652 — Epoxy Bond Coat	712
660 — Name Plates	

19—05 CONSTRUCTION ESTIMATES

The official Engineer's Estimate which is used for subsequent bid comparison is prepared by the Estimates and Specifications Office and processed through the Director of the Design Area for final approval by the Executive Director prior to advertising for bids. On Federal-aid projects the Engineer's Estimate is also subject to review and approval by the Federal Highway Administration. This estimate is considered a confidential document which is not available for public distribution.

19—05.01 IN—HOUSE DESIGNS

The construction cost estimates for projects designed by Highway Authority personnel are developed by the Estimates and Specifications Office from the plans and data furnished by the Highway Design Office and the Structural Design Office.

The Estimates and Specifications Office reviews the construction plans and computes the quantities for all applicable pay items except for those such as earthwork for which the estimate quantities have been already furnished by the designers. As part of his review the estimator ascertains that all necessary details and notes pertaining to pay items have been included in the plans. Any omissions or discrepancies are discussed and clarified with the designers.

From the quantities computed by the estimator and furnished by the designers the Summary of Quantities tabulation and the Proposal Schedule are prepared. In addition the estimator determines the unit prices to be used in the preparation of the Engineer's Estimate.

19—05.02 CONSULTANT DESIGN

On projects for which the development of the final construction plans is performed by a consulting engineering firm under a contract with the Highway Authority, the Consultant is required to submit a detailed construction cost estimate covering all the work for which he has provided the design. This estimate is reviewed by the Estimates and Specifications Office and is subsequently used for the preparation of the official Engineer's Estimate and the Proposal Schedule to be included in the Contract Book.

The construction cost estimate to be submitted by the Consultant should be in a format similar to the sample illustrated in Figure 19—D. The following explanatory notes apply to these estimates:

1. Project Title and A. C. Project Code are as furnished by the Highway Authority.
2. Length in kilometers and in miles will be shown to three decimal places.
3. The project estimate will be subdivided by the following units of work as applicable:
   a. Roadway — where roadway construction on more than one numbered highway, other than incidental construction, is to be included in a single contract, then each such roadway is a separate unit. In most cases where a contract includes construction on more than one highway each will have a separate project number. The roadway items for interchanges are assigned to the highway identified by the project title and number.
   b. Each bridge size structure, those with opening in excess of 6.1 meters (20 Ft.) as per AASHTO definition, is a separate unit.
   c. Traffic control devices including signs, pavement markings and signals.
   d. Highway lighting.
   e. Rest areas, scenic overlooks and landscaping.
   f. Utility relocation work — each utility is a separate unit.

4. The Item No. will be the same as the item number appearing in the Summary of Quantities in the construction plans and as will appear in the Proposal Schedule.
5. The Class of Work will be as it will appear in the Proposal Schedule and in accordance with the wording in the basis of payment section in the applicable standard specification or special provision.
6. The unit price for each item will be as determined by the estimator and agreed upon with the Estimates and Specifications Office.
7. All pay items appearing in the Summary of Quantities in the construction plans shall also appear in the construction cost estimate. When a pay item appears in more than one unit in the construction cost estimate, the sum of the quantities for that item shall agree with the total shown in the Summary of Quantities.

The consultant shall also submit to the Highway Authority copy of the detailed quantity computation sheets in support of his estimate for major item such as excavation and embankment, pavement, structure items and structural concrete. When the quantities have been determined by the use of computer programs it will be satisfactory to submit copy of the computer printout.

The specifications for some pay items provide for more than one method of measurement and basis of payment. For example, Hot Plan Mix Bituminous Pavement, Standard Specification 401, may be measured and paid by the ton or by the square meter. Prior to computing the estimated quantity for such items, the consultant shall as-certain with the Highway Authority the method of measurement and payment that the Authority customarily prefers to use for such item for the particular type of project that the consultant is designing. For instance, the current practice of the Authority is to specify measurement and payment by square meter on projects when the hot plant mix bituminous pavement item consists of only one layer of hot plant mix surface course 2.5 centimeters or less in compacted thickness.

19–05.03 UNIT PRICES

The following guide lines apply to the estimating of unit prices for use in the construction cost estimates:

1. The basic guide for unit prices is the records of bid prices maintained by the Highway Authority. However, in using this bid price data the following factors must be considered and appropriate adjustment made:

a. The location of the project as compared to those for which bid price data is available.
b. The major classes of work included in the project and the type of prime contractor that will be likely to bid. For example, resurfacing projects are likely to be bid by specialized paving contractors while major projects including substantial amounts of earthwork, structural concrete and paving will most likely be bid by the larger general contractors.
c. The quantity of the item involved as compared to the bid price data.
d. Availability and location of material sources with respect to the project.
e. The expected date of letting and the estimated effect of inflationary trends.
f. The expected conditions of the construction market at the time of letting.
g. Special conditions present in the project which may affect the unit prices of certain items. For example, normal rates of production on some items may be reduced by special conditions such as limitations on working hours.

