CHAPTER 8

TRAFFIC BARRIERS AND FENCING

CONTENTS

CONTENTS

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES

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 National Cooperative Highway Research Program (NCHRP) Report 118, published in 1971, updated and superseded previous NCHRP reports and extended scope of coverage to all types of traffic barriers.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.

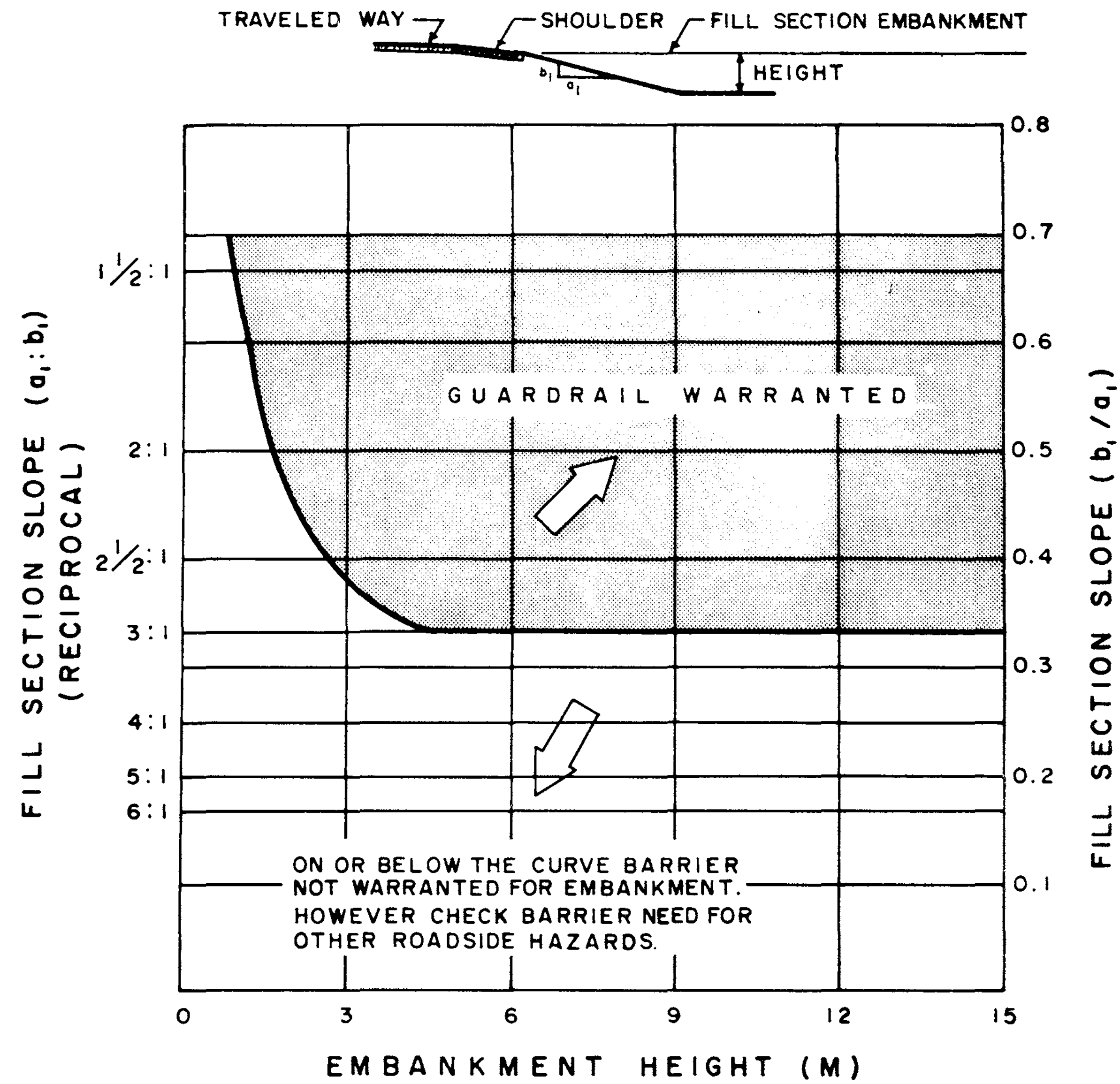
Figure 8—F outlines the procedure to follow to determine roadside barriers needs for fill and cut sections and roadside obstacles. The procedure should be followed for each roadside hazard until barrier need is established.

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.

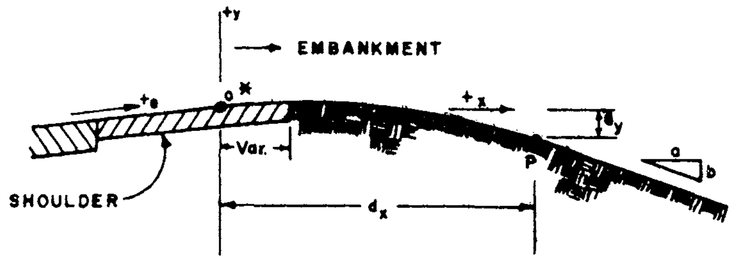
A transition section is warranted when there is a significant change in the lateral strength or lateral stiffness of a roadside barrier.



WARRANTS FOR FILL SECTION EMBANKMENTS.

FIGURE 8-A

* NOTE: BEGINING OF ROUNDING MAY BE WITHIN SHOULDER WIDTH, IF DESIRED, PROVIDED SLOPE OF SHOULDER DOES NOT BECOME EXCESSIVE.



ROADSIDE ELEVATION

EQUATIONS

	Metric	
$y = x\left[e - \frac{6.9x}{V^2\sin^2\phi}\right]$ $0 \le x \le d_x$	$y = x\left[e - \frac{2.1x}{V^2\sin^2\phi}\right]$ $0 \le x \le d_x$	(III-A-1)
$d_x = \frac{V^2\sin^2\phi}{13.8}\left[e - \frac{b}{a}\right]$	$d_x = \frac{V^2\sin^2\phi}{4.2}\left[e - \frac{b}{a}\right]$	(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

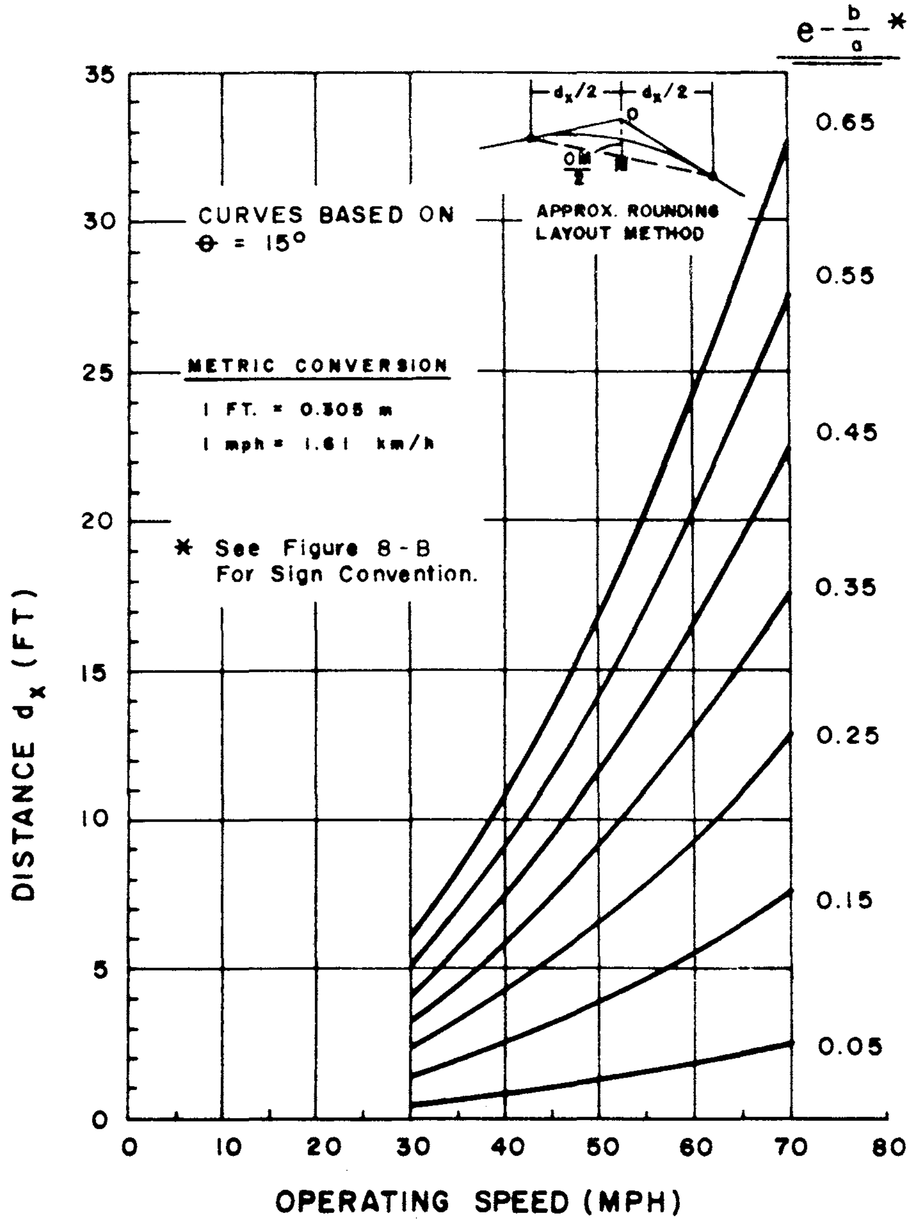
ϕ = vehicle encroachment angle (deg), or the angle between vehicle heading and tangent to roadway.

"O" = shoulder slope tangent point, and origin of x-y axis.

"P" = side slope tangent point.

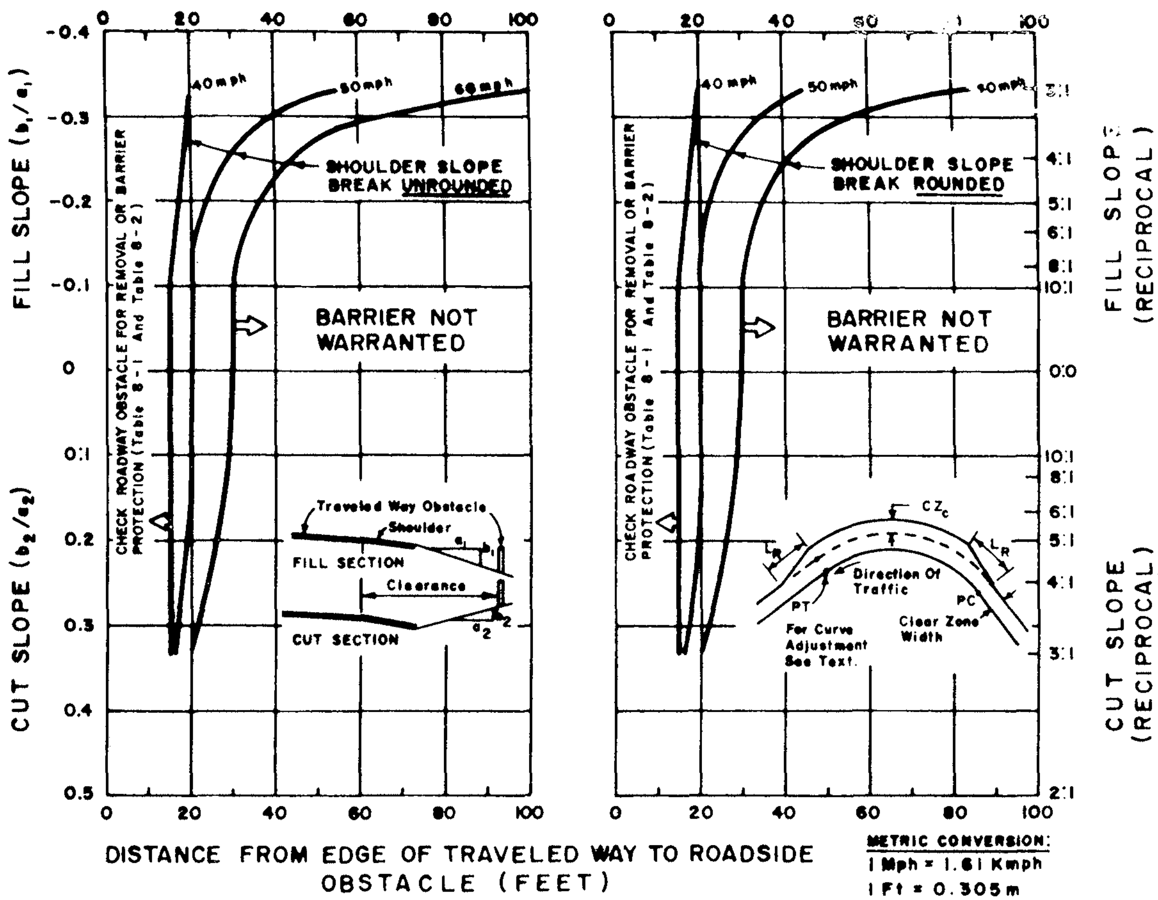
ROUNDING PARAMETERS AND EQUATIONS.

FIGURE 8-B



LATERAL ROUNDING DISTANCE, d_x, VERSUS OPERATING SPEED.

FIGURE 8-C



$CZ_c = R\left(1 - \cos \frac{L_R D}{100}\right)$

(Side Slope - 0:1 Or Flatter)

D = Degree Of Curve

R = Radius Of Curve

L_R = Runout Length

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

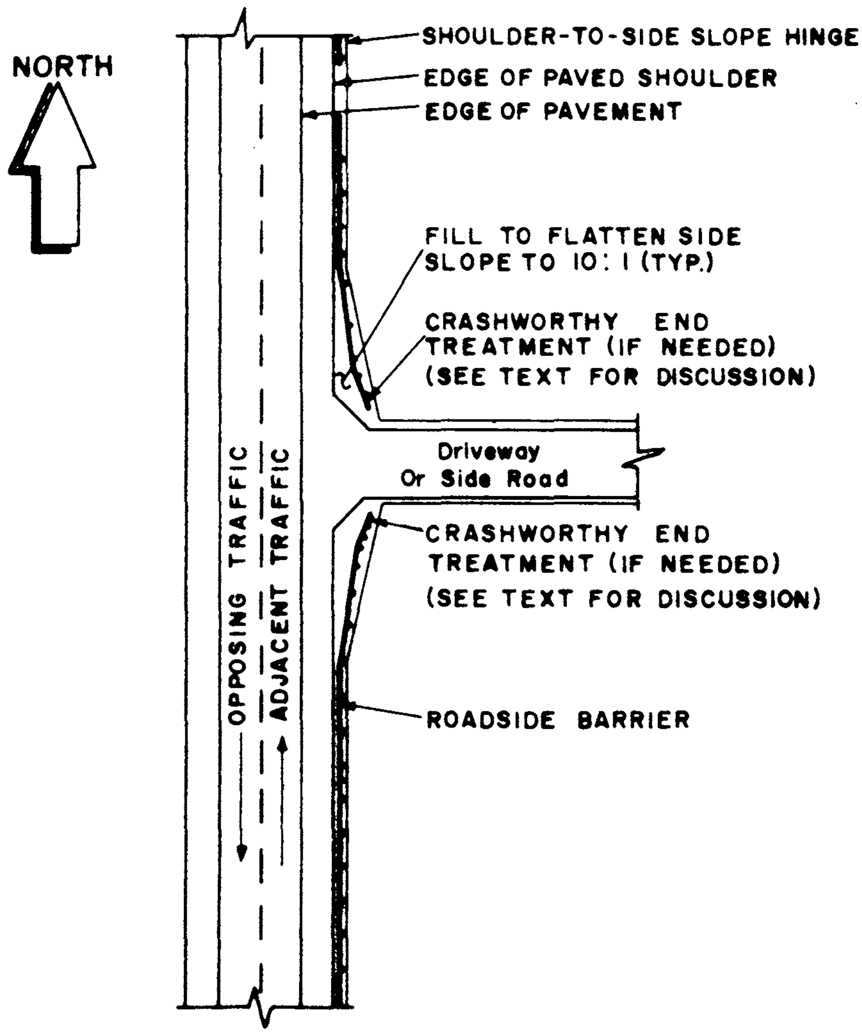
[1]All Roadside Obstacles Within The Clear Zone Should Be Removed If Possible, Otherwise Provide Barrier Protection.

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)	Shy Line Offset-Ls (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 **

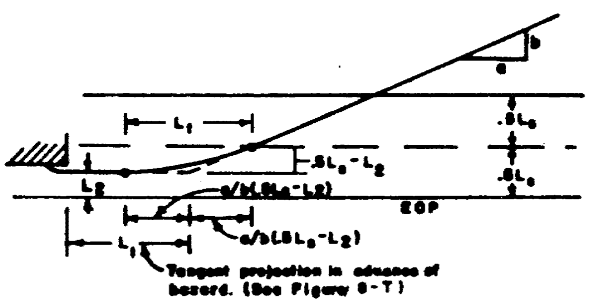
*When $L_2 < .5L_s$, L_1 shall have a minimum length = $\frac{2a}{b}(.5L_s - L_2)$

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 illustrated 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.

