A SUPPLEMENT

TO

A GUIDE FOR SELECTING, DESIGNING AND LOCATING TRAFFIC BARRIERS

PREPARED

BY

THE TEXAS TRANSPORTATION INSTITUTE

MARCH, 1980

TABLE OF CONTENTS

CORRECTIONS

JANUARY 1980

TO

AASHTO GUIDE FOR SELECTING, LOCATING, AND DESIGNING TRAFFIC BARRIERS (1977)

Page 16 - Dimension "CZ_c" should read "ΔCZ_c".

Page 17 - Change:
"$\Delta CZ_c = R(1-\cos \frac{L_R D^o}{100})$ (slide slope-0.1 or flatter)

To: ". . . [side slope = -0.1 or flatter].

Comment: Words in brackets are not part of formula.

Page 29 - Section E-E: Change "60'" to "30'"

Section A-A: Change "40'" to "20'"

Page 49 - Last line in 3rd full paragraph, change "Section III-B-3 and III-B-4"
To: "Section III-E-3 and III-E-4"

Page 52 - Next to last paragraph, change "Two" to "Three".

Page 61 - Change "...positive if sloping downward"
To: "...negative if sloping downward."

Page 64 - Change heading: "Shyline offset (ft)"
To: "Shyline offset, L_s (ft)"

Change instructions under left side of table to read "*when $L_2 < 0.5L_s$, L_t shall have a..."

Page 4 - In the first line of the last paragraph change "Underlined" to "Italized" and "Appendix I" to "Appendix J".

Page 105 - In the last line of the seventh paragraph change reference (145) to (57).

Page 317 - In reference 57 change 1975 to 1976 and add: (Report No.'s FHWA-RD-77-3 and 4).

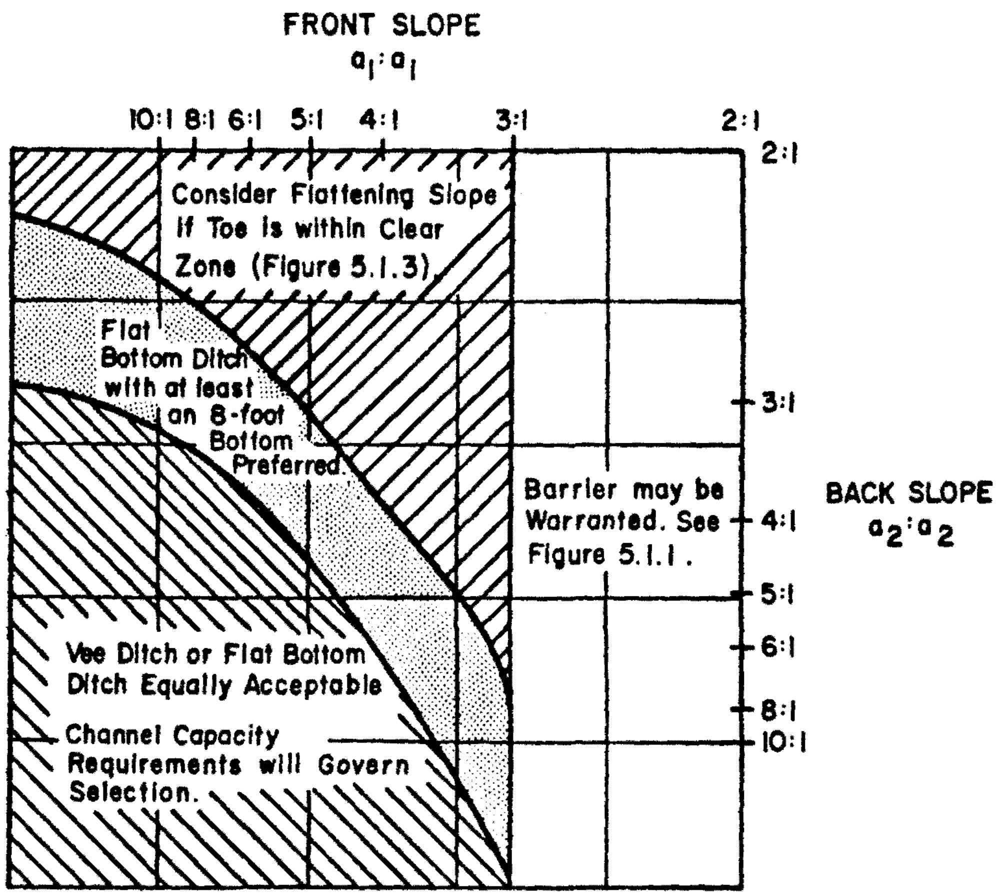
Pages 294 & 322 - Change the last reference under 1976 and 1977 on page 294 and reference 145 on page 322 to read, "Modified Breakaway Cable Terminals for Guardrails and Median Barriers," NCHRP Research Results Digest No. 102, May, 1978.

Page 37 - Line 3 of the description of G3 should read, "6" x 6" x 0.188" steel tube."

SUGGESTED DESIGN CURVE

FOR ROADSIDE DITCHES

This graph is a composite of Figure III-A-7, III-A-8 and III-A-9 in the Barrier Guide. The composite graph eliminates a great deal of the confusion associated with the interpretation of the ditch design criteria presented in the guide.



1 ft = 0.305 m

IMPACT BEHAVIOR OF BARRIERS ON NONLEVEL TERRAINS

BY

HAYES E. ROSS, JR., AND DARRELL G. SMITH

TEXAS TRANSPORTATION INSTITUTE

TEXAS A & M UNIVERSITY

Copy of a paper presented at the National ASCE Meeting, Atlanta Georgia October 23-25, 1979. ASCE PREPRINT No. 3634

ABSTRACT

IMPACT BEHAVIOR OF BARRIERS
ON NONLEVEL TERRAIN

by

Hayes E. Ross, Jr., and Darrell G. Smith

Six full-scale crash tests were conducted to evaluate the impact behavior of two widely used roadside barriers when placed on a 6:1 side slope. Four of the six tests involved a standard W-beam rail on metal posts (G4(1S) system) and the other two tests involved a three-cable barrier mounted on metal posts (G1 system). The tests were conducted and evaluated in accordance with national guidelines for testing of roadside appurtenances.

Based on the results, it is recommended that the G4(1S) system not be placed on 6:1 or steeper side slopes. Placement of the G1 system on a 6:1 side slope is acceptable provided ample space exists between the barrier and the hazard it is shielding.

KEY WORDS: Automobiles, Highways, Nonlevel Terrain, Safety, Slopes, Tests, Traffic Barriers

IMPACT BEHAVIOR OF BARRIERS ON NONLEVEL TERRAIN

by

Hayes E. Ross, Jr.[1], M, ASCE, and Darrell G. Smith[2]

INTRODUCTION AND SCOPE

Impact behavior of a roadside or median barrier is dependent on a number of factors, including size and spacing of posts, size and mounting height of rail or beam, offset of beam from posts, soil conditions, and roadside conditions between the edge of the traveled way and the barrier. Little is known about the effects of the latter factor although it may have the greatest influence on performance. In general, barriers have been designed and tested for flat terrain conditions even though roadside and median barriers are commonly placed on side slopes, in depressed medians, in ditch bottoms, etc.

At the inception of this study trips were made to several states to survey current barrier placement practices and to solicit input from various state transportation personnel. It was found that there are four basic conditions for which roadside and median barriers are typically placed on nonlevel terrain. These are illustrated in the photographs of Figures 1 through 4. First, barriers used to shield bridge piers, overhead sign bridge supports, or other rigid objects in depressed medians or on side slopes are often placed as near to the object as the barrier design permits. In many cases this places the barrier on the side slope as shown in Figure 1. Secondly, barriers used to shield bridge abutments or other rigid objects near the shoulder are often flared away from the shoulder and terminated. As a consequence a portion of the barrier is placed on the side slope as illustrated in Figure 2. Thirdly,

[1]Research Engineer and Professor, TTI, Texas A&M University, College Station, Texas.

[2]Research Associate, TTI, Texas A&M University, College Station, Texas.

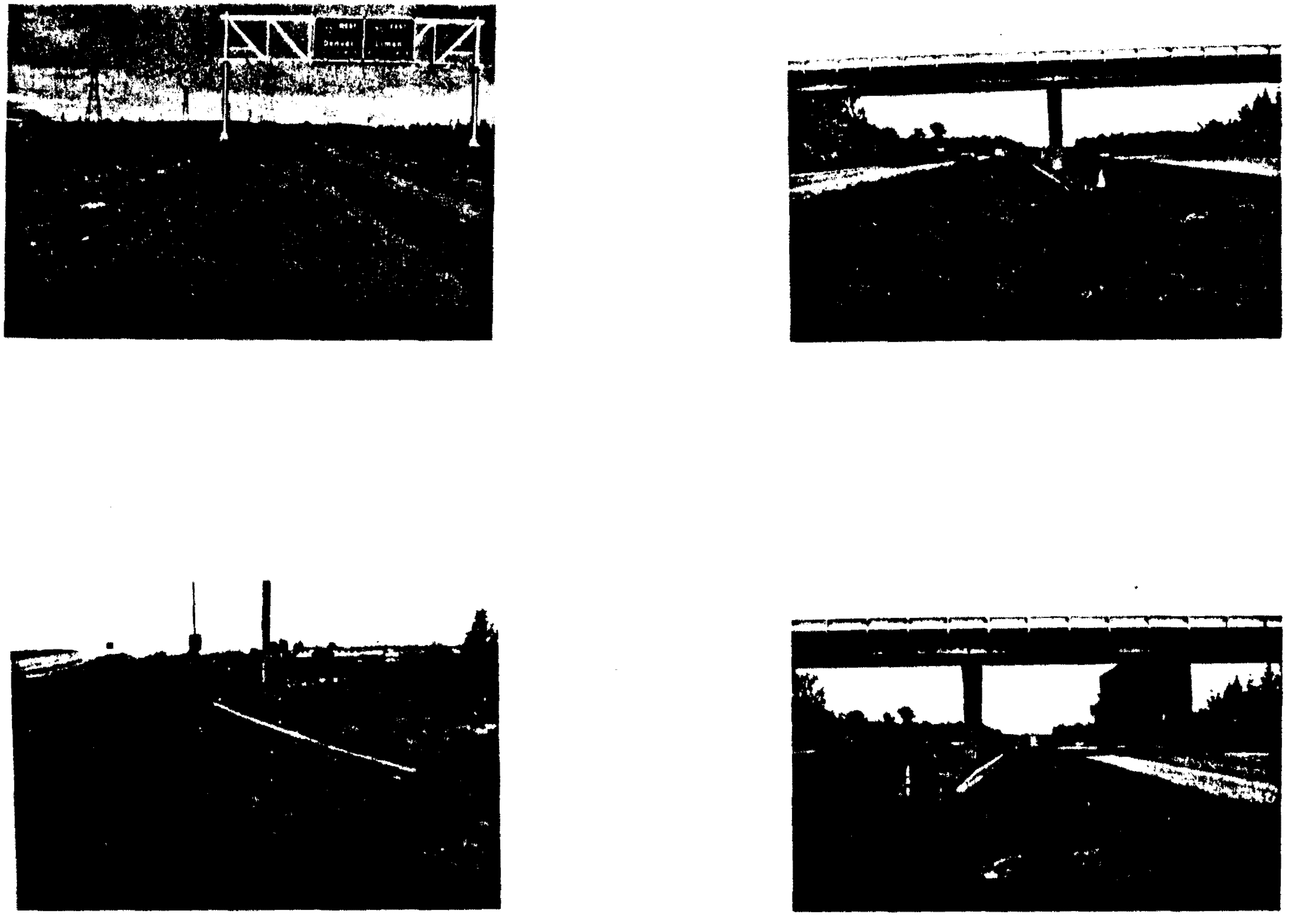
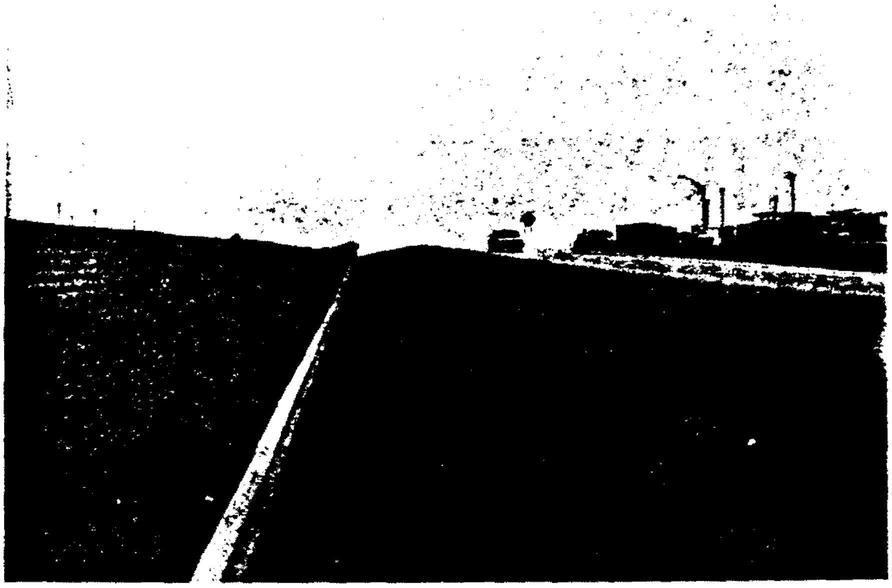


Figure 1. Barriers shielding rigid objects

Figure 2. Flared barriers

Figure 3. Barrier on barn roof section



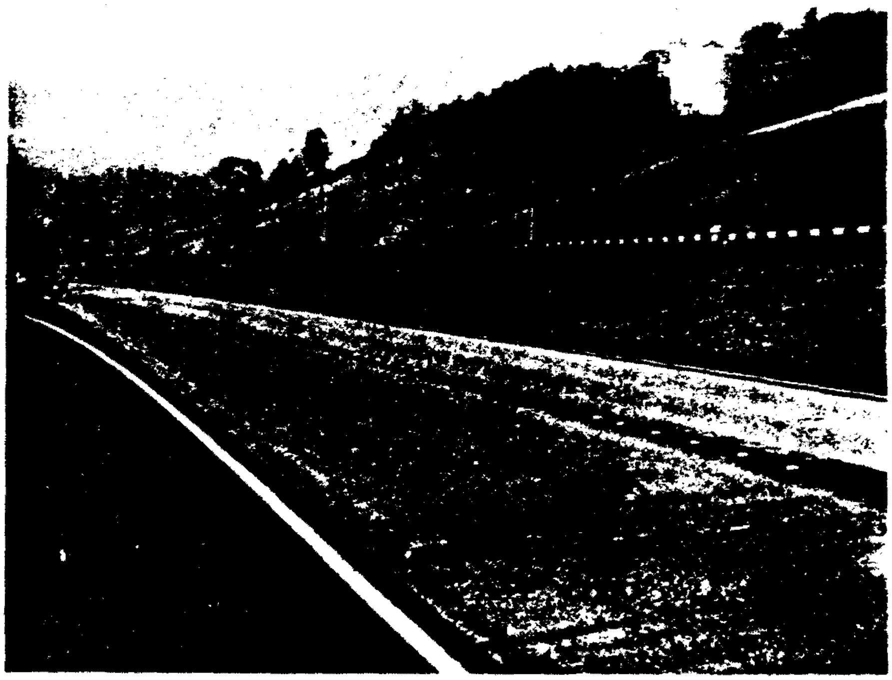


Figure 4. Median barriers.

roadside barriers are sometimes placed on "barn roof" sections in high-fill areas. Typically the roadside is composed of a shoulder, then a relatively flat sloped embankment (usually a 6:1 slope) which may extend up to 20 ft (6.1 m) laterally and finally a relatively steep embankment (usually 2:1 or steeper). In this case the barrier is placed on the 6:1 slope to shield the steeper embankment. This is illustrated in Figure 3. The last condition, which is not as common as the other conditions mentioned, involves median barriers used to prevent cross-over head-on accidents that are placed on stepped or depressed medians. This is illustrated in Figure 4.

To gain insight on behavior of typical barriers on nonlevel terrain, two roadside barriers were evaluated through a full-scale crash test program. These were the G1[a] system and the G4(1S)[a] system. The G1 system consists of three steel cables mounted on "weak" posts while the G4(1S) system consists of a standard steel W-beam mounted on "strong" posts. Selection of these systems was based on four factors: (a) both are operational (as per Reference 1); (b) both are widely used; (c) both are used to varying degrees on nonlevel terrain conditions; and (3) the G1 barrier is a "flexible" system which may undergo considerable lateral movement on impact while the G4(1S) barrier is a "semi-rigid" system and will displace much less than the G1 system for a given set of impact conditions.

Selection of a 6:1 slope was based on an evaluation of previous research involving computer simulation of vehicle trajectory on side slopes (Appendix F of Reference 4). The reference work showed that a vehicle could possibly vault a typical roadside barrier placed near the shoulder on slopes steeper than approximately 10:1 to 8:1. It was concluded that a 6:1 slope would be in the

---

[a]Designations are consistent with those contained in Reference 4.

critical range for lateral barrier offsets up to approximately 12 ft (3.66 m) from the edge of the shoulder.

This paper was condensed from a report to the Federal Highway Administration [6].

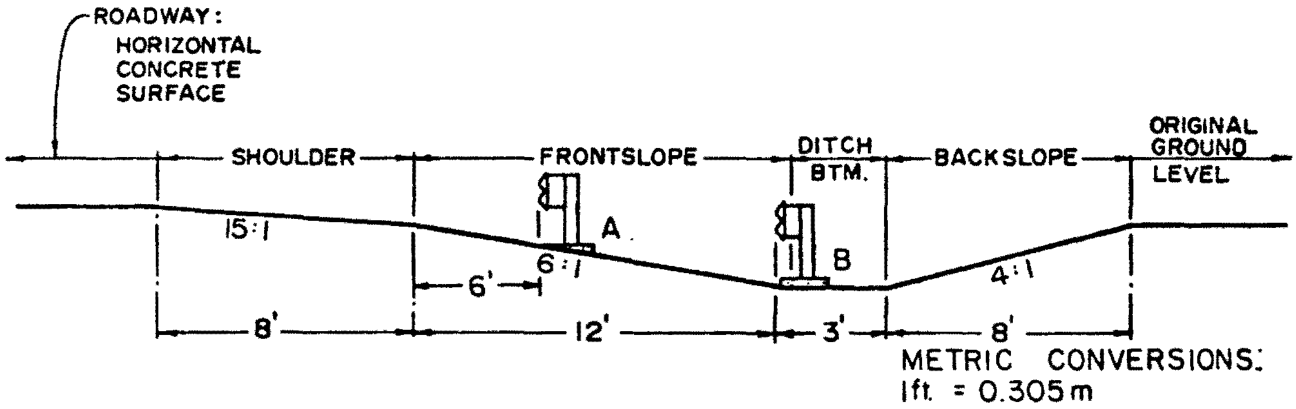
TEST CONDITIONS AND EVALUATION CRITERIA

Test Site. The test site, shown in Figure 5, was designed to represent a common roadside section defined by the road surface itself, a shoulder, a side slope, and a back slope. The road surface consisted of an existing concrete surface (airport apron). An 8 ft (2.4 m) shoulder area was cut on a 15:1 slope, and a 12 ft (3.7 m) side slope was cut on a 6:1 slope. A 3 to 4 ft (0.9 to 1.2 m) ditch bottom was added to aid in drainage and a 4:1 back slope returned the configuration to the original ground level. The existing horizontal concrete surface has a downgrade slope parallel to the rail of 1% and the test slopes were constructed to parallel this drainage pattern.

Length of the installed roadside barrier was 200 ft (61.0 m) in each case excluding the rigid anchors on both ends. Two sets of anchor foundations were installed, one locating the face of the guardrail 6 ft (1.8 m) from the edge of the shoulder (installation A) and the other locating it 12 ft (3.7 m) from the shoulder (installation B).

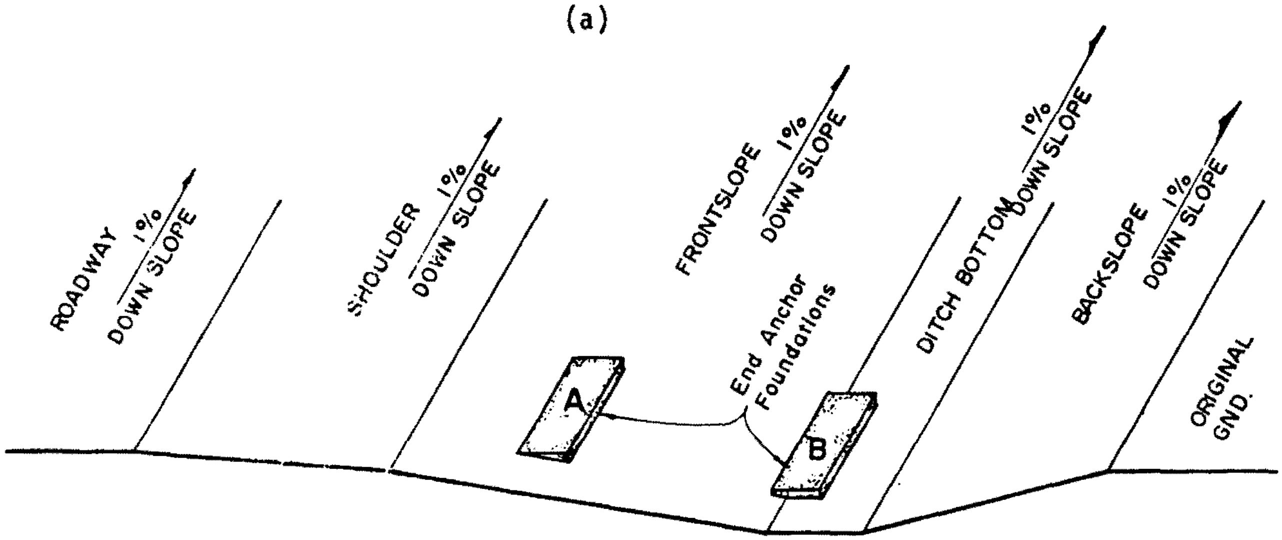
Description of Barrier Systems. Reference should be made to Figure 6 for details of the two barrier systems described below.

G4(1S) Blocked-Out W-Beam. This system consisted of a standard 12 gauge steel W-beam mounted on W6 x 8.5 steel posts. The blockout was a W6 x 8.5, 14 in. (35.6 cm) long steel block which was bolted to the steel post. The top of the rail was 27 in. (68.6 cm) above ground level at the post. The posts were spaced 6.25 ft (1.91 m) center to center, and they were set 42 in. (106.7 cm) in an 18 in. (45.7 cm) diameter drilled hole and then backfilled with a well graded base material. This roadside barrier system, which was used in tests 1



Cross Sectional View

(a)



Isometric View

(b)

Figure 5. Test site geometry.

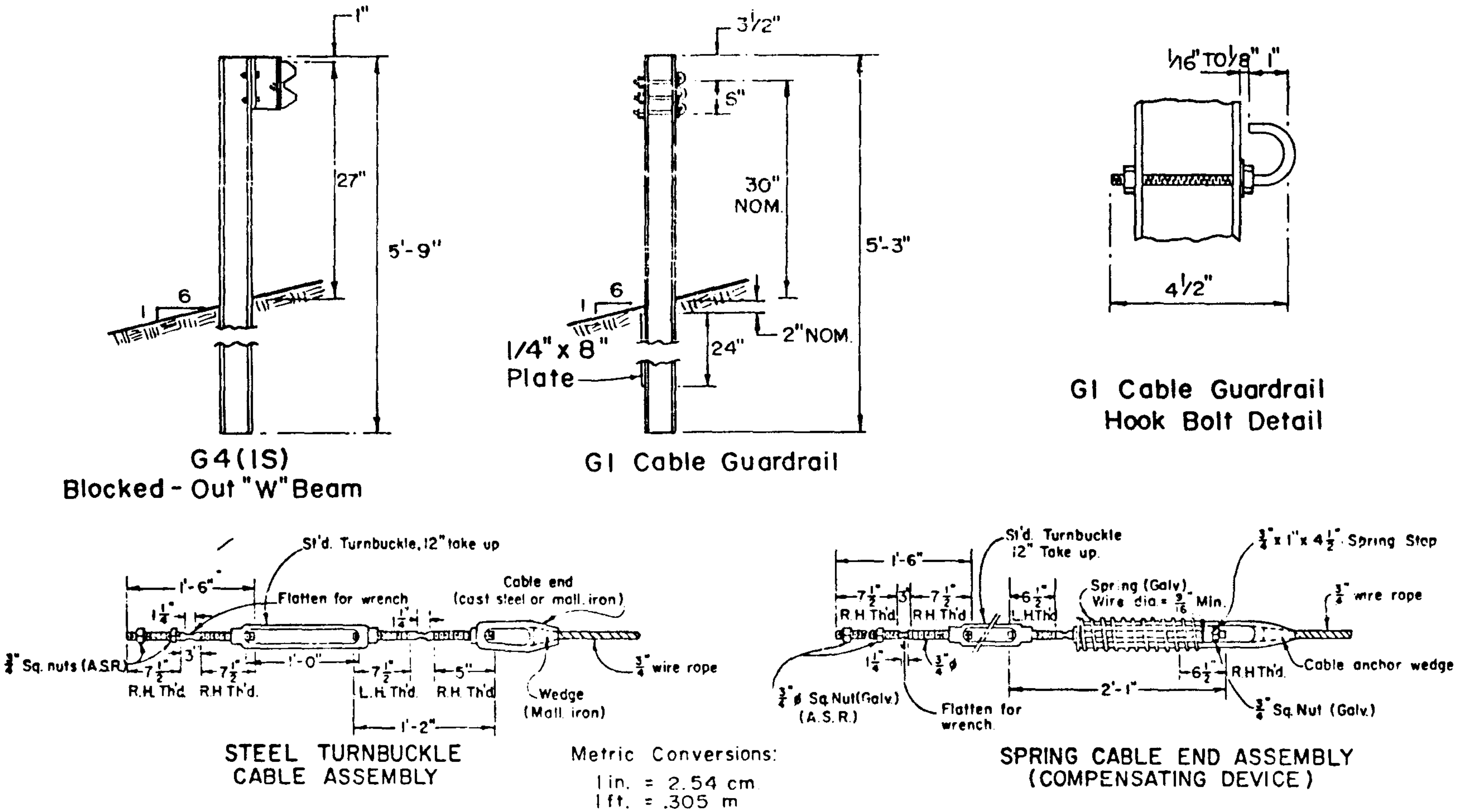


Figure 6. Roadside barrier systems and details.

through 4, is shown in Figure 7.

G1 Cable Guardrail. This system consisted of three 3/4 in. (1.9 cm) diameter pretensioned cables mounted on S3 x 5.7 steel posts. The top cable was 30 in. (76.2 cm) from ground level, and the cables were spaced 3 in. (7.6 cm) apart. The cables were attached to the steel posts by 5/16 in. (0.79 cm) diameter steel hook bolts. A 1/4 in. x 8 in. x 24 in. (.64 cm x 20.3 cm x 61.0 cm) steel bearing plate was welded to the back flange of each post. The posts were spaced 16 ft (4.9 m) apart center to center, and they were driven 29.5 in. (74.5 cm) into the soil.