2. Many items will require a specific unit price analysis. Such analysis will consider the costs of labor, materials, equipment, incidentals, overhead and profit. In estimating overhead costs consideration must be given as to whether the contract will or will no include a pay item for Mobilization, Standard Specification 151, since the latter provides for direct pay for several items which would otherwise be considered under overhead costs.

3. The Engineer's Estimate does not attempt to predict the low bid but rather to arrive at a reasonable bid based on a realistic analysis of costs. Under good competitive conditions the bids submitted will normally range above and below the Engineer's Estimate and the unit prices for major items should approximate those previously determined by the estimator.

19—05.04 CONTRACT TIME

The Highway Authority contracts customarily specify the contract time allowed for completion of the work in terms of calendar days although occasionally working days may be specified.

Production rates used in determining allowable contract time are normally bases on 8 hours work days and 44 hours per week; legal holidays excepted. However, for projects where specific completion dates must be met, extra shifts or overtime may have to be considered in determining production rates and contract time. In such cases the bidders are warned of this condition in the special provisions includes in the contract book.

Care must be excersided in the determination of the contract time. A severe time requirement imposed upon a contractor will very probably be reflected in his bid prices and the Authority will be paying a premium on a particular project which may no be absolutely necessary. Also, since the General Provisions included in each contract provide for payment of liquidated damages by the contractor for failure to complete the project on time, it is very important that a reasonable contract time be allowed to alleviate possible differences between the contractor and the Authority. All contract time determinations will be based on a normal work day production rates unless specifically directed otherwise by the Director of the Design Area.

1. For large complex projects the contract time is determined by developing a schedule following the Critical Path Method (CPM). In developing the schedule, particular attention must be given to the sequence of construction operations to determine the order in which the work will progress and which items can be performed concurrently or will overlap. Other factors to be considered include:

a. Work to be done by others such as demolition of buildings and utility relocations.
b. Possible delays in clearing of the righ-of-way.
c. Days lost due to adverse weather.
d. Delivery of materials such as fabricated steel for structures.
e. Limitations on construction operations imposed by the specifications.
f. The magnitude of the project which will have a bearing on the size of the work force and the amount and type of equipment to be used by the contractor to attain economically desirable productions rates.

2. For the smaller, simpler projects a CPM schedule is not required. For such projects a bar diagram schedule will be satisfactory. However, the same factors affecting the scheduling of more complex projects will have to be considered.

3. Figure 19—E shows a format used by the Estimates and Specifications Office to compute contract time for simple projects. The following remarks apply to the use of this form:

a. Under Item I the work items covering the construction operations are considered in normal sequence with provision for overlapping and concurrent performance. Average rates of work consistent with the size and type of project are used. Total working days required are thus obtained and shown in Item II.
b. Item III provides for converting from working days to calendar days. The "K" factor to be used for different locations through-out the Commonwealth are shown on Table 19—3. This "K" factors have been developed taking into consideration: the average number of non-working rain days at each location, non-work holidays, and that only 5 1/2 working days per week are available under normal working conditions.

c. Item IV provides an allowance for additional time required for laboratory testing of materials. This allowance will depend on the type of construction project bu normally 30 days are allowed.

d. Item V provides for the consideration of special factors that may affect the duration of the work in a particular project such as delay in availability of portion of the right-of-way, delivery of certain materials, settlement time requirements on surcharged embankments, maintenance of traffic requirements, utility work by others, etc.

Consultants preparing construction plans for the Authority are required to submit a contract time analysis. The type of analysis required will depend on the complexity of the project and will be as agreed upon with the Authority for each projects. The principles covered above will apply. The daily production rates proposed to be used shall be submitted for review and approval by the Authority prior to developing the contract time analysis.

19 06 CONTRACT BOOK

The Contract Book is the book furnished by the Highway Authority to prospective bidders to be used for the submission of proposals. Upon award to a successful bidder, the Contract Book is used to execute the contract between the Highway Authority, represented by the Executive Director, and the contractor.

The Contract Book is normally assembled by the Estimates and Specifications Office of the Design Area after reviewing the plans, estimates, and special provisions submitted by the designer.

The Contract Book is composed of the following items which are incorporated in the book in the same order as listed:

1. COVER — The Highway Authority has a standard format for the cover. For projects designed by consultants this cover is furnished by the Estimates and Specifications Office.
2. ADDENDUMS — Any addendums issued subsequent to the publication of the original contract book are subsequently incorporated as part of the book.
3. TITTLE PAGE — Includes the title of the project, the road number, the beginning and end stations, the municipality where located, the H.A. code number and the Federal aid project number is applicable.
4. TABLE OF CONTENTS — Listing of all the documents includes in the book and the pages in each set.
5. AUTHENTICATION PAGE — Page identifying the project and indicating the officials and dates when the contract book was submitted, recommended and approved.
6. MEMOIR — Page identifying the project and summarizing the work include under the contract. The sources of financing are indicated on Federal-aid projects.
7. ADVERTISEMENT — Copy of the advertisement(s) for bids to be published.
8. REQUIRED CONTRACT PROVISIONS, FEDERAL-AID CONSTRUCTIONS CONTRACTS — The latest edition issued by the Federal Highway Administration of these required provisions (Form PR-1273) is used. These cover Federal requirements on equal employment opportunity, non-segregation of facilities, payment of predetermined minimum wages, records of materials an labor cost, subletting or assignment of the contract, safety and accident prevention, false statements, and implementation of the Clean Air Act. Also included are:
   a. A listing of the applicable minimum wage rates by job classifications issued by the U. S. Secretary of Labor.
   b. Sample certification on non-discrimination in employment to be submitted by the bidder.