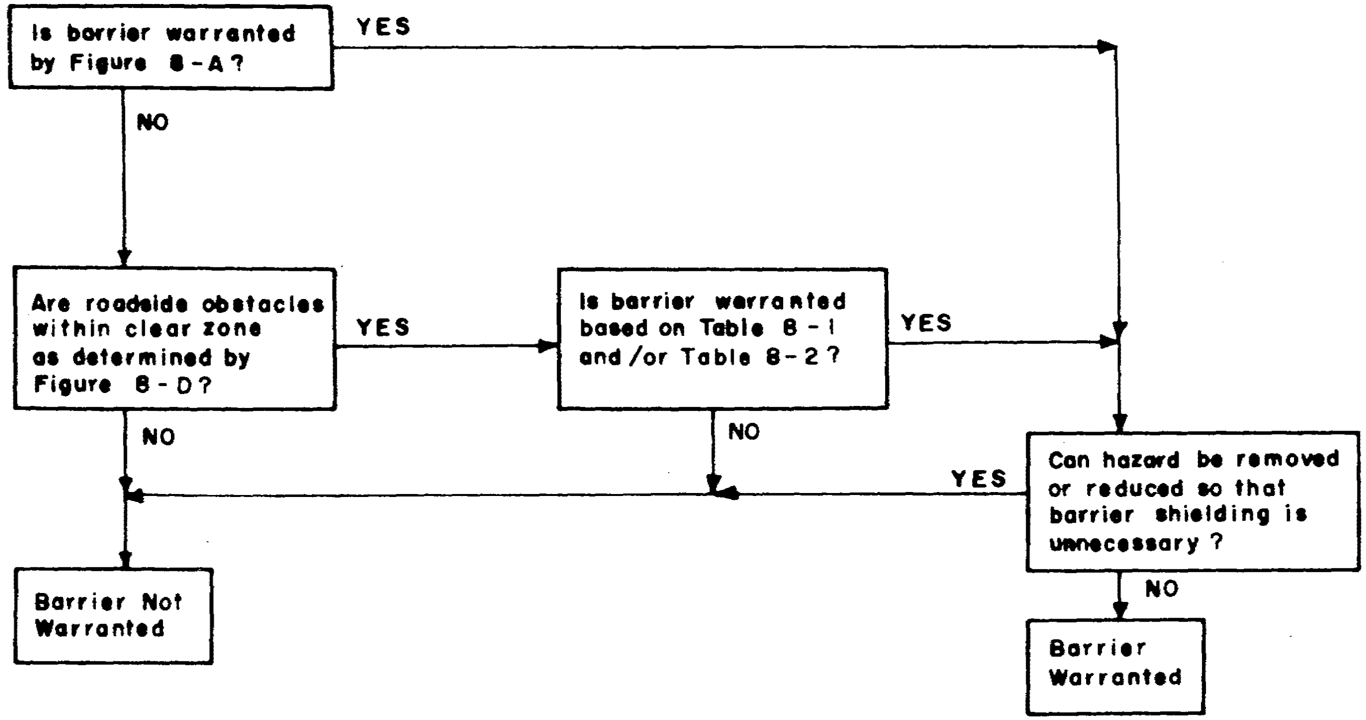
[2]Breakaway or yielding design is desirable regardless of distance from traveled way.

[3]See discussion in text.

[4]A judgment decision (see discussion in text).

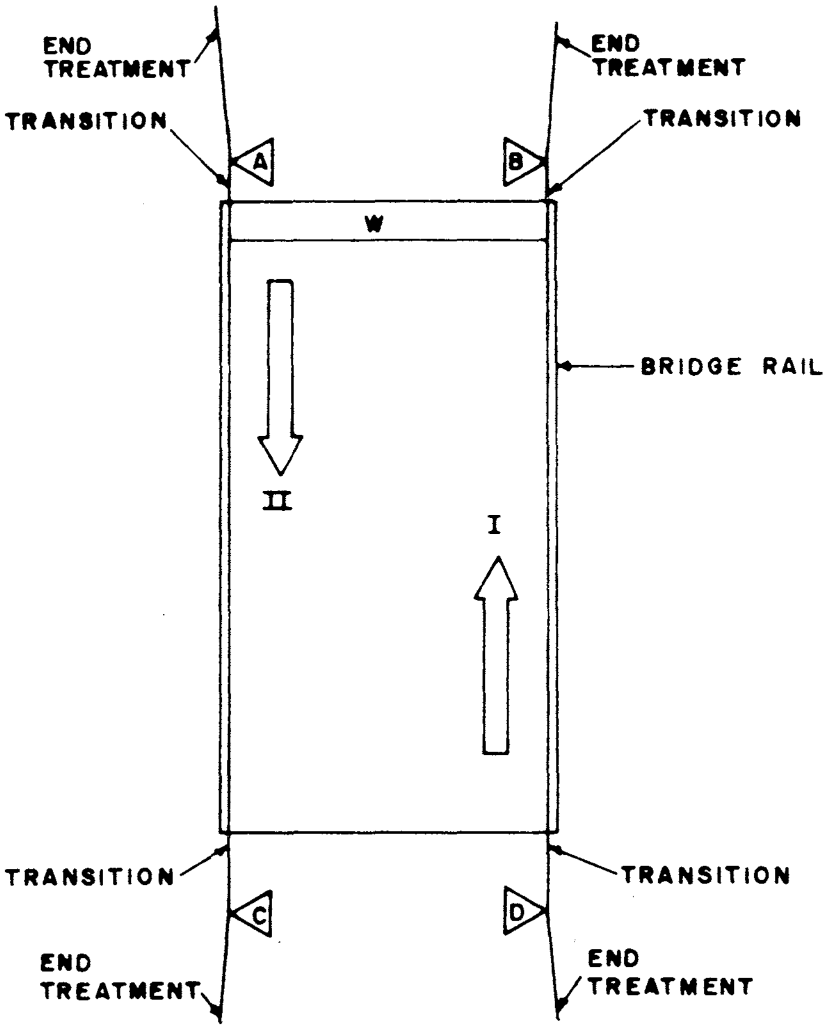
Metric Conversions:

1 lb-sec = 4.45 N-sec
1 in =0.0254 m



SUMMARY OF ROADSIDE BARRIER WARRANTS.

FIGURE 8-F

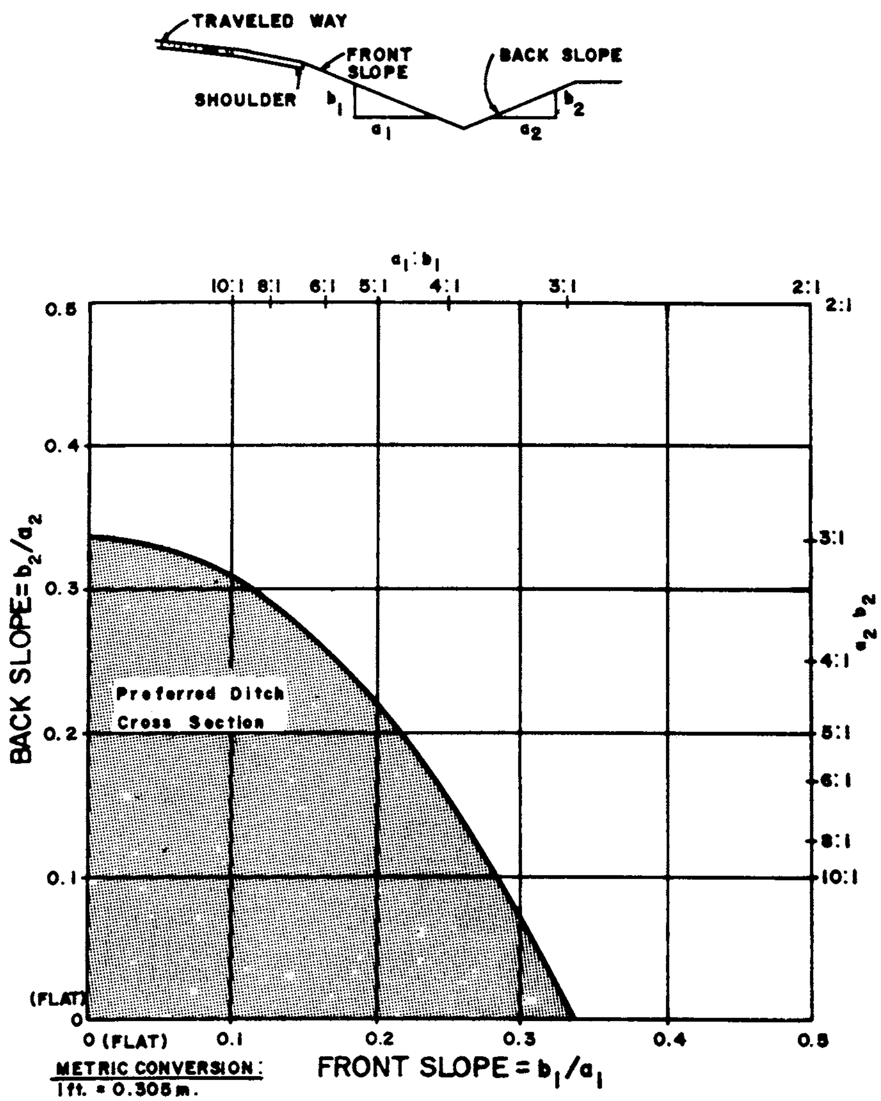


TRAFFIC DIRECTION	DISTANCE BETWEEN BRIDGE RAILS-W(ft.)	APPROACH BARRIER REQUIRED AT *
I AND II	≤ 2 X Clear zone width (see Fig. 8-D)	A,B,C,D
I AND II	> 2 X Clear zone width (see Fig. 8-D)	A,D
II ONLY	ALL WIDTHS	A,B
I ONLY	ALL WIDTHS	C,D

Check roadside for other warranting features.

BRIDGE APPROACH BARRIER CRITERIA.

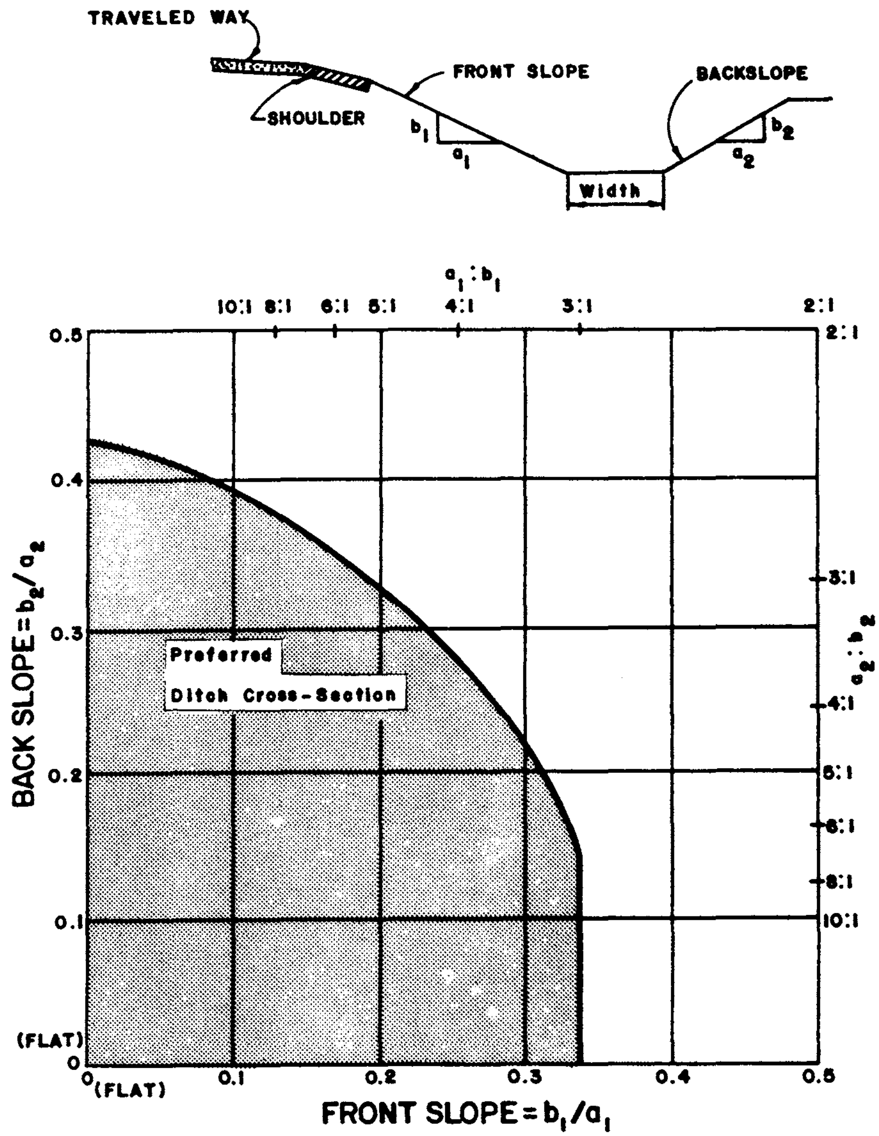
FIGURE 8-G



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

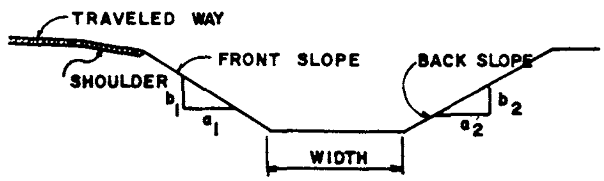


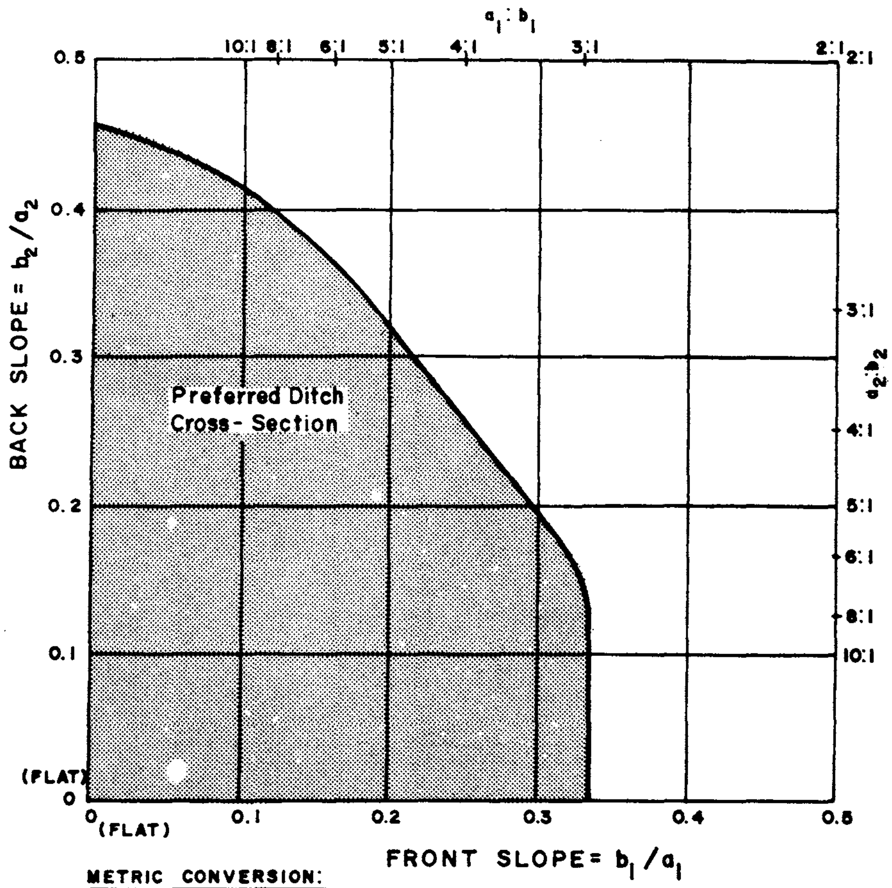
METRIC CONVERSION:
1ft. = 0.305 m.

PREFERRED DITCH SECTIONS, B FOR:

(a) Trapezoidal Ditch, Bottom Width = 4 ft. To 8 ft., Or
(b) Round Ditch, Bottom Width = 8 ft. To 12 ft.

FIGURE 8-J





METRIC CONVERSION:
1ft. = 0.305m

PREFERRED DITCH SECTIONS, C FOR:

(a) Trapezoidal Ditch, Width > 8ft.; 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.