Cables were attached to the downstream end anchor by turn-buckles, and the upstream end of each cable was attached to a spring compensating device. The cables were pretensioned to approximately 1000 lbs (454 kg) before the test. This system, which was used in tests 5 and 6, is shown in Figure 8.

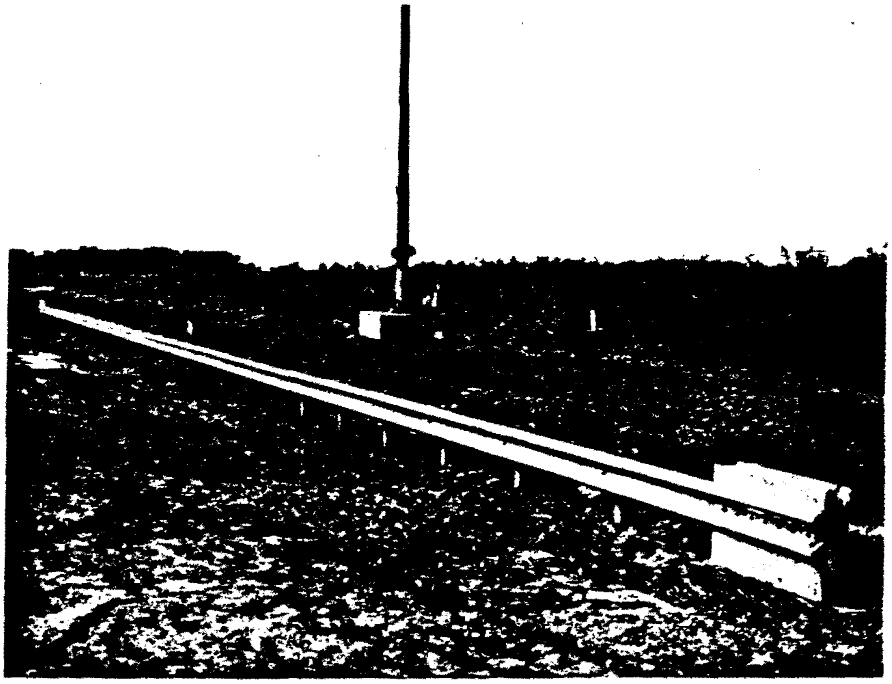
Evaluation Criteria. Reference 5 states that three appraisal factors are to be considered for test of a longitudinal barrier: (a) structural adequacy, (b) impact severity, and (c) vehicle trajectory hazard. In summary, criteria for each appraisal factor are:

(a) Structural Adequacy - The test article shall redirect the vehicle; hence, the vehicle shall not penetrate or vault over the installation.

(b) Impact Severity - Where the test article functions by redirecting the vehicle, the maximum vehicle acceleration (50 ms avg) measured near the center of mass should be less than the following values:

Maximum Vehicle Accelerations (g's)

Lateral	*Longitudinal*	*Total*	*Remarks*
3	*5*	*6*	*Preferred*
5	*10*	*12*	*Acceptable*



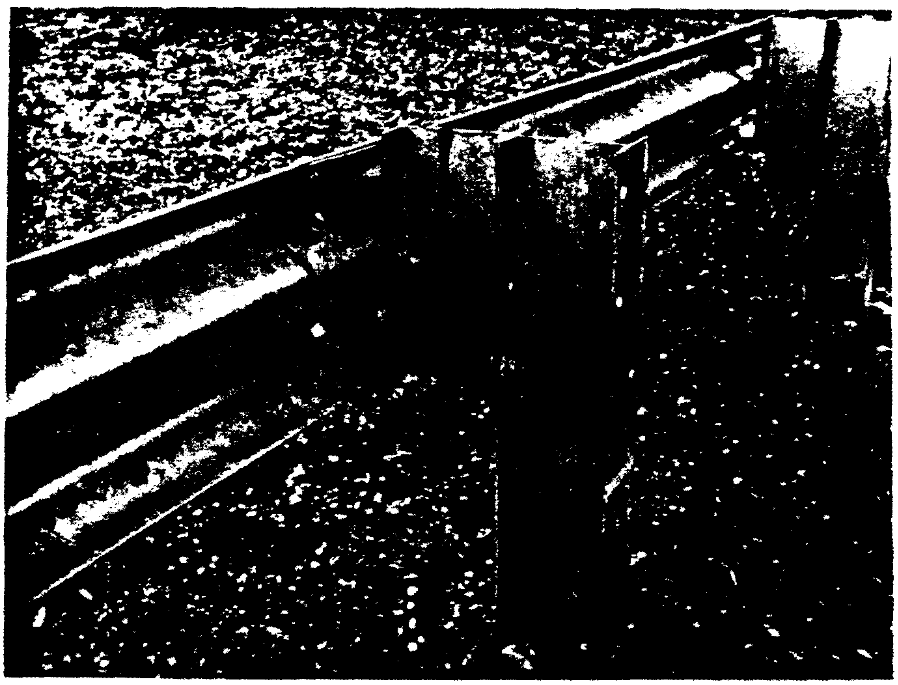
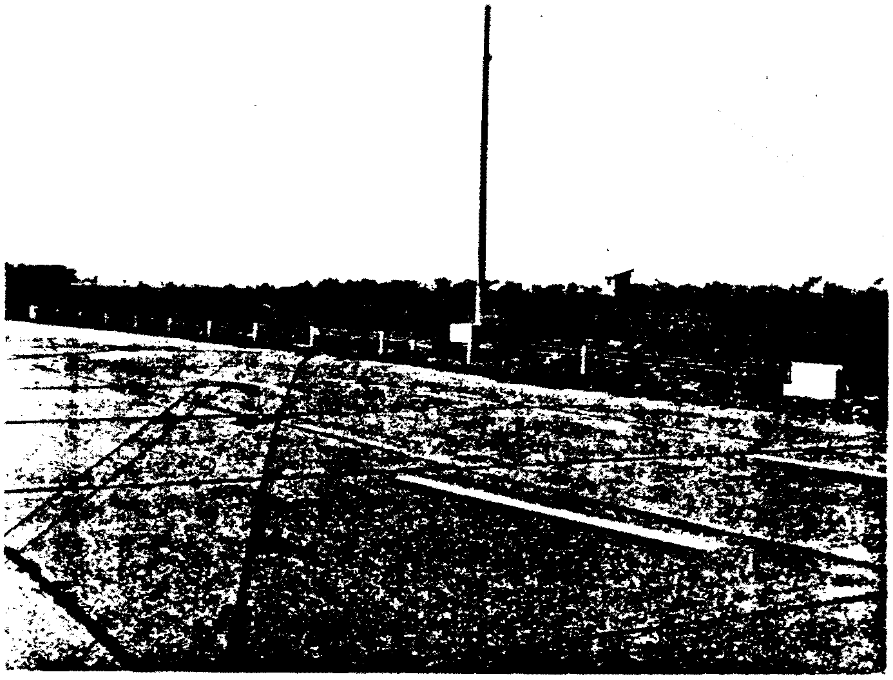


Figure 7. G4(1S) barrier installed on 6:1 slope.



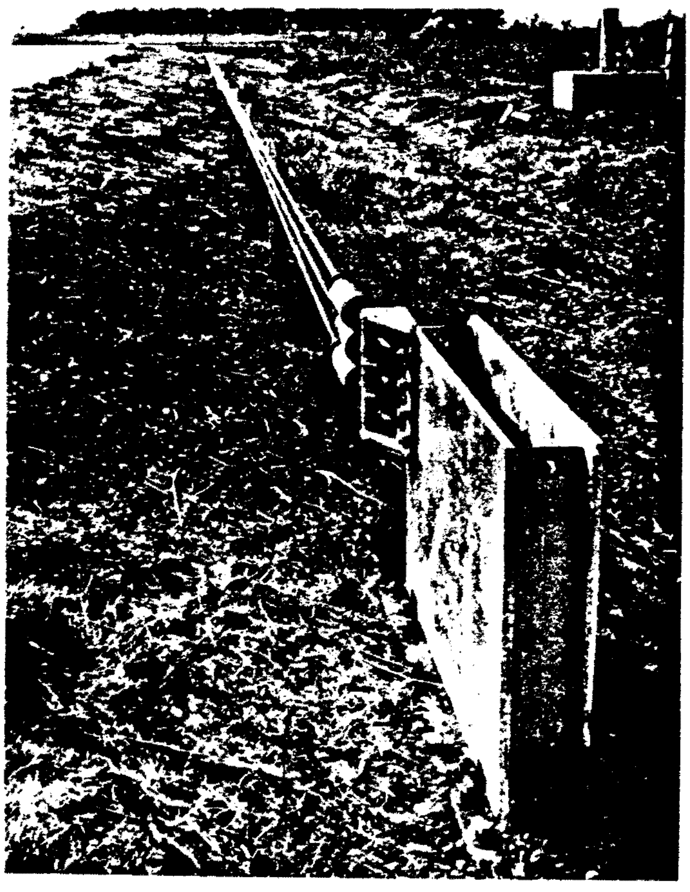


Figure 8. G1 cable rail installed on 6:1 slope.

These rigid body accelerations apply to impact tests at 15°
or less.

(c) *Vehicle Trajectory Hazard - After impact, the vehicle trajectory and final stopping position shall intrude a minimum distance into adjacent traffic lanes.*

Two tests are recommended [5] to evaluate a roadside barrier along its "length of need" (excludes end treatments). A strength test in which the barrier is impacted at 60 mph (96.5 km/h) by a 4500 lb (2043 kg) vehicle encroaching at 25° is recommended. The primary purpose of this test is to evaluate the *structural adequacy* of the barrier. The second test involves a 60 mph (96.5 km/h) impact by a 2250 lb (1022 kg) vehicle encroaching at 15°. This test is designed primarily to evaluate the *impact severity* of the barrier.

Vehicle damage was assessed after each test in accordance with two national rating scales, namely TAD [7] and SAE [2].

TEST RESULTS

Shown in Table 1 is a summary of the six crash tests and results obtained therefrom.

Test 1. This was a *structural adequacy* test of the G4(1S) system for a 6 ft (1.8 m) offset. Upon impact the lower part of the bumper just cleared the top of the rail and the car vaulted over the rail with little redirection.

Test 2. Test 2 was a nonstandard test but was conducted for two primary reasons: (1) to determine if the barrier was structurally adequate for a lower encroachment angle (15° versus 25°); and (2) to provide data for validating and updating barrier computer simulation programs (to be used later to supplement the crash test program). The car was contained and smoothly redirected. However, the car would have crossed adjacent traffic lanes thereby posing a potential trajectory hazard.

Table 1. Summary of crash test results[a]

TEST NO.	BARRIER TYPE	BARRIER OFFSET (ft)[b]	VEHICLE WEIGHT (lb)	IMPACT SPEED (mph)	IMPACT ANGLE (deg)	ADHERENCE TO PERFORMANCE SPECIFICATIONS[c] STRUCTURAL ADEQUACY?	IMPACT SEVERITY?	EXIT ANGLE?
1	G4(1S)	6.0	4500	62.83	25.0	No[d]	N/A	d
2	G4(1S)	6.0	4500	63.30	14.75	Yes	Yes	No[e]
3	G4(1S)	12.0	4500	62.9	26.25	No[f]	N/A	f
4	G4(1S)	12.0	2300	58.2	14.75	Yes	Yes	No[e]
5	G1	6.0	4500	59.6	24.75	Yes	N/A	Yes
6	G1	6.0	2250	58.4	17.25	Yes	Yes	Yes

[a]All barriers tested were placed on a 6:1 side slope.

[b]Distance from outer edge of shoulder to face of barrier.

[c]See Section V-A for discussion of performance specifications.

[d]Vehicle vaulted over barrier.

[e]Subjective evaluation.

[f]Vehicle penetrated through fractured rail element.

N/A - Not Applicable.

<u>Metric Conversions:</u>

1 ft = 0.305 m
1 lb = 0.454 kg
1 mph = 1.609 km/h

Test 3. This was a *structural adequacy* test of the G4(1S) system for a 12 ft (3.7 m) offset. Upon impact the vehicle began to redirect. However, the combined action of lateral, longitudinal, and vertical loads on the rail and right front wheel snagging on support posts resulted in a complete fracture of the rail. The right front wheel and portions of the wheel assembly were torn free of the vehicle. The vehicle penetrated the rail and came to rest approximately 90 ft (27.5 m) beyond the point of impact just behind the barrier. It is noted that post and rail material properties were in compliance with recommended standards.

Test 4. This was an *impact severity* test of the G4(1S) system for a 12 ft (3.7 m) offset. The car was contained and smoothly redirected. However, the car would have crossed adjacent traffic lanes thereby posing a potential trajectory hazard.

Test 5. This was a *structural adequacy* test of the G1 system for a 6 ft (1.8 m) offset. The car was contained and smoothly redirected and there was no trajectory hazard. Maximum dynamic deflection of the cables was 9.5 ft (2.9 m).

Test 6. This was an *impact severity* test of the G1 system for a 6 ft (1.8 m) offset. The car was contained and smoothly redirected, decelerations were below suggested limits, and there was no trajectory hazard. Maximum dynamic deflection of the cables was 4.2 ft (1.3 m).

CONCLUSIONS

Conclusions drawn as a result of the six tests reported herein are:

(1) The G4(1S) roadside barrier system does not satisfy *structural adequacy* requirements when placed on a 6:1 slope at offsets up through 12 ft (3.7 m). In other words, the barrier, when placed as stated, will not contain and redirect a 4500 lb (2043 kg)

automobile impacting at 60 mph (96.5 km/h) and an encroachment angle of 25°.

(2) The G4(1S) system, when placed on a 6:1 slope and a 6 ft (1.8 m) offset, will contain and smoothly redirect a 4500 lb (2043 kg) automobile impacting at 60 mph and an encroachment angle of 15°. Although not proven by the test, it is the authors' opinion that the G4(1S) system will satisfy *impact severity* requirements when placed on a 6:1 slope and a 6 ft (1.8 m) offset.

(3) The G4(1S) system satisfies *impact severity* requirements when placed on a 6:1 slope at a 12 ft (3.7 m) offset. In other words, the barrier, when placed as stated, will contain and smoothly redirect a 2250 lb (1022 kg) automobile with tolerable decelerations when impacting at 60 mph (96.5 km/h) and an encroachment angle of 15°.

(4) Post-impact vehicle trajectory was less than desirable following the G4(1S) tests in which the vehicle was redirected (tests 2 and 4). Results of these two tests could be interpreted to mean that a *vehicle trajectory hazard* existed, i.e., after impact, trajectory of the vehicle would pose a hazard to traffic in adjacent lanes.

(5) The G1 roadside barrier system, when placed on a 6:1 slope at a 6 ft (1.8 m) offset, satisfied all performance specifications for a roadside barrier, i.e., *structural adequacy, impact severity,* and *vehicle trajectory hazard.* When compared to the G4(1S) system, improved performance of the G1 system is attributed to the 30 in. (76.2 cm) mounting height of the top cable (versus 27 in. (68.6 cm) for the W-beam). The cables remained at essentially the

same height following impact while the W-beam in the G4(1S) system rotated backward and downward, creating a ramp for the vehicle.

RECOMMENDATIONS

Results of limited tests reported herein form a basis for the tentative recommendations which follow.

(1) Roadside or median barriers utilizing the standard W-beam, mounted 27 in. (68.6 cm) above ground, should not be placed on 6:1 or steeper slopes for offsets up to 12 ft (3.7 m). Offset is the lateral distance from the shoulder's edge to the face of the barrier. When placed within these boundaries the barrier cannot be expected to contain and redirect an automobile leaving the shoulder at 60 mph (96.5 km/h) with an encroachment angle equalling or exceeding 25°. In other words, the barrier will not meet current performance specifications regarding "structural adequacy" [5]. Barrier performance for offsets greater than 12 ft (3.7 m) is unknown and therefore no recommendation can be made regarding placement beyond this distance. Trajectory analysis [4] indicates an errant automobile with the above encroachment conditions would strike the barrier at or below the normal or level terrain impact height for offsets greater than 12 ft (3.7 m). It must be noted that the G4(1S) system did contain and redirect an automobile at 6 ft (1.8 m) and 12 ft (3.7 m) offsets for a 60 mph (96.5 km/h), 15° encroachment angle. Statistics have shown that approximately 80% of all errant vehicles leave the travel way at an angle of 15° or less. Barrier systems now in place on 6:1 slopes utilizing a 27 in. (68.6 cm) W-beam can thus be expected to contain and redirect a large majority of errant vehicles.

(2) The G1 roadside barrier system is acceptable for placement on side slopes 6:1 or flatter. However, care must be exercised in its placement to insure an adequate distance behind the barrier for displacement during impact. A lateral displacement of approximately 10 ft (3.1 m) can be expected if the barrier is impacted by a full-size car traveling at 60 mph (96.5 km/h) encroaching at 25°. Hence, the barrier should be placed 10 ft (3.1 m) or more laterally from rigid objects. Tests [3] have shown the G1 system will contain and redirect an automobile when placed approximately 18 in. (45.7 cm) from embankments with slopes as steep as 2:1 even though the barrier may deflect 10 ft (3.1 m) or more. However, in the absence of test data or other supporting information, it is recommended that the G1 system be placed 10 ft (3.1 m) or more laterally from embankments or drop-offs with slopes steeper than 2:1.

REFERENCES

1. Bruce, R. W., Hahn, E. E., Iwankiw, N. R., "Guardrail/Vehicle Dynamic Interaction", Report No. FHWA-RD-77-29, March, 1976.

2. "Collision Deformation Classification, Recommended Practice J224a", Society of Automotive Engineers, New York, 1973.

3. Graham, M. D., et al., "New Highway Barriers: The Practical Application of Theoretical Design", Highway Research Record 174, 1967.

4. "Guide for Selecting, Locating, and Designing Traffic Barriers", 1977 American Association of State Highway and Transportation Officials (AASHTO).

5. "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances", Transportation Research Circular No. 191, Transportation Research Board, February, 1978.

6. Ross, H. E., Jr., and Smith, D. G., "Impact Behavior of Roadside Barrier on Nonlevel Terrain -- Crash Test Study", Research Report 3659-1, Texas Transportation Institute, Texas A&M University, April, 1979.

7. "Vehicle Damage Scale for Traffic Accident Investigators", Traffic Accident Data Project Bulletin No. 1, National Safety Council, 1971.

ACKNOWLEDGMENTS

Research reported in this paper was sponsored by the Federal Highway Administration under Contract DOT-FH-11-9343. The authors are grateful to FHWA for their permission to publish this work. Mr. Morton S. Oskard of FHWA served as technical contract manager, and his guidance and cooperation were appreciated.

NOTICE

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policy of the Department of Transportation.

This report does not constitute a standard, specification, or regulation.

TABLE OF ACCIDENT COSTS

(Adapted from The NHTSA Accident Cost Data)

Assumptions

Fatal Accident Cost = $300,000

Injury Accident Cost = 7,500

PDO Accident Cost = 500

Severity Index	% PDO Accidents	% Injury Accidents	% Fatal Accidents	Total Accidents
0	100	0	0	$ 500
1	85	15	0	$ 1,550
2	70	30	0	$ 2,250
3	55	45	0	$ 3,650
4	40	59	1	$ 7,425
5	30	65	5	$ 20,025
6	20	68	12	$ 41,200
7	10	60	30	$ 94,500
8	0	40	60	$183,000
9	0	21	79	$238,575
10	0	5	95	$285,375

EXAMPLE

SI = 5.7

Cost For SI 5.0 $20,025

Cost For SI 6.0 41,200

Difference = $21,175

70% of Difference = 14,822

Cost For SI 5.7 = $34,847

REVISED
A COST-EFFECTIVENESS SELECTION
PROCEDURE FOR BARRIERS

Introduction - This section contains a revised cost-effectiveness procedure for selection of barriers. The primary difference is the change for present worth analysis to annual cost analysis, thus, permitting comparison of alternatives of different service lives.

Introduction

Collisions involving vehicles with roadside objects represent a problem inherent to any existing highway facility. Consequently, roadside safety improvement programs have evolved to provide guidance in eliminating those problem locations where attention is vitally needed. For the most part, these programs share the following policy base.

- Obstacles which may be removed should be eliminated.
- Obstacles which may not be removed should be relocated laterally or in a more protected position.
- Obstacles which may not be moved should be reduced in impact severity. Breakaway devices and flattened side slopes offer such an improvement.
- Obstacles which may not be otherwise treated should be shielded by attenuation or deflection devices.

While the above mentioned points of design summarize the available alternatives, the questions of "where, when or how" are often left unanswered. Limited funds are also a factor most agencies face. The designer is thus confronted with the problem of selecting those alternatives which offer the greatest return in terms of safety benefits.

The purpose of this cost-effective selection procedure is to provide a technique for comparing alternate solutions to problem locations. Present value of the total cost of each alternative is computed over a given period of time, taking into consideration initial costs, maintenance costs, and accident costs. Accident costs incurred by the motorist, including vehicle damage and personal injury, are considered together with accident costs incurred by the highway department or agency. Selection of the alternative with the least total cost would normally be made.

With regard to traffic barriers, the cost-effective procedure can be used to evaluate three alternatives:

1. Remove or reduce hazard so that shielding is unnecessary;
2. Install a barrier; or
3. Do nothing, i.e., leave hazard unshielded.

The third option normally would 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 one 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 procedure presented herein has been adopted from the work of Ross, et.al. (1) and permits objective evaluation of the options at a given site. The procedure included in this document is more generally applicable and is recommended for general use.

5.1.62 Applications

Implementation of the cost-effective procedure primarily involves the determination of several input values. The computations are simple and require only basic mathematics. It should be noted that during the course of the text, the work "obstacle" is used quite frequently. In this context, the term is meant to apply to either a hazard or improvement, whichever the case may be. The following steps summarize the procedure to be followed in the cost-effective analysis.

1. From existing or proposed geometry determine the following:

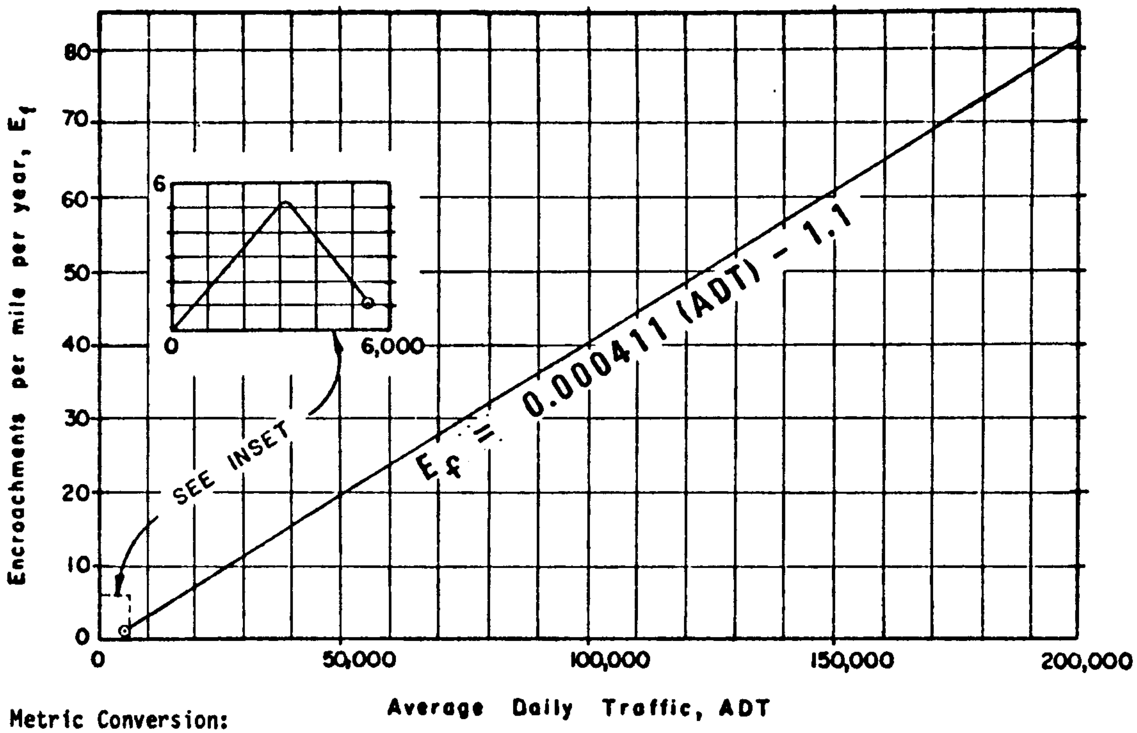
   A = lateral placement of the roadside obstacle from EOP (in feet).

   L = horizontal length of the roadside obstacle (in feet).

   W = width of the roadside obstacle (in feet).

2. From volume counts or estimates, determine the average daily traffic, ADT (vehicles per day). This value should represent the two-way volume flow.

3. Determine the encroachment frequency, E (vehicle encroachments per mile per year), from Figure 5.1.16. Figure 5.1.16 was obtained from data discussed previously. Other available data or



Metric Conversion:

1 Encroachment/mi =

.6214 Encroachments/km

Figure 5.1.16 Encroachment Frequency

adjustments of the above may be used at the discretion of the designer. This latitude offers an option to the user and helps to preserve the generality of the model.

4. Determine the collision frequency, C_f (accidents per year), from the appropriate nomograph given in Figures 5.1.17 and 5.1.18 (dependent on obstacle length). The nomographs combine the over-all geometry with a given encroachment frequency to yield the collision frequency. Collision frequency, C_f, is the predicted number of times a given obstacle will be impacted by an errant vehicle per year. The nomographs are used in the following manner.

- Locate and mark the encroachment frequency, E_f, on vertical axis (1)
- On horizontal axis (2) locate the lateral placement, A, and construct a vertical reference line the full height of the graph.
- Locate and mark the point where the lateral placement reference line intersects the width, W, curve in consideration.
- Project a horizontal line to the right from that point to the vertical axis (3) and mark the point of intersection.
- Locate and mark the point where the lateral placement reference line intersects the length, L, curve in consideration.
- Project a horizontal line to the left from this point to the vertical axis (4) and mark the point of intersection.
- Lay a straight-edge across the points marked on (3) and (4) and construct a line to intersect vertical axis (5). Mark the point of intersection.
- From the point determined construct a line to vertical axis (6) keeping approximately parallel to guidelines. Mark the point of intersection.
- Lay a straight-edge across the marked points on vertical axes (1) and (6) and construct a line connecting the two. Read the collision frequency, C_f, where the line intersects the collision frequency axis.