TABLE 19–3

"K" FACTORS FOR CONTRACT TIME ESTIMATES

LOCATION	K
Adjuntas 2 N	1.79
Adjuntas (Garzas Dam)	2.31
Aguada (Coloso)	2.08
Aguadilla (Calero Camp)	1.86
Aguadilla (Ramey Air Force Base)	1.86
Aguirre	1.72
Aibonito	1.87
Arecibo 2 ESE	2.02
Arecibo (Cambalache Exp. Forest)	1.51
Arecibo (Los Caños)	1.80
Arroyo (Yaurel 3 NNE)	2.00
Barceloneta 2 NNW	1.78
Barranquitas	2.07
Bayamón (Hato Tejas)	2.19
Cabo Rojo	1.70
Cabo Rojo (Puerto Real)	1.74
Caguas	2.02
Canovanas 2 N	2.36
Cayey	1.92
Cayey (Jajome Alto)	2.23
Cataño	2.22
Cidra 3 E	1.83
Coamo Dam	1.58
Comerío Falls	2.20
Corozal	2.22
Culebra Island	1.58
Dorado 4 W	2.29
Ensenada	1.57
Fajardo IE	2.23
Fajardo (Paraiso)	2.18
Guánica (Santa Rita)	1.54
Guayama	1.90
Guayama (Carite Camp Tunnel)	2.58
Guayama (Josefa)	1.85
Guayama (Plant 1)	2.30
Guayama (Melania Dam)	1.61
Guayama (Sabater)	1.69
Guayanilla	1.54
Guayanilla (Central San Francisco)	1.55
Gurabo	1.97
Humacao I SW	2.78
Humacao (San Cristobal)	2.20
Isabela 4 SW	2.03
Isabela (Moca Camp)	1.96
Jayuya	1.92
Juana Díaz Camp	1.75
Juana Díaz (Guayabal Reservoir)	1.83
Juana Díaz (Potala)	1.58
Juana Díaz (Río Cañas)	1.67
Juncos I E	2.03
Lajas	1.74
Lares	2.27
Manatí	2.01
Maricao	2.10
Maricao (Fish Hatchery)	2.28
Maricao (Indiera Baja)	2.19
Maunabo I SW	1.72
Mayagüez	2.19
Moca (Aceituna)	1.95
Mona Island	1.63
Morovis	2.11
Naguabo 6 W	2.34
Naguabo (Rio Blanco 500)	3.21
Naguabo (Río Blanco 1,800)	5.18
Orocovis (Matrullas Dam)	2.54
Patillas Dam	2.19
Peñuelas Salto Garzas	2.00
Ponce	1.62
Quebradillas	2.04
Quebradillas (Guajataca Dam)	2.25
Rincón 2 NNW	1.93
Río Grande El Verde	2.51
Río Piedras	2.24
Salinas (Río Jueyes)	1.63
San Germán	1.80
San Juan WB Airport	2.09
San Juan WB City	2.03
San Lorenzo Espino	2.56
San Sebastián	2.24
Santa Isabel 3 NW	1.57
Toa Baja Constancia	2.10
Trujillo Alto (Saint Just)	2.11
Utuado	1.92
Utuado (Caonillas)	2.07
Utuado (Dos Bocas)	2.13
Vieques Island Esperanza	1.85
Villalba 2 N	2.20
Villalba (Caonillas)	1.98
Villalba (Toro Negro Reservoir)	2.49
Villalba (Guineo Reservoir)	2.58
Yabucoa I NE	2.43
Yauco	1.54
El Yunque (La Fe)	2.40

c. Sample of Form PR-1391, "Federal-aid Highway Construction Contractors Monthly EEO Report."
d. Certification form regarding Executive Orders Nos. 10925, 11114 and 11246.

9. MANDATORY DECREE NO. 44 — The latest issuance of this decree on minimum wages applicable to the construction industry as promulgated by the Minimum Wage Board of the P. R. Department of Labor.

10. INSTRUCTIONS TO BIDDERS — These are special instructions to bidders not otherwise covered by other contract documents. These generally include, but are not limited to, such items as:

a. Labor and wage requirements not covered elsewhere.
b. Non-Collusion affidavit.
c. Insurance requirements.
d. Restrictions on advertising signs.
e. Noise and dust control.
f. Work to be done by utilities.
g. Submission of CPM schedule.
h. CIAA stamps.
i. Call bidders attention to any recent changes in General Provisions.

