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16. Abstract

The guide presents the results of a synthesis of current information on the various elements of traffic barrier systems, including warrants, structural and strength characteristics, maintenance characteristics, selection criteria, and placement data. Criteria on these elements are summarized for each of the four basic barrier types, namely, roadside barriers (heretofore commonly referred to as guardrails), median barriers, bridge rails and crash cushions. A chapter on a cost-effective selection procedure is included, primarily to provide the highway engineer with an *alternate* approach to the more conventional means of establishing barrier need and a barrier selection if warranted.

The information is presented in two volumes. Volume I contains essential guidelines relevant to the different design elements of each barrier system. Volume II, which is actually a technical appendix, contains supporting data and is a valuable supplement to the basic guidelines.

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GUIDE FOR SELECTING, LOCATING, AND DESIGNING TRAFFIC BARRIERS

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Volume I: Guidelines

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for

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PREFACE

This guide was prepared through a cooperative effort involving the Task Force for Traffic Barrier Systems of the AASHTO Operating Subcommittee on Design, the Federal Highway Administration, and the Texas Transportation Institute of Texas A&M University. The Task Force served as an advisory group to the FHWA contract manager and to the researchers. Members of the Task Force and other members of a technical advisory committee are listed at the end of the preface.

The guide presents the results of a synthesis of current information on the various elements of traffic barrier systems, including warrants, structural and strength characteristics, maintenance characteristics, selection criteria and placement data. Criteria on these elements are summarized for each of the four basic barrier types, namely, roadside barriers (heretofore commonly referred to as guardrails), median barriers, bridge rails and crash cushions. A chapter on a cost-effective selection procedure is included, primarily to provide the highway engineer with an *alternate* approach to the more conventional means of establishing barrier need and a barrier selection if warranted.

The information is presented in two volumes. Volume I contains essential guidelines relevant to the different design elements of each barrier system. Volume II is a technical appendix containing support data to supplement the basic guidelines.

References have generally been limited in the guide to preserve a clear, straightforward presentation. Citations are given if further study by the reader will enhance the guidelines or if a complete summary of the referenced work could not be presented in the guide. A complete bibliography on the subject of traffic barriers is included in Volume II.

It must be noted that the criteria contained herein will undoubtedly be refined and amended in the future. The designer is therefore obligated to remain current on new concepts and criteria and to obtain the latest revision to this and other pertinent documents.

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GLOSSARY

Area of Concern - An object or roadside condition that warrants the shielding of a traffic barrier.

Barrier Warrant - A criterion that identifies an area of concern which should be shielded by a traffic barrier. The criterion may be a function of relative safety, economics, etc., or a combination of factors.

Bridge Rail - A longitudinal barrier whose primary function is to prevent an errant vehicle from going over the side of the bridge structure.

Clear Distance - Minimum lateral distance from the edge of the traveled way needed by a driver of an errant vehicle to either regain control and begin a return to the roadway or to slow the vehicle to a safe speed. Unshielded rigid objects and certain other hazards should not be permitted in the area between the edge of the traveled way and the clear distance.

Crash Cushion - A barrier whose primary function is to decelerate an errant vehicle to a safe speed or to stop it. Examples are the sand filled plastic barrels, steel drums, etc.

Crashworthy Barrier - One that can be impacted by a vehicle at or below the anticipated operating speed of the roadway with low probability of serious injury to the vehicle's occupants.

Experimental Barrier - One that has performed satisfactorily in full-scale crash tests and promises satisfactory in-service performance.

Impact Angle - For a longitudinal barrier, it is the angle between a tangent to the face of the barrier and a tangent to the vehicle's path at impact. For a crash cushion, it is the angle between the axis of symmetry of the crash cushion and a tangent to the vehicle's path at impact.

Length of Need - Total length of a longitudinal barrier, measured with respect to centerline of roadway needed to shield an area of concern.

Longitudinal Barrier - A barrier whose primary function is to redirect an errant vehicle away from a roadside or median hazard. The three types of longitudinal barriers are roadside barriers, median barriers, and bridge rails.

Median Barrier - A longitudinal barrier used to prevent an errant vehicle from crossing the portion of a divided highway separating the traveled ways for traffic in opposite directions.

Operational Barrier - One that has performed satisfactorily in full-scale crash tests and has demonstrated satisfactory in-service performance.