An example demonstrating the application of one of the nomographs is given in Figure 5.1.19. It may be necessary to adjust the collision frequency in locations where the geometry and traffic conditions are critical. Off-ramp gore areas represent such a situation, and an upward adjustment factor of 3 has been suggested. Mathematically, the collision frequency is given in the expression below.

$$C_f = \frac{E_f}{10,560} \left[(L + 62.9) \cdot P[Y \geq A] + 5.14 \sum_{J=1}^{J=W} P[Y \geq A + 6.0 + \frac{2J - 1}{2}] \right]$$

where,

the variables A, L, W and E are as previously defined

and,

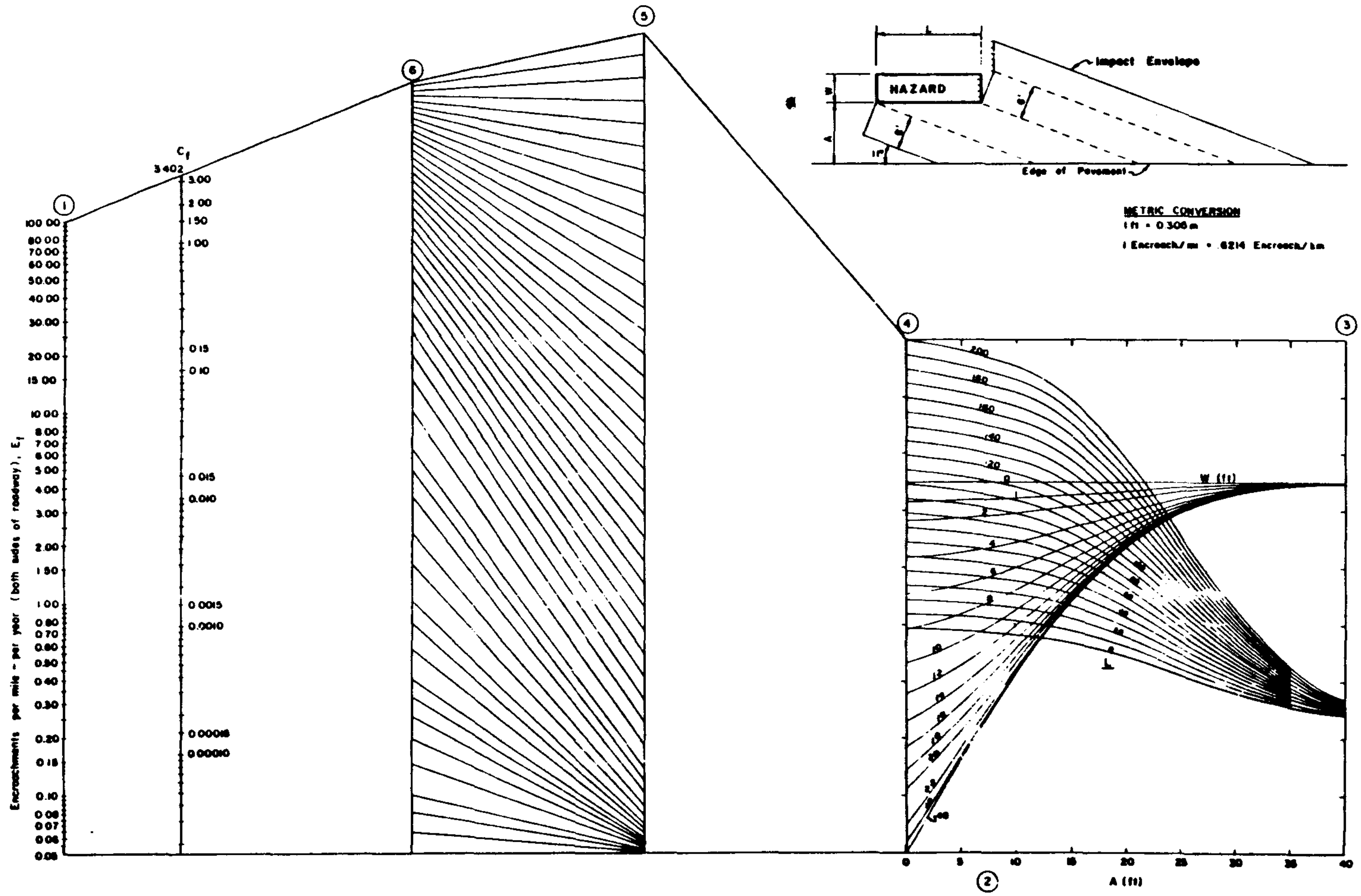
Y = the lateral displacement, in feet (metres), of the encroaching vehicle, measured from the edge of the traveled way to the longitudinal face of the roadside obstacle;

P[Y ≥ ....] = probability of a vehicle lateral displacement greater than some value. These probabilities may be taken from Figure 5.1.20;

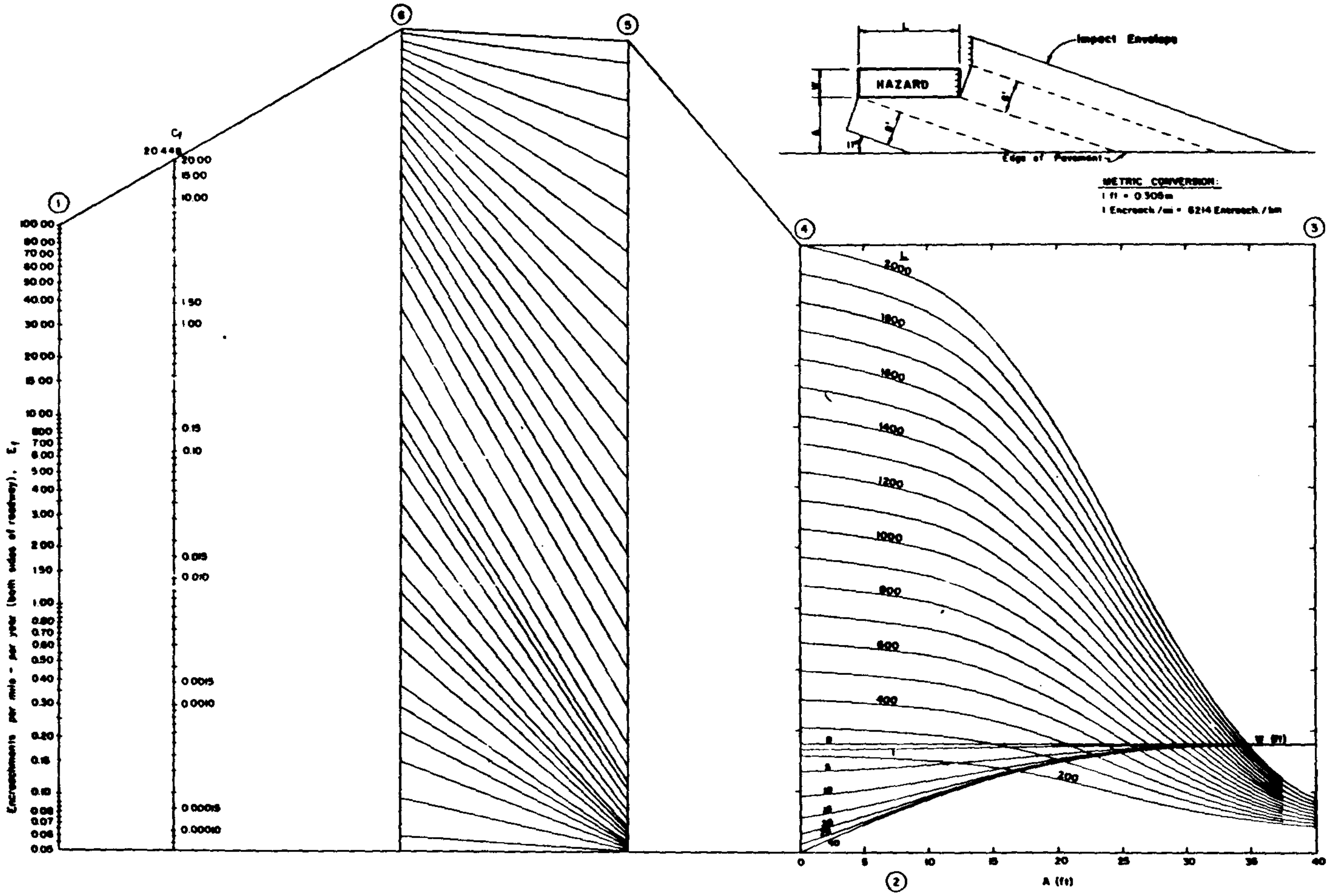
and

J = the number of the 1-ft (.3 m) wide obstacle-width increment under investigation. (If the obstacle is not a whole number of feet (metres) wide, the number of increments investigated is obtained by rounding the width down to the nearest whole foot (metre).

5. Assign a severity index to the obstacle of concern. Hazards can be denoted according to the hazard classification codes given in Table 5.1.11. It is suggested that the severity index be chosen on a scale of 0 to 10 according to the criteria given in Table 5.1.12. For example, if it is estimated that an impact with the obstacle will result in injuries or a fatality 60 percent of the time, select an index of 7. Corresponding to the index is an estimated accident cost which includes those costs associated with vehicle damage and occupant injuries and/or fatalities. Figure 5.1.21 is a graphic representation of accident cost versus severity index. Discretion is advised in assigning severity indices and the designer is encouraged to exhaust all available objective data before resorting to judgment.



Collision Frequency Nomograph Lengths from 0 - 200 Feet



Collision Frequency Nomograph Lengths from 200 - 2000 Feet

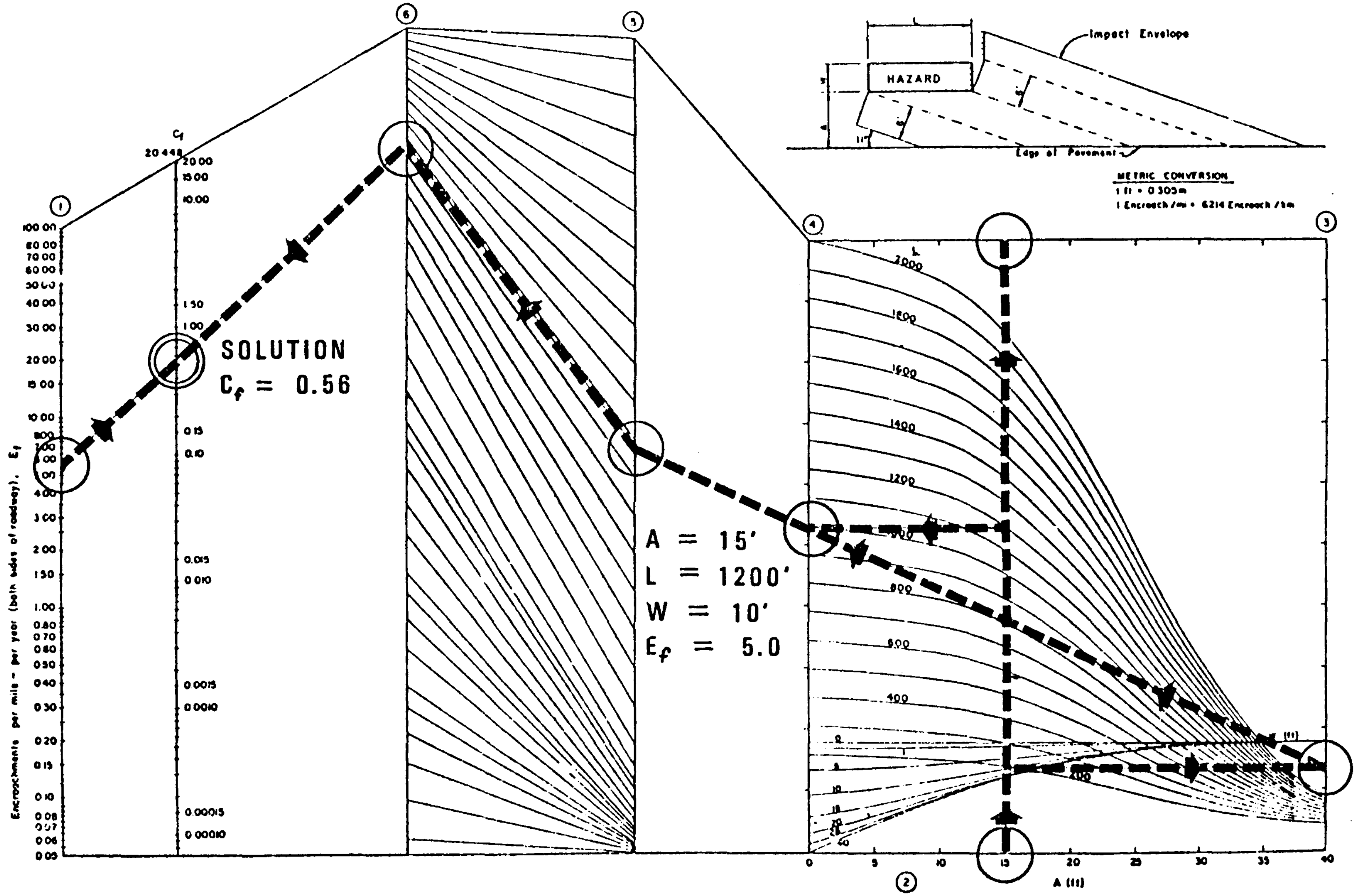
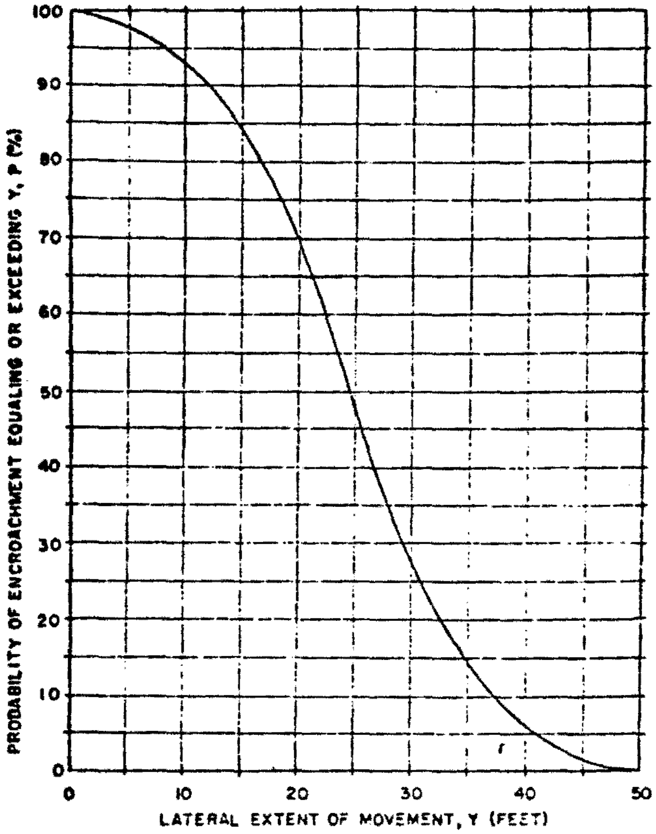


Figure 5.1-19 Collision Frequency Nomograph,
Length From 200-2000 Feet
(Example Solution)



1 ft. = .305 m

Figure 5.1.20 Lateral Displacement Distribution

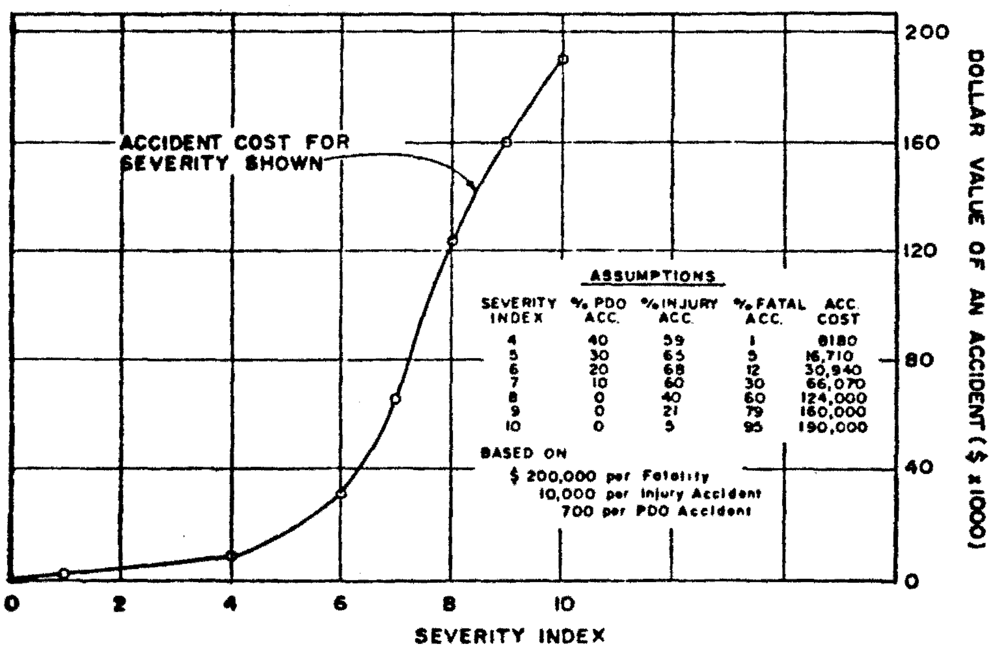


Figure 5.1.21 Average Occupant Injury and Vehicle Damage Costs (2)

TABLE 5.1.11 HAZARD CLASSIFICATION CODES

Note: Circled Codes denote Point Hazard

Identification Code	Descriptor Codes
(01.) Utility Poles	(00)
(02.) Trees	(00)
(03.) Rigid Signpost	(01) single-pole-mounted (02) double-pole-mounted (03) triple-pole-mounted (04) cantilever support (05) overhead sign bridge
(04.) Rigid Base Luminaire Support	(00)
05. Curbs	(01) mountable design (02) non-mountable design less than 10 inches high (03) barrier design greater than 10 inches high
06. Guardrail or Median Barrier	(01) w-section with standard post spacing (6 ft-3 in.) (including departing guardrail at bridge) (02) w-section with other than standard post spacing (including departing guardrail at bridge) (03) approach guardrail to bridge--decreased post spacing (3 ft-1 in.) adjacent to bridge (04) approach guardrail to bridge--post spacing not decreased adjacent to bridge (05) post and cable (06) Metal Beam Guard Fence (Barrier) (in median) (07) median barrier (CMB design or equivalent
07. Roadside Slope	(01) sod positive slope (02) sod negative slope (03) concrete-faced positive slope (04) concrete-faced negative slope (05) rubble rip-rap positive slope (06) rubble rip-rap negative slope

GUARDRAIL END TREATMENT CODES

1 Not beginning or ending at structure - Safety treated
2 Not beginning or ending at structure - Not safety treated
3 Beginning or ending at structure - Full-beam connection
4 Beginning or ending at structure - Not full-beam connection

TABLE 5.1.11 (cont.)

08. Ditch (includes erosion, rip-rap runoff ditches, etc.—does not include ditches formed by intersection of front and back slopes	(00)
09. Culverts	(01) headwall (or exposed end of pipe culvert)
	(02) gap between culverts on parallel roadways
	(03) sloped culvert with grate
	(04) sloped culvert without grate
10. Inlets	(01) raised drop inlet (tabletop)
	(02) depressed drop inlet
	(03) sloped inlet
11. Roadway under Bridge Structure	(01) bridge piers
	(02) bridge abutment, vertical face
	(03) bridge abutment, sloped face
12. Roadway over Bridge Structure	01 open gap between parallel bridges
	02 closed gap between parallel bridges
	(03) rigid bridgerail—smooth and continuous construction
	(04) semi-rigid bridgerail—smooth and continuous construction
	(05) other bridgerail--probable penetration, snagging, pocketing or vaulting
	06 elevated gore abutment
13. Retaining Wall	(01) face
	02 exposed end
14. Miscellaneous Point Hazards	(01) pedestal base > 6 in. above ground, < 1 ft. diam.
	(02) pedestal base > 6 in. above ground, > 1 ft. diam.
	(03) historical monument < 1 ft. wide
	(04) historical monument > 1 ft. wide

TABLE 5.1.12 SEVERITY INDICES

Identification Code	Descriptor Code	End Treatment Code Beginning	End Treatment Code Ending	Severity-Index
1. Utility Pole				
1	0	-	-	7.1
2. Trees				
2	0	-	-	8.0
3. Rigid Signpost				
3	1	-	-	4.7
3	2	-	-	7.2
3	3	-	-	7.2
3	4	-	-	7.2
3	5	-	-	8.1
4. Rigid Base Luminaire Support				
4	0	-	-	7.5
5. Curbs				
5	1	-	-	2.4
5	2	-	-	4.1
5	3	-	-	3.7
6. Guardrail or Median Barrier				
6	1	1	1	3.7
6	1	1	2	4.0
6	1	1	3	3.6
6	1	1	4	4.5
6	1	2	1	5.6
6	1	2	2	5.7
6	1	2	3	5.3
6	1	2	4	5.7
6	1	3	1	3.3
6	1	3	2	3.3
6	1	3	3	3.3
6	1	3	4	4.6
6	1	4	1	4.5
6	1	4	2	4.7
6	1	4	3	4.5
6	1	4	4	5.0
6	2	1	1	3.9
6	2	1	2	4.2
6	2	1	3	3.8
6	2	1	4	4.7
6	2	2	1	5.8
6	2	2	2	5.9
6	2	2	3	5.5
6	2	2	4	5.9
6	2	3	1	3.5
6	2	3	2	3.5
6	2	3	3	3.5
6	2	3	4	4.8
6	2	4	1	4.7
6	2	4	2	4.9
6	2	4	3	4.7
6	2	4	4	5.0
6	3	1	1	3.7
6	3	1	2	4.0
6	3	1	3	3.3
6	3	1	4	4.5
6	3	2	1	5.6
6	3	2	2	5.0
6	3	2	3	3.9
6	3	2	4	5.0
6	3	3	1	3.2
6	3	3	2	3.2
6	3	3	3	3.2
6	3	3	4	4.4
6	3	4	1	4.0
6	3	4	2	4.5
6	3	4	3	3.9
6	3	4	4	4.7
6	4	1	1	3.7
6	4	1	2	4.0
6	4	1	3	3.6
6	4	1	4	4.5
6	4	2	1	5.6
6	4	2	2	5.7
6	4	2	3	5.3
6	4	2	4	5.7
6	4	3	1	3.3
6	4	3	2	3.3
6	4	3	3	3.3
6	4	3	4	4.6
6	4	4	1	4.5
6	4	4	2	4.7

TABLE 5.1.12 SEVERITY INDICES (cont.)

Identification Code	Descriptor Code	End Treatment Code Beginning	End Treatment Code Ending	Severity-Index
6	4	4	3	4.5
6	4	4	4	5.0
6	5	1	1	3.9
6	5	1	2	3.9
6	5	1	3	3.9
6	5	1	4	3.9
6	5	2	1	3.9
6	5	2	2	3.9
6	5	2	3	3.9
6	5	2	4	3.9
6	5	3	1	3.9
6	5	3	2	3.9
6	5	3	3	3.9
6	5	3	4	3.9
6	5	4	1	3.9
6	5	4	2	3.9
6	5	4	3	3.9
6	5	4	4	3.9
6	6	1	1	4.4
6	6	1	2	4.4
6	6	1	3	4.4
6	6	1	4	5.0
6	6	2	1	5.6
6	6	2	2	5.7
6	6	2	3	5.3
6	6	2	4	5.7
6	6	3	1	4.0
6	6	3	2	4.4
6	6	3	3	4.0
6	6	3	4	4.6
6	6	4	1	4.5
6	6	4	2	4.7
6	6	4	3	4.5
6	6	4	4	5.0
6	7	1	1	4.2
6	7	1	2	4.2
6	7	1	3	4.2
6	7	1	4	4.2
6	7	2	1	4.2
6	7	2	2	4.2
6	7	2	3	4.2
6	7	2	4	4.2
6	7	3	1	4.2
6	7	3	2	4.2
6	7	3	3	4.2
6	7	3	4	4.2
6	7	4	1	4.2
6	7	4	2	4.2
6	7	4	3	4.2
6	7	4	4	4.2

Identification Code	Descriptor Code	End Treatment Code Beginning	End Treatment Code Ending	Severity-Index
7. Roadside Slope				
7	1	-	-	3.0
7	2	-	-	3.0
7	3	-	-	2.5
7	4	-	-	2.5
7	5	-	-	5.1
7	5	-	-	5.1
8. Ditch				
8	1	-	-	0.0
9. Culverts				
9	1	-	-	7.9
9	2	-	-	5.5
9	3	-	-	3.3
9	4	-	-	7.7
10. Inlets				
10	1	-	-	5.7
10	2	-	-	3.1
10	3	-	-	3.3
11. Roadway Under Bridge Structure				
11	1	-	-	9.3
11	2	-	-	9.3
11	3	-	-	2.5
12. Roadway Over Bridge Structure				
12	1	-	-	7.2
12	2	-	-	5.5
12	3	-	-	3.3
12	4	-	-	3.0
12	5	-	-	9.3
12	6	-	-	9.3
13. Retaining Wall				
13	1	-	-	3.3
13	2	-	-	9.3
14. Miscellaneous Point Hazards				
14	1	-	-	7.5
14	2	-	-	9.3
14	3	-	-	7.5
14	4	-	-	9.3

Metric Equivalent Equation

$$C = \frac{E_f}{2{,}000} [(L + 19.2) \cdot P[Y \geq A] + 5.14 \sum_{J=1}^{J=W} P[Y \geq A + 1.8 + \frac{2J - 1}{2}]]$$

E_f in Encroachments/km/yr

L, Y, A, and W in metres

(The width of J may be taken as 1 metre with the number of J units equal W rounded to the nearest whole number.)

This equation may be implemented directly into the cost analysis or used as a double-check for the collision frequency nomographs. Computation of the collision frequency for multiple objects requires special procedures.

6. Determine the initial cost of the obstacle, C_I. If it is already in place, its initial cost may be assumed to equal zero. For example, if a group of median bridge piers had been in existence for ten years, then the initial cost of a no improvement alternative would be taken to be zero. On the other hand, improvements to such a hazard would require initial expenditures which should be so designated.

7. Determine the average damage cost to the obstacle per accident, C_D (present dollars).

8. Determine the average maintenance cost per year, C_M, associated with the upkeep of the obstacle (present dollars).

9. Determine the average occupant injury and vehicle damage cost per accident, C_{OVD}, which would be expected as a result of a collision (present dollars). Table 5.1.12 and Figure 5.1.21 may be used to determine C_{OVD} in the absence of more definitive data. Direct interpolation of the cost table in Figure 5.1.21 is suggested to increase the accuracy of the estimate.

10. Determine the useful life, T, of the obstacle (years).

11. Determine the capital recovery and sinking fund factors. CRF and SF for the useful life. "T" and a current interest rate come from Tables 5.1.13 and 5.1.14.

12. Estimate the expected salvage value of the obstacle, C_S, at the end of its useful life (future dollars).

13. Calculate the total annual cost, C_{A_T}, from the following equation:

$$C_{A_T} = C_I\,[CRF] + C_D C_f + C_M + C_{OVD} C_f - C_S(SF)$$

or, to determine those costs which are directly incurred by the highway department (or implementing agency), (C_{A_D}), use the equation below:

$$C_{A_D} = C_I\,[CRF] + C_D C_f + C_M - C_S(SF)$$

These total annual costs represent an estimated value related to some appurtenance/barrier. Any number of locations or alternatives may be evaluated by utilizing this method, and a priority listing may be established. The alternative with the least total annual cost is the preferable alternative.