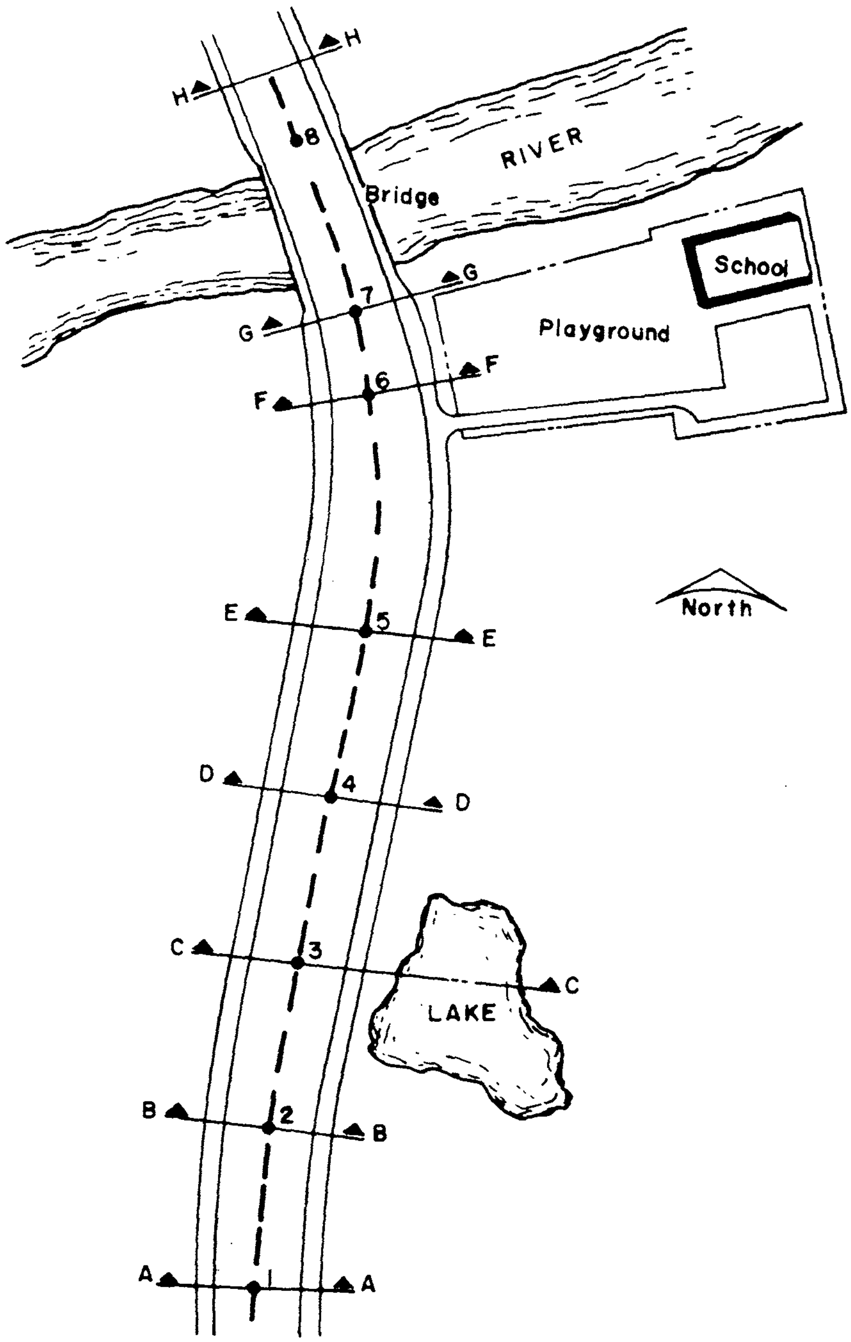
8—05 STRUCTURAL AND SAFETY CHARACTERISTICS

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

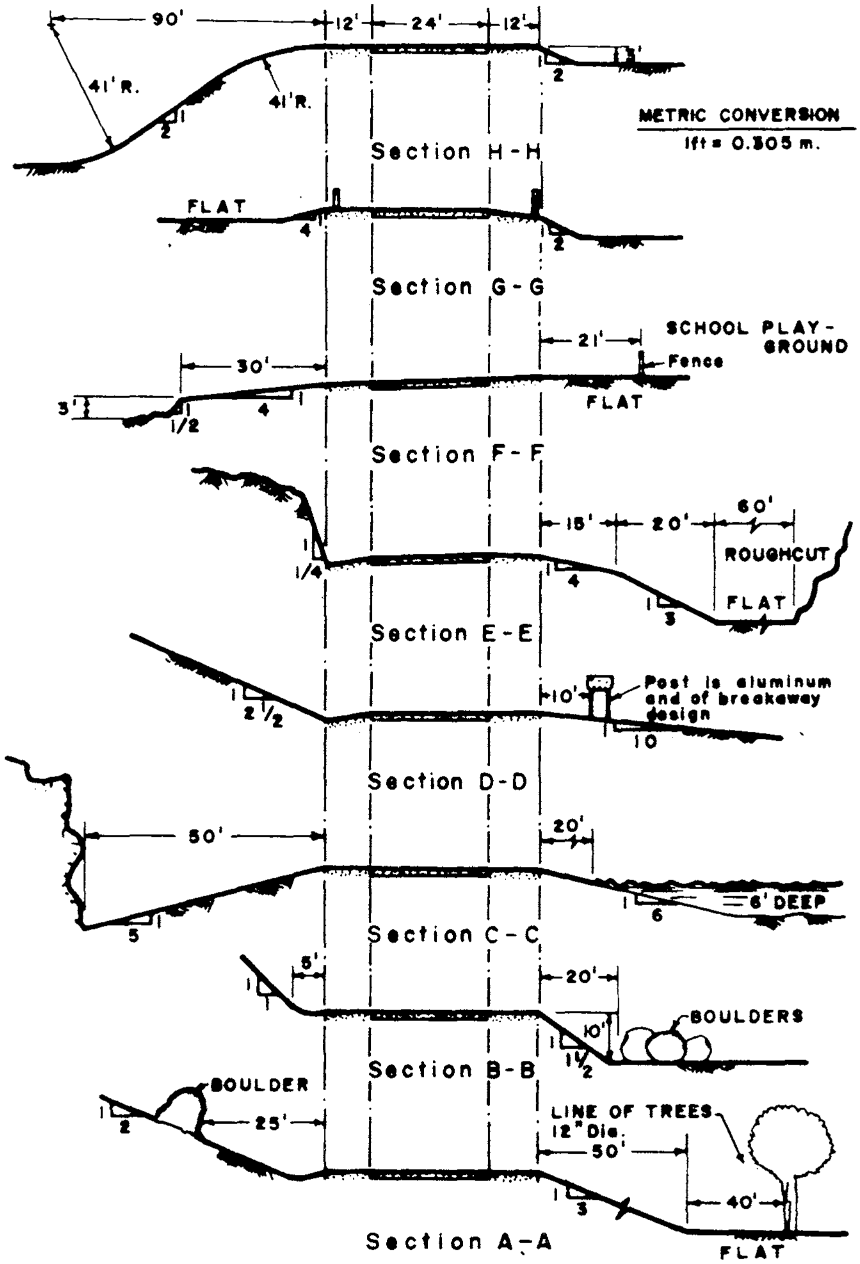
Transition sections are necessary to provide continuity of protection when two different roadside barriers join, when a roadside barrier joins another barrier system (weak-post to strong-post), or when a roadside barrier is attached to a rigid object (such as concrete barrier or bridge parapet).

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.

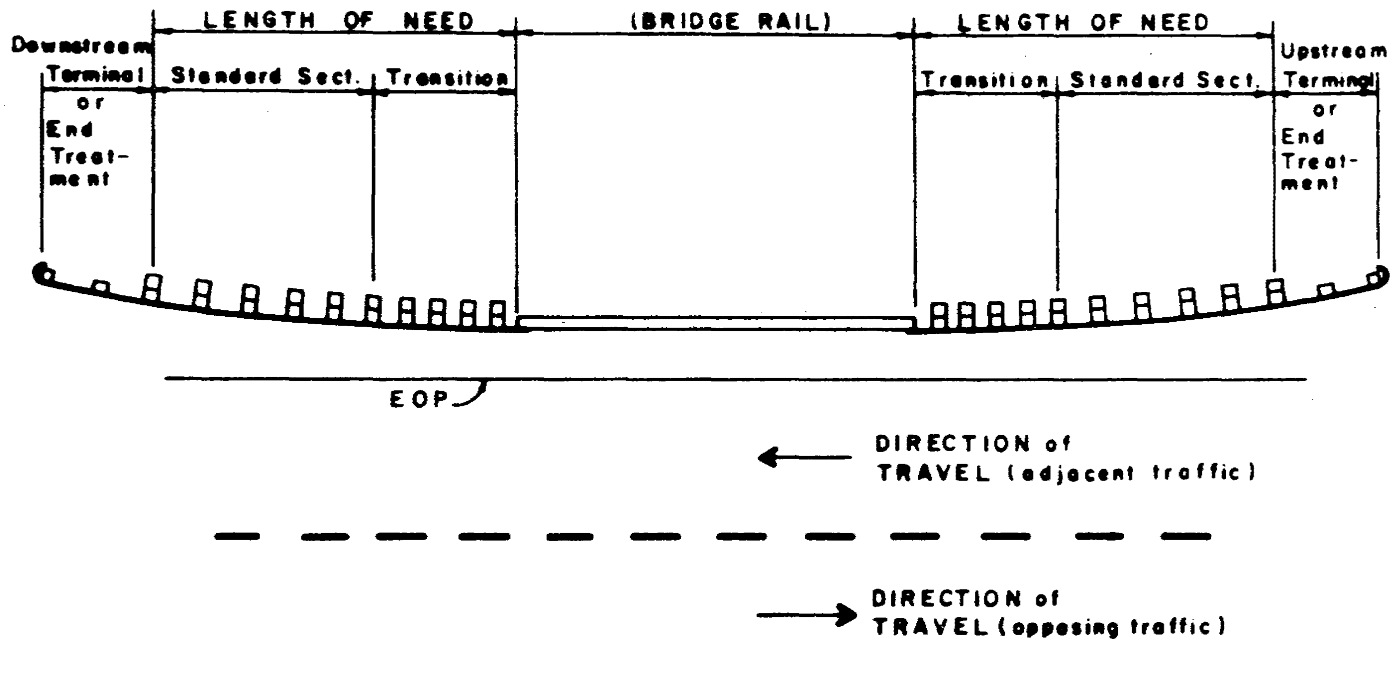
The length of the transition should be such that significant changes in the lateral stiffness do not occur within a short distance. The transition length should approximate 12 times the difference in dynamic deflection between joining barriers. For example, the dynamic deflection of system G4(1S) is 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

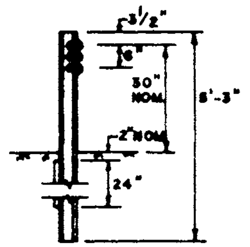
FIGURE 8-M

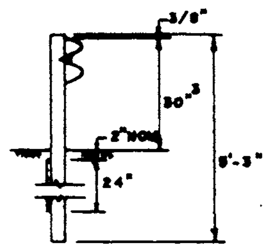


DEFINITION OF ROADSIDE BARRIER ELEMENTS.

FIGURE 8-N

Metric Conversions
1 ft. = 0.305m
1 in. = 25.4 mm
1 mph = 1.61 km/hr
1 lb. = 0.454kg



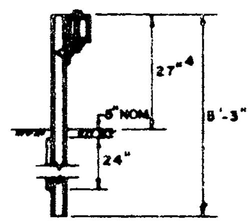
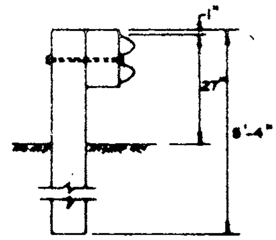


SYSTEM	G1 Cable Guardrail		G2 "W" Beam (Steel Weak Post)	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	 16' 0" S3x5.7 steel Three 3/4" diameter Steel Cables ----- 5/16" diameter Steel hook bolts ¼"x8"x24" steel plate welded to post		 12' 6" Nominal) S3x5.7 steel Steel "W" Section, 12 GA. ----- 5/16" diameter Steel bolt ¼"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 5/8" dia. steel bolt [illegible] [illegible] 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 = 15°	IMPACT ANGLE = 25°	IMPACT ANGLE = 15°	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

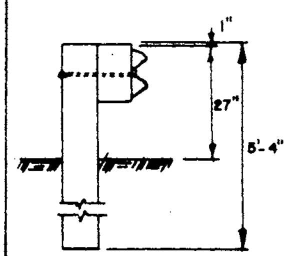
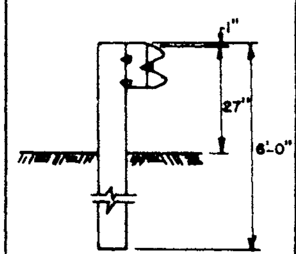
[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

[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(1S) 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" W6 x 8.5 Steel Post Steel 'W' section, 12 GA W6 x 8.5 x 14" 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)

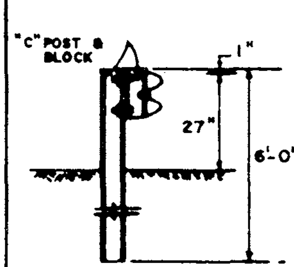
[3] Maximum permanent deflection

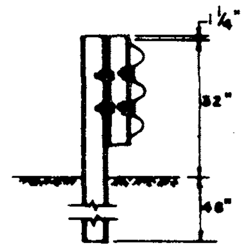
[4] Tests show that a "W" section back-up plate, 1 ft. in length, must be placed behind rail elements at intermediate posts (non-splice posts).

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	64 (23) Blocked-Out "W" Beam (Steel "C" Posts)		69. Blocked-Out "Thrie Beam" (Steel Post)	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	 6' 3" 4 1/3"x 8-3/8" x 3/16" "C" steel Post Steel W section, 12 GA. 4 1/3" x5 3/8" x 3/16" "C" steel post[3] 5/8" diameter bolt None		 6' 3" W 6 x 8.5 steel Thrie Beam, steel W 6x8.5 and M14 x 17.2, steel 2 5/8" diameter steel bolts UNAV	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 25°	IMPACT ANGLE = 15°	IMPACT ANGLE = 25°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	 NO TEST	 50.0 4323	 50.1 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 15° test and M14x17.2 block-out was used in 25° 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 Deflection (ft.) [1]	Acceleration at 15° (G's) [2]			Accelerations at 25° (G's) [2]			Is Barrier Hadware 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.

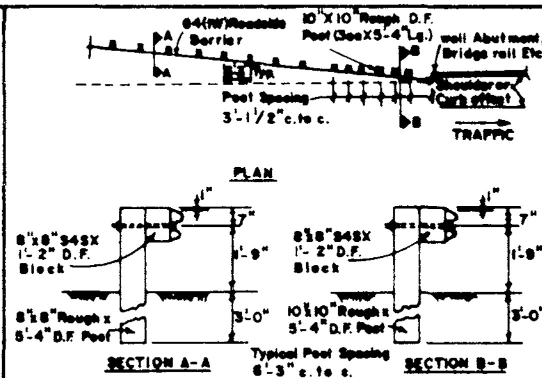
[2] 50 millisecond average.

[3] See reference 22, 23.

[4] Maximum permanent deflection.

Metric Conversion: 1 ft. = 0.305 m.

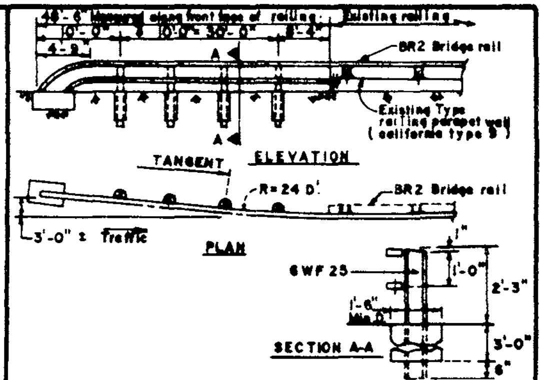
[5] To be included in a revised edition of reference 22 and 23.

Metric Conversions 1 ft. = 0.305m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb = 0.454 kg		
SYSTEM	T1 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.) 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	 58.6 4297 UNAV 19.0 8.8 UNAV 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" x 2" x 0.25" 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.) 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	 60.0 4540 0.23 UNAV UNAV UNAV 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.

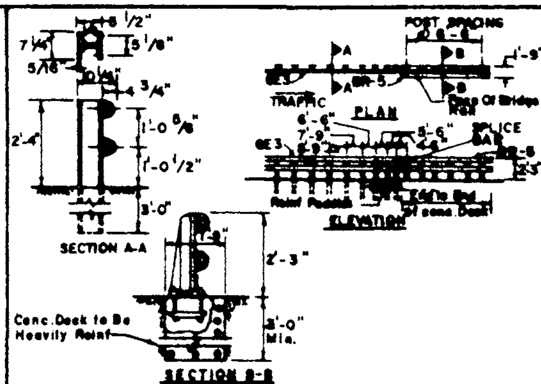
Other method to eliminate the problem of vehicle impalement on roadside barrier ends is to use a turned-down-barrier end. Standard model No. 1 of the Puerto Rico Highway Authority, uses this method. However, tests have shown that some turned-down end designs can cause impacting vehicles to vault and 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.

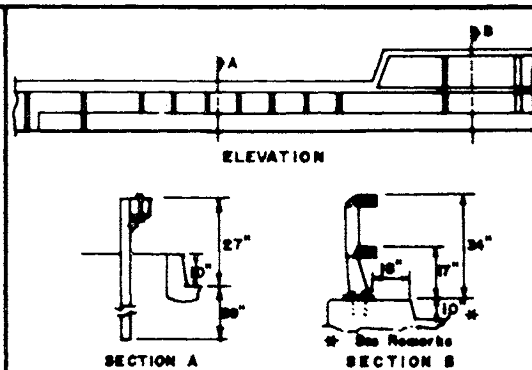
The extent of barrier damage for given impact conditions will depend on the strength of the barrier. Where available, Tables 8—3 thru 8—6 give the barrier damage as a result of a crash test for specific impact conditions. Table 8—15 summarized the available field data from a gross survey made of several states.