Research and Development Barrier - One that is in the development stage and has had insufficient full-scale tests and in-service performance to be classified otherwise.

Roadside Barrier - A longitudinal barrier used to shield hazards between the edge of the traveled way and the clear distance. It may also be used to shield hazards in extensive areas between the roadways of a divided highway. It may occasionally be used to protect pedestrians or "bystanders" from vehicular traffic.

Roadway - The portion of a highway, including shoulders, for vehicular use.

Shy Distance - Distance from the edge of the travel way beyond which a roadside object will not be perceived as an immediate hazard by the typical driver, to the extent that he will change his vehicle's placement or speed.

Traffic Barrier - A device used to shield a hazard that is located on the roadside or in the median, or a device used to prevent crossover median accidents. As defined herein, there are four classes of traffic barriers, namely, roadside barriers, median barriers, bridge rails, and crash cushions.

Traveled Way - The portion of the roadway for the movement of vehicles, exclusive of shoulders and auxiliary lanes.

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Many others contributed to this effort both directly and indirectly to whom the authors are most grateful.

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I. INTRODUCTION

I-A. Background

An extensive effort has been made in recent years to improve highway safety. To accomplish this, a major emphasis has been placed on the elimination of hazardous roadside conditions and on the improvement of traffic barriers to shield those hazards that can not be eliminated. Numerous studies have been made at the national, state, and local level. These studies have focused on a wide range of traffic barrier subjects, including warrants, impact performance, and economics.

Highway Research Board Special Report 81 (5), published in 1964, National Cooperative Highway Research Program (NCHRP) Report 36 (6), published in 1967, and NCHRP Report 54 (2), published in 1968, contained state-of-the-practice information on traffic barriers. NCHRP Report 118 (1), published in 1971, updated and superseded previous NCHRP reports.

I-B. Purpose of Guide

Since the publication of NCHRP Report 118 (1), additional research has been done in the traffic barrier area and additional inservice experience has been gained on existing traffic barrier systems. *The purpose of this document is to summarize the current state of knowledge and to present specific design guidelines for highway traffic barriers. The guidelines establish the conditions which warrant barrier protection, the type of barriers available, their strength, safety, and maintenance characteristics, selection procedures, and how the barrier should be installed dimensionally or geometrically.*

Also presented in the guide is a cost-effective selection procedure. This procedure is presented as an alternate to the more conventional selection procedures. In the conventional procedures, barrier need is usually based on an evaluation of the relative hazard of the barrier versus the hazard of the unprotected obstacle. The barrier is warranted if the obstacle is more hazardous to the motorist than the barrier itself. In the cost-effective procedure, need is based on an evaluation of the costs associated with the barrier versus the costs associated with the unprotected obstacle. Initial costs, maintenance costs, and accident costs are included in the evaluation. In addition to establishing need, the procedure can also be used to compare the cost-effectiveness of various barrier systems.

For the purpose of this guide all traffic barriers are classified as one of two basic types, namely, *longitudinal barriers* and *crash cushions*. Longitudinal barriers function primarily by redirecting errant vehicles. Crash cushions function primarily by decelerating errant vehicles to a stop. Roadside barriers (guardrail, etc.), median barriers, and bridge rails are the three types of longitudinal barriers. Each of these types performs a particular function as does the crash cushion and these functions are delineated in this guide.

It has been said that a traffic barrier is like life insurance - it is good to have as long as it is not needed. Although this is an overstatement, it cannot be overemphasized that a traffic barrier is itself a hazard. Every effort should be made in the design stage to eliminate the need for traffic barriers. Existing roadways should be upgraded when feasible to eliminate hazardous conditions that require barrier protection. A traffic barrier should be installed discriminately and only when it is unfeasible to remove the hazardous condition.

I-C. Application of Guide

The contents of this document are intended as *guidelines* for those responsible for the design, installation, and maintenance of traffic barriers. It will have applications primarily to high speed facilities since the vast majority of studies to date have concerned such facilities. However, all available criteria relevant to low speed, low volume roadways are included. In this regard, the chapter on cost-effectiveness can be used to evaluate the effects of traffic conditions on traffic barrier needs.