Summary of Variable Definitions

- A = lateral placement of the roadside obstacle from EOP (feet) [metre]
- L = horizontal length of the roadside obstacle (feet) [metre]
- W = width of the roadside obstacle (feet) [metre]
- ADT = average daily traffic (vehicles per day, two-way)
- E_f = encroachment frequency (encroachments per mile per year) [encroachments per kilometre per year]
- C_f = collision frequency (accidents per year)
- SI = severity index
- CI = initial cost of the obstacle (present dollars)
- C_D = average damage cost per accident incurred to the obstacle (present dollars)
- C_M = average maintenance cost per year for the obstacle (present dollars)
- C_{OVD} = average occupant injury and vehicle damage cost per accident (present dollars)
- C_S = estimated salvage value of the obstacle (future dollars)
- C_{A_T} = total present worth cost associated with the obstacle (dollars)
- C_{A_D} = total present worth direct cost associated with the obstacle (dollars)
- CRF, SF = capital recovery and sinking fund factor for some current interest rate

TABLE 5.1.13 CAPITAL RECOVERY FACTORS (CRF)

Useful Life T (years)	Interest Rate i (Percent)												
	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
1	1.000	1.010	1.020	1.030	1.040	1.050	1.060	1.070	1.080	1.090	1.100	1.110	1.120
2	0.500	0.508	0.515	0.523	0.530	0.538	0.546	0.553	0.561	0.567	0.576	0.584	0.592
3	0.333	0.340	0.347	0.353	0.360	0.367	0.374	0.381	0.388	0.395	0.402	0.409	0.416
4	0.250	0.256	0.263	0.269	0.275	0.282	0.288	0.295	0.302	0.302	0.315	0.322	0.329
5	0.200	0.206	0.212	0.218	0.225	0.231	0.237	0.244	0.250	0.257	0.264	0.271	0.277
6	0.167	0.173	0.179	0.185	0.191	0.197	0.203	0.210	0.216	0.222	0.230	0.236	0.243
7	0.143	0.149	0.155	0.161	0.167	0.173	0.179	0.186	0.192	0.199	0.205	0.212	0.219
8	0.125	0.131	0.137	0.142	0.149	0.155	0.161	0.167	0.174	0.181	0.187	0.194	0.201
9	0.111	0.116	0.123	0.128	0.134	0.141	0.147	0.153	0.160	0.167	0.174	0.181	0.188
10	0.100	0.106	0.111	0.117	0.123	0.130	0.136	0.142	0.149	0.156	0.163	0.170	0.176
11	0.091	0.096	0.102	0.108	0.114	0.120	0.127	0.133	0.140	0.147	0.154	0.161	0.168
12	0.083	0.089	0.095	0.100	0.107	0.113	0.119	0.126	0.133	0.140	0.147	0.154	0.161
13	0.077	0.082	0.088	0.094	0.100	0.106	0.113	0.120	0.127	0.134	0.141	0.148	0.155
14	0.071	0.077	0.083	0.089	0.095	0.101	0.108	0.114	0.121	0.128	0.136	0.143	0.150
15	0.067	0.072	0.078	0.084	0.090	0.096	0.103	0.110	0.117	0.124	0.131	0.139	0.147
16	0.063	0.068	0.074	0.080	0.086	0.092	0.099	0.106	0.113	0.120	0.128	0.136	0.143
17	0.059	0.064	0.070	0.076	0.082	0.089	0.095	0.102	0.110	0.117	0.125	0.132	0.140
18	0.056	0.061	0.067	0.073	0.079	0.086	0.092	0.099	0.107	0.114	0.122	0.130	0.137
19	0.053	0.058	0.064	0.069	0.076	0.083	0.090	0.097	0.104	0.112	0.120	0.128	0.136
20	0.050	0.055	0.061	0.067	0.074	0.080	0.087	0.094	0.102	0.110	0.117	0.126	0.134
21	0.048	0.053	0.059	0.065	0.071	0.078	0.085	0.092	0.100	0.108	0.116	0.124	0.132
22	0.045	0.051	0.057	0.063	0.069	0.076	0.083	0.090	0.098	0.106	0.114	0.122	0.130
23	0.043	0.049	0.055	0.061	0.067	0.074	0.081	0.089	0.096	0.104	0.113	0.121	0.129
24	0.042	0.047	0.053	0.059	0.066	0.072	0.080	0.087	0.095	0.103	0.111	0.120	0.128
25	0.040	0.045	0.051	0.057	0.064	0.071	0.078	0.086	0.094	0.102	0.110	0.118	0.127
26	0.038	0.044	0.050	0.056	0.063	0.070	0.077	0.085	0.093	0.101	0.109	0.118	0.127
27	0.037	0.042	0.048	0.055	0.061	0.068	0.076	0.083	0.091	0.100	0.108	0.117	0.126
28	0.036	0.041	0.047	0.053	0.060	0.067	0.075	0.082	0.090	0.099	0.107	0.116	0.125
29	0.034	0.040	0.046	0.052	0.059	0.066	0.074	0.081	0.090	0.098	0.106	0.115	0.125
30	0.033	0.039	0.045	0.051	0.058	0.065	0.073	0.081	0.089	0.097	0.106	0.115	0.124

TABLE 5.1.14 SINKING FUND FACTOR (SF)

Useful Life T (years)	Interest Rate i (Percent)												
	0.1	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0.500	0.498	0.495	0.493	0.490	0.488	0.486	0.483	0.481	0.477	0.476	0.474	0.472
3	0.333	0.330	0.327	0.323	0.320	0.317	0.314	0.311	0.308	0.305	0.302	0.299	0.296
4	0.250	0.246	0.243	0.239	0.235	0.232	0.228	0.225	0.222	0.219	0.215	0.212	0.209
5	0.200	0.196	0.192	0.188	0.185	0.181	0.177	0.174	0.170	0.167	0.164	0.161	0.157
6	0.167	0.163	0.159	0.155	0.151	0.147	0.143	0.140	0.136	0.132	0.130	0.126	0.123
7	0.143	0.139	0.135	0.131	0.127	0.123	0.119	0.116	0.112	0.109	0.105	0.102	0.099
8	0.125	0.121	0.117	0.112	0.109	0.105	0.101	0.097	0.094	0.091	0.087	0.084	0.081
9	0.111	0.106	0.103	0.098	0.094	0.091	0.087	0.083	0.080	0.077	0.074	0.071	0.068
10	0.100	0.096	0.091	0.087	0.083	0.080	0.076	0.072	0.069	0.066	0.063	0.060	0.056
11	0.091	0.086	0.082	0.078	0.074	0.070	0.067	0.063	0.060	0.057	0.054	0.051	0.048
12	0.083	0.079	0.075	0.070	0.067	0.063	0.059	0.056	0.053	0.050	0.047	0.044	0.041
13	0.077	0.072	0.068	0.064	0.060	0.056	0.053	0.050	0.047	0.044	0.041	0.038	0.035
14	0.071	0.067	0.063	0.059	0.055	0.051	0.048	0.044	0.041	0.038	0.036	0.033	0.030
15	0.067	0.062	0.058	0.054	0.050	0.046	0.043	0.040	0.037	0.034	0.031	0.029	0.027
16	0.063	0.058	0.054	0.050	0.046	0.042	0.039	0.036	0.033	0.030	0.028	0.026	0.023
17	0.059	0.054	0.050	0.046	0.042	0.039	0.035	0.032	0.030	0.027	0.025	0.022	0.020
18	0.056	0.051	0.047	0.043	0.039	0.036	0.032	0.029	0.027	0.024	0.022	0.020	0.017
19	0.053	0.048	0.044	0.039	0.036	0.033	0.030	0.027	0.024	0.022	0.020	0.018	0.016
20	0.050	0.045	0.041	0.037	0.034	0.030	0.027	0.024	0.022	0.020	0.017	0.016	0.014
21	0.048	0.043	0.039	0.035	0.031	0.028	0.025	0.022	0.020	0.018	0.016	0.014	0.012
22	0.045	0.041	0.037	0.033	0.029	0.026	0.023	0.020	0.018	0.016	0.014	0.012	0.010
23	0.043	0.039	0.035	0.031	0.027	0.024	0.021	0.019	0.016	0.014	0.013	0.011	0.009
24	0.042	0.037	0.033	0.029	0.026	0.022	0.020	0.017	0.015	0.013	0.011	0.010	0.008
25	0.040	0.035	0.031	0.027	0.024	0.021	0.018	0.016	0.014	0.012	0.010	0.008	0.007
26	0.038	0.034	0.030	0.026	0.023	0.020	0.017	0.015	0.013	0.011	0.009	0.118	0.007
27	0.037	0.032	0.028	0.025	0.021	0.018	0.016	0.013	0.011	0.010	0.008	0.117	0.006
28	0.036	0.031	0.027	0.023	0.020	0.017	0.015	0.012	0.010	0.009	0.007	0.116	0.005
29	0.034	0.030	0.026	0.022	0.019	0.016	0.014	0.011	0.010	0.008	0.006	0.115	0.005
30	0.033	0.029	0.025	0.021	0.018	0.015	0.013	0.011	0.009	0.007	0.006	0.115	0.004

5.1.55 Example 1 - Roadside Slope

In the first example, it is desired that criteria be established to indicate when it is cost-effective, in terms of ADT and side-slope, to shield an embankment. It is assumed that an operating speed of approximately 60 mph (96.6 km/hr) exists. The general geometry of the roadside is illustrated in Figure 5.1.22. For purposes of analysis, both the average daily traffic, ADT, and the roadside slope will be considered as variables. Values assigned to other variables are assumed to fall within a reasonable expected range. The following analysis will consider shielding with a roadside barrier first and then the alternative of no shielding.

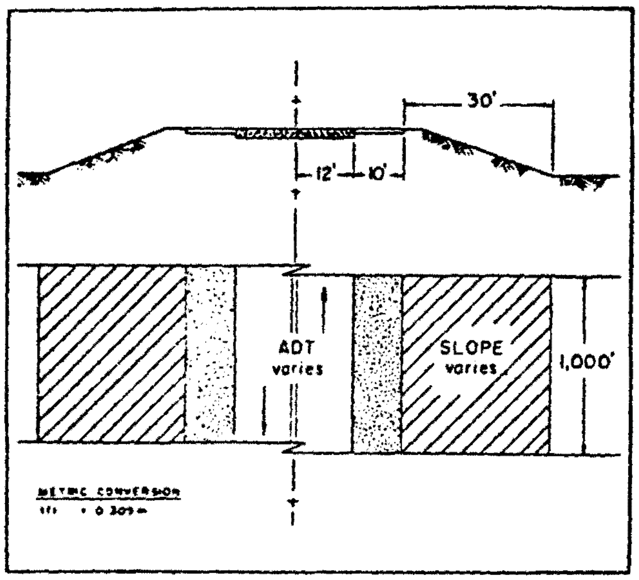


Figure 5.1.22 Roadside Slope Geometry

Roadside Barrier

Before this alternative can be considered in the cost-effectiveness procedure, the flared end-treatment geometry should be established by implementing the barrier flare criteria set forth in Section 5.1.44. On the basis of these criteria, the flared sections were assumed to exhibit the following general geometry:

- The average offset equals 15 ft (4.6 m).
- The horizontal length of the flared sections equals 256 ft (78.0 m).
- And the total rail length needed equals 257 ft (78.4 m).

These lengths represent the total length of need of the flared section plus a breakaway cable terminal treatment.

In continuing, the roadside barrier analysis involves two distinct computations. In the first case, costs associated with the flared portion of the barrier are computed. Then, costs associated with the barrier proper or the tangent section are computed. The two are then combined to determine the total cost. However, a minor adjustment must be made in determining the collision frequency since the flared portion and the barrier proper are joined at a common point. The following general rule applies in this and other such cases:

For two objects joined together, use the actual length (L) of the object with the highest severity index (SI) and subtract 31.4 (9.6 for metric equivalent) from the length of the other object when determining their respective collision frequencies.

This rule is illustrated in the following example. Note that the cost determination steps follow the format previously outlined.

Flared End Treatment

1. $A = 15$ ft (4.6 m)

   $L = 256$ ft (78.0 m)

   $W = 1$ ft (.305 m) (rail width)

2. ADT = 10,000 (assumed)

3. $E_f = 3.2$

4. $C_f = 0.078$ (Actual length is used to determine C_f because SI for flared section is higher than for barrier proper.)

5. Code 06-01-1; SI = 3.7

6. C_I = \$13.00 (assumed) per foot at 257 ft (78.39 m)

   C_I = \$3,341

7. C_D = \$225

8. C_M = \$1.50 per foot per year (assumed) at 257 ft (78.4 m);

   C_M = \$386

9. C_{OVD} = \$7,192 at SI = 3.7 (Figure 5.1.21)

10. T = 15 years

11. CRF = 0.117 ; SF = 0.037 — at an assumed rate of 8%

12. C_S = \$3.00 per foot (assumed) at 257 ft (78.4 m)

    C_S = \$771

13. CA_T = 3341 (0.117) + 225 (0.078) + 386 + 7192 (0.078) - 771 (0.037)

CA_T = \$1,327

CA_D = 3341 (0.117) + 225 (0.078) + 386 - 771 (0.037)

CA_D = \$766

Barrier Proper

1. A = 10 ft (3.05 m)

   L = 1000 ft (305 m)

   W = 1 ft (.31 m)

2. ADT = 10,000

3. E_f = 3.2

4. C_f = 0.29 based on L - 31.4 or 968.6 ft (295 m) (See Example 1)

5. Code 06-01-3-2; SI = 3.3 (See Table 5.1.10)

6. C_I = \$13.00 per foot (assumed) at 1000 ft (305 m);

   C_I = \$13,000

7. C_D = \$225 (assumed)

8. C_M = \$1.50 per foot per year (assumed) at 1000 ft (305 m);

   C_M = \$1,500

9. C_{OVD} = \$5,874 at SI = 3.3

10. T = 15 years

11. i = 8%

    CRF = 0.117

    SF = 0.037

12. C_S = \$3.00 per foot (assumed at 1,000 ft (305 m);

    C_S = \$3,000

13. C_{A_T} = 13000 (0.117) + 225 (0.29) + 1500 + 5874 (0.29) - 3000 (0.037)

    = 1521 + 65 + 1500 + 1703 - 111

    C_{A_T} = \$4,678

    C_{A_T} = \$2,975

TOTAL C_{A_T} = 1327 + 4678 = \$6,005

TOTAL C_{A_D} = 766 + 2975 = \$3,741

These two total costs represent values associated with an average daily traffic equaling 10,000 vehicles per day. The above steps are repeated for higher values of ADT until enough data points are determined to plot CA_T versus ADT. Ultimately, the total barrier values as a function of average daily traffic will be used in the alternative comparison.

Unprotected Slopes

Another alternative which should be considered involves no shielding at all. This alternative requires no direct expenditures since it is assumed that the problem involves existing roadways. Consequently, only the total costs (to include occupant and vehicle damage) can significantly indicate the benefits/disbenefits associated with no shielding of the embankment.

For purposes of analysis, four slopes have been considered as variables in addition to the average daily traffic control. These slopes and their respective estimated severities for assumed site conditions are as follows:

- (3.5:1) slope - severity index equals 3.5
- (3:1) slope - severity index equals 4.0
- (2.5:1) slope - severity index equals 4.5, and
- (2:1) slope - severity index equals 5.0

(Note that for fills steeper than about 3:1 the height of fill should be expected to influence severity.)

Although the slope severities are not specifically identified in the hazard inventory information, a severity index is listed for a negative slope. Assuming that this negative slope represents an average situation and that a 4:1 slope is approximately average, then the severity index of a 4:1 slope would be found to equal 3.0. Furthermore, since the severity index of the roadside barrier is greater than that of the 4:1 slope, then in no way can the barrier be more cost-effective. By taking the average slope as a base, the severities of the other gradients were estimated, and occupant and vehicle damage costs were assigned. The initial, damage, maintenance, and salvage costs were all taken to be zero since it is assumed that the existing geometry requires no direct expenditures. By choosing the average daily traffic again to equal 10,000 vehicles per day and considering a 3.5:1 slope, the costs may be determined by the following steps:

1. $A = 10$ ft (3.05 m)

$L = 1{,}000$ ft (305 m)

$W = 30$ ft (9.15 m)

2. $ADT = 10{,}000$

3. $E_f = 3.2$

4. $C_f = 0.30$

5. $SI = 3.5$

6. $C_I = \$0$

7. $C_D = \$0$

8. $C_M = \$0$

9. $C_{OVD} = \$6{,}533$ at $SI = 3.5$

10. $T = 15$ years

11. CRF = 0.[illegible] } at an assumed interest rate of 8%

SF = 0.037

12. $C_S = \$0$

13. $C_{AT} = 0 + 0 + 0 + 6535\ (0.30) - 0$

$= \$9{,}961$

$C_{AD} = \$0$

Total costs for the four slopes and varying volumes are calculated in a similar manner to provide the basis of comparison for the no protection alternative.

Comparison

The various situations can best be compared by plotting curves of total present cost versus average daily traffic. Such a set of curves is shown in Figure 5.1.23. By interpreting the data the following conclusions may be drawn:

1. Unprotected slopes of 3:1 and flatter are more cost-effective than the barrier for an average daily traffic up to and in excess of 50,000 vehicles per day; i.e., the barrier is not warranted;

2. The 2.5:1 slope, unprotected, (assumed severity 4.5) becomes less cost-effective than the barrier for an average daily traffic equal to or above 12,000 vehicles per day; and

3. The 2:1 slope, unprotected, (assumed severity 5.0) becomes less cost-effective than the barrier for an average daily traffic equal to or above 10,000 vehicles per day.

This analysis serves to provide some insight as to where roadside barrier protection of slopes may or may not be more cost-effective. General design guidelines or policies may be established and, more importantly, justified in terms of the highest returns in safety.

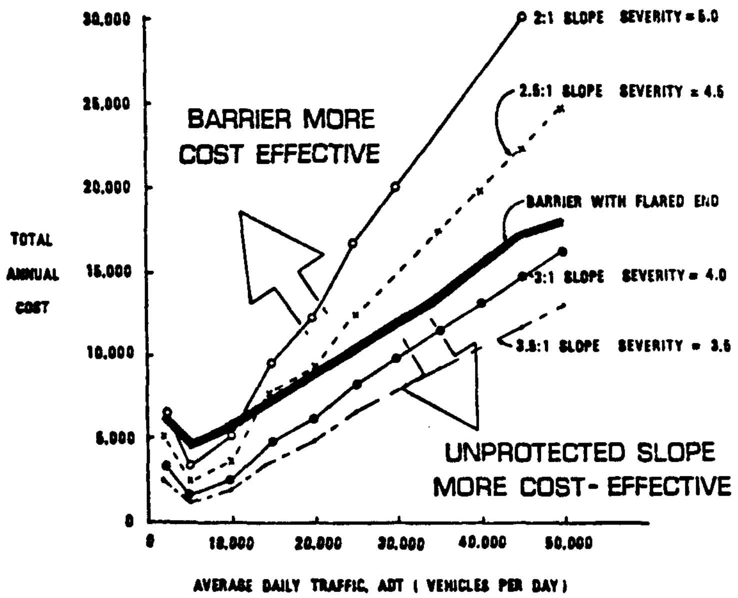


Figure 5.1-23 Cost Comparison Curves

General Comments

1. The analysis, as presented in this problem, involves only those costs associated with one side of the highway facility. If the same conditions exist on the opposite side, then the total costs for both sides would be double those previously determined.

2. The average daily traffic should represent the two-way volume flow since the volume split is built into the analysis procedure. This adjustment is effected by the collision frequency nomographs.

3. The useful life of a roadside slope is taken to be 15 years, which is obviously not the real case. However, there is little difference in the economic factors beyond 15 years.

4. This example illustrates how the procedure can be used to determine the cost-effectiveness of two basic options, i.e., barrier shielding versus no shielding of slopes, for a given location. Although not considered here, the next desirable step may be to establish a priority or ranking system for reducing hazards within a given roadway system. The objective would be to make improvements that offer the greatest return in terms of safety. The following equation may be used for determining a ranking factor, R:

$$R = \frac{C_{A_H} - C_{A_I}}{C_{A_{D_I}}}$$

where

C_{A_H} = annual cost associated with the unshielded hazard over the period T;

C_{A_I} = annual cost associated with the improvement over the period T; and

$C_{A_{D_I}}$ = annual cost to the highway department or agency associated with the improvement.

Improvements should be made to those hazards having the highest value R first. Note that if the numerator is negative, the improvement would not be cost-effective. In Example 1, the ranking factor for placing a roadside barrier to shield the 2:1 slope (assumed severity 5.0) for an ADT of 25,000 would be computed as follows:

C_{A_H} = \$16,710 (Slope) (From Figure 5.1.21)

C_{A_I} = \$10,612 (Barrier) (From Figure 5.1.21)

$C_{A_{D_I}}$ = \$3,530 (From previous calculations)

thus

$$R = \frac{16,710 - 10,612}{3,530}$$

or

$$R = 1.7$$

5.1.54 Example 2 - Bridge Piers

Figure 5.1.24 shows a typical bridge pier hazard. Three alternatives will be considered in the cost analysis as follows:

1. No protection of the bridge piers

2. Protection of the bridge piers with a roadside barrier rail

3. Protection of the bridge piers with a combination roadside barrier rail and crash cushion system

Subsequent to the cost calculations, a comparison of the three operations will be made based on a present worth basis, and the most cost-effective design will be identified. Note that the steps in the analysis correspond to those described in the introduction of the section above.

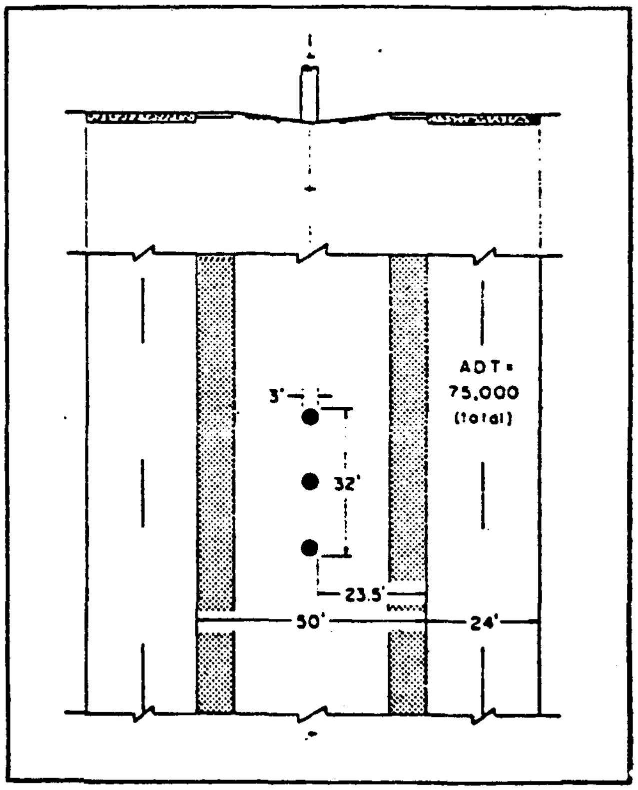


Figure 5.1.24 Bridge Pier Hazard

No Protection

1. A = 23.5 ft (7.17 m) or approximately 23 ft (7.02 m);

   L = 32 ft (9.75 m) and:

   W = 3 ft (.92 m)

2. ADT = 75,000 (assumed)

3. E_f = 31.0

4. C_f = 0.17

5. Code -01; SI = 9.3 (See Table 5.1.10)

6. C_I = $0 (since the piers are existing)

7. C_D = $0 (assumed)

8. C_M = $0 (assumed)

9. C_{OVD} = $169.340 at SI = 9.3

10. T = 20 years

11. CRF = 0.102 } at an interest rate of 8%

12. SF = 0.022 }

    C_S = $0

13. C_{A_T} = 0 (.102) + 0 (0.17) + 0 + 169.340 (0.102) - 0 (0.022)

    = $17,273

    C_{A_D} = $0

or considering collisions with both ends of the bridge pier hazard,

C_{A_T} = $34,545

C_{A_D} = $0

These figures represent the present costs associated with no protection to the roadway hazard. The total cost, as would be expected, is quite substantial due to the severity associated with impacting a fixed bridge pier, while the total direct cost is zero since no improvements are involved. Although the existing geometry may not offer the best alternative, it must be calculated for use as a basis in comparison.

Roadside Barrier

Before the cost analysis can be implemented for this option, specific attention needs to be directed toward identifying the barrier flare geometry. From the barrier flare criteria outlined previously, (See Section 5.1.44) the placement values to be used in the cost procedure were assumed to be the following:

1. The average offset for the flared sections equals 16 ft (4.88 m)

2. The projected longitudinal length of the barrier flare equals 151 ft (46.01 m)

3. The actual length of the barrier flare equals 153 ft (46.67 m).

In determining the total costs associated with roadside barrier protection, two separate calculations will be made - one considering collisions with the barrier flare and the other involving impacts to the barrier proper. The sum of these two costs will represent the total value associated with the roadside barrier alternative. Note that costs for one direction of travel are computed, then doubled, to obtain costs for both directions of travel. It is assumed that a crashworthy end treatment is used at the upstream terminal.

Barrier Flare

1. A = 16 ft (4.88 m),

   L = 151 ft (46.01 m)

   W = 1 ft (.31 m)

2. ADT = 75,000

3. E_f = 31.0

4. C_f = 0.52 (Actual length is used to determine C_f, because SI for flared section is higher than for barrier proper.)

5. Code 06-01-1-1 SI = 3.7 (Table 5.1.10)

6. C_I = $13.00 per foot (assumed) at 153 ft (46.67 m), thus

   C_I = $1,989

7. C_D = $225 (assumed)

8. C_M = $1.50 per foot per year (assumed) at 153 ft (46.67 m);

   C_M = $230

9. C_{OVD} = $7,192 at SI = 3.7

10. T = 20 years

11. CRF = 0.102 } at 8%

    SF = 0.022 }

12. C_S = $1.50 per foot (assumed) at 153 ft (46.67 m)

    C_S = $230

13. C_{A_T} = 1989 (0.102) + 225 (0.52) + 203 + 7192 (0.52) - 230 (0.022)

= \$4,285

C_{A_D} = \$545

Barrier Proper

1. A = 13.5 ft (4.12 m);

   L = 32 ft (9.76 m); and

2. ADT = 75,000

3. E_f = 31.0

4. C_f = .17 Based on L - 31.4 = 0.6 ft (0.2 m) (See rule in Section 5.1.52.)

5. Code 06-01-3-2 SI = 3.3 (Appendix E)

6. C_I = \$13.00 per foot (assumed) at 32 ft (4.12 m); thus, C_I = \$416

7. C_D = \$225 (assumed)

8. C_M = \$1.50 per foot per year (assumed) at 32 ft (4.12 m); thus

   C_M = \$48

9. C_{OVD} = \$5,874 at SI = 3.3

10. T = 20 years

11. CRF = 0.102

    SF = 0.022

12. C_S = \$1.50 per foot (assumed) at 32 ft (4.12 m); thus C_S = \$48

13. C_{A_T} = 416 (0.102) + 225 (0.17) - 48 + 5874 (0.17) - 48 (0.022)

    = \$1,078

    C_{A_D} = \$79

The total barrier costs may now be found by totaling the values for the flare and the barrier proper. Furthermore, the total amounts considering shielding for both sides may be attained by doubling the costs associated with collisions from one side.