Metric Conversions 1 ft. = 0.305m 1 in. = 25.4 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; MOUTINGS - standard hardware; FOOTINGS - none.	
IMPACT PERFORMANCE	IMPACT ANGLE 15°	IMPACT ANGLE 25°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb)	NO TEST	56.0 3965
BARRIER Dynamic Deflection (ft.)	↓	1.4
VEHICLE ACCELERATIONS (G's)[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 G3 Approach Rail to BRS Bridge Rail	
BARRIER DESCRIPTION	POST SPACING 4'0"; POST TYPE-S8 x 5.7 steel for approach rail, fabricated steel for bridge rail; BEAM TYPE 6x6" x 0.188" steel tubing for approach rail, TS 8" x 3" x 1/4" Steel for bridge rail; OFFSET BRACKETS L5" 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	NO TEST	
Speed (mph)		54.0
Vehicle Weight (lb.)		3600
BARRIER		
Dynamic Deflection (ft.)		4.6
VEHICLE ACCELERATIONS (G's)[1]		
Lateral		UNAV
Longitudinal		UNAV
Total		9.4
VEHICLE TRAJECTORY		
Exit Angle (deg.)		2
Roll Angle (deg.)		less than 10
Pitch Angle (deg.)		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.

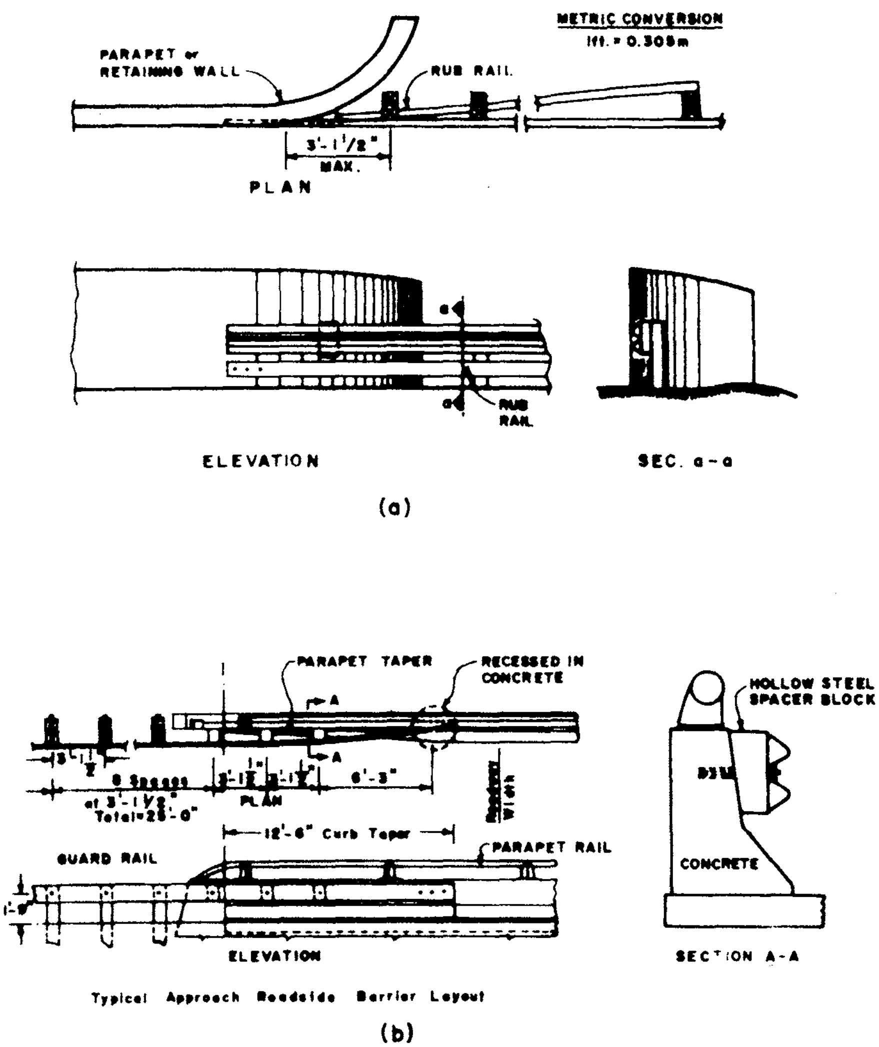
8–08.01 UNIFORM CLEARANCE AND DISTANCE BETWEEN BARRIER AND HAZARD

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.

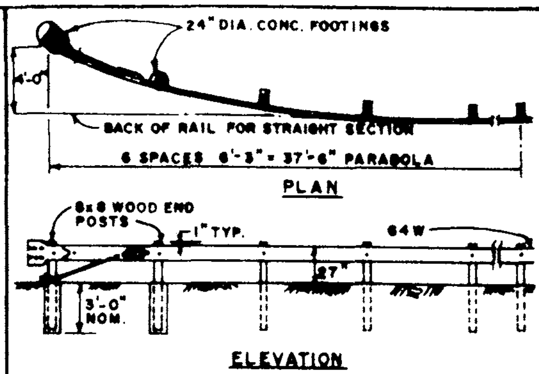
The barrier-to-hazard distance for rigid objects should not be less than the dynamic deflection of the barrier for impact by a full-size automovile at impact conditions of approximately 25 degrees and 60 mph.

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.



W-BEAM TO PARAPET CONNECTION CONCEPTS.

FIGURE 8-P

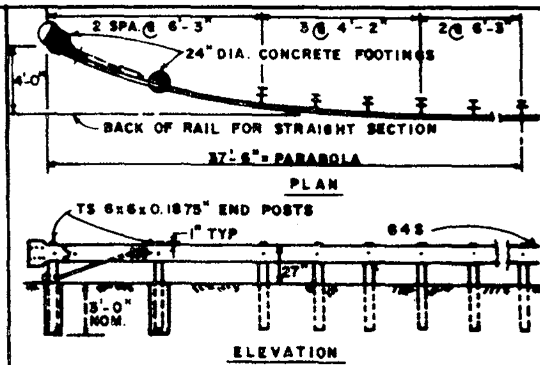
Metric Conversions 1 ft = 0.305m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg		
SYSTEM	[illegible] Breakaway Cable Terminal (Wood Post)	
BARRIER DESCRIPTION	TYPICAL POST-8"x8" Douglas Fir; TERMINAL POTS-8"x8" Douglas Fir with 2-3/8" diameter hole through neutral axis; ANCHORAGE-Cable assembly (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) Angle (deg.) Vehicle Weight (lb.)	 60.7 0 3800	 62.0 27 3900
BARRIER Deceleration Distance (ft.)	 UNAV	 5.3[3]
VEHICLE ACCELERATIONS (G's)[1] Lateral Longitudinal Total	 1.5 9.2 UNAV	 3.4 7.2 UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)	 Behind rail UNAV UNAV	 ≈30 ≈0 ≈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	GET 2 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) Angle (deg.) Vehicle Weight (lb.)	 62.0 0 4423	 58.0 24 4202
BARRIER Deceleration Distance (ft.)	 UNAV	 ≈4.0[3]
VEHICLE ACCELERATIONS (G's)[1] Lateral Longitudinal Total	 2.4 9.0 UNAV	 5.6 8.2 UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)	 Behind rail ≈0 ≈0	 ≈30 11 ≈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[1]	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.

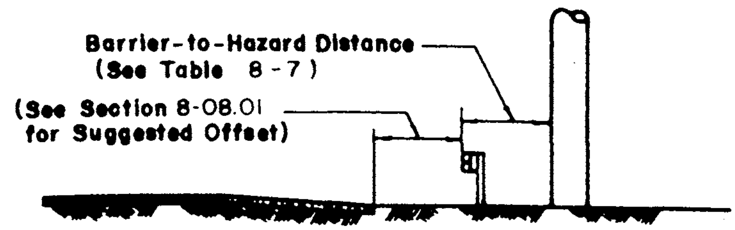
Table 8–17 contains the runout length (L_R), flare rate (a:b), and shy line offset (L_S) as a function of ADT (Average Daily Traffic) and design speed. Shy line offset is defined as a distance beyond which a roadside object will not be perceived as a threat by a driver. The roadside barrier should be 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 desirab' to install new systems on an experimental basis.

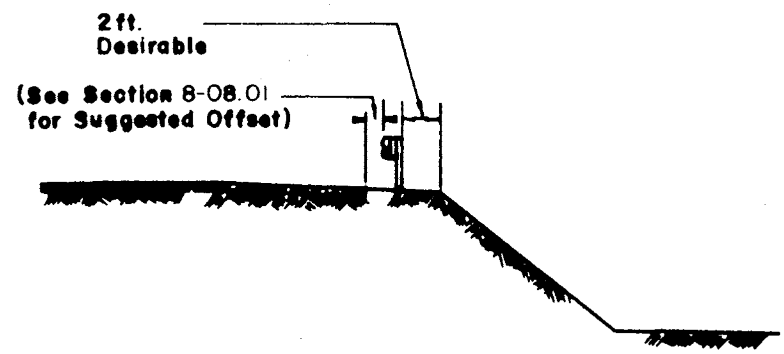
SELECTION CRITERIA FOR ROADSIDE BARRIERS.

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

$\left| e - \frac{a}{b} \right| > 0.1$ or if $\frac{a}{b} > -0.1$

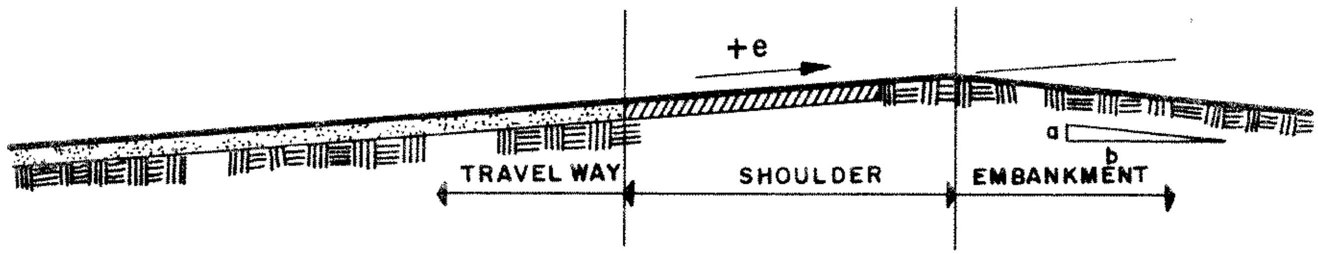
WHERE

e = Shoulder Slope Rate, Positive If Sloping Upward

$\frac{a}{b}$ = Embankment Slope Rate, Positive If Sloping Downward

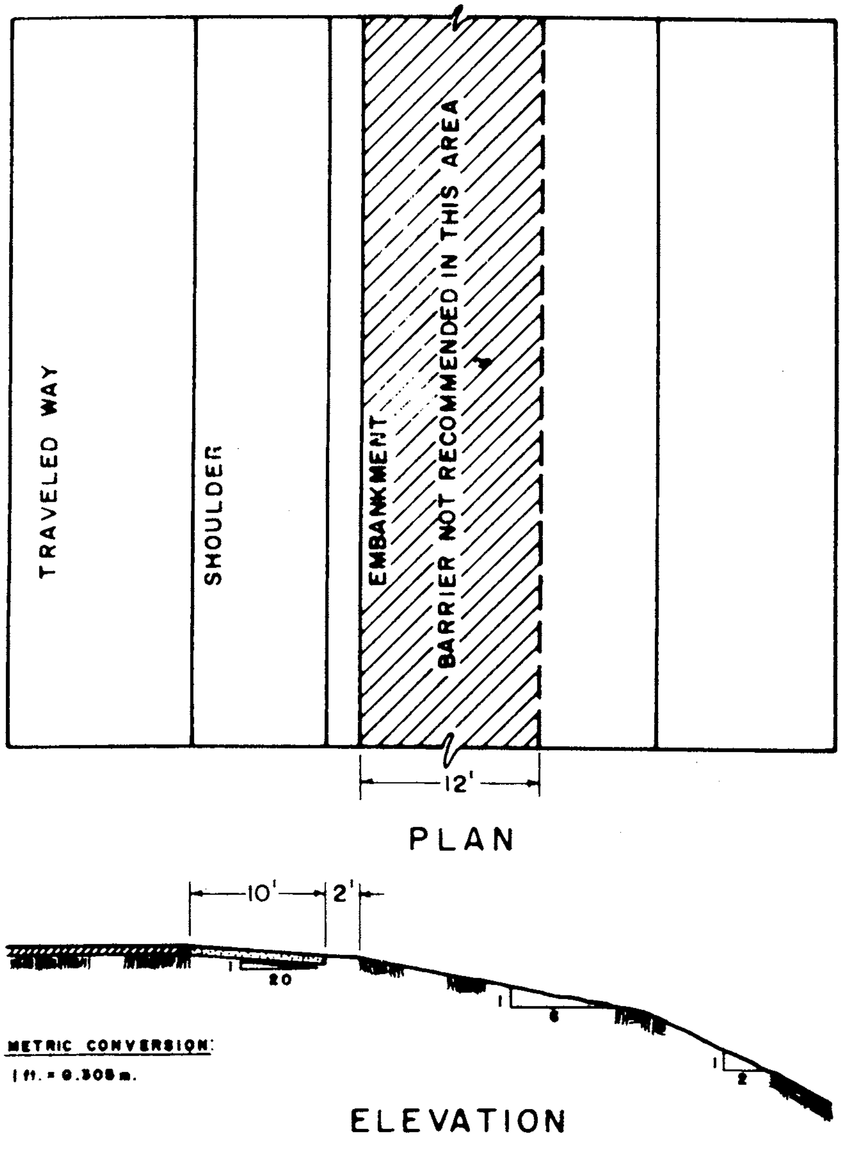
NOTE:

See Text For Exceptions To Criterion



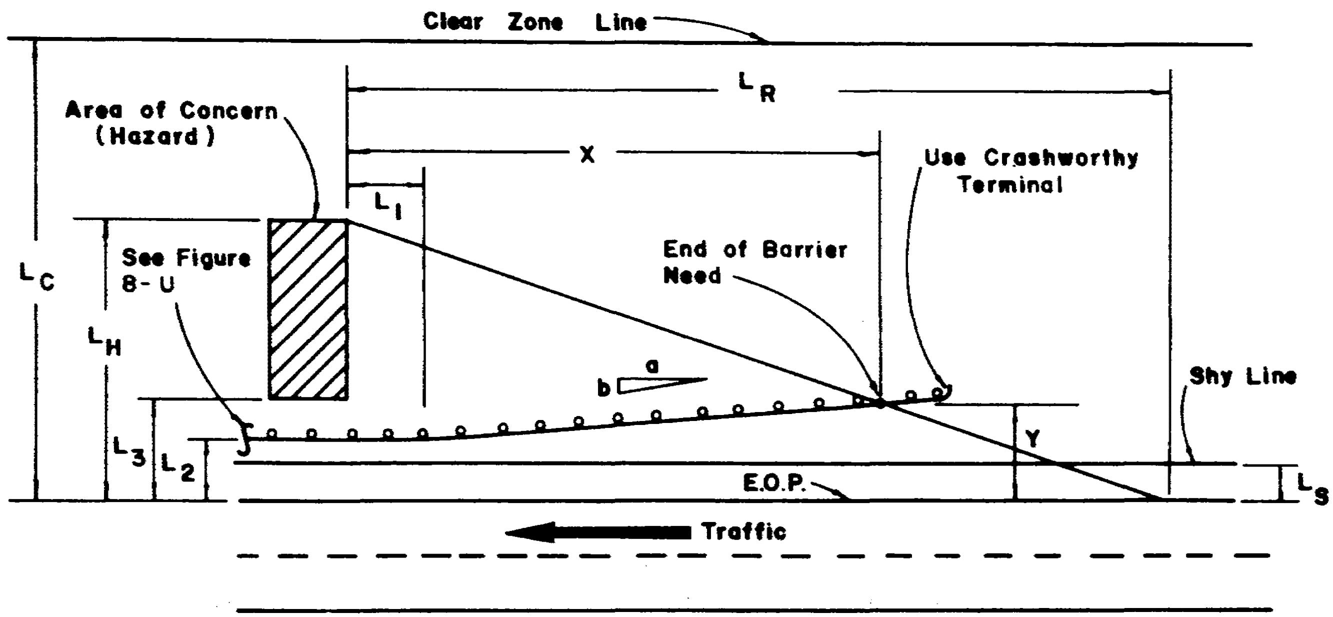
ROADSIDE BARRIER LATERAL PLACEMENT CRITERION.