The guide will have applications to both new and existing roadways. Consideration should be given to the application of the principles and criteria presented in the guide for new construction. A survey of existing facilities should be made and substandard conditions should be identified with reference to the guide. Unnecessary barriers should be removed, substandard barriers should be upgraded or replaced with acceptable systems, improperly located barriers should be relocated, and, if warranted, barriers should be installed to shield hazardous conditions which cannot be removed. It is recognized that limited budgets may preclude the full implementation of these guidelines. In those cases, a priority system should be established to insure that cost-effective alternatives are employed.

The guide relates primarily to the *protective* aspects of traffic barriers. These guidelines must be considered together with social, environmental, and economic factors.

Due to the complex nature of the subject matter, much of the criteria contained in this guide is by necessity based on subjective data. In some areas, only general suggestions and recommendations can be made. It can therefore not be overemphasized that *application of these guidelines must be made in conjunction with sound evaluation of the facts and engineering judgment to effect the proper solution.*

I-D. Format of Guide

The main body of the guide is contained in Chapters II through VI. Chapter II summarizes criteria used in the evaluation of the different barrier types. Chapters III through VI contain criteria relevant to the four barrier types, respectively. Each of these chapters is, to the extent possible, autonomous. For example, Chapter IV contains guidelines for median barrier warrants, the structural and safety characteristics of operational median barriers, maintenance characteristics, a selection procedure, placement recommendations, and suggested procedures for upgrading substandard median barrier systems. To avoid repetition and a voluminous document, reference is sometimes made to other parts of the guide if common criteria exists between different barrier types.

Separation of the guide subjects by barrier type is not meant to imply that each type can be independently designed, selected, and installed. *A systems or integrated approach should be used to insure compatibility of design of each of the barrier elements.* For example, the selection of a bridge rail should be based in part on the type of roadside approach barrier to be used. The impact performance of the transition between the two systems depends heavily on the compatibility of the two rail systems.

Supporting data and design procedures are given in the Appendix. A bibliography of traffic barrier literature, indexed by year and barrier type, is also presented in the Appendix.

Underlined numbers in parenthesis refer to references listed in Appendix I. *Note that a list of references is included in both volumes of the Guidelines.*

II. EVALUATION CRITERIA

Various factors may affect the determination of barrier need and, if warranted, the barrier best suited for the given conditions. Safety requirements, economic constraints, environmental constraints, and in some cases traffic control constraints are all factors the designer must usually confront. This guide addresses primarily the safety requirements and the economic constraints.

It is the purpose of this chapter to summarize criteria used in the guide to evaluate the different elements in design.

II-A. Warrants

A survey of various state practices showed that barrier warrants are usually based on an evaluation of the relative hazard of the barrier versus the unshielded hazard. In some cases, warrants are also based on the probability of run-off-the-road accidents and economic factors.

To the extent possible, warrants presented in this guide are based on objective criteria. All of the warrants are based on the premise that *a traffic barrier should be installed <u>only</u> if it reduces the <u>severity</u> of potential accidents*. It is important to note that the probability or frequency of accidents will not in general affect the *severity* of potential accidents. As has been stated (<u>18</u>), "If it is judged that a guardrail installation is not necessary at a particular embankment (that is, the guardrail is a greater hazard than the embankment)...., such a decision remains valid whether one or one thousand vehicles run off the road at that point."

Warrants may also be established by the cost-effective procedure presented in Chapter VII. Through this procedure, factors such as design speed and traffic volume can be evaluated in relation to barrier need. Costs associated with the barrier (installation, maintenance, and accident costs) are compared with costs associated with the unshielded hazard. Typically, the cost-effective procedure can be used to evaluate three options: (1) remove or reduce the hazard so that it no longer needs to be shielded, (2) install a barrier, or (3) leave the hazard unshielded. The third option would normally be cost effective only on low volume and/or low speed facilities, where the probability of accidents is low. The procedure also allows one to evaluate the cost effectiveness of any number of barriers that could be used to shield the hazard.

As new and additional data become available on accidents involving traffic barriers, the relative hazard of barriers versus unshielded hazards and other factors, the warrants presented herein should be updated. Each agency using this guide is encouraged to record and document such information and to make it available to the public. Such data will also greatly enhance the applicability of the cost-effectiveness technique of Chapter VII.

Although the warrants cover a wide range of roadside conditions, special cases or conditions will arise for which there is no clear choice. Such cases must be evaluated on an individual basis, and, in the final analysis, must usually be solved by engineering judgment.