Therefore, for protection to one end:

Total C_{A_T} = 4285 + 1078 = \$5,363

Total C_{A_D} = 545 + 79 = \$624

for protection of both ends:

Total C_{A_T} = \$10,726

Total C_{A_D} = \$1,248

Roadside Barrier/Crash Cushion System

The third alternative considered in the bridge pier analysis will be an integrated crash cushion - longitudinal barrier system. The crash cushion will be utilized as an end treatment to shield the end piers and the ends of the roadside barrier. The roadside barrier is placed along the 32 foot length (9.8 m) to shield the interior pier. Costs for each of the subsystems may be determined given their respective geometrics, and a total present worth may be fixed.

Crash Cushion - End Treatment

1. A = 21 ft (6.4 m),

   L = 25 ft (7.6 m),

   W = 8 ft (2.4 m)

2. ADT = 75,000 (assumed)

3. E_f = 31.0

4. C_f = 0.12 Based on L - 31.4 = -6.4 ft (-2.0 m) (See rule in Section 5.1.53)

5. Code 15-00-0-0 SI = 1.0 (Table 5.1.10)

6. C_I = \$5,000 (assumed)

7. C_D = \$1,000 (assumed)

8. C_M = \$150 (assumed)

9. C_{OVD} = \$2,095 at SI = 1.0

10. T = 20 years

11. CRF = 0.102, SF = 0.022 } at an assumed interest rate of 8%

12. C_S = 0.0

13. C_{A_T} = (5000) (0.102) + 1000 (0.12) + 150 + 2095 (0.12) - 0 (.022)

    = \$1,031

    C_{A_D} = \$780

Roadside Barrier

1. $A = 21$ ft (6.4 m),

$L = 32$ ft (9.8 m),

$W = 1$ ft (0.305 m)

2. ADT = 75,000

3. $E_f = 31.0$

4. $C_f = 0.19$ (Actual length is used to determine C_f because SI for roadside barrier is higher than for crash cushion.)

5. Code 06-01-3-3 SI = 3.3 (Table 5.1.10)

6. C_I = \$13.00 per foot (assumed) at 32 ft (9.8 m); thus C_I = \$416

7. C_D = \$225 (assumed)

8. C_M = \$1.50 per foot per year (assumed) at 32 ft (9.8 m); thus,

C_M = \$48

9. C_{OVD} = \$5,874 at SI = 3.3

10. T = 20 years

11. CRF = 0.102, SF = 0.022 } at an assumed interest rate of 8%

12. C_S = \$1.50 per foot (assumed) at 32 ft (9.8 m); thus C_S = \$48

13. $C_{A_T} = 416\ (0.102) + 225\ (0.19) + 48 + 5874\ (0.19) - 48\ (0.022)$

= \$1,248

C_{A_D} = \$132

Considering both the costs for the attenuator and the longitudinal barrier, the total system present worth values may be compared as follows:

For protection of one end:

Total C_{A_T} = 1031 + 1248 = \$2,279

Total C_{A_D} = 780 + 132 = \$912

and for shielding for both sides:

Total C_{A_T} = 2 (2279) = \$4,558

Total C_{A_D} = 2 (912) = \$1,824

Comparison

Table 5.1.15 summarizes the results of this example. By collectively reviewing the three proposed alternatives, several observations and conclusions may be outlined. However, the significance of these observations must be weighed in light of the assumptions made and the values assigned to the various parameters. While these values are thought to be typical, they may not be representative of all areas.

1. While the no shielding alternative requires no direct expenditures, it does represent a very substantial total annual cost in terms of accident losses.

2. On an annual cost basis, the roadside barrier/crash cushion system offers the best alternative. However, it does require a somewhat higher direct expenditure.

3. The ranking factor indicates that of the two improvements, the roadside barrier would provide the greatest return per dollar spent.

TABLE 5.1.15 EXAMPLE COMPARISON

OPTION	Direct Annual Cost, C_{A_D} (\$)	Total Annual Cost, C_{A_T} (\$)	Ranking Factor, R
1. No Shielding	0	\$34,545	--
2. Shielding by Roadside Barrier	\$1,248	\$10,726	19.1
3. Shielding by Crash Cushion/ Roadside Barrier	\$1,824	\$ 4,558	16.4

General Comments

1. Practically speaking, the main interest in comparing alternatives two and three is to objectively decide whether the shorter, more expensive and less severe crash cushion would/would not enjoy an advantage over the longer, lower cost and higher severity barrier rail.

2. The main purpose of this example is to demonstrate the use of the cost-effectiveness approach in weighing several alternative solutions for one problem location. Other roadside hazard locations may be evaluated in a similar manner to organize a complete facility inventory and a set of ranking factors.

5.1.55 Example 3 - Elevated Gore Abutment

In this example, an elevated gore abutment has been chosen for analysis, and both costs for the hazard and an improvement will be determined. By referencing the layout shown in Figure 5.1.25, those inputs necessary for the calculations may be obtained, and the procedure may be initiated. Also, higher than normal encroachments that are common to such a location will be considered in the analysis, and adjustments will be made accordingly. Furthermore, the evaluation will consider only collisions with the exposed gore and crash cushion, whichever the case may be. Also, the equation for C_f will be applied in lieu of the nomographs to demonstrate its use.

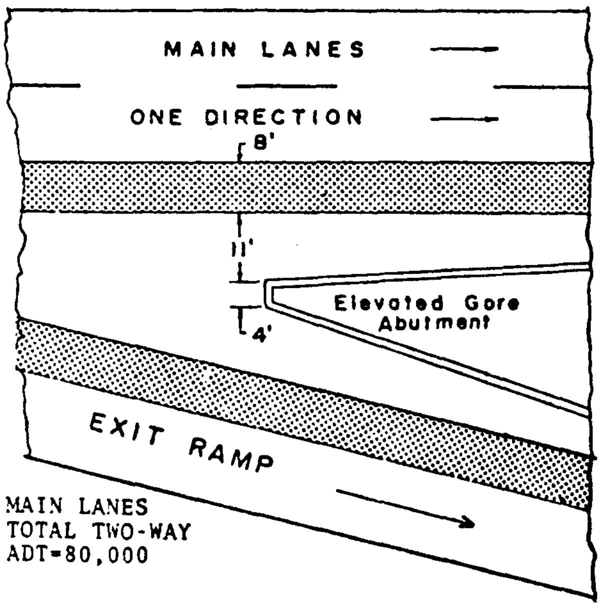


Figure 5.1.25 Elevated Gore Abutment

Existing Hazard

1. A = 19 ft (5.8 m);

   L = 1 ft (.305 m); and

   W = 4 ft (1.2 m)

2. ADT = 80,000

3. E_f = 33.5

4. C_f by using equation may be determined as below:

$$C_f = \frac{33.5}{10,560} (1 + 62.9) (.73) + 5.14 (0.455 + 0.405 + 0.360 + 0.325)$$

C_f = 0.17 and by applying an adjustment factor of 3.0 for higher than normal encroachments (assumed),

C_f (adjusted) = 3 (0.17) = 0.52

5. Code 12-06-0-0 SI = 9.3 (Table 5.1.10)

6. C_I = \$0

7. C_D = \$0 (assumed)

8. C_M = \$0 (assumed)

9. C_{OVD} = \$169,412 at SI = 9.3

10. T = 15 years

11. CRF = 0.117, SF = 0.037 } at an assumed interest rate of 8%

12. C_S = \$0

13. C_{A_T} = 0 (0.117) + 0 (0.52) + 0 + \$169,412 (0.52) - 0 (0.037)

    = \$88,094

    C_{A_U} = \$0

Crash Cushion Improvement

1. A = 17 ft (5.2 m);

   L = 25 ft (7.6 m); and

   W = 8 ft (2.4 m)

2. ADT = 80,000

3. E_f = 33.5

4. C_f by using the equation may be determined as below:

$$C_f = \frac{55.5}{10,560} (25 + 62.9)(0.79) + 5.14 (0.550 + 0.505 + 0.455 + 0.405 + 0.360 + 0.320 + 0.290 + 0.260)$$

C_f = 0.27 and by applying an adjustment factor of 3.0 for higher than normal encroachments (assumed)

$$C_f \text{ (adjusted)} = 3 (0.27) = 0.81$$

5. Code 15-00-0-0 SI 1.0 (Table 5.1.10)
6. C_I = \$5,000 (assumed)
7. C_D = \$1,000 (assumed)
8. C_M = \$200 (assumed)
9. C_{OVD} = \$2,095 at SI = 1.0
10. T = 15 years
11. CRF = 0.117, SF = 0.037 } at an assumed interest rate of 8%
12. C_S = \$0 (assumed)
13. $C_{A_T} = 5000 (0.117) + 1000 (0.81) + 200 + 2095 (0.81) - 0 (0.037)$

    $= \$3,292$

    $C_{A_D} = \$1,595$

By comparing the total costs related to each of the two situations, it may be seen that from a safety standpoint the advantage obviously lies with the improvement alternative. The ranking factor for this site would be 53 which further points out the benefits, in terms of increased safety, that can be realized by installing a crash cushion at such a zone.

In those locations where the traffic-geometric relationships become critical, the collision frequency may be adjusted upward at the discretion of the designer. A factor of 3.0 has been proposed for gore areas, and this seems to be a legitimate number; however, in locations where the variables are not so critical, possibly a lower factor would be appropriate. The decision on such an adjustment would rely strictly on the user's knowledge of the field and his engineering judgment.

5.1.56 Example 4 - Isolated Roadside Obstacles

As has been emphasized throughout this section, the most desirable roadside is one that is relatively flat and free of roadside hazards. If ample recovery room is provided, a driver of an errant vehicle will be able to return to the traveled way or safely stop the vehicle. Removal or relocation of hazards, or the installation of a breakaway device should always be the first option considered. However, various situations may sometimes dictate that isolated obstacles such as small trees or small utility poles be located within the desirable recovery area. In such cases, the designer often is faced with the question: Should the obstacle be shielded by a barrier, even though it is obvious that the hazard potential of the barrier is less than the obstacle? The following example illustrates how this question can be answered by the cost-effectiveness procedure.

<u>Existing Hazard - No Protection</u>

Assume that the existing hazard conditions are the same as those in Example 2 except that instead of three bridge piers the obstacles are three small trees located on the roadside instead of the median. All of the parameters defined under no protection of Example 2 therefore apply here,[1] with one exception and that is the SI of the trees which is assumed as 5.0. It will be further assumed that the SI of the trees does not change over the 20-year period. Should this not be the case, the procedure presented herein would not be applicable. Selection of an SI for such obstacles must be based primarily on engineering judgment due to an absence of objective criteria. From Figure 5.1.21:

$$C_{OVD} = \$16,710$$

Thus,

$$C_{A_T} = 16,710 (0.102)$$

$$C_{A_T} = \$1704$$

and

$$C_{A_D} = \$0$$

<u>Protection by Roadside Barrier</u>

All of the parameters from the Example 2 Roadside Barrier Section apply here.

Thus,

$$C_{A_T} = \$10,726$$

and

$$C_{A_D} = \$1,248$$

Comparison

The most cost-effective alternative in this case is to leave the trees unshielded (assuming they cannot be removed) since the numerator of the ranking equation "R" is negative. Although the trees would have a greater hazard potential per accident, the considerably greater target area of the barrier and its closer proximity to the traveled way would result in considerably more barrier impacts than tree impacts. However, as the length of the line of trees increases, the difference in the cost of the two alternatives decreases. At some length of unshielded trees the barrier would become more cost effective. The reader should also remember that the size of the tree is very signigicant in this analysis. Repeated solutions similar to the one above for different lengths of unshielded trees will reveal the break-even point where the barrier will be cost-effective.

REFERENCES

1. AASHTO, Guide For Selecting, Locating and Designing Traffic Barriers, 1977.

2. Weaver, Graeme D. and D.L. Woods. Cost-Effectiveness Evaluation of Roadside Safety Improvements on Texas Highways. Research Report 15-2F, Texas Transportation Institute, 1976.

U. S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

SUBJECT	FHWA BULLETIN
FHWA Sponsored Research to Now Consider the Mini-Sized Car (1,700-1,800 pounds)	April 26, 1979

As a result of energy conservation policies, environmental, economic, and other concerns, passenger vehicles are becoming smaller and lighter. The highway designs and decisions in the future can be responsive to this changing vehicle fleet as the FHWA will now include the mini-sized car as a test vehicle in its res[illegible] at improving roadway design and roadside safety.

The FHWA is actively pursuing, through research and development, the design of highway barrier systems (i.e., guardrails, bridge rails, and median barriers) and supports for signs, luminaires, and utility poles that will safely accommodate the array of these newer vehicles. This means the crash testing studies that have been so successful in the past using 4,500 pound full-size cars and 2,250 pound compact cars, will include from now on the 1,700-1,800 pound mini-sized car. This smaller size car is particularl important in the design of breakaway or yielding sign supports and barrier geometrics.

Initial FHWA sponsored research with mini-sized cars has recently involved crash testing into bridge rails and small sign supports. For future research, the mini-sized car will be used to provide needed insight into the effects of the changing vehicle fleet on the highway.

In addition to the mini-sized car, FHWA is also using schoolbuses, intercity buses, and even tractor-trailer trucks in its research to determine what is needed at the other end of the scale to retain heavy vehicles in collisions with highway barrier systems.

Several studies are underway and more are scheduled that should provide sound evidence on which to base judgments on selecting and designing highway safety appurtenances for various kinds of highways.

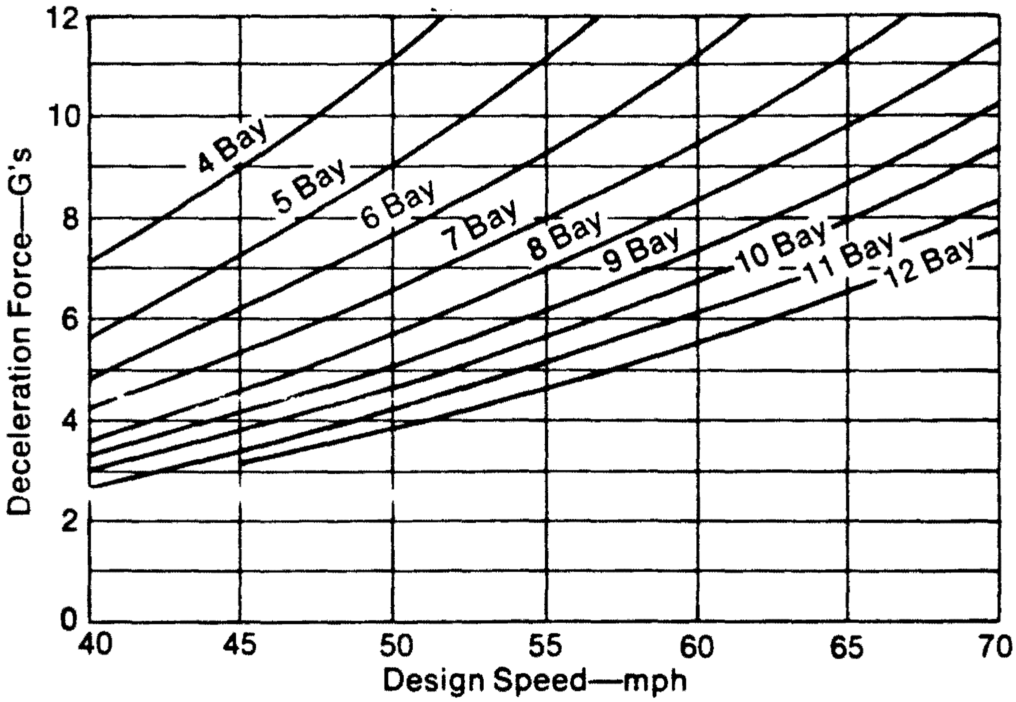
for G. D. Love
Associate Administrator for
Research and Development

H. L. Anderson
Associate Administrator for
Safety

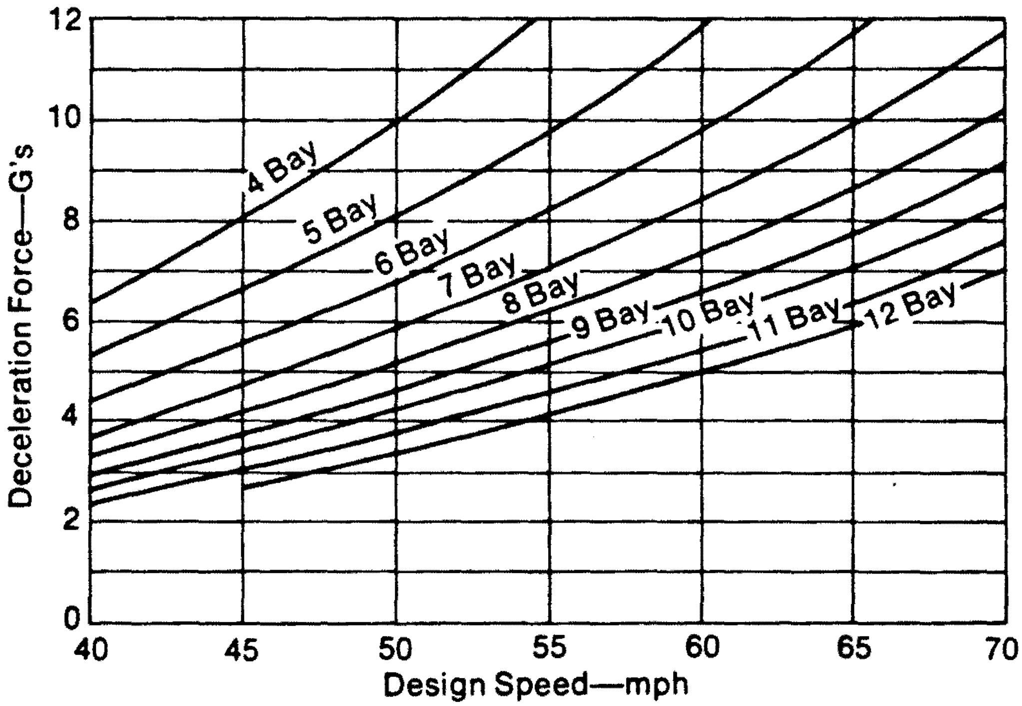
DISTRIBUTION: H-WDM-4 OPI: HHS-12

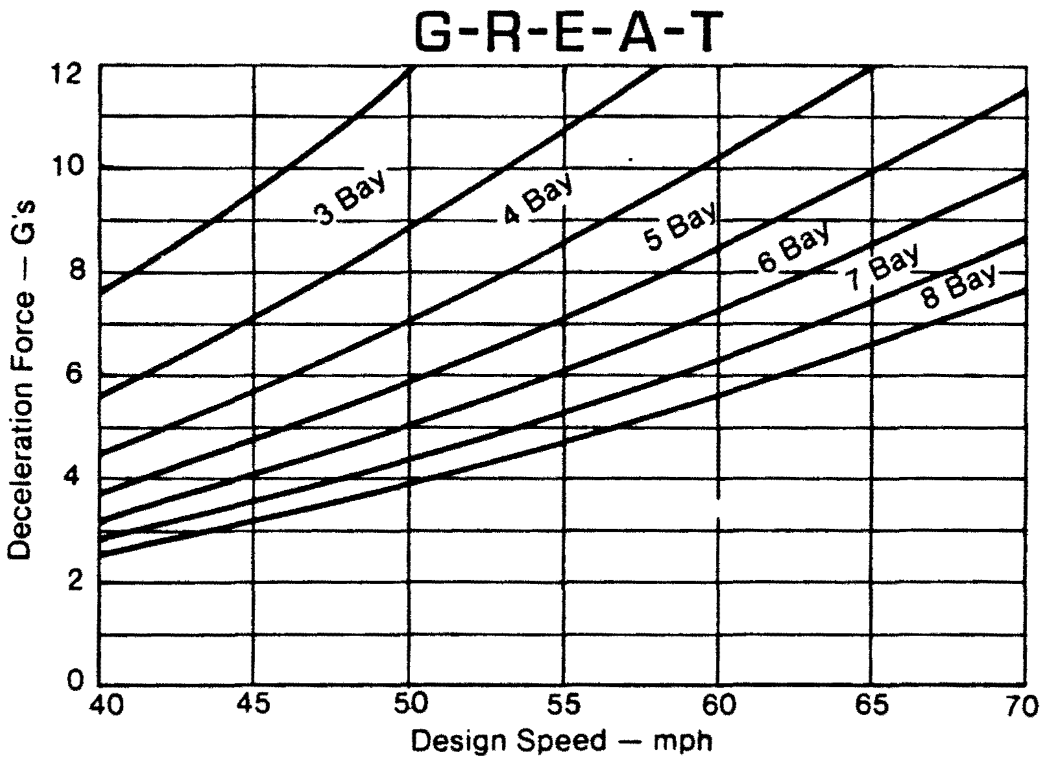
CRASH CUSHION DESIGN CURVES

HI-DRO CELL



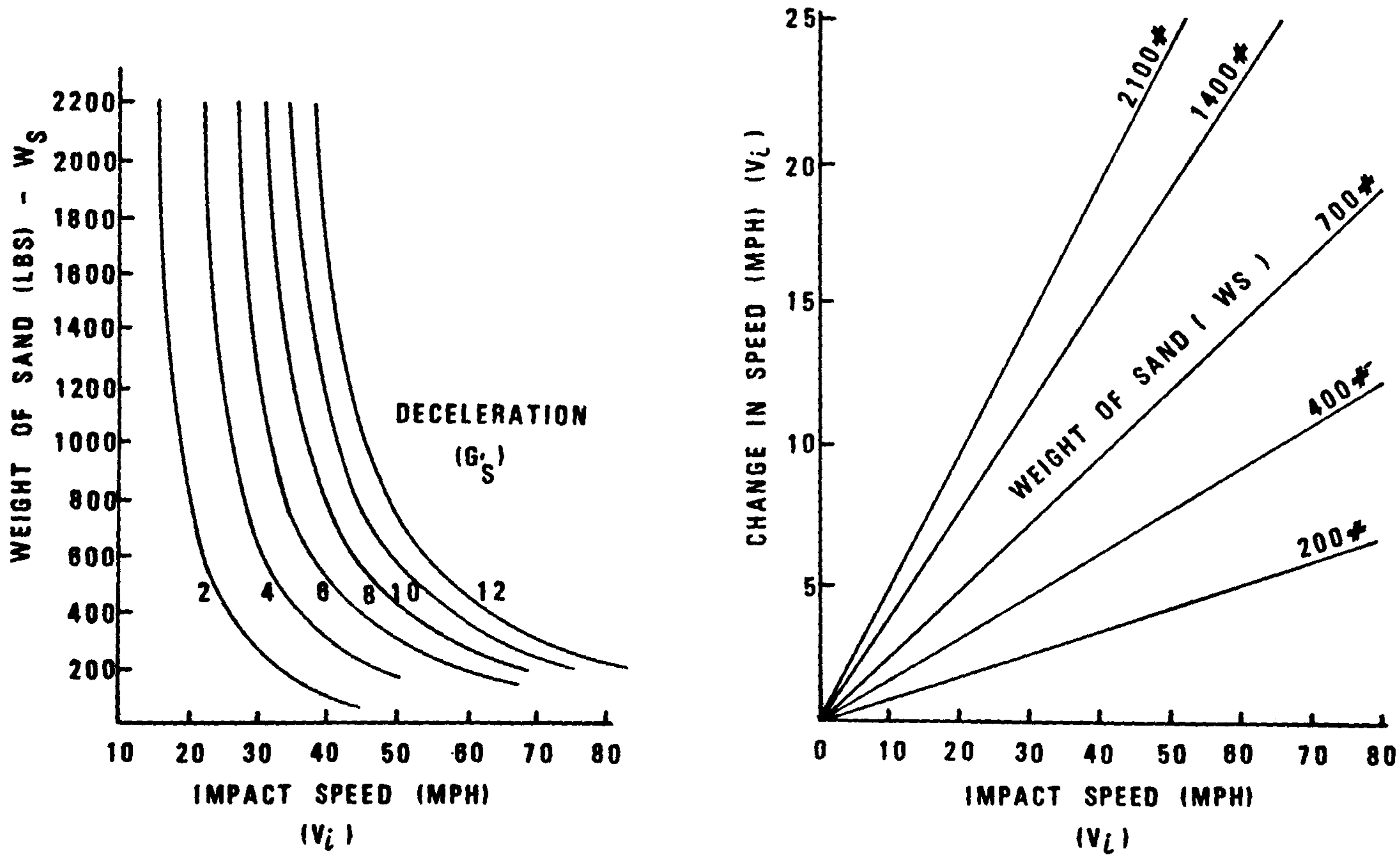
HI-DRI CELL



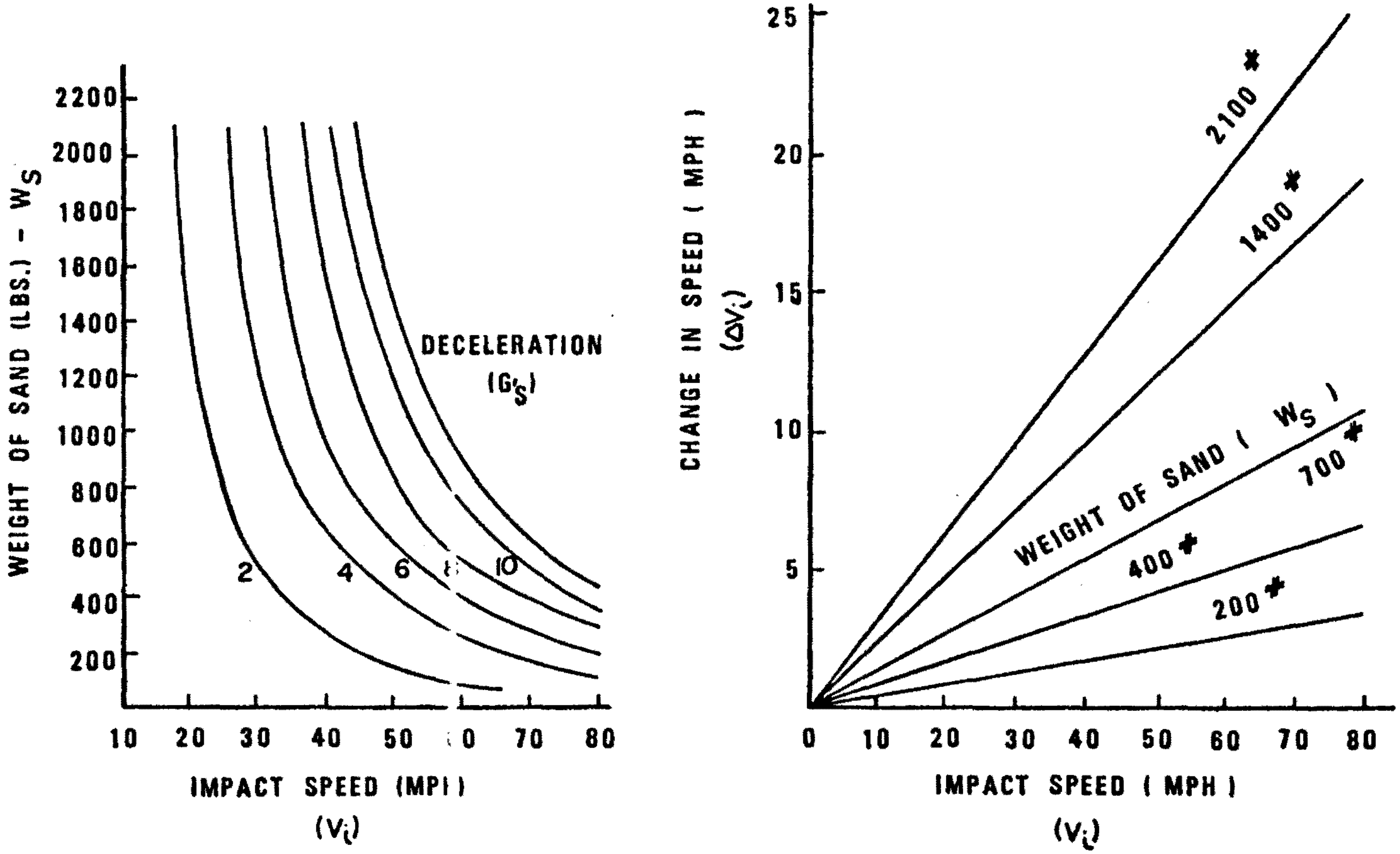


G-R-E-A-T
Deceleration Force — G's
12
10
8
6
4
2
0
40
45
50
55
60
65
70
Design Speed — mph
3 Bay
4 Bay
5 Bay
6 Bay
7 Bay
8 Bay