Care should be taken not to include under these special instructions items or requirements that should more properly be shown on the plans or covered by special provisions.

11. ENVIRONMENTAL COMMITMENTS — Applicable to Federal-aid projects only. This is a listing of special measures to be taken by the contractor and the Highway Authority during the construction of the project to minimize air, noise and water pollution, as indicated in the Environmental Statement for the project submitted by the Highway Authority and approved by the Environmental Quality Board.

12. GENERAL PROVISIONS — Section 100 of the H. A. Interim Standar Specifications covering the general provisions of the contract are being included in full in each book until such time as these are definitely adopted and printed in book form.

13. SPECIAL PROVISIONS — Special provisions applicable to the particular project.

14. INTERIM STANDARD SPECIFICATIONS Includes the Interim Standard Specification applicable to each direct pay item included in the proposal schedule for the particular project. These are being included until such time as the standard specifications are definitely adopted and printed in book form.

15. COMPLEMENTAL STANDARD SPECIFICATIONS — Includes all the interim non-pay item standard Specification which are referred to in and complemental the standard specification covering pay items includes in the proposal.

16. BID BOND — The standard bid bond format of the Highway Authority to be execute by bidder and a surety company.

17. PROPOSAL SCHEDULE — Standard schedule listing all contract pay items to be completed by the bidder. For each item the following information is shown:

a. Item number.
b. Specification number.
c. Item code number.
d. Approximate quantity.
e. Unit of measurement.
f. Item title with space for bid unit price to be filled by bidder in words.
g. Unit price to be filled by bidder in figures.
h. Total amount bid to be filled by bidder.

18. STATEMENT OF THE BIDDER — Standard format to be completed by the bidder covering his address, financial statement, equipment he has available, equipment to be purchased, previous similar contract completed, contract currently on hand, description of his organization, person(s) to supervise the work, and proposed construction methods.

19. CONTRACT — Standard contract form to be executed by successful bidder after award of contract.

20. PERFORMANCE BOND — Standard performance bond format to be executed by sucessful bidder and a surety company prior to executing project contract.

21. PAYMENT BOND — Standard payment bond format to be executed by the successful bidder and a surety company prior to execution of the project contract.

19—07 STANDARD MODELS

Standard Models are drawings of frequently used construction items which have been standardized by the Design Area of the Highway Authority for general use on highway improvement projects.

The designer should use these standard models wherever applicable in preference to special designs. The current practice of the Highway Authority is to list in the index all the standard models applicable to a project and to include these in the construction plans set. However, when only one or two of the several items that are detailed on a standard model are applicable to a project, it may be preferable to include these particular details in the appropriate project plan sheets rather than including the complete standard model for an additional plan sheet.

NO.	TITLE AND DESCRIPTION
PROTECTION BARRIERS	
1	Corrugated Steel Beam Guard Rail (Strong Post Typical Installation) covers details of the corrugated metal beam type guard rail including post and end treatments.
1A	Corrugated Steel Beam Guard Rail (Strong Post Typical Installation) Covers details of the installation of corrugated steel beam type and ends of structure including end anchors.
1A—1	Typical Installation of Guard Rail (Strong Post)
IB	Corrugated Steel Beam Guard Rail Median Barrier Installation — (Strong Post)
1C	New Jersey Type Concrete Median Barrier Details Covers details of the New Jersey type concrete barrier curb including details of end treatment, pedestrian openings and lighting pole installation.
1D	Retaining Wall Covers details of rubble concrete retaining walls varying in height from 1.00 to 6.00 meters.
FENCES	
2	BARBED WIRE FENCE Covers details of three standard types (A, B and C) of barbed wire fence including details of posts.

2A WIRE MESH FENCE
Covers details of standard wire mesh fence including fittings and gate.

2B WIRE MESH FENCE FOR CONTROL OF ACCESS
Covers details of standard wire mesh fence using steel wire rope cable in lieu of top rail pipe.

SIGNS AND MARKERS

3 KILOMETER AND HECTOMETER POSTS
Covers details of standard metal type KM and HM marker including details of posts and placement.

3A KILOMETER AND HECTOMETER POSTS
Same as Model 3 but includes also details of the Federal aid project markers. For use on FA projects only.

3D-1
3D-2 CONSTRUCTION WARNING SIGNS
Two sheets covering details of the plates and messages of the most commonly used construction warning and regulatory signs.

3D-3
3D-4 WARNING SIGNS
Two sheets covering details of the plates and messages of several warning and regulatory signs not included in the DTPW Traffic Signs Manual.

3E MOUNTING DETAILS FOR SMALL SIGNS — SINGLE POST
Covers the installation of single signs and sign assemblies on single post including details of the steel channel type post.

3E-1 MOUNTING DETAILS FOR SMALL SIGNS — TWO POSTS
Covers the installation of single signs and sign assemblies requiring two posts.