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) = $\frac{480}{400}$ x 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

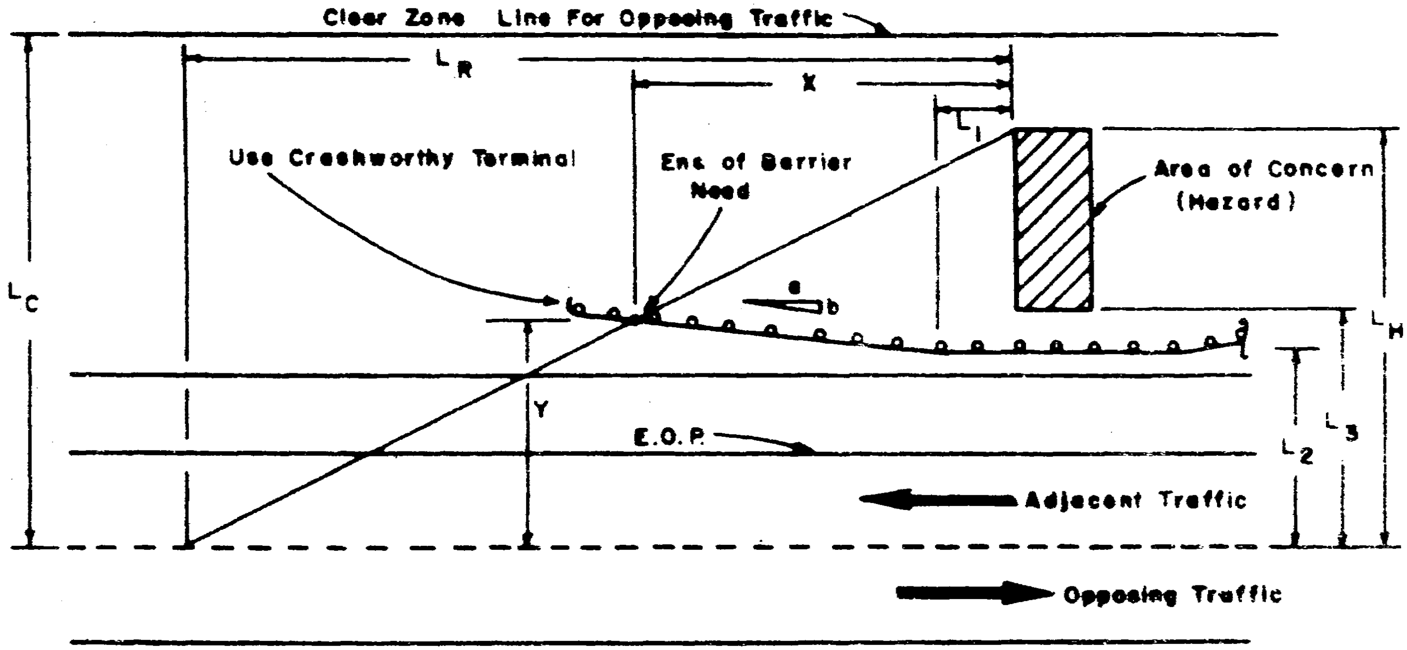
Some existing roadside barriers are not necessary while others are substandards and will not meet the minimum requirements discussed in previous sections. In this section a procedure is introduced for upgrading substandard systems and to eliminate the unnecessary ones.

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.

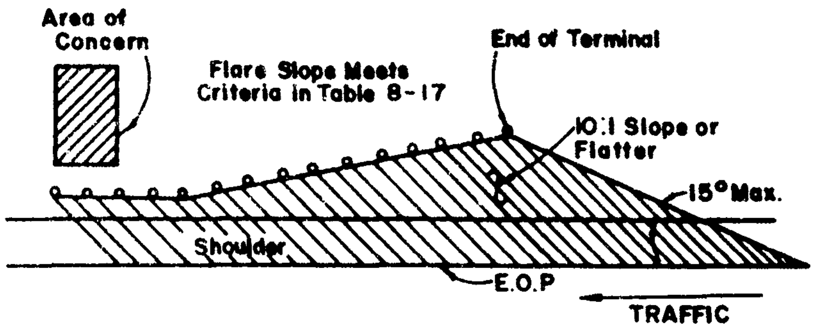
All personnel performing this inspection (design, construction or maintenance), should stay abreast of current traffic barrier standards and guidelines as well as promising new research findings.

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.

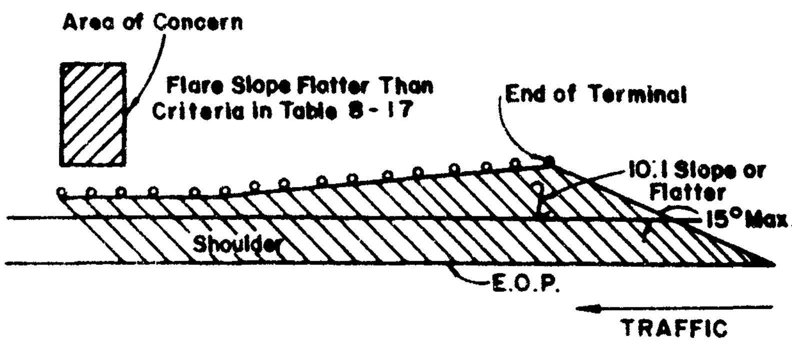


APPROACH BARRIER LAYOUT FOR OPPOSING TRAFFIC.

FIGURE 8-U



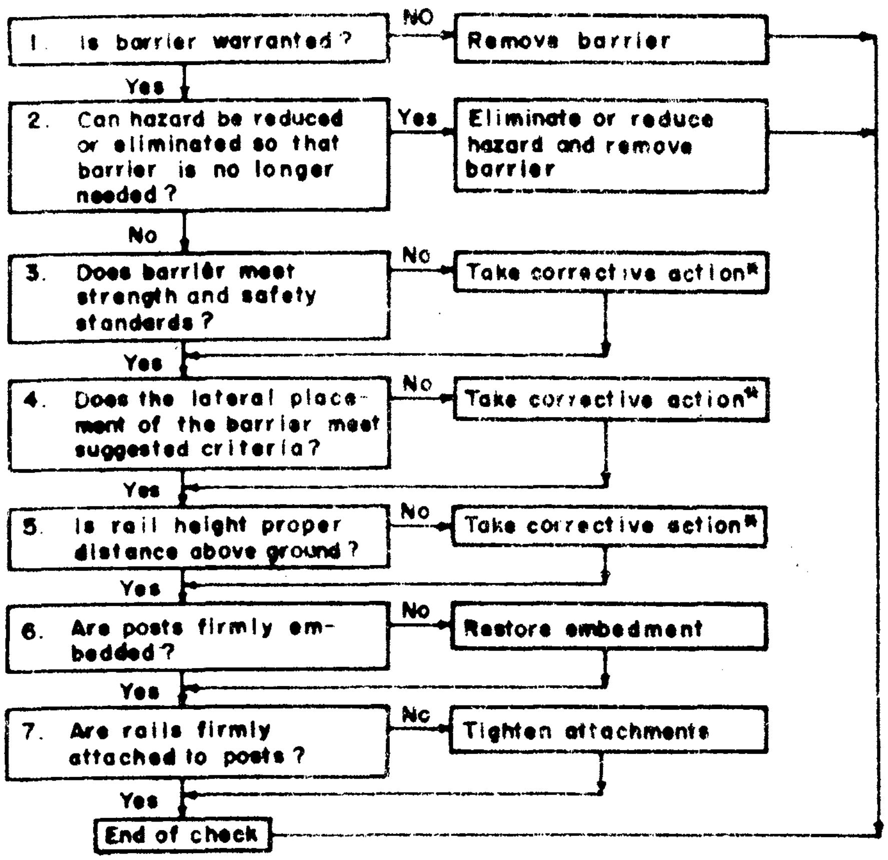
(A) Desirable



(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.

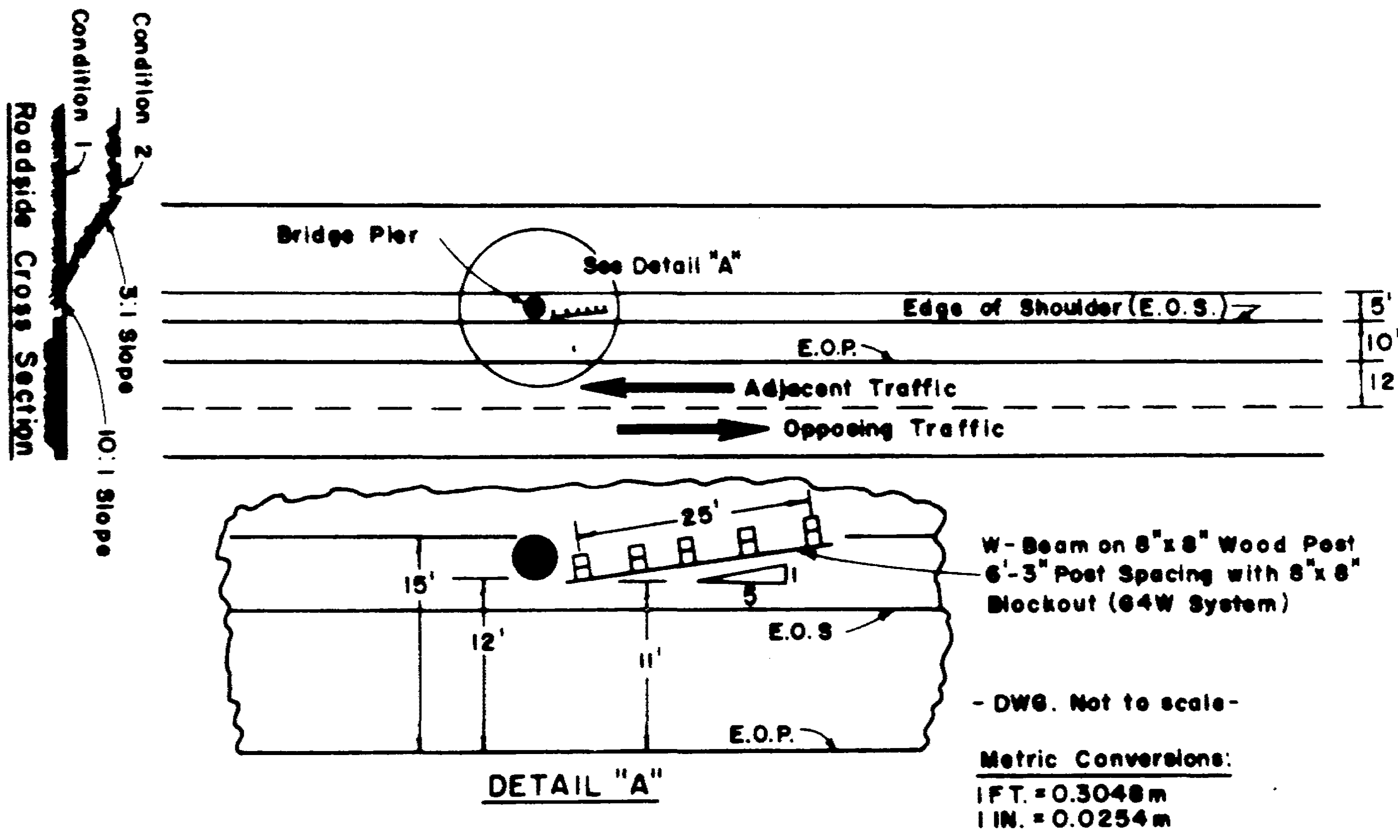
3. Due to the limited space between the edge of the shoulder and the pier, the barrier must be stiffened in the area of the pier (this system could also be replaced by a concrete barrier as will be discussed in following sections). The dynamic deflection of the G4(1W) system is 2.8 ft. Thus the W-beam 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 G6 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.

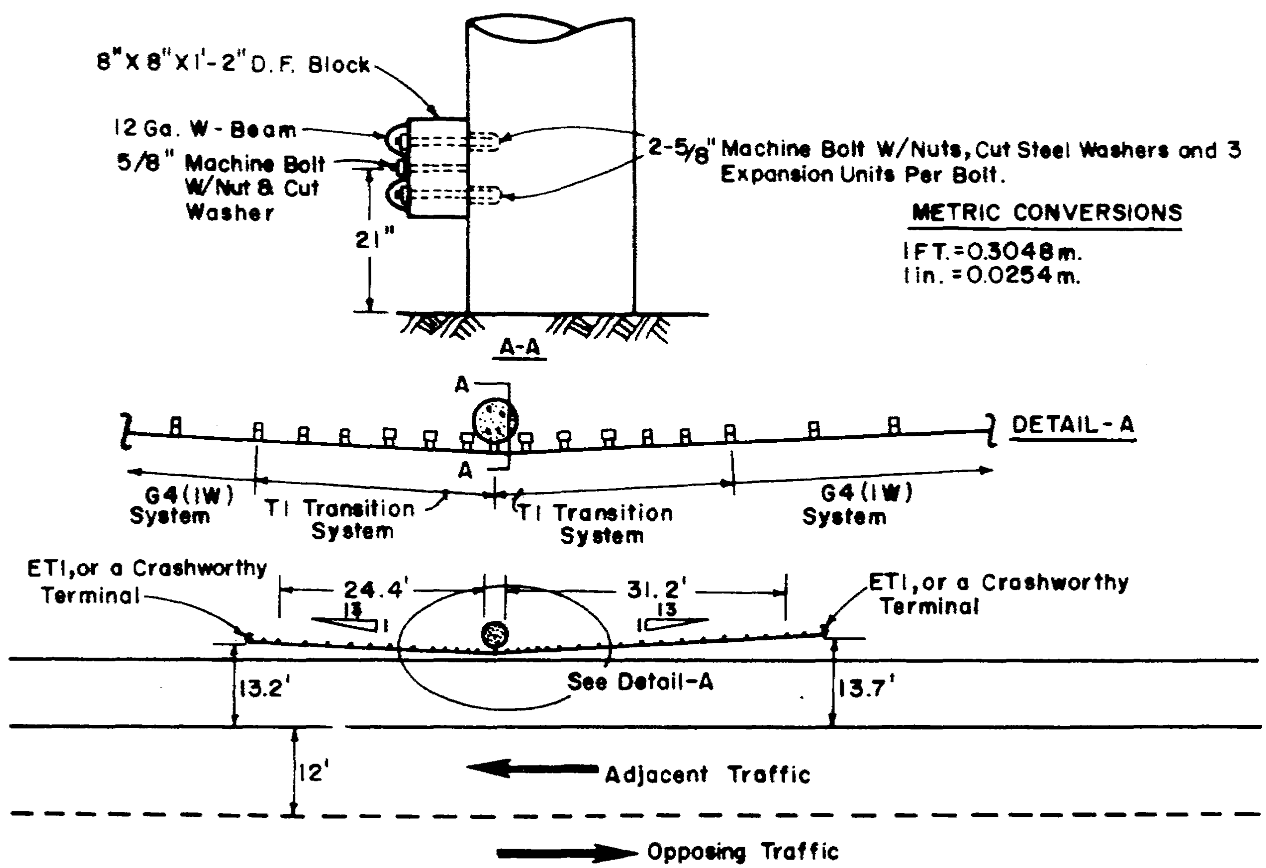
It should be emphasized that the suggested designs shown in this example are not the only one acceptable. There are other designs which would serve the intended purpose. A crash cushion layout might be appropiate or a concrete barrier half section, as will be discussed in following sections. However, 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.

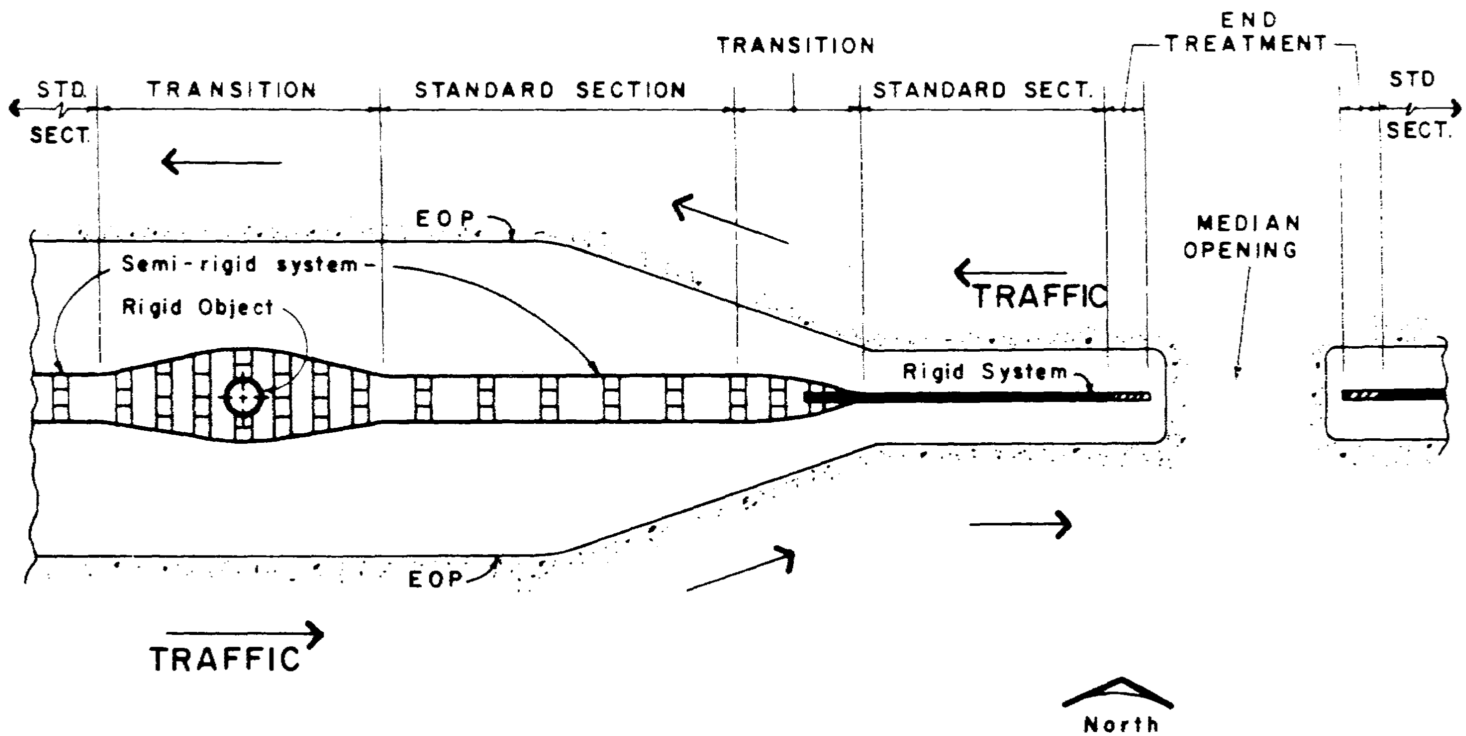
8-10.1 WARRANTS FOR MEDIAN BARRIERS

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.