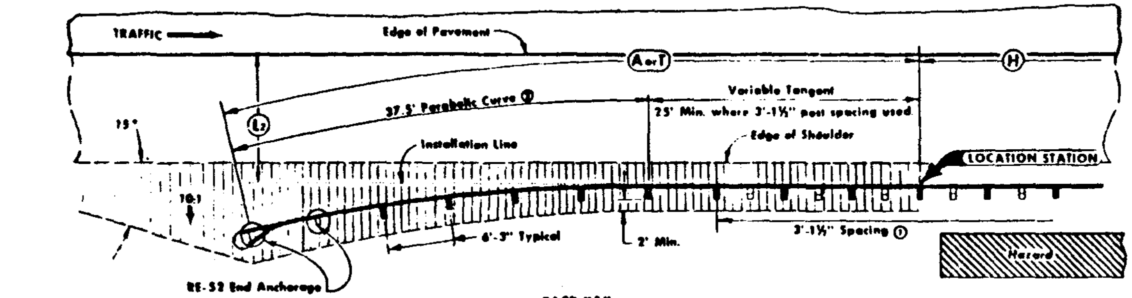
DESIGN CHART FOR 36" DIAMETER INERTIA BARRIER
2250 LB. DESIGN VEHICLE



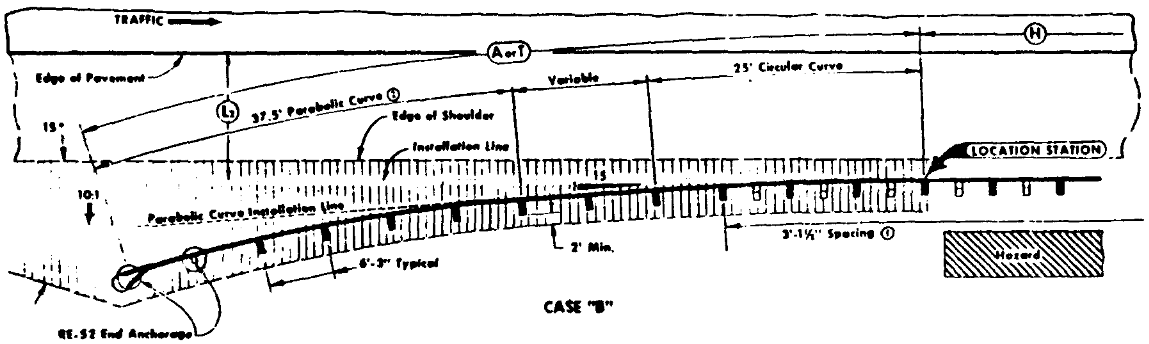
DESIGN CHART FOR 36'' DIAMETER INERTIA BARRIER
4500 LB. DESIGN VEHICLE



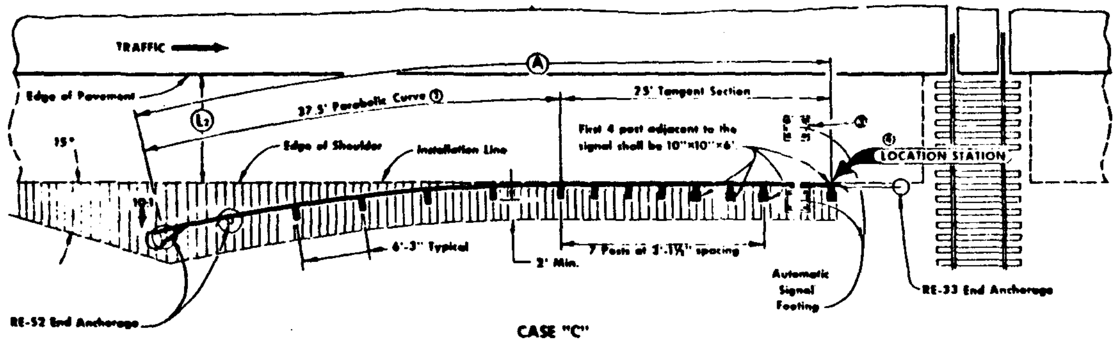
SUGGESTED ROADSIDE BARRIER FLARE DESIGN



CASE "A"



CASE "B"



CASE "C"

③ 25' of Circular Curve will be required in place of 25' Tangent Section when Automatic Signal Footing is located on Shoulder.

④ Location Station shall center signal footing between first two posts.

GENERAL NOTES:

Details indicated hereon are for installation of formed steel beam guardrail for hazardous obstructions located adjacent to the traveled way. For information regarding individual installations, refer to Tabulation of Beam Guardrail Installations, other Standard Road Plans and detailed project plans for additional data. Any modifications to these layouts shall be at the direction of the engineer.

In areas where the guardrail diverges from the installation line, a smooth profile shall be established. It is the intent of this plan to provide a 10:1 slope from the edge of the shoulder to two feet back of the guardrail post as shown hereon. For specific requirements and details refer to other Standard Road Plans and tabulations.

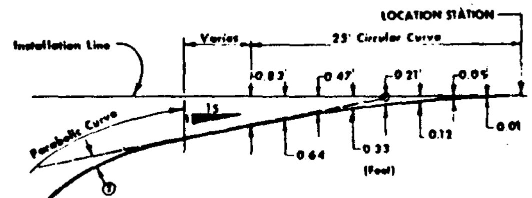
Guardrail shall be lapped towards the hazard.

Price bid for contract items shall be considered full compensation for furnishing all materials and constructing guardrail essentially as indicated hereon.

Contract items for guardrail construction are:
- Formed Steel Beam Guardrail
- Beam Guardrail Posts
- Beam Guardrail End Anchorages (By Type)

① Where hazard is 4'-6" or more from installation line, all post spacing shall be 6'-3". When hazard is less than 4'-6" (3 ft. for box culvert) from installation line, the post spacing adjacent to the hazard and to a point approximately 19 ft. in front of the hazard shall be 3'-1½". When the guardrail is intended to be attached to the hazard, refer to typical attachment details on Standard Road Plan RE-55.

② Refer to Standard Road Plan RE-52 for details of Parabolic Curve Section.



OFFSETS FOR CURVED PORTIONS OF GUARDRAIL
(CASE B&C)

Highway Division

STANDARD ROAD PLAN **RE-54**

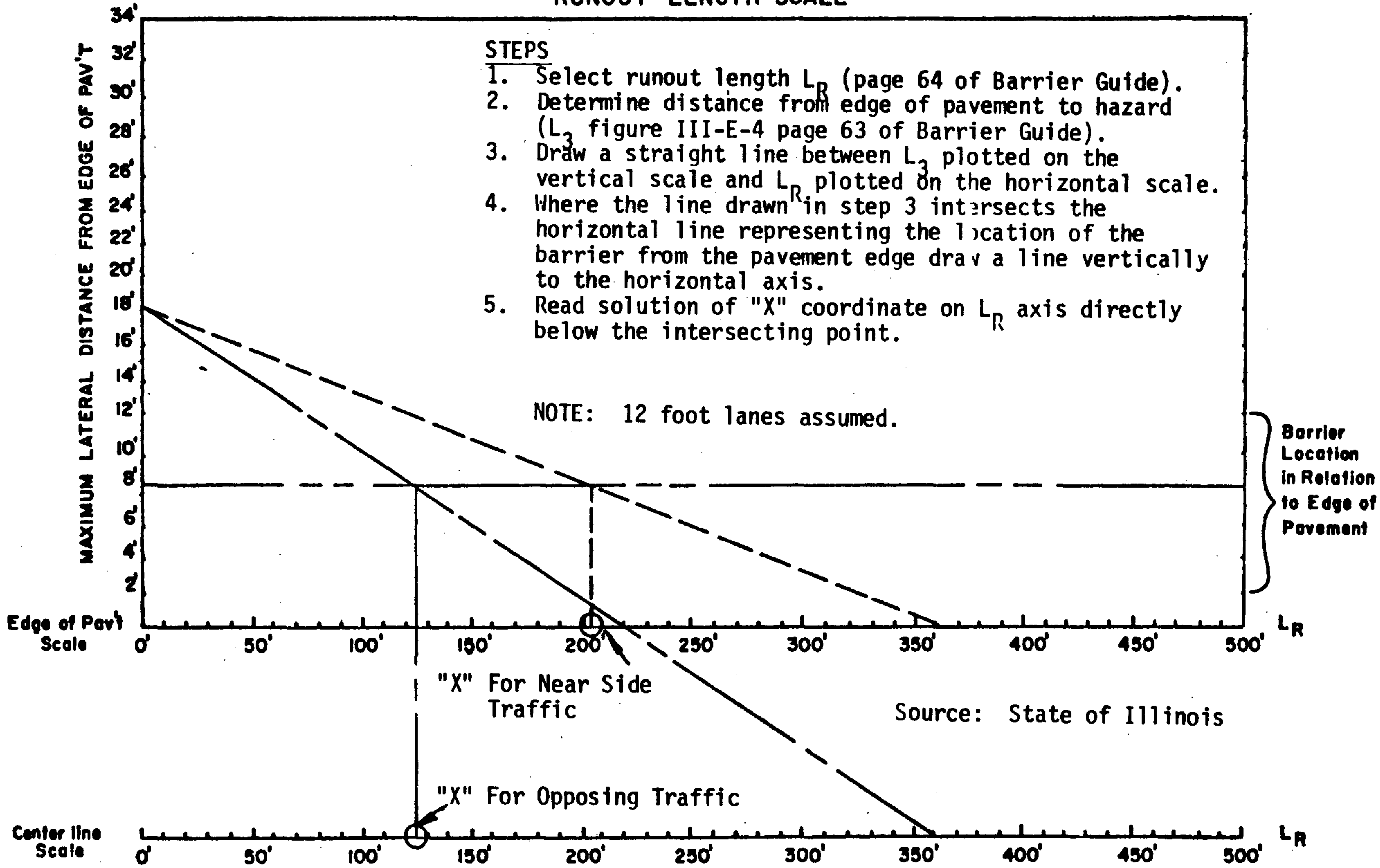
RECOMMENDED — ROAD DESIGN ENGINEER — DATE

APPROVED — DATE

GUARDRAIL INSTALLATIONS
(SIDE HAZARD, TWO-WAY TRAFFIC)

SAMPLE GRAPHIC SOLUTION TO LENGTH OF NEED EQUATION

RUNOUT LENGTH SCALE

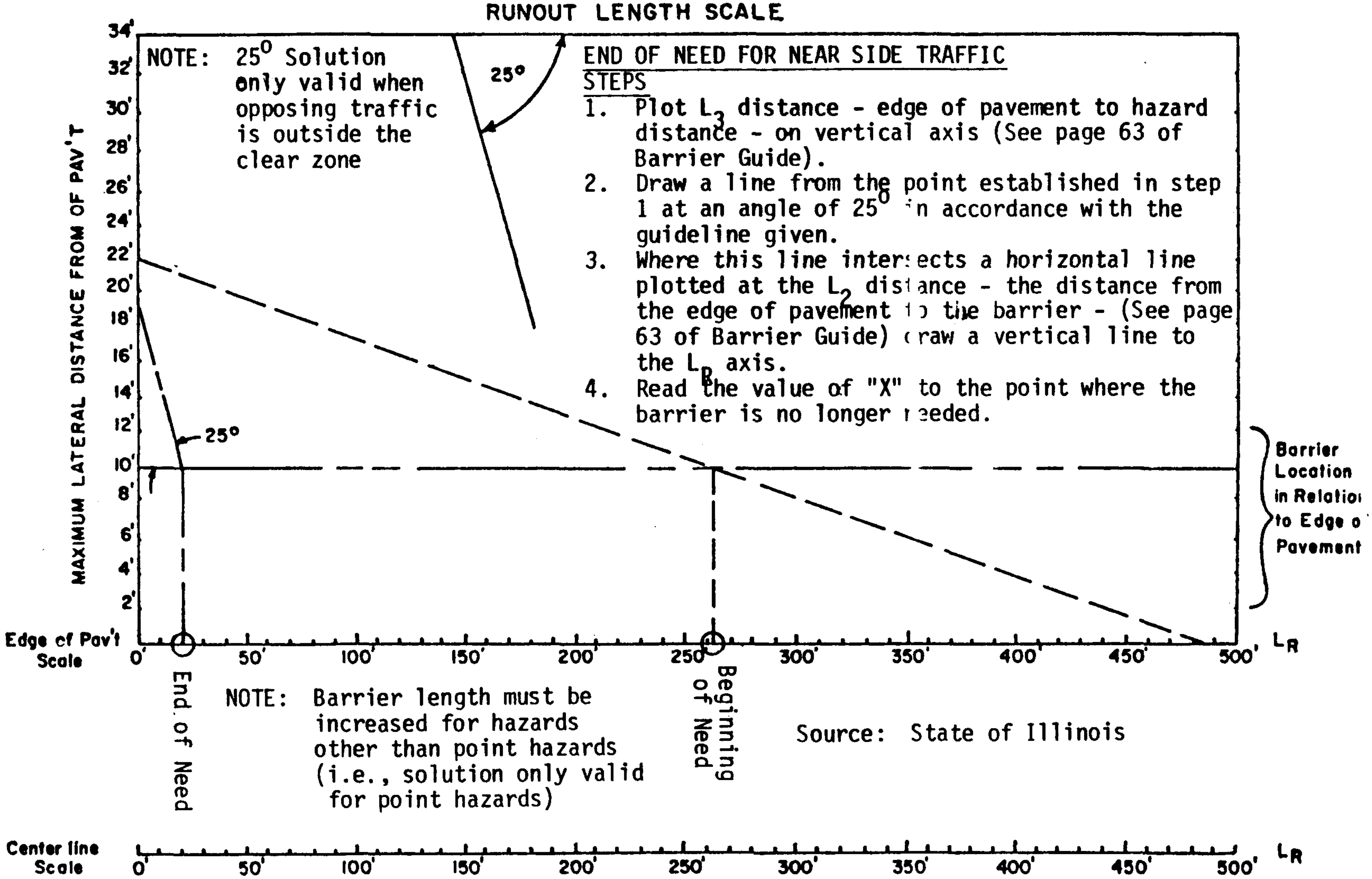


EXAMPLE ——— Represents length of need in front of hazard located 18' from edge of pavement when operating speed is 60 mph, and design traffic volume (ADT) is 5200 .

——— Represents length of need in front of hazard under same conditions except the vehicle is approaching from the opposite direction.

—--— Represents Barrier location in relation to edge of pavement.

Feet x 0.305 = Metres



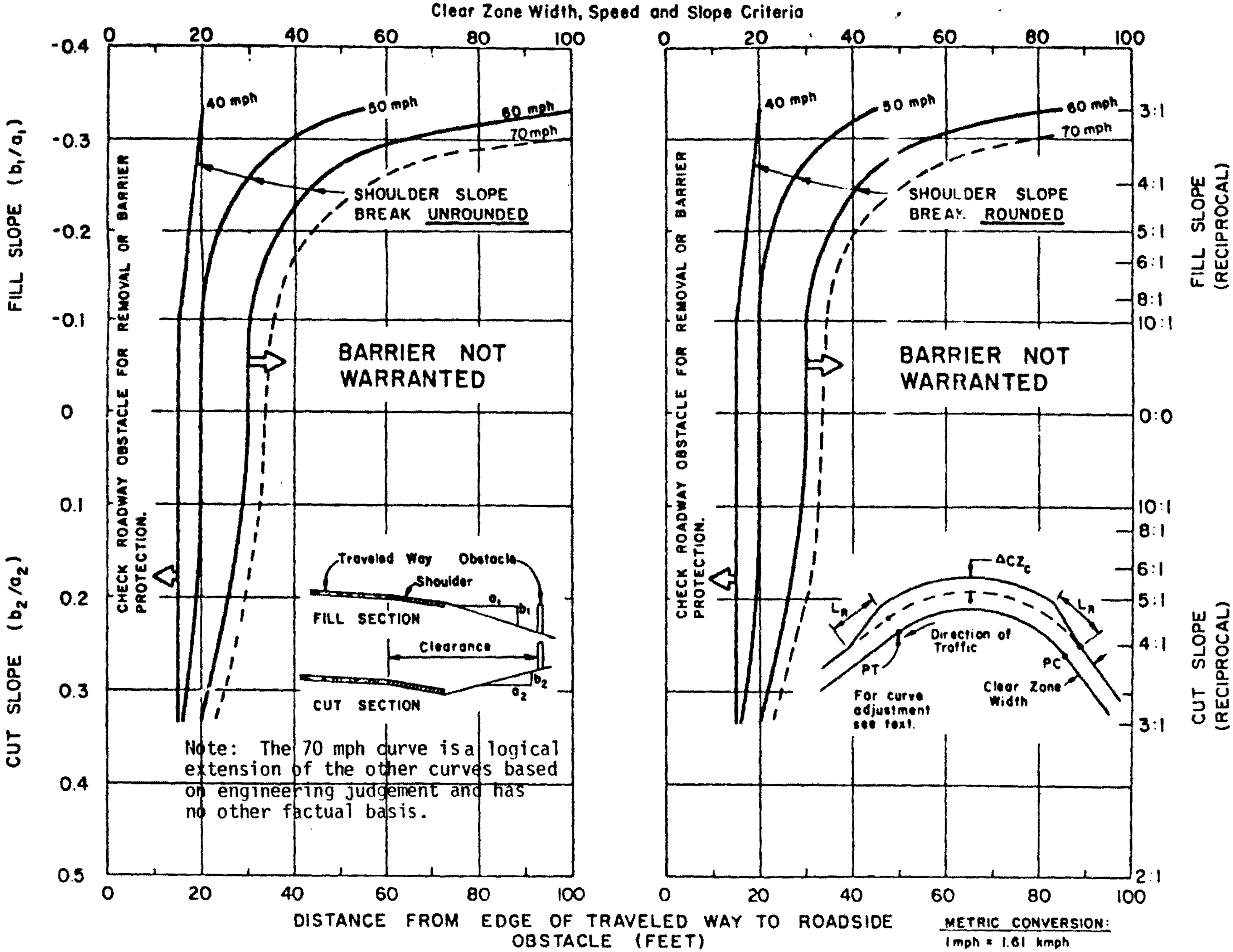
EXAMPLE ——— Represents length of need in front of hazard located 19' from edge of pavement when operating speed is 70 mph, and design traffic volume (ADT) is 7000.

– – – Represents L_3, length to be omitted from length of need.

–·–· Represents Barrier location in relation to edge of pavement.

Feet x 0.305 = Metres

Source: FHWA Regional Office, Homewood, Illinois



SUGGESTED 70 MPH CLEAR ZONE WIDTH FOR VARIOUS SIDE SLOPES

CLEAR ZONE REQUIREMENTS

NOTE: Values come from curves on page 58.

Source: State of Illinois

FOR DEGREE OF CURVE:

TANGENT

		CUT SECTION						FILL SECTION					
SPEED	VOL.	3:1	4:1	5:1	6:1	8:1	10:1	10:1	8:1	6:1	5:1	4:1	3:1
40 MPH	800-2000	15	15	15	15	15	15	15	16	17	18	19	20
	2000-6000	15	15	15	15	15	15	15	16	17	18	19	20
	6000+*	15	15	15	15	15	15	15	16	17	18	19	20
50 MPH	800-2000	17	19	20	20	20	20	20	20	22	25	30	53
	2000-6000	17	19	20	20	20	20	20	20	22	25	30	53
	6000+	17	19	20	20	20	20	20	20	22	25	30	53
60 MPH	800-2000	20	25	26	27	28	29	31	32	33	37	45	100
	2000-6000	20	25	26	27	28	29	31	32	33	37	45	100
	6000+	20	25	26	27	28	29	31	32	33	37	45	100

* "+" means greater than the value indicated.

NOTE: Values obtained by adding ΔCZ to the value in Table on page 59.

CLEAR ZONE REQUIREMENTS

$$\Delta CZ_c = R\left(1 - \cos\frac{L_R D^{\circ}}{100}\right) \text{ (slide slope} - 0.1 \text{ or flatter)}$$

ΔCZ_c = increase in clear zone for curve – ft. (m.)

D° = degree of curve – 100 ft. arc def. (100 m arc def.)

R = radius of curve – ft. (m.)

L_R = runout path length (Table III-E-1) – ft. (m.)

Page 64, Barrier Guide

FOR DEGREE OF CURVE: 1°

		CUT SECTION						FILL SECTION					
SPEED	VOL.	3:1	4:1	5:1	6:1	8:1	10:1	10:1	8:1	6:1	5:1	4:1	3:1
40 MPH	800-2000	18	18	18	18	18	18	18	19	17	22	22	24
	2000-6000	19	19	19	19	19	19	19	20	22	23	24	25
	6000+	20	20	20	20	20	20	20	21	23	24	25	27
50 MPH	800-2000	22	25	26	26	26	26	26	26	29	32	39	69
	2000-6000	25	26	27	27	27	27	27	27	30	34	40	72
	6000+	27	28	29	29	29	29	29	29	32	36	44	77
60 MPH	800-2000	26	32	34	35	36	38	40	42	43	48	58	80
	2000-6000	27	34	36	37	38	40	42	44	45	50	62	137
	6000+	29	37	38	40	41	43	45	47	48	54	66	147

CLEAR ZONE REQUIREMENTS

FOR DEGREE OF CURVE :

2°

		CUT SECTION						FILL SECTION					
SPEED	VOL.	3:1	4:1	5:1	6:1	8:1	10:1	10:1	8:1	6:1	5:1	4:1	3:1
40 MPH	800-2000	22	22	22	22	22	22	22	23	25	26	28	29
	2000-6000	23	23	23	23	23	23	23	26	26	28	29	31
	6000 +	25	25	25	25	25	25	25	27	28	30	32	33
50 MPH	800-2000	27	30	32	32	32	32	32	32	35	40	48	85
	2000-6000	30	33	35	35	35	35	35	35	38	44	52	93
	6000 +	32	36	38	38	38	38	38	38	42	47	57	101
60 MPH	800-2000	33	41	43	44	46	47	51	52	54	60	73	163
	2000-6000	35	44	46	48	50	51	55	56	58	65	79	177
	6000 +	40	49	51	53	55	56	60	61	63	70	84	182

CLEAR ZONE REQUIREMENTS

FOR DEGREE OF CURVE:

3^{o}

		CUT SECTION						FILL SECTION					
SPEED	VOL.	3:1	4:1	5:1	6:1	8:1	10:1	10:1	8:1	6:1	5:1	4:1	3:1
40 MPH	800-2000	25	25	25	25	25	25	25	27	28	30	32	33
	2000-6000	28	28	28	28	28	28	28	30	32	34	35	37
	6000+	30	30	30	30	30	30	30	32	34	36	38	30
50 MPH	800-2000	32	36	38	38	38	38	38	38	42	47	57	101
	2000-6000	36	40	42	42	42	42	42	42	46	52	63	112
	6000+	40	45	47	47	47	47	47	47	52	59	70	125
60 MPH	800-2000	38	48	50	52	54	56	60	62	64	71	87	193
	2000-6000	42	53	56	58	60	62	66	68	70	79	96	213
	6000+	48	60	63	65	67	70	74	77	79	89	108	240

CLEAR ZONE REQUIREMENTS

FOR DEGREE OF CURVE:

4°

		CUT SECTION						FILL SECTION					
SPEED	VOL.	3:1	4:1	5:1	6:1	8:1	10:1	0:1	8:1	6:1	5:1	4:1	3:1
40 MPH	800-2000	29	29	29	29	29	29	29	31	33	35	37	39
	2000-6000	32	32	32	32	32	32	32	34	36	38	40	43
	6000+	35	35	35	35	35	35	35	37	40	42	44	47
50 MPH	800-2000	37	42	44	44	44	44	44	44	48	55	66	117
	2000-6000	42	47	49	49	49	49	49	49	54	61	73	131
	6000+	48	53	56	56	56	56	56	56	62	70	84	149
60 MPH	800-2000	45	57	59	61	64	66	70	72	75	84	102	227
	2000-6000	50	62	65	67	70	73	77	80	83	92	112	250
	6000+	56	71	74	76	80	82	88	90	94	105	127	283

CLEAR ZONE REQUIREMENTS

FOR DEGREE OF CURVE :

5^{o}

		CUT SECTION						FILL SECTION					
SPEED	VOL.	3:1	4:1	5:1	6:1	8:1	10:1	10:1	8:1	6:1	5:1	4:1	3:1
40 MPH	800-2000	32	32	32	32	32	32	32	34	36	38	40	43
	2000-6000	36	36	36	36	36	36	36	38	41	43	45	48
	6000+	40	40	40	40	40	40	40	43	45	48	50	53
50 MPH	800-2000	42	47	49	49	49	49	49	49	54	61	73	131
	2000-6000	48	53	56	56	56	56	56	56	62	70	84	149
	6000+	54	61	64	64	64	64	64	64	70	80	96	171
60 MPH	800-2000	51	64	67	69	72	75	79	82	85	95	115	257
	2000-6000	57	71	75	77	81	83	89	91	95	106	129	286
	6000+	66	87	86	89	93	96	102	105	109	122	148	330