3E-2 MOUNTING DETAILS FOR SMALL SIGNS — BREAK—AWAY POST
Covers the installation of single signs or sign assemblies on two break-away posts. Includes detail of steel I posts and break-away features.

3E-3
3E-4
3E-5 MOUNTING DETAILS FOR DESTINATION AND DISTANCE SIGNS
Three sheets covering complete details on the installation of large destination signs on two or three break-away posts. Includes details of posts, break-away features, hardware an foundations.

3E-6 CANTILEVER SIGN SUPPORT
Covers details of cantilever steel pipe sign support of the break-away and non break-away types for use in special conditions of restricted space.

3E-7 SIGN BRACKETS — TYPES "A" AND "B"
Covers details of special steel brackets to be used for small signs mounting where on offset position is required.

DRAINAGE

4 CURB INLET
Covers details of standard curb opening type inlet with appron.

4A GRATE INLET FOR MEDIAN OR SIDE DITCH

4A-1 GRATE INLET FOR MEDIAN
Similar to Model 4A but drop type on 18 R. C. pipe.

4B GRATE INLET
Covers grate inlet for use at curbed roadside. Includes details of grate.

4C GRATE INLET UNDER CONCRETE BARRIER CURB

4D INLET AND/OR OUTLET FOR PIPE CULVERT
Covers details of tapered end sections for R. C. pipes.

4E HEADWALLS TYPES "A" & "B"
Covers details of standard R. C. headwalls for single and multiple (up to 3) pipe culverts.

4F MANHOLE TYPE "A"
Details of standard R. C. manholes for pipe sizes up to 72" in diameter.

4F—1 MANHOLE TYPE "B"
Details of standard manholes with grate inlet for pipe sizes up to 96" in diameter.

4F—2 PRECAST CONCRETE MANHOLE
Details of standard precast concrete manholes, 48" and 60" in diameter.

4G COMBINATION CONCRETE CURB, GUTTER AND SPILLWAY
Details of standard 18" diameter half-section pipe spillway.

4H SLOTTED DRAIN DETAIL
Covers details of special longitudinal narrow grate for use with C.M. pipe.

FIEL OFFICES AND/OR LABORATORIES

5A FIELD OFFICE TYPE "A"
Details of the 10' x 16' field office building Type A described in Standard Specification 611.

5B FIELD LABORATORY TYPE "B"
Details of the 11 1/2' x 12' field laboratory building Type B.

5C FIELD LABORATORY TYPE "C"
Details of the 10' x 16' field laboratory building Type C.

5D FIELD OFFICE AND LABORATORY TYPE "D"
Details of the 12' x 22' combined field office and laboratory building Type D.

5E FIELD OFFICE AND LABORATORY TYPE "E"
Details of the 11 1/2' x 12' combined field office and laboratory building Type E.

SAFETY

6 WHEELCHAIR RAMP — TYPICAL LOCATION AND DETAILS

HIGHWAY LIGHTING

7A ALUMINUN LIGHTING POLES
Details of aluminum light standard for 30 Ft. mounting heights including foundations, bases, service pedestals, bracket arms and wiring.

7B STEEL LIGHTING POLES
Similar to 7A but for steel poles.

7C CONCRETE LIGHTING POLES
Similar to 7A but for reinforced concrete poles.

7D HIGH MAST LIGHTING POLES
Details of 80 Ft. tapered steel poles for high mast illumination including foundations, bases, luminaire clusters and wiring.

7E—1 LIGHTING SUBSTATION —POLE MOUNTED
Details of pole mounted substations for lighting circuits.

7E—2 LIGHTING SUBSTATION — PAD MOUNTED
Details of pad mounted substations for lighting circuits.

7F LUMINAIRE DETAILS
Details of various types of luminaires for use with conventional poles, high masts and at underpasses.

19—08 STANDARD TYPICAL SECTION SHEETS

The Design Area has developed a set of standard typical cross section sheets for certain road classes. These standard sheets are available to the designer for incorporation in the project plans. However, it is the responsibility of the designer to review the application of the details and notes shown on these standard sheets to his particular project and to make such revisions and additions as may be required for each individual project.

In addition to the typical road cross sections, these sheets include tables of superelevation, curve widening, cut and fill slopes; important notes; and details of concrete gutters, automobile entrances, protection ditches, curb and gutters, and right-of-way markers.

The following are the standard typical section sheets currently available:

T.S. A—2	For two—lane roads with a pavement width of 7.30 meters and 3.00 M. paved shoulders.
T.S. B—1 T.S. B—1 (AUX.)	For secondary two—lane roads with a pavement width of 6.10 meters and 1.75 M. paved shoulders.
T.S. B—2 T.S. B—2 (AUX.)	For secondary two—lane roads with a pavement width of 5.50 meters and 1.25 M. paved shoulders.
T.S. C—1 T.S. C—1 (AUX.)	For municipal two—lane roads with a pavement width of 4.90 meters and 1.25 M. paved shoulders.
T.S. C—2 T.S. C—2 (AUX.)	For municipal roads with a pavement width of 4.00 meters and 1.25 M. paved shoulders.