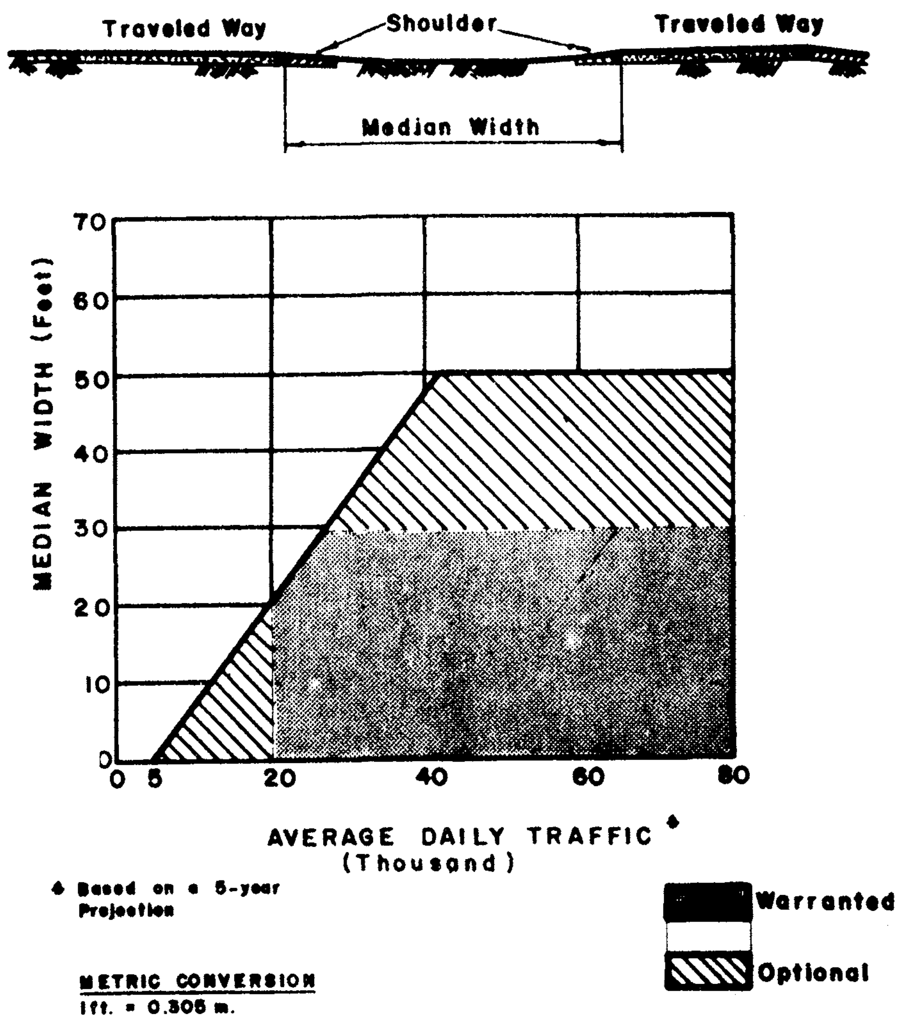
8—11.1 STANDARD SECTIONS OF MEDIAN BARRIERS

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).

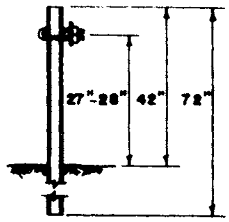
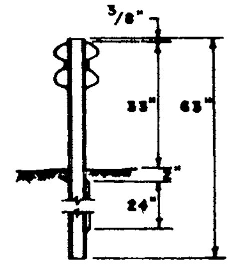
The Concrete Median Barrier (CMB) illustrated in Standard Model 1—C is a modification of previously used models. Its configuration is the New Jersey shape. Some variations have been made in the reinforcement and footings based in previous experience. Reference should be made to the Puerto Rico Highway 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

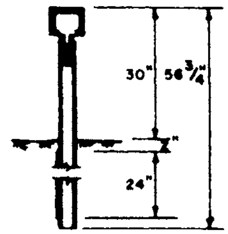
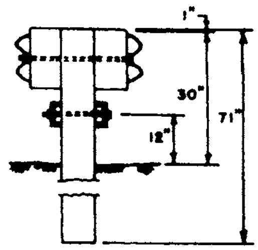
Metric Conversions
1 ft. = 0.305m
1 in. = 25.4mm
1 mph = 1.61 km/hr
1 lb. = 0.454kg

				
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

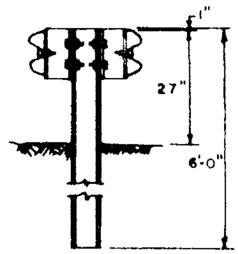
Metric Conversions 1 ft. = 0.305m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg				
SYSTEM	MB3 Box Beam		MB4W Blocked-Out "W" Beam (Wood Posts)	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	 6' 0" S3x5.7 8"x6"x 1/4" Steel tube None Steel paddles 8"x1/4"x24" Steel plate welded to Post		 6' 3" 8 x 8 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.	

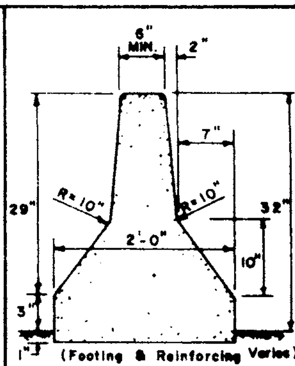
UNAV– unavailable
[1] 50 millisecond average unless otherwise noted
[2] If available, see summary in Appendix A (AASHTO Barrier Guide)
[3] 6"x8" post acceptable alternate based on G4(2W) test results.
[4] 6"x8"x14" block acceptable base on G4(2W) test results.

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



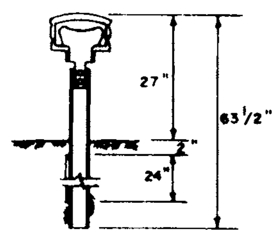
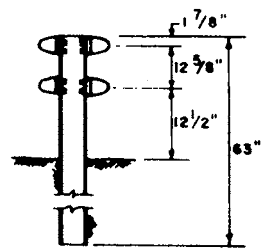


SYSTEM	MB4S Blocked-Out "W" Beam (Steel Posts)		MB5 Concrete Median Barrier	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	6'-3" W6X8.5 [3] Two steel "W" sections Two W6X8.5 [4] 5/8" diameter steel bolts None		Continuously poured, reinforced, sloped face, concrete 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

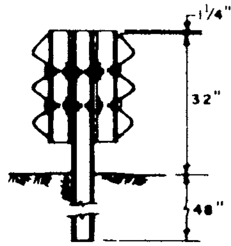
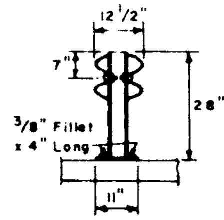
TABLE 8-21

Metric Conversions 1 ft = 0.305m 1 in. = 25.4 mm 1 mph = 1.61km/hr 1 lb = 0.454kg	 		 	
SYSTEM	MB7 Aluminum Strong Beam		MB8 Aluminum Balance Beam	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	 6' 3" Aluminum I or steel S3 x 5.7 Aluminum extrusions None Steel or aluminum paddles 8" x 3/16 x 24 stee or aluminum Plate		 12' 6" 5 1/2" x 7 1/4" H section aluminum 5 1/2" x 7 1/4" H section aluminum Four standard aluminum extrusions None Standard Hardware None	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 26.6°	IMPACT ANGLE = 7°	IMPACT ANGLE = 25°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	 53.0 4000	 62.7 4057	 51.0 4000	 56.0 4000
BARRIER Dynamic Deflection (ft.)	 1.50	 7.20	 UNAV	 UNAV
VEHICLE ACCELERATIONS (G's)[1] Lateral Longitudinal Total	 UNAV UNAV UNAV	 4.10 3.70 UNAV	 0.70 1.00 UNAV	 4.0[3] 9.0[3] UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)	 UNAV UNAV UNAV	 UNAV UNAV UNAV	 4 UNAV UNAV	 ≈0 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 POST TYPE BEAM TYPE OFFET BRACKETS MOUNTINGS FOOTINGS	6' 3" W6x8.5 Two Thrie Beams W6x8.5 5/8" diameter steel bolts UNAV		6' 3" W6x8.5 steel Two steel "W" sections None 5/8" diameter bolt 7"x11"x 5/8" steel Plate	
IMPACT PERFORMANCE	IMPACT ANGLE = 17°	IMPACT ANGLE = 25°	IMPACT ANGLE = 14.7°	IMPACT ANGLE = 25°
IMPACT CONDITION Speed (mph) Vehicle Weight (lb.)	 54.1 2200	 66.1 4500	 63.4 4200	 57.3 3640
BARRIER Dynamic Deflection (ft.)	 0.33	 3.17	 1.00	 1.50
VEHICLE ACCELERATIONS (G's)[1] Lateral Longitudinal Total	 5.30 2.00 UNAV	 6.30 6.60 UNAV	 6.30 4.30 UNAV	 UNAV 10.0 UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)	 ≈2.0 0 0	 less than 10 0 0	 3.8 0 0	 19.7 less than 10 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 Deflection (ft.)[1]	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.

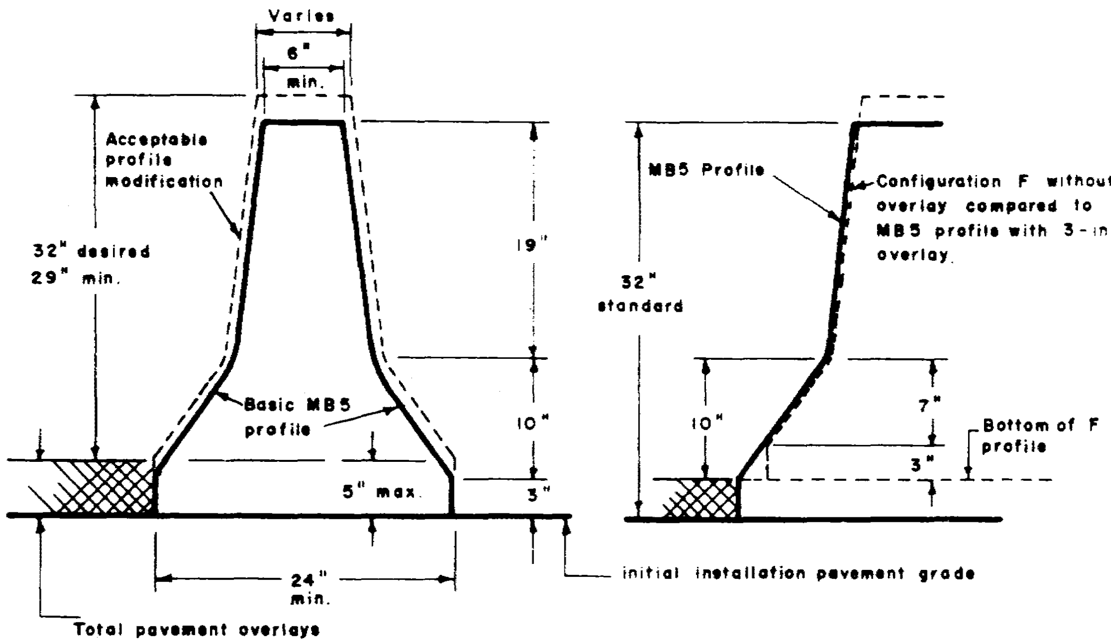
2. The length of the transition should be such that significant changes in the lateral stiffness do not occur within a short distance. The transition length should be at least 33 feet.

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. = .0254m

PAVEMENT OVERLAY CONSIDERATIONS.

FIGURE 8-CC

TABLE 8-26 – SUGGESTED MEDIAN BARRIES AS RELATED TO MEDIAN WIDTH

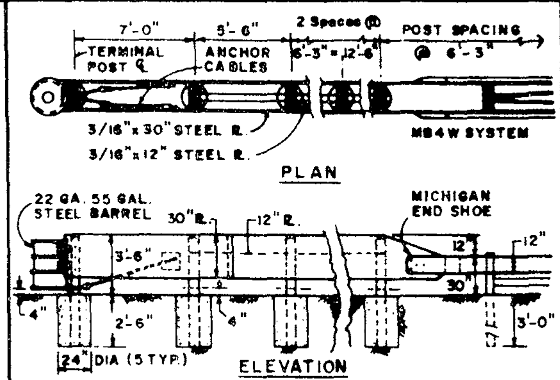
Median Width	Suggested Barrier [1]
Up to 18 feet	MB 4-S or MB-5
18 to 30 feet	MB 4-S or MB-5
30 to 50 feet	MB 4-S or MB-3

[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.

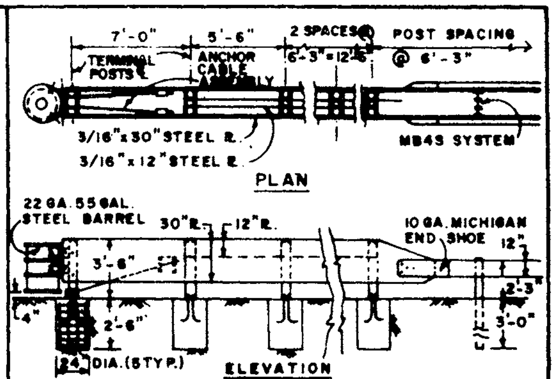


SYSTEM	[illegible] Median Barrier Breakaway Cable Terminal (Wood Post)	
BARRIER DESCRIPTION	TYPICAL POST-6"x8" Douglas Fir; TERMINAL POST-6"x8" Southern Pine with 2 3/8" diameter hole drilled through neutral axis; ANCHORAGE - Cable assembly (see sketch); FOOTING - 24" diameter, 30" deep concrete for terminal posts, other posts require none; TYPICAL RAIL - steel "W" section, 12 GA.; TERMINAL RAIL - 3/16"x30" steel plate; OFFSET BRACKETS - 6"x8" Southern Pine block.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		NO TEST
Speed (mph)	64.8	
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 145

OPERATIONAL MEDIAN BARRIER END TREATMENTS, A

TABLE 8-27



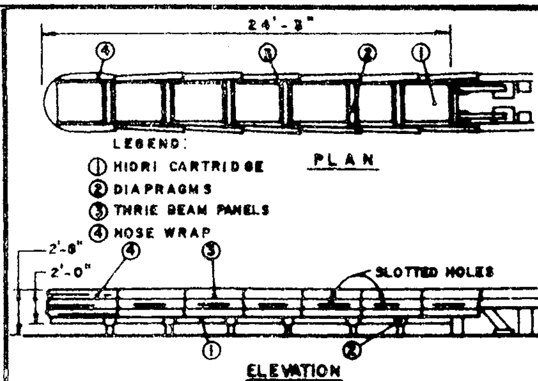
Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr. 1 lb. = 0.454 kg.		
SYSTEM	MBET 2 Median Barrier Breakaway Cable Terminal (Steel Post)	
BARRIER DESCRIPTION	TYPICAL POST-W6x8.5 steel; TERMINAL POST-TS 6"x6"x0.1875" steel breakaway design; ANCHORAGE-Cable assembly (see sketch); FOOTING-24" diameter, 30" deep concrete for terminal posts, other posts require none; TYPICAL RAIL-steel "W" section, 12 GA; TERMINAL RAIL-3/16"x30" steel plate; OFFSET BRACKETS-6"x6" steel blocks.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	58	62
Angle (deg.)	0	25
Vehicle Weight (lb.)	4600	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.)	≈15	≈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 145 (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) 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.)	 62.0 0 Pontiac Sedan UNAV UNAV 15.0[3] UNAV UNAV less than 10 less than 10	 63.0 20 1966 Buick LeSabre UNAV 8.0[3] 5.0[3] UNAV 8 0. 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 46° 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

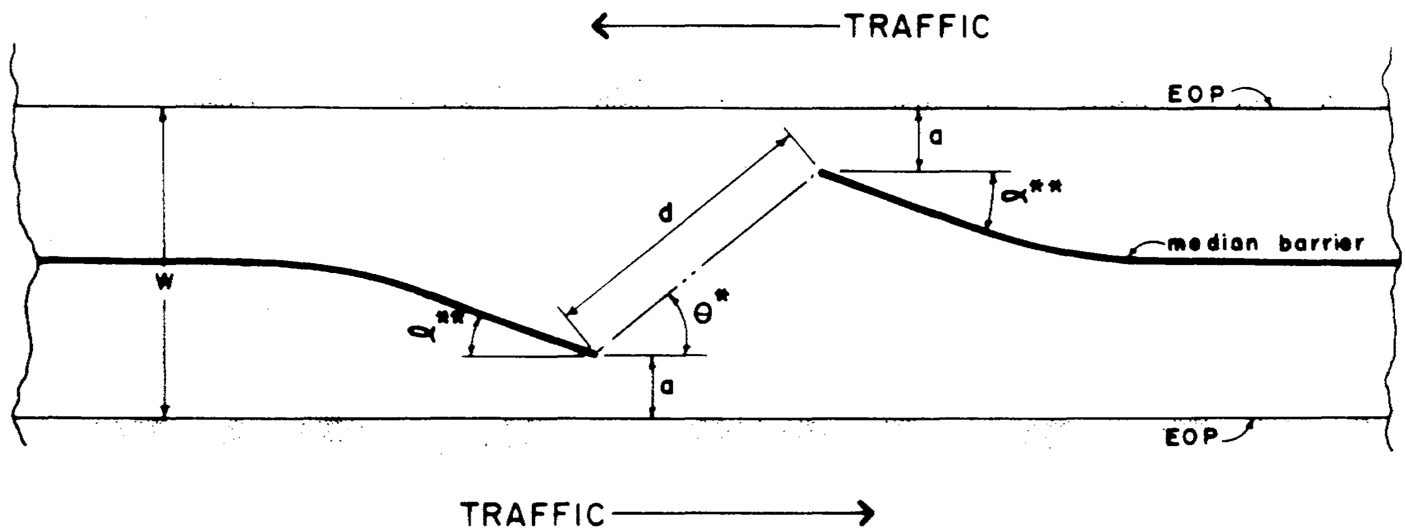
The flare rate of the terminals in this opening should adhere to the criteria given in Section 8--08.04.