CLEAR ZONE REQUIREMENTS

FOR DEGREE OF CURVE:

6°

		CUT SECTION						FILL SECTION					
SPEED	VOL.	3:1	4:1	5:1	6:1	8:1	10:1	10:1	8:1	6:1	5:1	4:1	3:1
40 MPH	800-2000	36	36	36	36	36	36	36	38	41	43	45	48
	2000-6000	40	40	40	40	40	40	40	43	45	48	50	53
	6000+	45	45	45	45	45	45	45	48	51	54	57	60
50 MPH	800-2000	47	52	55	55	55	55	55	55	60	69	82	147
	2000-6000	54	61	64	64	64	64	64	64	70	80	96	171
	6000+	62	69	73	73	73	73	73	73	80	91	109	195
60 MPH	800-2000	57	71	75	77	81	83	89	91	96	106	129	286
	2000-6000	64	81	84	87	91	94	100	103	107	119	145	323
	6000+	75	94	98	102	106	110	116	120	124	139	169	376

CLEAR ZONE REQUIREMENTS

FOR DEGREE OF CURVE :

7°

		CUT SECTION						FILL SECTION					
SPEED	VOL.	3:1	4:1	5:1	6:1	8:1	10:1	10:1	8:1	6:1	5:1	4:1	3:1
40 MPH	800-2000	39	39	39	39	39	39	39	42	44	47	49	52
	2000-6000	44	44	44	44	44	44	44	47	50	53	56	59
	6000+	50	50	50	50	50	50	50	53	57	60	63	67
50 MPH	800-2000	52	58	61	61	61	61	61	61	67	76	91	163
	2000-6000	60	67	71	71	71	71	71	71	78	81	106	190
	6000+	70	78	82	82	82	82	82	82	90	102	123	219
60 MPH	800-2000	64	80	83	86	90	93	99	102	106	118	144	320
	2000-6000	71	90	94	97	101	105	111	115	119	133	162	360
	6000+	83	105	110	113	118	122	130	134	139	155	189	420

CLEAR ZONE REQUIREMENTS

FOR DEGREE OF CURVE :

8°

		CUT SECTION						FILL SECTION					
SPEED	VOL.	3:1	4:1	5:1	6:1	8:1	10:1	10:1	8:1	6:1	5:1	4:1	3:1
40 MPH	800-2000	43	43	43	43	43	43	43	46	49	52	54	57
	2000-6000	49	49	49	49	49	49	49	52	55	59	62	65
	6000+	55	55	55	55	55	55	55	59	62	66	69	73
50 MPH	800-2000	57	64	67	67	67	67	67	67	74	84	100	179
	2000-6000	66	74	78	78	78	78	78	78	86	97	117	208
	6000+	76	85	90	90	90	90	90	90	99	112	135	241
60 MPH	800-2000	69	87	91	94	98	102	108	112	116	129	157	350
	2000-6000	79	99	103	107	112	115	123	126	131	146	178	396
	6000+	92	115	121	125	130	135	143	148	153	171	208	463

CLEAR ZONE REQUIREMENTS

FOR DEGREE OF CURVE

9°

		CUT SECTION						FILL SECTION					
SPEED	VOL.	3:1	4:1	5:1	6:1	8:1	10:1	10:1	8:1	6:1	5:1	4:1	3:1
40 MPH	800-2000	46	46	46	46	46	46	46	49	52	55	58	61
	2000-6000	53	53	53	53	53	53	53	57	60	64	67	71
	6000+	60	60	60	60	60	60	60	64	68	72	76	80
50 MPH	800-2000	61	68	72	72	72	72	72	72	79	90	108	192
	2000-6000	72	81	85	85	85	85	85	85	94	106	127	227
	6000+	84	94	99	99	99	99	99	99	109	124	148	265
60 MPH	800-2000	75	95	99	103	107	110	118	121	125	140	171	380
	2000-6000	85	107	112	116	121	125	133	137	142	159	193	430
	6000+	101	126	132	137	143	147	157	161	167	187	228	506

CLEAR ZONE REQUIREMENTS

FOR DEGREE OF CURVE :

10°

		CUT SECTION						FILL SECTION					
SPEED	VOL.	3:1	4:1	5:1	6:1	8:1	10:1	10:1	8:1	6:1	5:1	4:1	3:1
40 MPH	800-2000	50	50	50	50	50	50	50	53	57	60	63	67
	2000-6000	57	57	57	57	57	57	57	61	64	68	72	76
	6000+	65	65	65	65	65	65	65	69	73	78	82	86
50 MPH	800-2000	66	74	78	78	78	78	78	78	86	97	117	208
	2000-6000	78	87	92	92	92	92	92	92	101	115	138	246
	6000+	91	102	107	107	107	107	107	107	118	143	160	286
60 MPH	800-2000	81	101	106	110	114	118	126	130	134	150	183	406
	2000-6000	92	115	121	125	130	135	143	148	153	171	208	463
	6000+	108	136	143	148	154	159	169	174	180	202	246	546

CLEAR ZONE REQUIREMENTS

FOR DEGREE OF CURVE :

12°

		CUT SECTION						FILL SECTION					
SPEED	VOL.	3:1	4:1	5:1	6:1	8:1	10:1	10:1	8:1	6:1	5:1	4:1	3:1
40 MPH	800-2000	56	56	56	56	56	56	56	60	63	67	71	75
	2000-6000	65	65	65	65	65	65	65	69	73	78	82	86
	6000+	74	74	74	74	74	74	74	79	84	89	93	98
50 MPH	800-2000	76	85	89	89	89	89	89	89	98	111	133	238
	2000-6000	89	100	105	105	105	105	105	105	116	131	157	281
	6000+	105	117	123	123	123	123	123	123	135	154	184	329
60 MPH	800-2000	92	115	121	125	130	135	143	148	153	171	208	463
	2000-6000	105	132	138	143	149	154	164	169	175	196	238	530
	6000+	124	156	163	169	177	182	194	199	207	231	282	626

CLEAR ZONE REQUIREMENTS

FOR DEGREE OF CURVE :

14°

		CUT SECTION						FILL SECTION					
SPEED	VOL.	3:1	4:1	5:1	6:1	8:1	10:1	10:1	8:1	6:1	5:1	4:1	3:1
40 MPH	800-2000	63	63	63	63	63	63	63	67	71	76	79	84
	2000-6000	73	73	73	73	73	73	73	78	83	88	92	97
	6000+	83	83	83	83	83	83	83	89	94	100	105	110
50 MPH	800-2000	85	95	100	100	100	100	100	100	110	125	150	267
	2000-6000	100	112	118	118	118	118	118	118	130	147	177	316
	6000+	118	132	139	139	139	139	139	139	153	174	208	372
60 MPH	800-2000	104	130	136	141	147	152	162	167	173	193	235	523
	2000-6000	118	148	155	160	167	173	183	189	196	219	267	593
	6000+	139	174	183	189	197	204	216	223	231	258	315	699

CLEAR ZONE REQUIREMENTS FOR DEGREE OF CURVE:

16°

		CUT SECTION						FILL SECTION					
SPEED	VOL.	3:1	4:1	5:1	6:1	8:1	10:1	10:1	8:1	6:1	5:1	4:1	3:1
40 MPH	800-2000	69	69	69	69	69	69	69	74	78	83	87	92
	2000-6000	80	80	80	80	80	80	80	86	90	96	101	106
	6000+	92	92	92	92	92	92	92	98	104	110	116	122
50 MPH	800-2000	93	104	110	110	110	110	110	110	121	137	165	294
	2000-6000	111	124	131	131	131	131	131	131	144	164	196	350
	6000+	131	146	154	154	154	154	154	154	169	192	231	412
60 MPH	800-2000	114	143	150	155	161	167	177	183	189	212	258	573
	2000-6000	130	163	170	176	184	190	202	208	216	241	294	653
	6000+	153	192	201	208	217	224	238	245	254	284	346	769

CLEAR ZONE REQUIREMENTS

FOR DEGREE OF CURVE: 18°

SPEED	VOL.	CUT SECTION 3:1	4:1	5:1	6:1	8:1	10:1	FILL SECTION 10:1	8:1	6:1	5:1	4:1	3:1
40 MPH	800-2000	76	76	76	76	76	76	76	81	86	91	96	101
	2000-6000	88	88	88	88	88	88	88	94	99	106	111	117
	6000+	101	101	101	101	101	101	101	108	114	121	127	134
50 MPH	800-2000	102	114	120	120	120	120	120	120	132	150	180	321
	2000-6000	122	136	143	143	143	143	143	143	157	179	214	383
	6000+	143	160	168	168	168	168	168	168	185	210	252	450
60 MPH	800-2000	123	154	162	167	175	180	192	197	205	229	279	619
	2000-6000	141	177	185	192	200	207	219	226	234	262	319	709
	6000+	165	208	217	225	235	242	258	265	275	308	375	833

CLEAR ZONE REQUIREMENTS

FOR DEGREE OF CURVE :

20°

		CUT SECTION						FILL SECTION					
SPEED	VOL.	3:1	4:1	5:1	6:1	8:1	10:1	10:1	8:1	6:1	5:1	4:1	3:1
40 MPH	800-2000	82	82	82	82	82	82	82	88	93	98	103	109
	2000-6000	95	95	95	95	95	95	95	102	107	114	120	126
	6000+	110	110	110	110	110	110	110	118	124	132	139	146
50 MPH	800-2000	110	123	130	130	130	130	130	130	143	162	195	348
	2000-6000	131	146	154	154	154	154	154	154	169	192	231	412
	6000+	154	172	181	181	181	181	181	181	199	226	271	484
60 MPH	800-2000	132	166	174	180	188	194	206	212	220	246	300	666
	2000-6000	151	189	198	205	214	221	235	242	251	281	243	759
	6000+	176	221	231	239	250	258	274	282	293	327	399	886

GUIDELINES FOR DETERMINING GUARDRAIL NEED, LOCATION AND STANDARDS

Source: State of Georgia

CONTENTS

Revised: 11-9-77 - RMU
Revised: 9-25-78- RMU
Revised: 11-8-79 - RMU
Revised: 2-14-80 - RMU

NOTE: This material is provided for the readers use only. It does not constitute a policy of the Federal Highway Administration.

I. GUARDRAIL WARRANTY FOR FILL EMBANKMENT

Height and slope of roadway embankment are basic factors in determining guardrail need. In Figure 1 (A) below, an extrapolation of fill height and slope which falls above or to the right of the curve indicates an embankment hazard of a greater severity than the guardrail. A slope and height combination which falls below the curve indicates an embankment which is less severe than the guardrail. Guardrail should not be used for embankment protection if the slope height extrapolation falls on or below the curve, however other conditions such as fixed hazards, length of advancement, etc. may warrant guardrail.

WHERE FEASIBLE, THE FLATTENING OF WARRANTING SLOPES IS PREFERRABLE TO REQUIRING GUARDRAIL.

The warranty criteria shown in Figure 1 (A) is intended primarily for higher traffic volume and higher speed design rural type roads. In general, it is not cost-effective to require guardrail on the lower traffic volume

(continued on Page -2-)

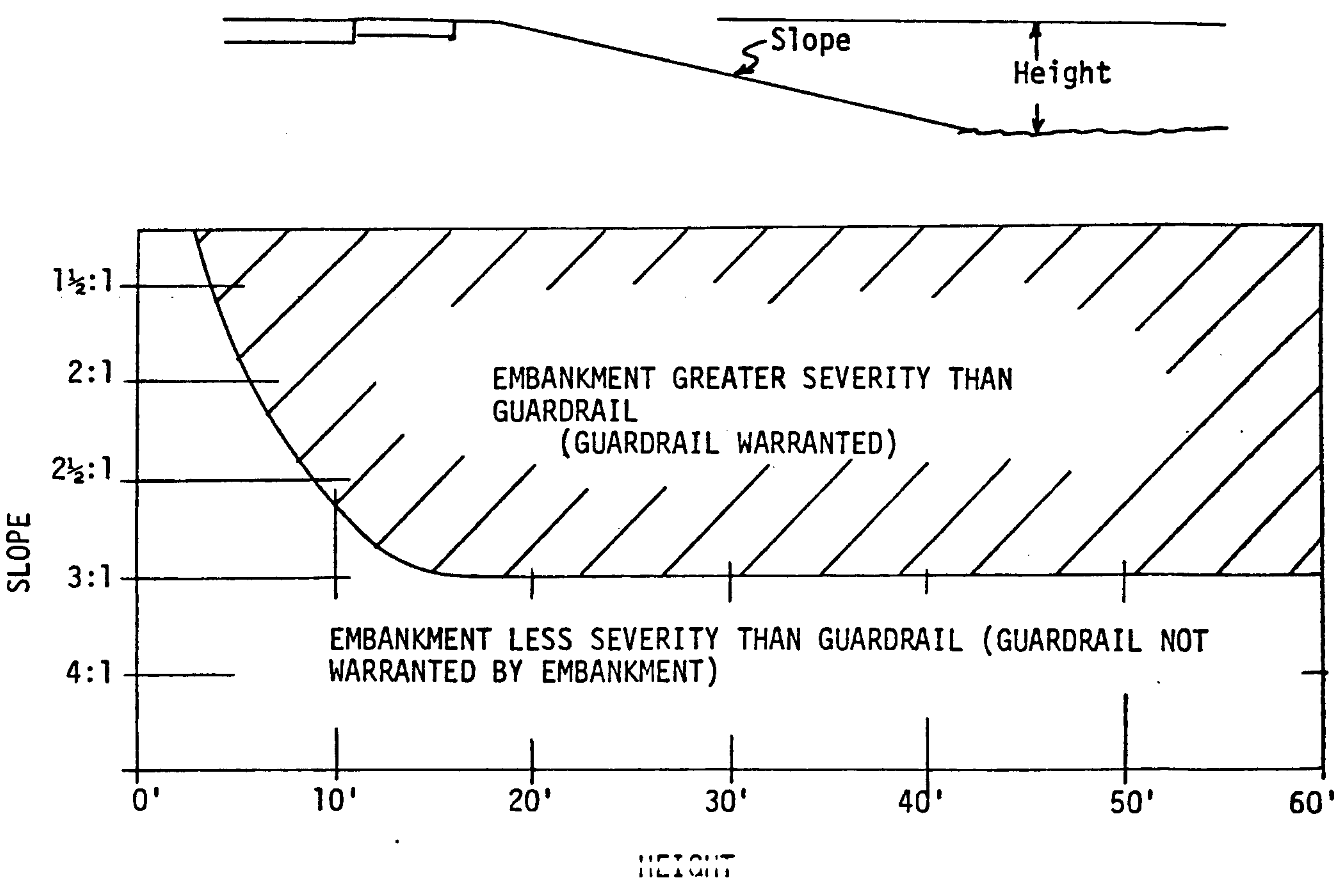


FIGURE NO. 1(A)

roads at every location where the embankment is of greater severity than the guardrail. Figures 1 (B), 1 (C), 1 (D), 1 (E) and 1 (F) were derived from the procedure described in Chapter VII of the AASHTO Guide for Selecting, Locating, and Designing Traffic Barriers and may be used for determining guardrail need on a cost-effective basis.

The warranting criteria given in Figure Nos. 1 (B), 1 (C), 1 (D), 1 (E), and 1 (F) are based on probably collision frequencies. Since adverse road conditions of particular sites may affect these frequencies, a higher level of protection than that suggested in the Figures would sometimes be justified. Such adverse road conditions may include horizontal and/or vertical alignment, route discontinuity, narrow lanes, narrow shoulders, inadequate superelevation on curves, long grades, lane drops, skid resistance, etc.

Where guardrail is required for warranting embankments, it should be extended the full length of need plus a length of advancement to prevent vehicle penetration behind the guardrail into the protected area. See the Standard Details and Section III and Figure No. 3 of these guidelines.

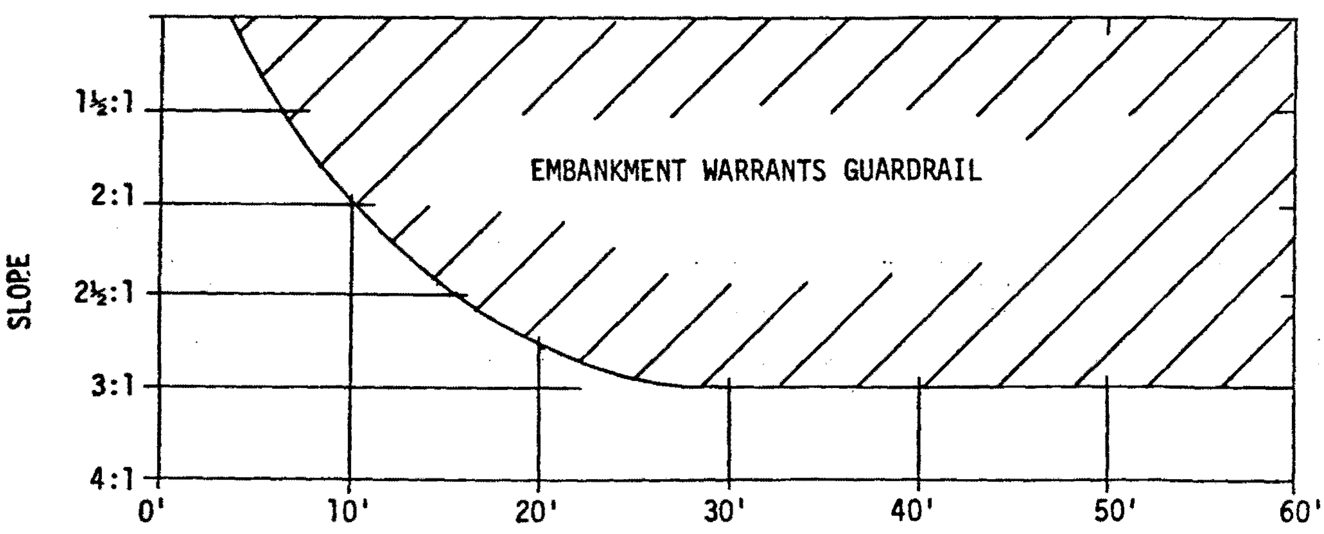


FIGURE NO. 1 (B) ---- For 1500+ to 3000 V.P.D.

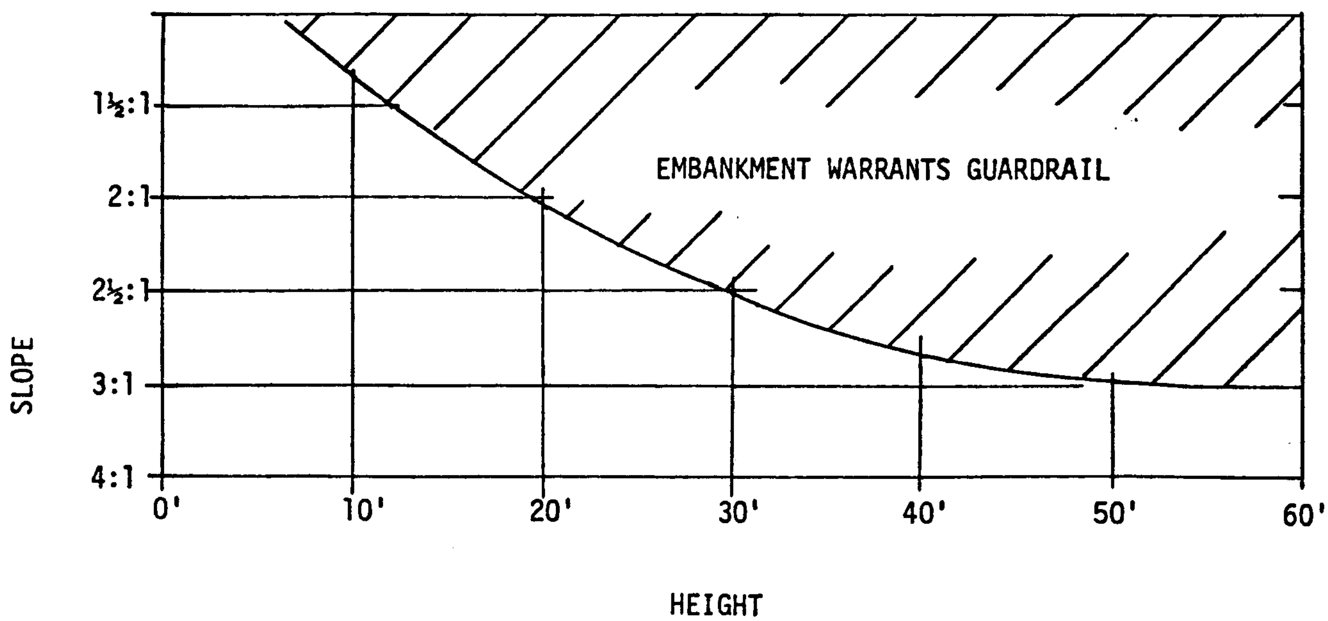


FIGURE NO. 1 (C) --- For 1000+ to 1500 V.P.D.

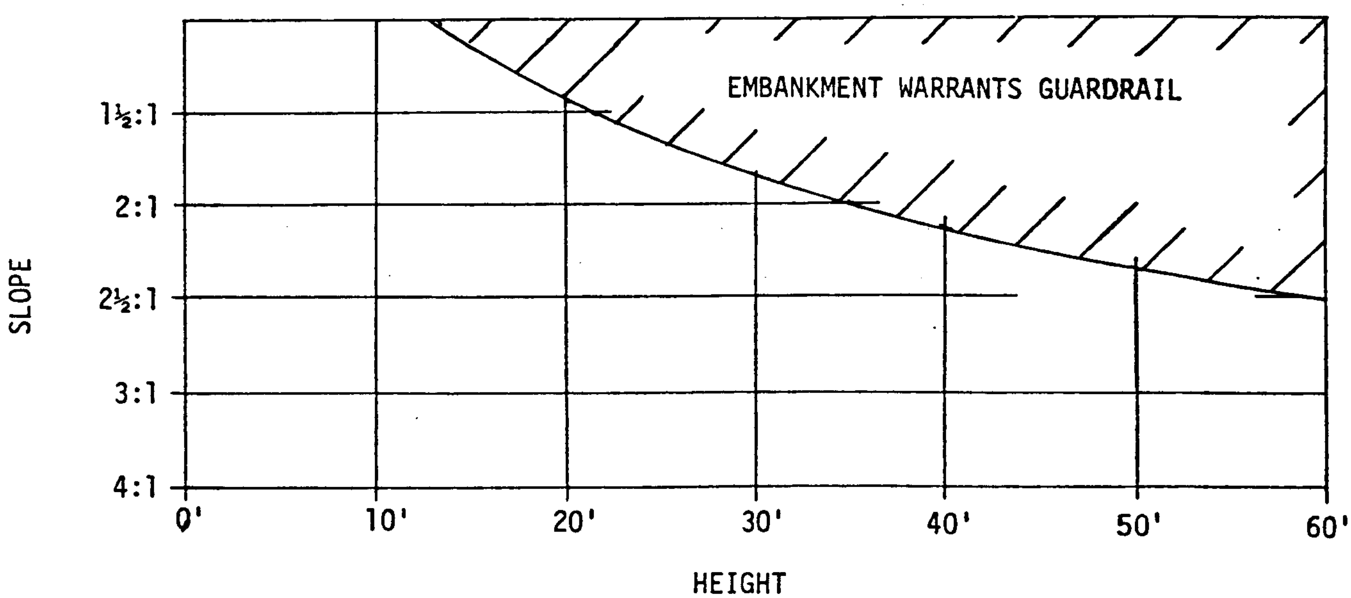


FIGURE NO. 1 (D) --- For 700+ to 1000 V.P.D.

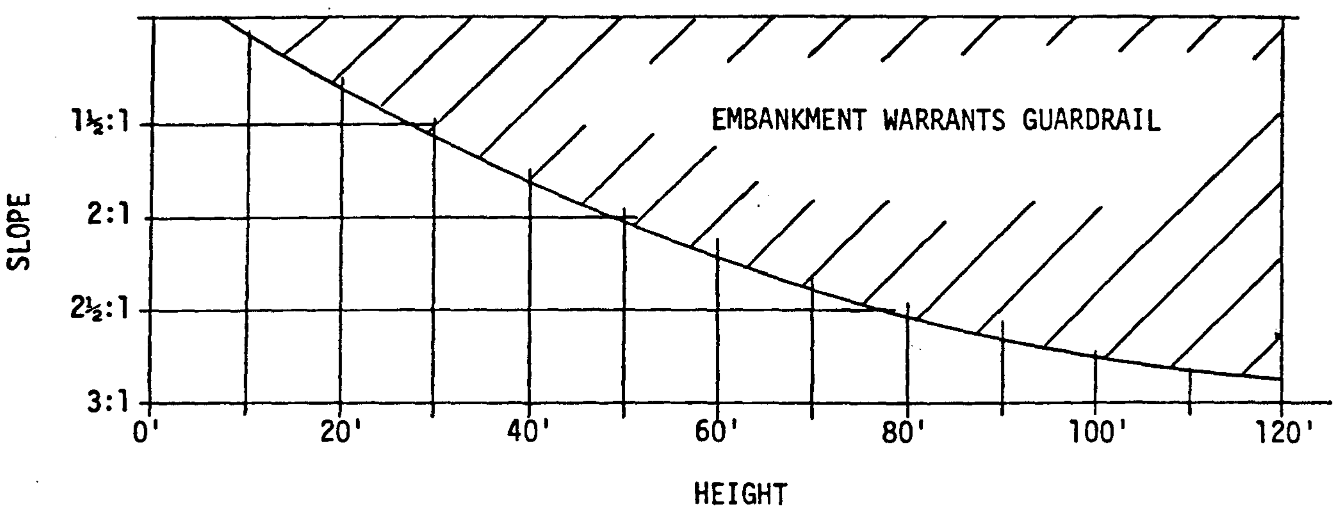


FIGURE NO. 1 (E) --- For 400+ to 700 V.P.D.