CHAPTER 20

COMPUTER PROGRAMS

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20—02	Installation Description	1
20—03	Computer Programs	1

COMPUTER PROGRAMS

INTRODUCTION:

The design process today requires large amount of information that must be collected, sorted, stored, organized in logical form, processed and retrieved in a presentable manner. Engineering computations require a great amount of data handling, mathematical operations and graphical representations which may be extremely difficult to do without the aid of a powerful computer.

To implement the manipulation of respective computations there are other advantages obtained through the use of computers such as:

1) The use of powerful programs which assist in the solution of specific problems.
2) Ability to create files for the storage and manipulation of specific project data.
3) The capacity of preparing graphic representations through the use of a plotter.
4) Rapid exchange of information is possible through the use of telecommunications network.
5) The use of interactive communications on rented time makes possible for government agencies and private offices to have access to a powerful tool for a very economical cost.

INSTALLATION DESCRIPTION

The Puerto Rico Highway Authority Information and System Center operates a powerful computer facility designed to handle scientific, engineering, mathematical, and commercial applications for the various Departments, Agencies and Public Corporations of the Commonwealth of Puerto Rico and for Private Users too. This Center operates very much like a Service Bureau, located in the basement of the Minillas South Building at Santurce, Puerto Rico.

The Information and System Center is equipped with an Honeywell-Multic 68 level computer with two (2) million of real core capacity and virtual storage. The Center also maintains magnetic tape equipment, direct access external storage devices, card readers and punches, high speed printers, and teleprocessing equipment. The Center operates Multics interactive mode, an innovation in computer technology that refers to the simultaneous utilization of the computer system by multiple users operating in real time, conversational mode.

More information can be obtained from the Operational Systems Office with the telephone number 726-6840.

COMPUTER PROGRAMS

In order to have an effective control of the expenditure of the Department of Transportation and Public Works resources in the design and construction of transportation facilities. The designer must become familiar with available computer programs. The following computer program descriptions are published for the guidance of the designers.

PROGRAM	DESCRIPTION	STATUS	REMARKS
ELOISA	Snyder method for hydrologic computations.	Operational	Developed by Engineer Martínez Alfonso
PREST	Pre-stressed structures	Operational	Adapted from a Portland Cement Association Program
TABS	Structural dynamic analysis	Operational	Developed by the University of California
BACKWTR	Stage elevations of water surface.	Operational	Developed by the Federal Highway Administration
HEC 1	Watershed hydrologic calculation using various convenient options.	Operational	Developed by the U.S. Corps of Engineers
HEC 2	Water surface profiles for critical and supercritical flows.	Operational	Developed by the U.S. Corps of Engineers
TR20	Watershed hydrologic calculations using various options.	Operational	Developed by the U.S. Soil Conservation Service
WSP2	Water surface profiles (subcritical flow).	Operational	Developed by the U.S. Soil Conservation Service
MITCAT	Catchment model —a very wide scope package with numerous convenient options as routing through lakes and pipes.	Operational	Developed by M.I.T.
COGO	For the solution of civil engineering geometric problems which entail manipulating such objects as points, lines, curves, alignments, traverses, profiles and general chain like objects.	Operational	Honeywell AH94-A, Rev. 1
STRESS	For the solution of structural engineering problems. May be used to perform preliminary and exact analysis of two or three dimensional framed structures.. Members and joints may be rigidly connected or pinned.	Operational	
RDS	Roadway analysis and design systems used in the solution of problems involving the location and design of almost any type of roadway. The basic system frame work and a majority of the computer routines are applicable to	Operational	Federal Highway Administration

PROGRAM	DESCRIPTION	STATUS	REMARKS
	a wide range of civil engineering problems requiring the excavation and embankment of materials, including railroads, waterways, and dykes.		
PMCS	Project Engineering Control for assisting in project planning and control in two major areas: (1) Scheduling via network and extranetwork representation and (2) Information handling for cost and resources projections for cost and progress reporting.	Operational	Honeywell: Project Management and Control System. DD59 Rev. 0
JSLAB	Analysis and design of concrete slab bridge in tabulated form.	Operational	Developed by Engineer Jorge Acevedo
ABEAM	Analysis and design of post-tensioned AASHTO Beam according with standard specifications for Highway Bridges adopted by the American Association of State Highway and Transportation Officials, tenth edition, 1969.	Operational	Developed by Engineer Jorge Acevedo
AASHBEAM	Analysis and design of post-tensioned AASHTO Beam according with standard specifications for highway bridges adopted by the American Association of State Highway and Transportation Officials, eleventh edition, 1973.	Operational	
OPTIBEAM	Optimization of Post-Tensioned AASHTO Beam according with standard specifications for highway bridges adopted by the American Association of State Highway and Transportation Officials, eleventh edition, 1973 (Research).	Operational	Developed by Engineer Jorge Acevedo
HYDRA	Hydraulics computations of bridge waterways for subcritical and super-criticals flows, determing backwater, embankment protection, spur dike necessity and expected scouring for piers and abutments.	Operational	Developed by Engineer Jorge Acevedo