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.

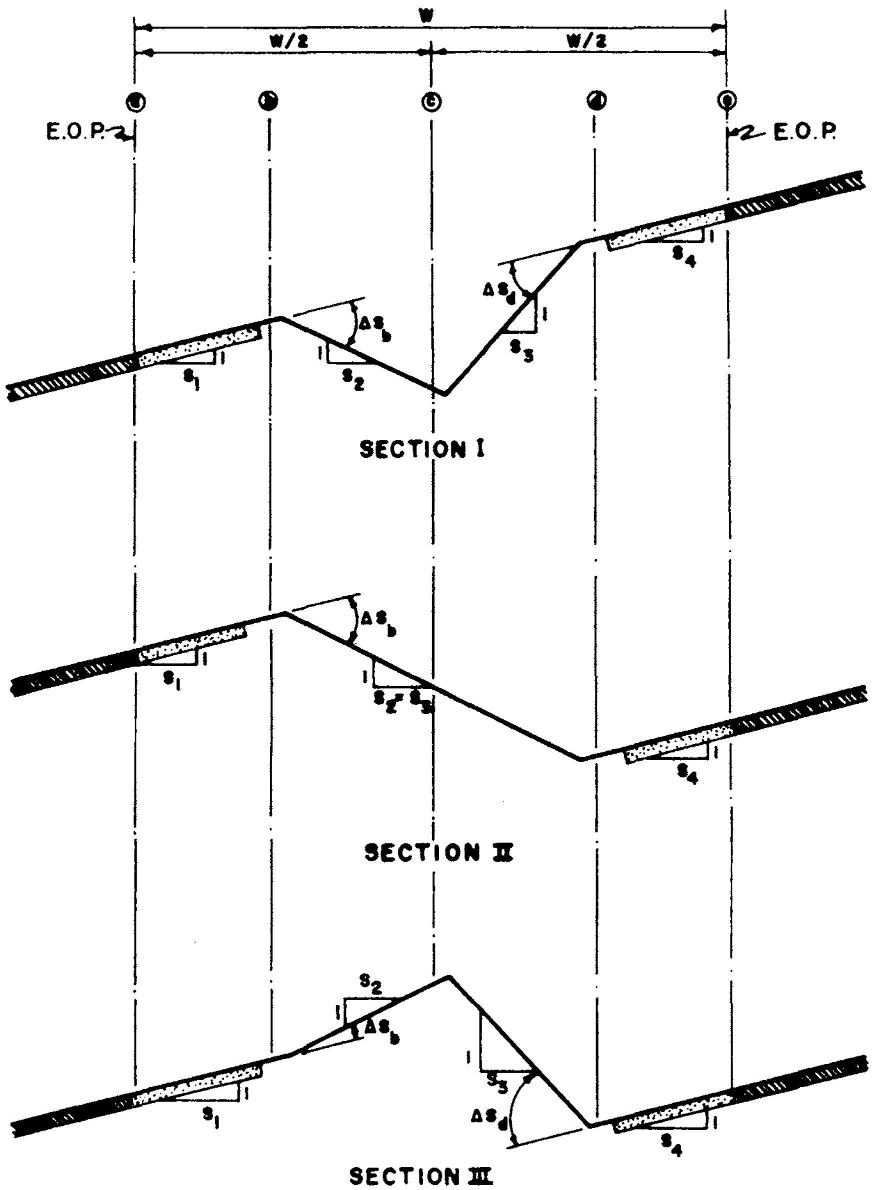
When a median barrier is warranted, the same barrier type should be used throughout the length of need, and the barrier should be placed in the middle of a flat median. However, in some situations as indicated in Sections I and II of Figure 8—EE, a barrier may be required at both sides of the median. 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.

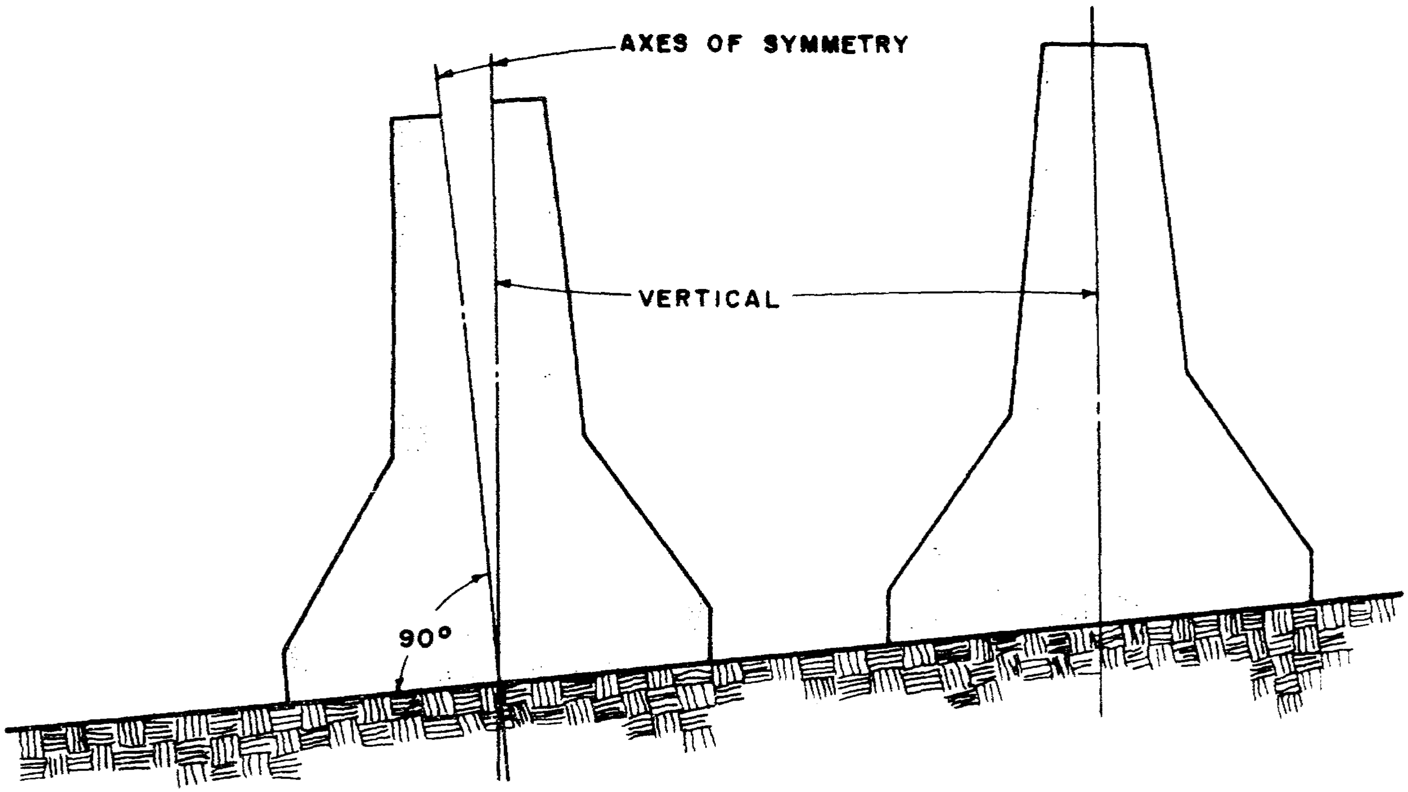
8—14.2 MEDIAN BARRIER FLARE RATES

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.

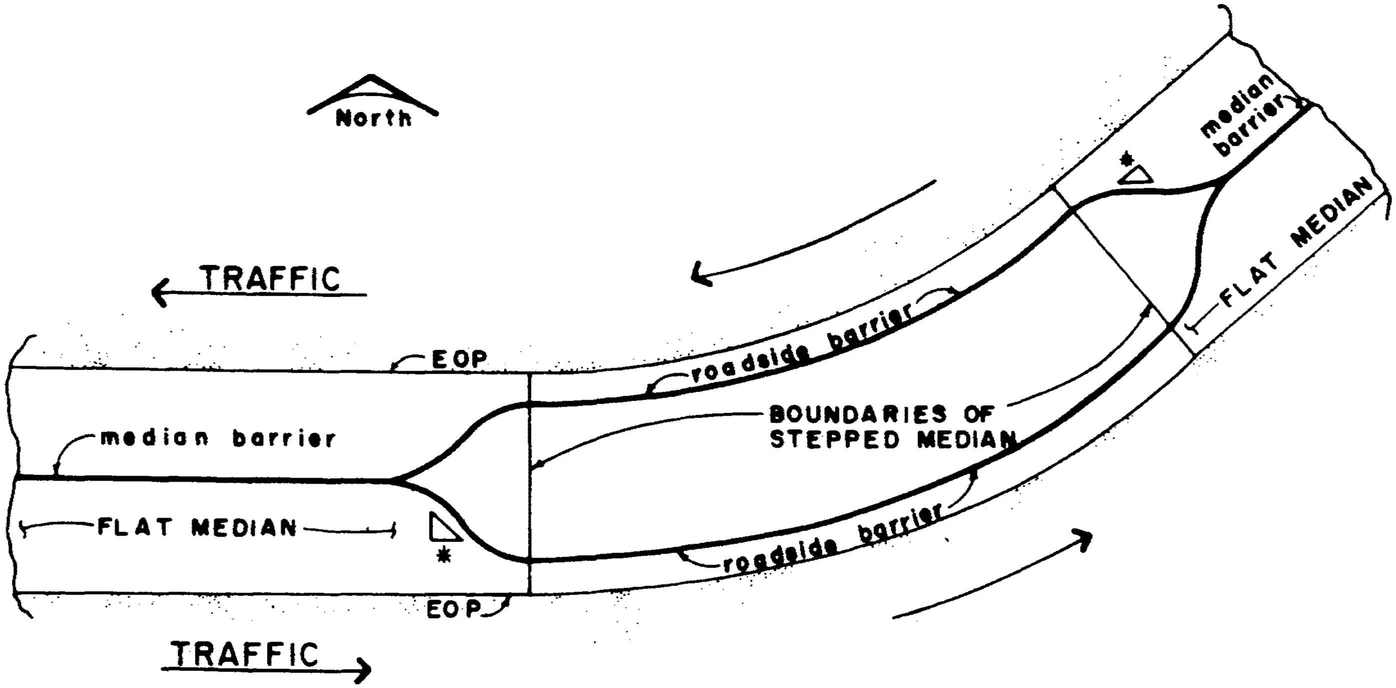
FIGURE 8-EE



(a) IDEAL (b) BEST COMPROMISE

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 - III 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.

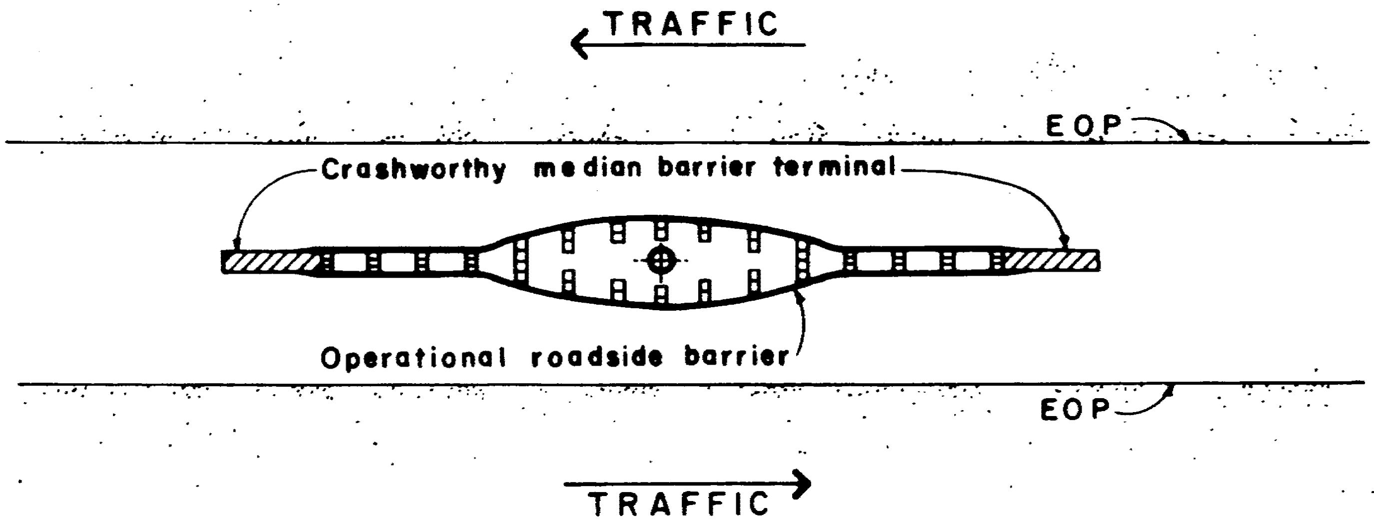
In some cases, the effective rail height will be decreased due to an accumulation of dirt, pavement overlays, etc. Dirt should be removed to return the barrier to its correct height. If necessary, and if the length and strength of the post and foundation permits, the rail can be raised to meet height 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

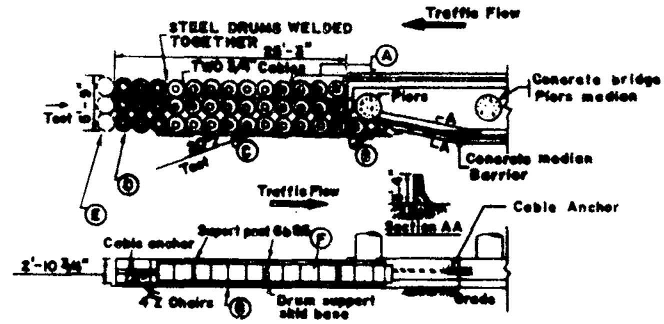
The following sections present the operational crash cushions and summarizes desirable structural and safety characteristics of a crash cushion. Also, discussed are the different crash cushion design concepts.

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	C1 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.

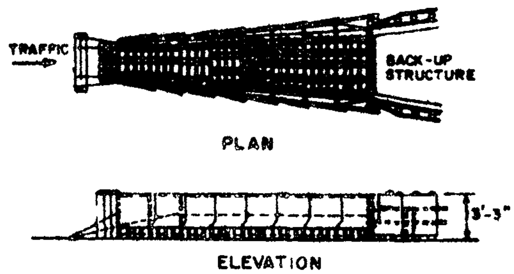
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	55.8	54.7
Angle	0	20
Vehicle Weight (lb.)	1790	4150
BARRIER		
Dynamic Deflection (ft.)	11.3	1.25
VEHICLE ACCELERATIONS (G's)[1]		
Lateral	UNAV	4.0[4]
Longitudinal	9.2[3]	3.9[4]
Total	UNAV	UNAV
VEHICLE TRAJECTORY		
Exit Angle (deg)	NOAP	≈20
Roll Angle (deg)	0	≈10
Pitch Angle (deg)	0	≈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 pipe 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-2'x4' 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 re-direction.

IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	61.8	57.0
Angle (deg)	0	9.0
Vehicle Weight (lb.)	4690	4780
BARRIER		
Deceleration Distance (ft.)	16.0	UNAV
VEHICLE ACCELERATIONS (G's)[1]		
Lateral	UNAV	5.2
Longitudinal	9.6	8.4
Total	UNAV	UNAV
VEHICLE TRAJECTORY		
Exit Angle (deg.)	NOAP	less than 10
Roll Angle (deg.)	0	0
Pitch Angle (deg.)	less than 10	0
BARRIER DAMAGE	Slight permanent damage	Several fender panels and 8 cells
REFERENCES	43	43
FIELD PERFORMANCE DATA[2]	YES	
REMARKS	Barrier performs well for head-on and side impacts.	