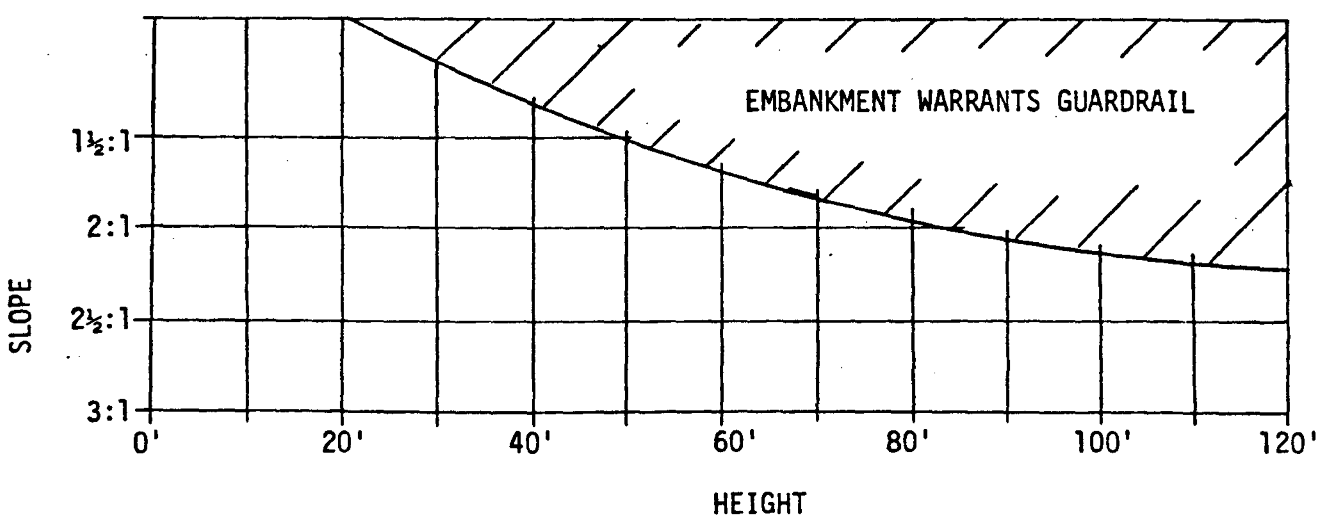


FIGURE NO. 1 (F) --- For 400 V.P.D. or Less

II. GUARDRAIL WARRANTY FOR ROADSIDE OBSTACLES

Roadside obstacles may be classified as nontraversable hazards or fixed objects. Obstacles located within the Clear Zone (see below) should be removed, relocated or made breakaway. If this is not feasible then guardrail should be considered, provided that the guardrail offers the least hazard potential.

1. Nontraversable Hazards.
   Examples of nontraversable hazards which may warrant gaurdrail are:

   a) rough rock cuts
   b) large boulders
   c) permanent bodies of water over 2 ft. in depth
   d) lines of large (over 6" diameter)trees
   e) drop-off with slope steeper than 1:1 and depth greater than 2 ft.

Because of the extended length of the hazard along the roadway, the probability of errant vehicles striking the nontraversable hazard is greater than that of a vehicle hitting a fixed object. Barrier need for rough rock cuts and large boulders is a matter of judgement.

2. Fixed Objects
   Examples of fixed objects which may warrant guardrail are:

   a) bridge piers and abutments at underpasses
   b) retaining walls and culverts
   c) fixed sign bridge supports
   d) trees with diameter over 6"
   e) wood poles or post with area greater than 50 $in.^2$

3. Clear Zone Width

   Clear zone is defined as the roadside border area, starting at the edge of the traveled way, available for safe use by errant vehicles. Previously, 30 ft. was considered to be the standard clear zone, but current guidelines shown in Figure No. 2 give clear values greater or lesser than 30 ft., depending on the roadside slopes, operating speed and traffic volume.

   The procedure for use of Figure No. 2 is as follows:

   a) Begin with appropriate roadside slope on chart. This will be the slope back of the shoulder. Where different slopes are encountered, an average "weighted" slope must be determined. The top portion of the chart represents slopes sloping toward the obstacles while the bottom portion represents slopes sloping away from the obstacle. Typical cases are depicted.

   b) Project from left to right until appropriate operating speed curve is intersected.

(continued on Page 7)

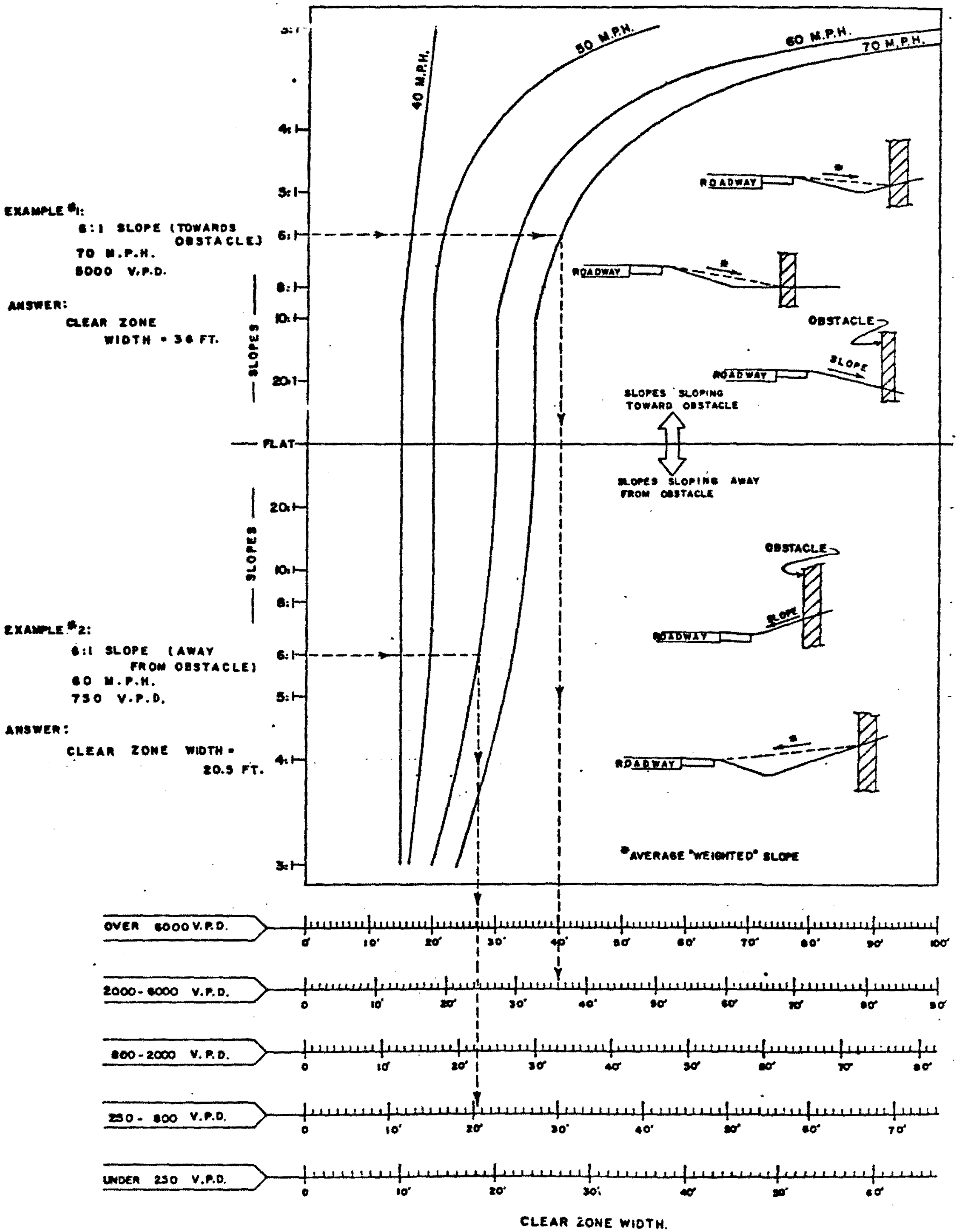


FIGURE NO. 2 - CLEAR ZONE WIDTH CRITERIA

c) Project down from this point to the traffic volume to read off the Clear Zone Width.

d) If the distance from edge of travel lane to face of obstacle is greater than the Clear Zone Width, guardrail is not warranted. If the distance from edge of travel lane to face of obstacle is less than the Clear Zone Width, guardrail (or other type barrier) may be warranted, provided the obstacle cannot be removed, relocated or made break-away and guardrail is less of a hazard than the obstacle.

It is recognized that the suggested clear zone criterion represents a significant change in previous guidelines. Strict adherence to this criterion may be impractical in many situations due to limited right-of way or other restricted conditions. The clear zone criterion shown in this figure does, however, represent the state of knowledge and underlines the fact that flat unobstructed roadsides are highly desirable.

It should also be noted that the Clear Zone Width Criterion in the Figure No. 2 may represent hazards which are located such that guardrail cannot be located on the embankment slope and locating guardrail on the shoulder may offer limited protection because of the relatively large distance between the obstacle and the guardrail. Such conditions, may be given individual consideration and an engineering judgement made as to the justification of guardrail provided the obstacle cannot be eliminated.

III. LENGTH OF NEED

Length of need is equal to the length of guardrail needed for the hazard or hazardous area plus a length of advancement of guardrail. The length of advancement is the length needed to prevent vehicle penetration behind the rail into the hazard or hazardous area.

Where slopes back of the graded shoulder are flat enough (see the following Section IV-2) the guardrail approach should be flared or the guardrail installation located back of the graded shoulder in order to minimize this length of advancement. In the more common instances, where slopes are steeper, the guardrail will run along the shoulder. Figure No. 3 depicts both cases. The minimum lengths in advance of "Hazardous Area" shown on the Standard Details will take care of most installations. Where greater lengths of advancement are desired, the formulas shown in Figure No. 3 may be used or a sketch of the location may be drawn to scale and the length of advancement measured.

Note that where Type 9 Anchorages are used, the length of advancement does not include break-away posts.

IV. GUARDRAIL LOCATION

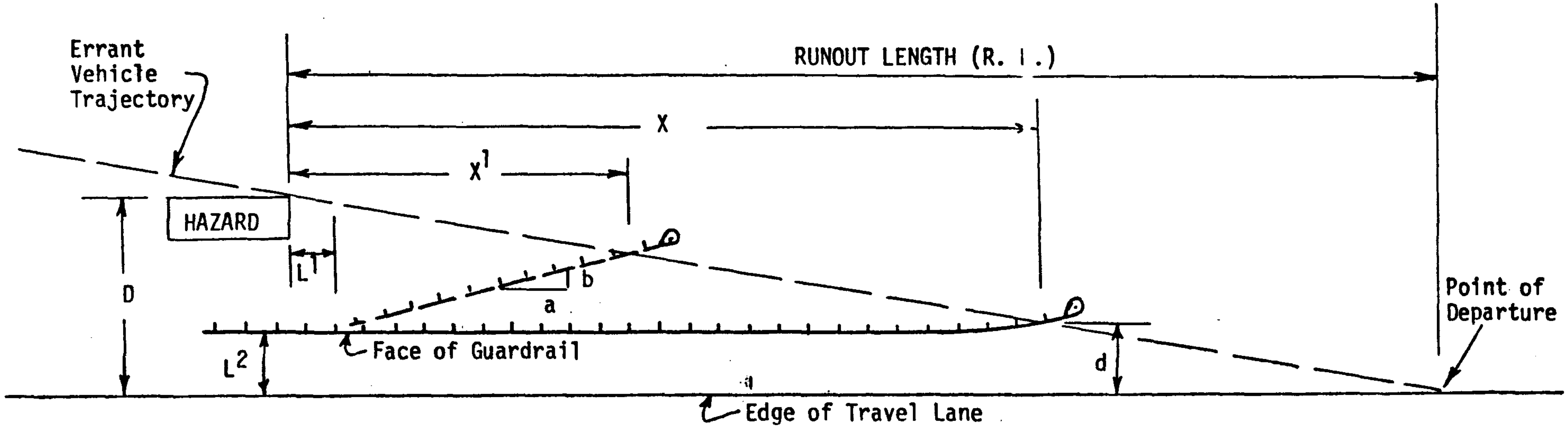
1. Guardrail Located on the Graded Shoulder

Guardrail required for fill embankment or other hazardous areas will usually be located on the graded shoulder with a 2 ft. offset between the face of the rail and the edge of shoulder. See Figure No. 4. Shoulders should be graded 2 ft. wider than normal to accommodate guardrail, except where the normal shoulder width is 14 ft. in which case no additional widening will be required for guardrail location.

OPERATING SPEED (mph)	RUNOUT LENGTH (R.L.) IN FEET					FLARE RATE* b/a
	OVER 6000 V.P.D.	2000 - 6000 V.P.D.	800 - 2000 V.P.D.	250 - 800 V. P. D.	UNDER 250 V.P.D.	
70	480	440	400	360	330	1/15
60	400	360	330	300	270	1/13
50	320	290	260	240	210	1/11
40	240	220	200	180	160	1/9

NOTE: Sketch shown below is only typical and does represent any particular standard.

*If Applicable (See III)



STANDARD INSTALLATION:

$$X = R.L. \times \frac{D - d}{D}$$

FLARED APPROACH:

$$X^1 = \frac{D + \left(\frac{b}{a}\right)L_1 - (L_2)}{\left(\frac{b}{a}\right) + \left(\frac{D}{R.L.}\right)}$$

WHERE:

D = Distance (ft.) from edge of travel lane to back of hazard or clear Zone Width whichever is lesser.

d = Distance (ft.) from edge of travel lane to guardrail terminal

FIGURE NO. 3 LENGTH OF ADVANCEMENT

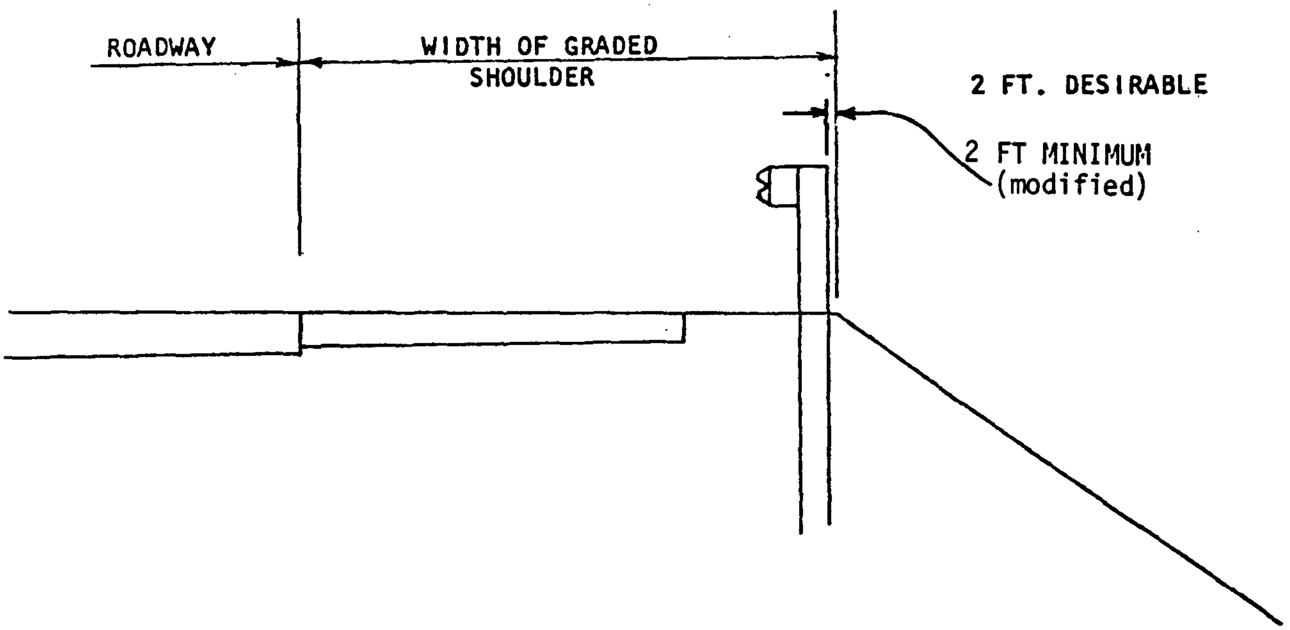
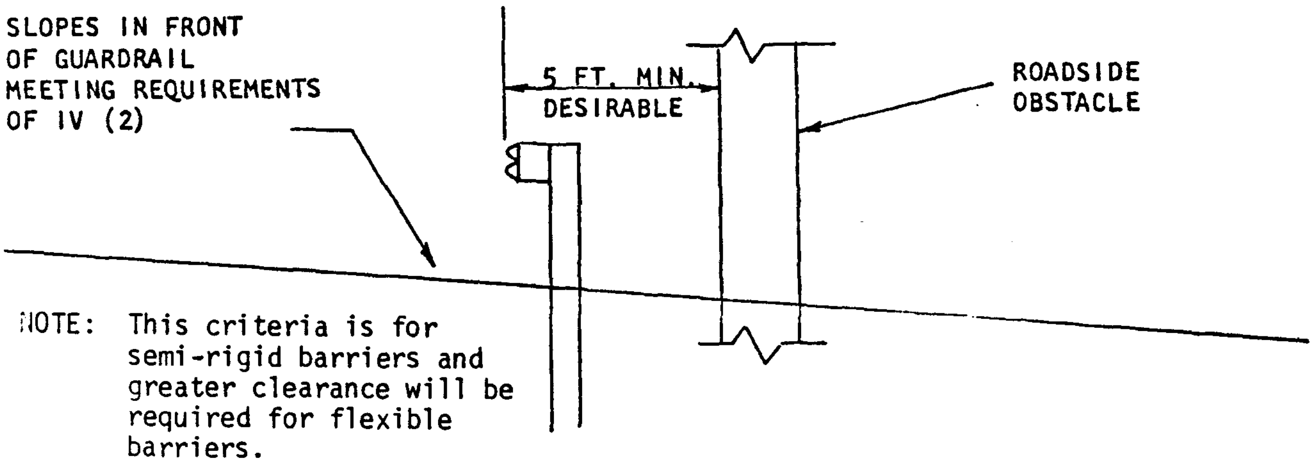


FIGURE NO. 4 - GUARDRAIL LOCATED ON THE GRADED SHOULDER



NOTE: This criteria is for semi-rigid barriers and greater clearance will be required for flexible barriers.

FIGURE NO. 5 - GUARDRAIL LOCATED IN FRONT OF ROADSIDE OBSTACLE

2. Guardrail Located Back of the Graded Shoulder

Where it is desirable to locate guardrail back of the graded shoulder (Fixed Objects, etc.) or where guardrail on the shoulder flares back of the shoulder edge (Type 9 Anchorages, etc.), negative slopes in front of the guardrail shall be 10:1 or flatter. Also, the algebraic difference between the shoulder slope and the slope in front of the guardrail should not be greater than 0.10.

Exceptions to this requirement are:

a) Guardrail may be located on slopes 6:1 or flatter provided the shoulder is adequately rounded or the guardrail is placed more than 12 ft. from the edge of the graded shoulder.

b) Where precurved (shop curved) sections of guardrail are used with Type 1 Anchorages, a portion of the precurved section not more than approximately 3 ft. in length may extend back of the graded shoulder onto normal slopes.

Where Type 9 Anchorages flare back of the graded shoulder, the area around the anchorage will be graded to 10:1 or flatter (See Stds. 4051 and 4052). The plans should show both the desired slopes and the required locations so that grading operations will be completed prior to the anchorage installation.

3. Roadside Obstacles

It is desirable that guardrail be located so that a 5 ft. offset is retained between the hazard and the face of guardrail, provided that negative slopes in front of guardrail meet the requirements stated above. See Figure No. 5.

4. Bridge Approaches

Guardrail will be located at bridge approaches as shown on the standards or construction details for a given class of road.

5. Guardrail Located Back of Curb.

Concrete curb and gutter, header curbs, or other rigid type curbs in front of guardrail should be avoided whenever possible. When it is absolutely necessary for curbs to be in front of guardrail, it is desirable for the guardrail to be located as far back from the curb as possible. (See Figure No. 6).

When it is necessary for the guardrail to be located closer (6' to 8') to the curb, "T" beam guardrail which has a greater rail height may be used to intercept the ramping trajectory caused by the curb. (See Figure No. 7) Where "T" beam guardrail is connected to the bridge end post, Standard 3054 should be used instead of Standard 3053.

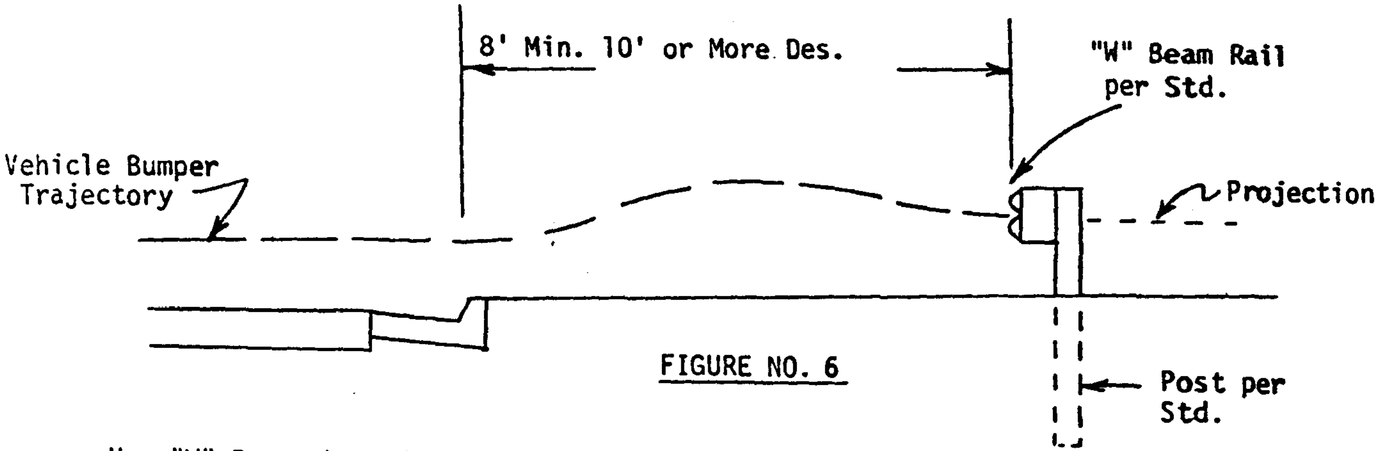


FIGURE NO. 6

Use "W" Beam where Guardrail is located 8' or more from face of curb. (Preferred Location)

NOT RECOMMENDED PRACTICE

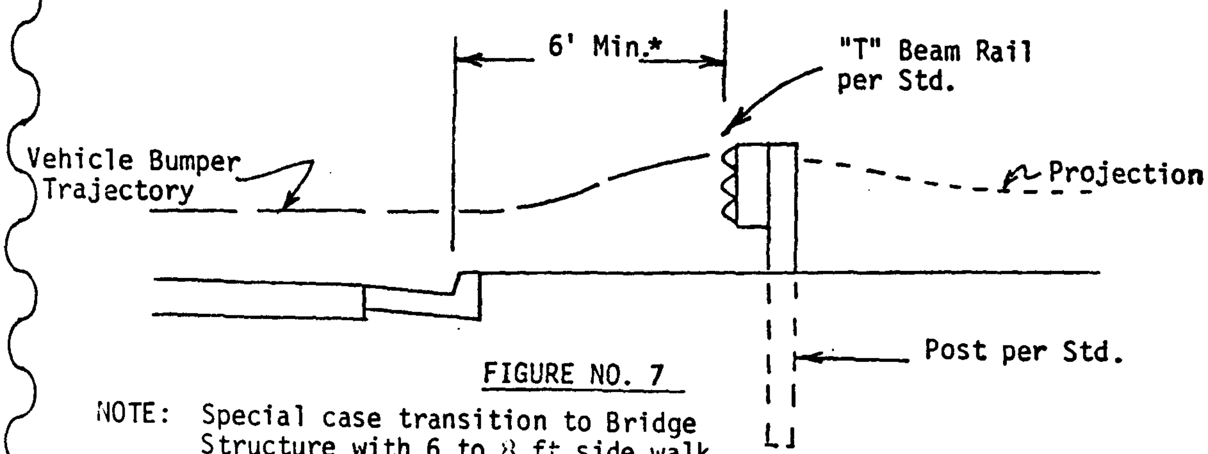


FIGURE NO. 7

NOTE: Special case transition to Bridge Structure with 6 to 8 ft side walk.

Use "T" Beam where guardrail is located 6' to 8' from curb.

*In special conditions 6' min. may be reduced if recommended by the Office of Traffic and Safety. (Requires FHWA approval on Federal-aid projects.)

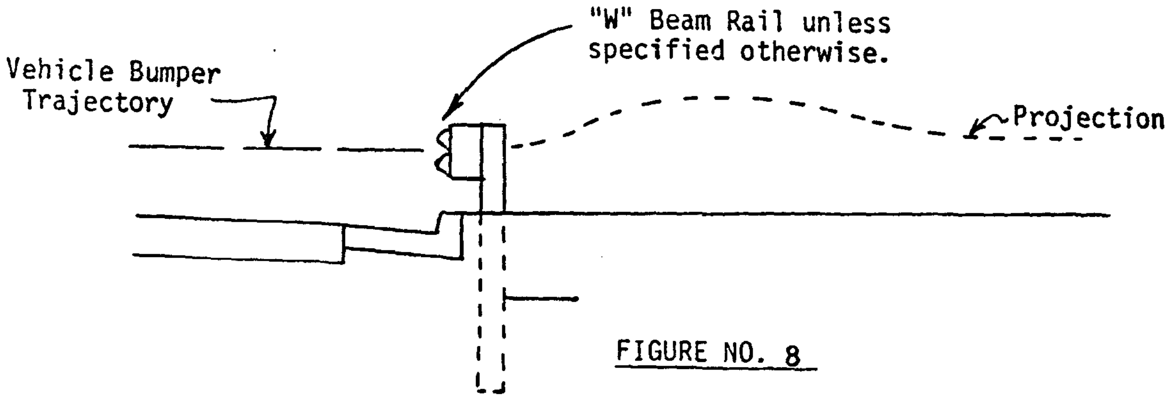


FIGURE NO. 8

Use where face of rail is in line with or in front of curb face. (Use only if alternates above are not available.)

When guardrail must be located even closer to the curb, the face of the rail should line up with gutter line.

V. CHART FOR SELECTING GUARDRAIL STANDARDS

(The chart below serves as a general guide and does not preclude the use of Special Details, Construction Details, Modification of Standards, Plan Details, etc., when needed)

	ROAD	STANDARDS FOR LOCATION OF GUARDRAIL	STANDARDS FOR GUARDRAIL ANCHORAGE	STANDARDS FOR RAIL TYPE & POST	BRIDGE END CONNECTIONS	
					END POST & END SHOE	ADD'L.POST LOCATION
Rural Type Designs	Class I	4051 & 4022-A	4050 & 4012-B	4010 & 4011	3053	4012-B
	Class II	4052 *	4050 & 4012-B**	4010 & 4011	3053	4012-B
	Class III, IV or V	4052 *	4050 & 4012-B**	4010 & 4011	3053	4012-B
Urban Type Designs	ROAD WITH CONC. CURB (a)	4280	4050	4270,4271 4010, 4011	3054	4012-B
	(b)	4280	4050	4010 & 4011	Type 5 Anchorage	
	(c)	4280	4050	4010 & 4011	3053	4012-B

*Standard 4022-A may also be used for Turn-outs.
**Two way traffic flow - Precurved rail section required with Type I Anchorage.

(a) Desirable width sidewalk across bridge (See Std. 4280 - Top detail)

(b) Narrow walk across bridge (See Std. 4280 - Middle Detail)

(c) Shoulder across bridge - Curb & Gutter (See Std. 4280 - Bottom Detail).

NOTE:

The following voided Standards should <u>not</u> be used:

4012, 4012-A, 4020, 4020-A, 4021, 4021-A, 4022, 4023 and 4024.

*U.S. GOVERNMENT PRINTING OFFICE : 1980 O-628-557/2648