PROGRAM	DESCRIPTION	STATUS	REMARKS
ASHOBM 75	Analysis and design of post-tensioned AASHTO Beam according with standard specifications for highway bridges adopted by the American Association of State Highway and Transportation Officials, Interim Specification 1975.	Testing Process	Developed by Engineer Jorge Acevedo
DISWATER	Hydrologic computations for small watershed to Puerto Rico.	Operational	Developed by Engineer Juan Virella
PILAPENA	Computer design of wall piers	Testing Process	Developed by Engineer Alejandro de la Peña
JOSE	Analysis and design of Cantilever Slab over AASHTO Beams.	Testing Process	Developed by Engineer José Caballero
BROWN	Hydraulic analysis including backwater for bridge waterway.	Operational	Adapted from Federal Highway Administration
CONBEAM	Analysis and design of continuous beams.	Operational	Adapted from Dept. of Transportation of California
PREBEAM	Analysis and design of Pre-tensioned beams.	Operational	Adapted from Dept. of Transportation of Texas.
OMNITAB	Program for statistical and Numerical Analysis. Consist of over 100 subroutines written in FORTRAN Language.	Implementation Process	Developed by the IOWA State University.
BMD	Biomedical Computer Program (X—Series Supplement) perform data processing and statistical tasks.	Implementation Process	Developed by the University of California.
ECASYM	Solution of system of equations.	Operational	Developed by Engineer Martínez Alfonso
SPSS	Statistical Package for the Social Sciences.	Operational	Reference: SPSS Manual 2nd. Edition Norman H. Nie
TSS	Multics time sharing system library. The TSS library system contains several object subprogram that can be use to solve problem in areas like mathematics, statistics, optimization, geometric on plotting.	Operational	Reference: Multics TSS library user's guide.

PROGRAM	DESCRIPTION	STATUS	REMARKS
EVACOST	Statistical studies of unit price for items involving in highway project.	Operational	Developed by Engineer Jorge Acevedo.
ESTADO	Computer monthly report for projects developed by Structural Design Office.	Operational	Developed by Engineer Jorge Acevedo.
TABLAS	Computer monthly report for projects developed by Structural Design Office in tabulated form.	Operational	Developed by Engineer Jorge Acevedo.
ESTUCAM	Computer monthly report for projects in process by Field Study Office.	Operational	Developed by Engineer Jorge Acevedo.
ACTPLAN	Computer report for projects in base Action Plan for the Structural Design Office.	Testing Process	Developed by Engineer Jorge Acevedo.
CALINE 2	Calculates downwinds concentrations of only carbo monoxide (CO) resulting from emission generated on the highway.	Operational	Developed by the California Dept. of Transportation.
NOISE 2	This program computes in a period of time of one (1) hour, the noise levels L(10) and L(50) produced by motors vehicles in highway.	Operational	Developed by Federal Highway Administration.
MOBILE 1	This program computes emissions of pollutants from motor vehicles, factors and methodology promulgated by the United State Environmental protections Agency (EPA).	Operational	

CHAPTER 21

ADMINISTRATIVE PROCEDURES FOR PROJECTS DESIGN

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CHAPTER 21

ADMINISTRATIVE PROCEDURES ON PROJECTS DESIGN

21—01 DESIGN CONTRACT PREPARATION

After awarding a design contract a Project Manager is assigned. The Project Manager is responsible for obtaining a copy of the contract and the correspondence files on the project for detailed study.

After studying the documents of the project, the Manager coordinates a meeting between the Consultant and himself. In this meeting there is an exchange of information and the ground rules for the monitoring of the contract are established.

21—02 CORRIDOR PRELIMINARY

The Project Manager is responsible for verifying that there is a written approval from Planning Area for the corridor and approval from the FHWA. The Manager should ensure that there are available on file the social, economic and environmental studies for this corridor stage. If any of the above approvals are missing the Project Manager will coordinate the necessary waiver, if applicable, from the Planning Area.

There must be a R.O.W. report at this stage. The Property Acquisition and Management Area must supply this report. If it is missing the Project Manager must request the same from the Property Acquisition and Management Area or a waiver from the report requirement.

21—03 ROUTE LOCATION

The Project Manager must verify that there is a Draft Environmental Statement prepared and that the FHWA has concurred with it. There must be a P. R. Planning Board Clearing House Approval on file. The Manager must verify that there is an FHWA approval of the route location and authorization to proceed with the design.

21—04 PRELIMINARY DESIGN

If any of the requirements mentioned in the Corridor and Route Location Stage have not been complied with the Project Manager is responsible for notifying the Director of the Design Area in order to obtain the necessary guidelines to follow in the applicable case. All the items in the previous phases should be in strict accordance with the P. R. Highways Authority Action Plan. If a requirement has not been met there must be a written waiver for the requirement or action must be initiated to comply with the requirement.