UNAV - unavailable, NOAP - not applicable

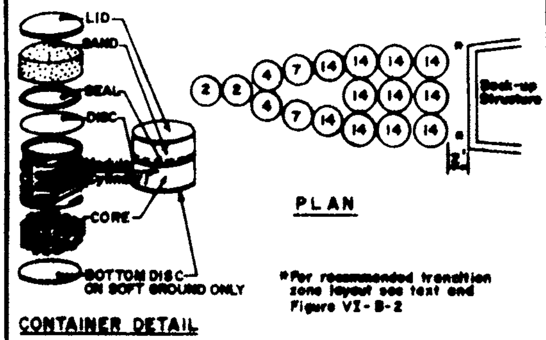
[1] 50 millisecond average unless otherwise noted

[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



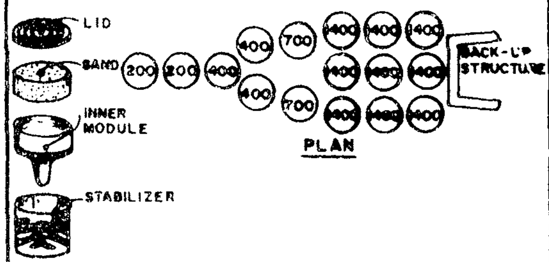
SYSTEM	C3 Fitch Inertial Barrier	
BARRIER DESCRIPTION	Specially manufactured plastic containers (36" in diameter and height) filled with sand. Standard weights are 200, 400, 700, 1400 and 2100 lb. Volume and density of sand may vary.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	59.0	57.0
Angle (deg)	0	15
Vehicle Weight (lb.)	1940	4770
BARRIER		
Deceleration Distance (ft.)	19.0	UNAV
VEHICLE ACCELERATIONS (G's)[1]		
Lateral	UNAV	UNAV
Longitudinal	8.7	7.9
Total	UNAV	UNAV
VEHICLE TRAJECTORY		
Exit Angle (deg.)	NOAP	No redirection
Roll Angle (deg.)	0	0
Pitch Angle (deg.)	15	≈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



CONTAINER DETAIL

SYSTEM	C4 Energite Inertial Barrier	
BARRIER DESCRIPTION	Specially manufactured plastic containers filled with sand. Standard size of container is 36" diameter top, 32" diameter base and 35 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.)	 58.4 0 4490	 59.3 10 4430
BARRIER Deceleration Distance (ft.)	 36.9	 46.0
VEHICLE ACCELERATIONS (G's)[1] Lateral Longitudinal Total	 UNAV 3.35 UNAV	 6.0[3] 2.0[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	48	48
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

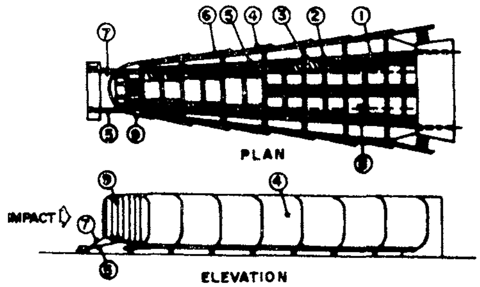
[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

[3] Acceleration calculated from stopping distance

OPERATIONAL CRASH CUSHION SYSTEMS, D

TABLE 8-36

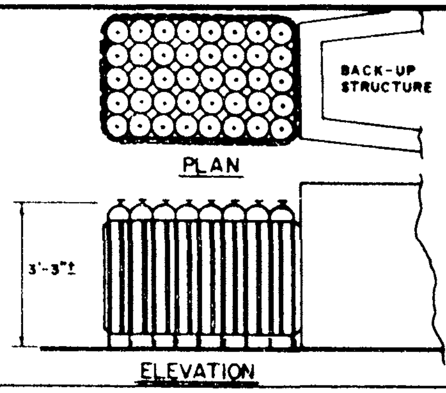
Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg	

SYSTEM	C6 Hi-Dri Cell Sandwich	
BARRIER DESCRIPTION	Heli-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. = 0.306m 1 in = 25.4mm. 1 mph = 1.61 km/hr 1 lb = 0.464 kg		
SYSTEM	C6 Hi-Dro Cell Cluster	
BARRIER DESCRIPTION	8" 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.	

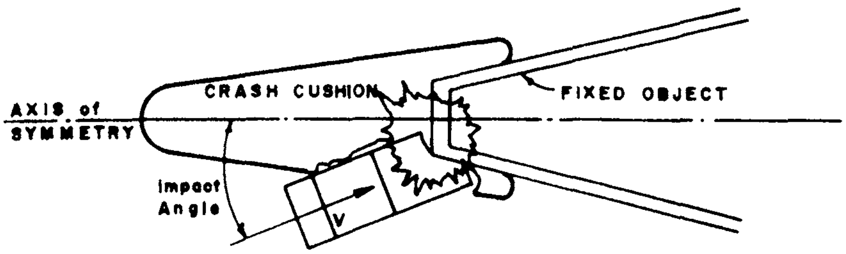
UNAV – unavailable

[1] 50 millisecond average unless otherwise noted

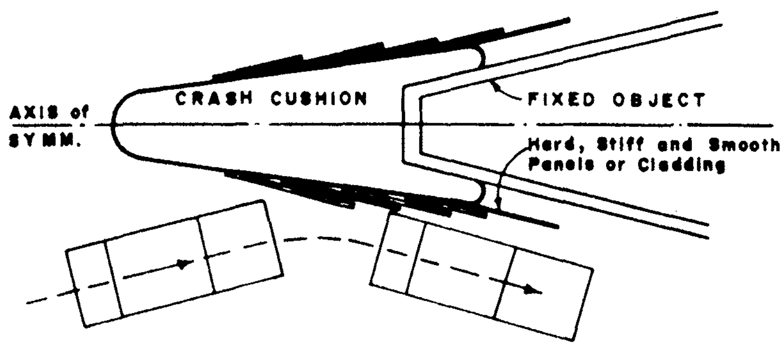
[2] If available, see summary in Appendix A (AASHTO Barrier Guide)

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 (C3 and C4) 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.

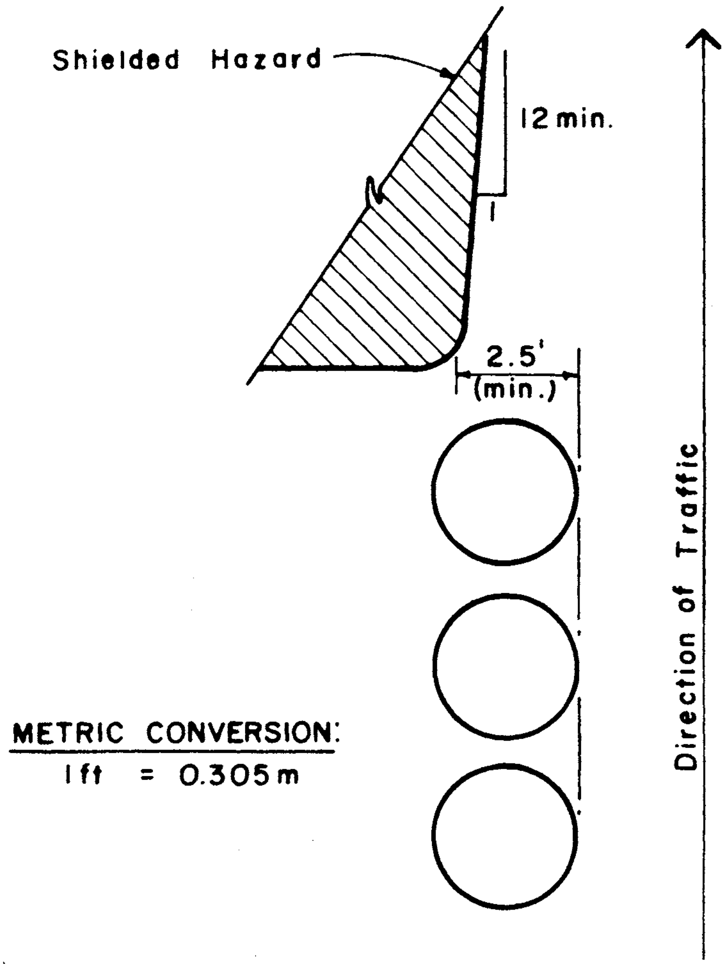
8—17.4 SYSTEM C5, HI-DRI CELL SANDWICH

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



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: Standard Sections and Transitions	Applicable Criteria: Longitudinal Barriers: Terminal	Applicable Criteria: Crash Cushions
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 Sand-wich (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.

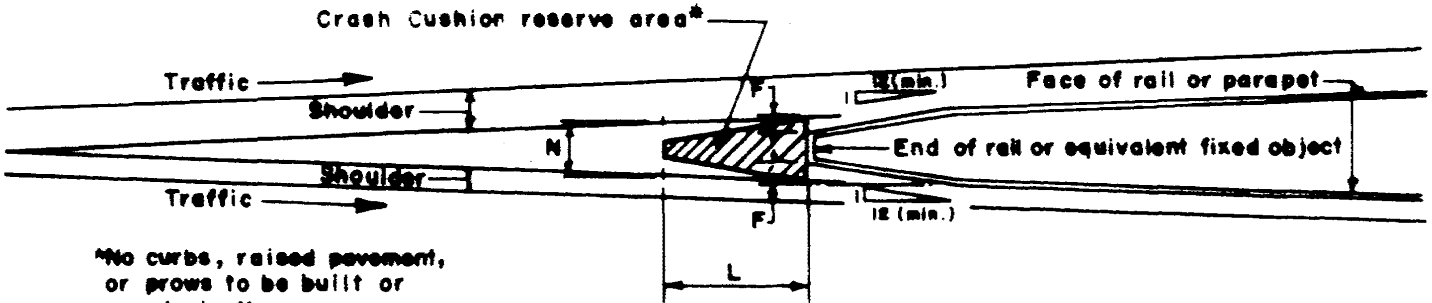
It is assumed, that a crash cushion is warranted and that a selection must be made.

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	

1Number in parenthesis is number of installations on which average installation cost is based.

2Number in parenthesis is number of hits on which average repair cost is bases.

3Property 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: No. of Hits	Hit Severity: P.D.O.[3]	Hit Severity: Injury	Hit Severity: Fatal	Comments
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)	$ 966 (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.

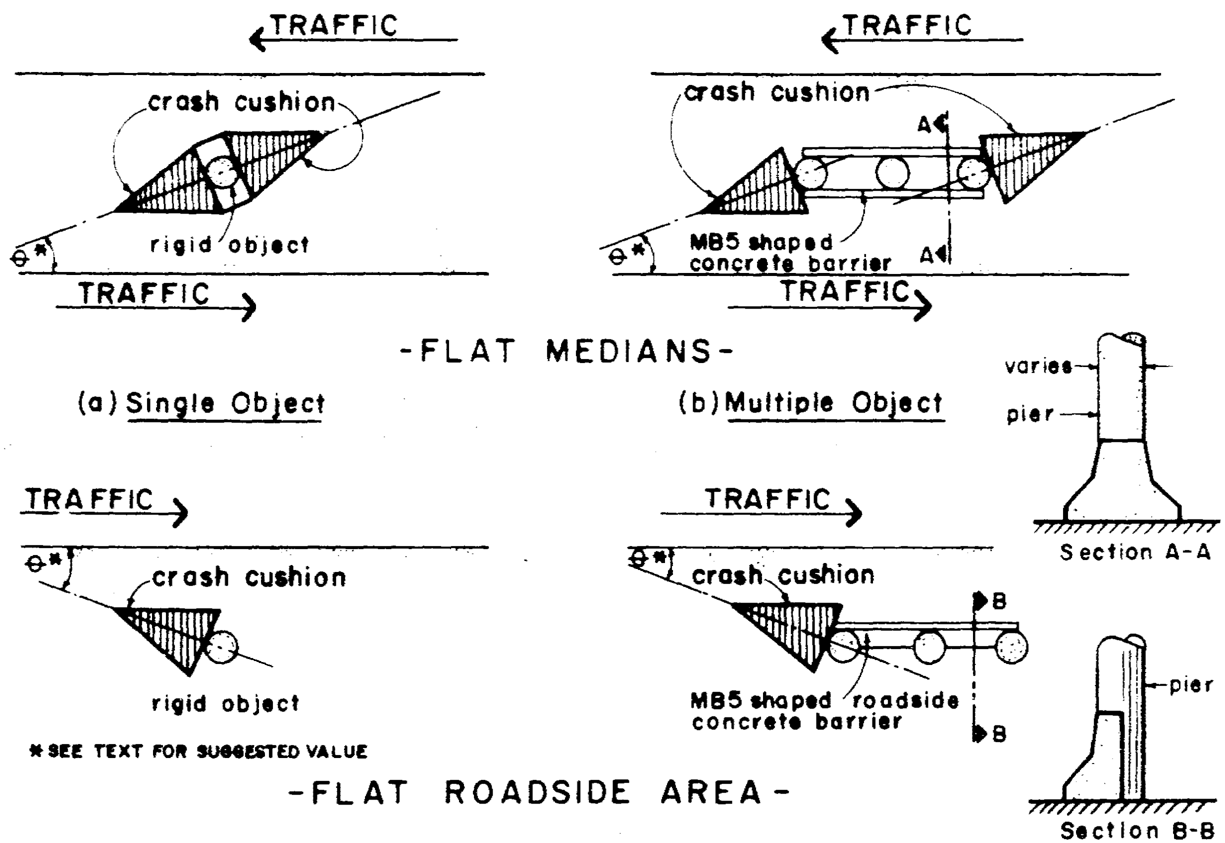
Chain link fence is primarily used on controlled-access highways in urban and suburban areas, and in rural areas in the vicinity of schools, industrial plants, clusters of dwellings and other generation of pedestrian and vehicular traffic.

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.

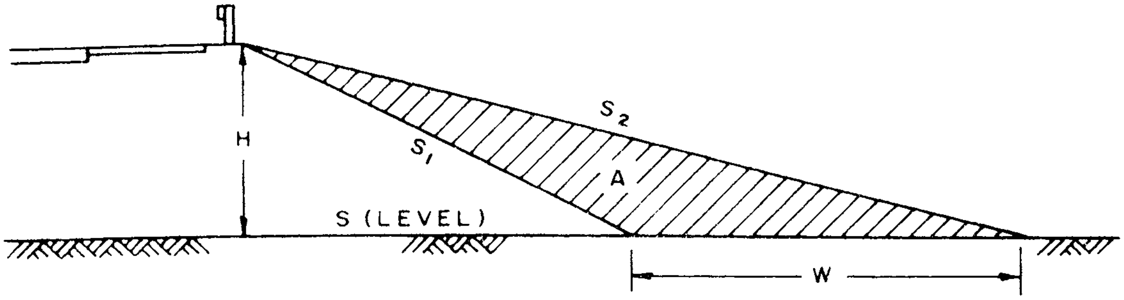
Care must be taken in the design and location of fencing at intersection to avoid unsafe restriction of sight distances.

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:

$$W = H\,(S_2 - S_1)$$

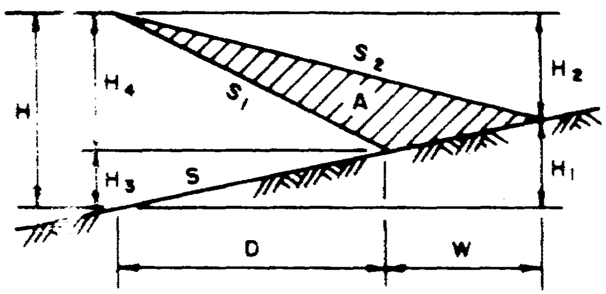
$$A = \tfrac{1}{2}\,HW = \tfrac{1}{2}\,H^2\,(S_2 - S_1)$$

$$K = AC_F + WC_R - C_G$$

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

$$H_1 = H\left(\frac{1}{S/S_2 + 1}\right)$$

$$H_2 = H - H_1$$

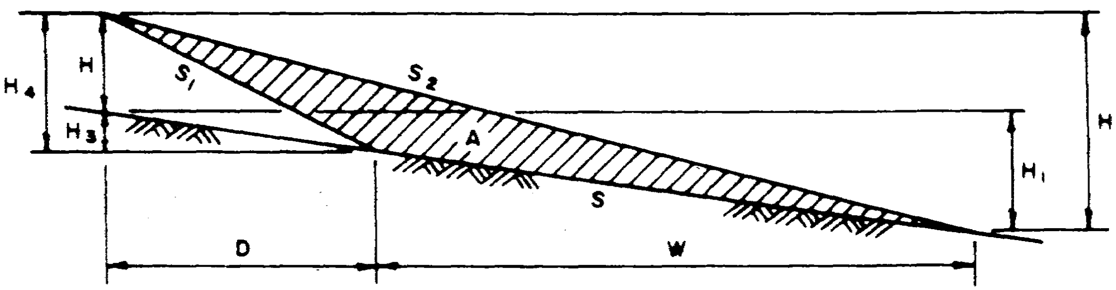
$$H_3 = H\left(\frac{1}{S/S_1 + 1}\right)$$

$$H_4 = H - H_3$$

$$D = H_3 S = H_4 S_1$$

$$W = H_2 S_2 - D$$

$$A = \tfrac{1}{2} H W$$



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
UPWARD	STEEP (5:1)	ADD. R.O.W. WIDTH (M.)	2.4	3.2	4.0	4.8	5.6	6.3	7.2	7.9
UPWARD	MODERATE (20:1)	ADDITIONAL FILL (M^3)	6.9	12.2	19.2	27.0	36.8	48.3	61.2	75.6
UPWARD	MODERATE (20:1)	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
LEVEL		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
DOWNWARD	MODERATE (20:1)	ADD. R.O.W. WIDTH (M.)	8.4	11.2	13.8	16.6	19.4	22.2	25.0	27.8
DOWNWARD	STEEP (5:1)	ADDITIONAL FILL (M^3)	75.0	133.3	208.4	300.0	408.3	533.4	675.0	833.3
DOWNWARD	STEEP (5:1)	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
UP (+)	MODERATE (20:1)	– 17	– 4	9	28	49	74	101	131
LEVEL		– 11	5	25	49	77	109	145	185
DOWN (–)	MODERATE (20:1)	1	21	48	81	120	165	215	271
DOWN (–)	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.