The Project Manager must verify that the Consultant has the traffic data and that a capacity analysis is done to verify that the correct standards are used for the design.

The Project Manager in coordination with the Consultant will determine the type of surveying data required for the project. The scope of work for the surveying crew is determined and the Project Manager will verify if our in-house Photogrammetric Office can perform the work or if it has to be let out for contract.

The Project Manager in coordination with the Consultant will determine what type of soil and geological data is required for this preliminary phase. The scope of work is determined and the Manager verifies if our in-house Soils Office can perform the work or if it has to be let out for contract.

The Project Manager in coordination with the Consultant will determine what kind of utilities will be involved in the project and what type of field work be necessary. The Manager will be responsible for verifying if our in-house Utilities Office can perform this phase of the design and field work or if it has to be let out for contract.

The Project Manager will ensure that the Consultant provides the structural design criteria and cost analysis and will submit the information to the Structural Design Office for verification and approval. Structural plans must be approved by the Structural Design Office.

The Project Manager will verify that all work related to the highway geometrics and other design work is done according to the standards set forth in the P. R. Highways Authority Design Manual and other technical publications.

The Project Manager will ensure that the Consultant determines the R.O.W. limits in the preliminary phase and includes the names of owners of record in the plans.

The Project Manager will ensure that the Consultant investigates in all Government Agencies if there is any private or public project, in the vicinity of the proposed road, that will affect the roadway design.

The Project Manager will ensure that a sufficiently detailed progress report is prepared and approved from the beginning of the design contract starting date. Before any invoice is processed for payment the Manager will visit the Consultant's Office and verify that the invoice is in accordance with the progress achieved. It will be a responsibility of the Project Manager to visit a Consultant approximately twice a month to verify the progress of the design work and to prepare a written report of each visit.

The Project Manager will coordinate an provide the D.T.P.W. "Unidad de Consultas" with information on the individual cases presented by the public and affected by the projects under design by Consultants.

21—05 ADMINISTRATIVE PRELIMINARY DESIGN APPROVAL

During the Final stage of the preliminary design the Project Manager will provide the FHWA with all the design information required for FHWA approval of the preliminary set of plans. Before the final approval of the preliminary plans by the FHWA the results of the design public hearing must be summarized and action taken on the adverse comments. After the preliminary plans are finished and the public hearing has been held the Project Manager will ensure that the FHWA approval is granted. A set of preliminary plans should be sent to the Construction Area for their comments before the final approval of the preliminary plans is granted to the Consultant. The Project Manager will ensure that the endorsement of the applicable Design Offices in the Design Area is obtained before final approval.

21—06 FINAL DESIGN

During the final design stage the Project Manager will ensure through periodic visits that the Consultant is following established guidelines and provides in the drawings enough information about the following items: surveying, soil and geological data, environmental data, hydraulics and drainage, highway geometrics, structural, utilities and traffic controls.

The Project Manager will ensure that the final Land and Property Acquisition Plans are prepared within the time frame specified in the contract. The Property Acquisition and Management Area has to review the complete set of plans and after their review the Consultant will make the necessary corrections. The FHWA has to review the plans and approved the same. The Project Manager will coordinate the complete process.

Detailed cost and quantity estimates must be prepared by the Consultant and must be reviewed by the Office of Estimates and Specifications before the Project Manager can process the Final Construction Cost approval.

Depending on the contract requirements the Project Manager will ensure that the Consultant prepares a complete set of specifications and special provisions for the particular project.

During the final design stage the Consultant will proceed with the final coordination with the applicable Agencies and the Project Manager will ensure that any Government project affecting the highway design has been considered. The Project Manager will supply "Unidad de Consultas" on a per case basis with the required information on the final design.

21—07 FEDERAL HIGHWAY ADMINISTRATION AND PRHA-FINAL DESIGN APPROVAL

The Project Manager will submit the FHWA a complete set of plans, specifications and estimates for their approval. In addition to the FHWA approval the necessary in-house coordination must be complied with before Final Design Approval is granted to the Consultant.

A complete set of the Final Land Acquisition Plans will be sent to the FHWA for their approval. The Project Manager will coordinate all the required actions required to obtain the FHWA approval.

21—08 DESIGN LIQUIDATION PHASE

The Project Manager will process the approval of the final construction cost after the necessary internal coordination has been made.

After the approval of the final construction cost the CIAPR* Stamps must be provided by the Consultant when applicable.

The final invoice for the retainage can be processed after the necessary contract requirements like auditing, etc. have been complied with.

The Project Manager will supply the PRHA Offices with any required information once the design contract has reached this stage.

21—09 CONSTRUCTION PHASE

The Project Manager will attend, when required, contract award meetings and provide the Construction Area with any additional information required.

The Project Manager will assist the Construction Area with any design problems arising during the construction process.

*CIAPR — Institute of Engineers and Surveyors of Puerto Rico.