II-B. Structural and Safety Characteristics

A traffic barrier serves dual and often conflicting roles. It must be capable of redirecting and/or containing an errant vehicle without imposing untolerable conditions on the vehicle occupants. It should be able to do this for a range of vehicle sizes and weights, impact speeds, and impact angles. Compromises are sometimes necessary to achieve a balance between the structural and safety requirements.

To promote uniform testing and evaluation criteria for traffic barriers and other highway appurtenances, NCHRP Report 153 (4) was published. The recommended criteria and test procedures presented in the report are directed to the structural and safety performance of these appurtances.

Table II-B-1 summarizes the evaluation criteria as it relates to the different barrier types (4). As shown in the table, there are three appraisal factors used in the evaluation, namely (I) structural adequacy, (II) impact severity, and (III) vehicle trajectory hazard.

The most complex and controversial item in the evaluation criteria concerns maximum vehicle accelerations. While most agree that vehicle accelerations and impact severity are related, there is no concensus of opinion as to just how they are related. However, until more definitive criteria are established, the suggested acceleration values should be considered the best available guidelines.

Full scale crash tests are the suggested means for evaluating the structural and safety performance criteria of Table II-B-1. Shown in Table II-B-2 are the crash tests suggested to evaluate the different barrier types, taken from NCHRP Report 153. Each test is designed to

Table II-B-1. Dynamic Performance Criteria for Traffic Barriers

Dynamic Performance Factors	Evaluation Criteria	Applicable Criteria: Longitudinal Barriers: Standard Sections and Transitions	Applicable Criteria: Longitudinal Barriers: Terminals	Applicable Criteria: Crash Cushions
I. Structural Adequacy	A. The test article shall redirect the vehicle; hence, the vehicle shall not penetrate or vault over the installation.	XXX		
	B. The test article shall not pocket or snag the vehicle causing abrupt deceleration or spinout or shall not cause the vehicle to rollover. The vehicle shall remain upright during and after impact although moderate roll and pitching is acceptable. There shall be no loose elements, fragments or other debris that could penetrate the passenger compartment or present undue hazard to other traffic.	XXX	XXX	XXX
	C. Acceptable test article performance may be by redirection, containment, or controlled penetration by the vehicle.		XXX	XXX
	D. The terminal shall develop tensile and/or flexural strength of the standard section.		XXX	
II. Impact Severity	A. Where test article functions by redirecting vehicle, maximum vehicle accelerations (50 msec avg) measured near the center of mass should be less that the following values: Maximum Vehicle Accelerations (g's) Lat. / Long. / Total / Remarks 3 / 5 / 6 / Preferred 5 / 10 / 12 / Acceptable These rigid body accelerations apply to impact tests at 15 deg. or less.	XXX	XXX	XXX
	B. For direct-on impacts of test article, where vehicle is decelerated to a stop and where lateral accelerations are minimum, the maximum average permissible vehicle deceleration is 12 g as calculated from vehicle impact speed and passenger compartment stopping distance.		XXX	XXX
III. Vehicle Trajectory Hazard	A. After impact, the vehicle trajectory and final stopping position shall intrude a minimum distance into adjacent traffic lanes.	XXX	XXX	XXX
	B. Vehicle trajectory behind the terminal is acceptable.		XXX	

Table II-B-2. Recommended Crash Tests to Evaluate Impact Performance of Traffic Barriers

Barrier Type	Test Vehicle Weight,[a] lb	Impact Conditions Speed mph	Angle (deg.)[b]	Vehicle Kinetic Energy 1000 ft-lb	Impact Point[f]
I. Longitudinal Barrier					
A. Standard Section					
Test 1	4500	60	25[c]	540 ± 40	For post and beam system, midway between posts.
Test 2	2250	60	15[c]	270 ± 20	Same as Test 1.
B. Transition					
Test 1	4500	60	25[c]	540 ± 40	15 ft upstream of second system.
C. Terminal					
Test 1	4500	60	0[c]	540 ± 40	Center of nose device.
Test 2	4500	60	25[c]	540 ± 40	At beginning of standard section.
Test 3	2250	30	0[c]	68 ± 9	Center nose of device.
Test 4	2250	60	15[c]	270 ± 20	Midway between nose and beginning of standard section.
II. Crash Cushions					
Test 1	4500	60	0[d]	540 ± 40	Center nose of device.
Test 2	2250	60[e]	0[d]	270 ± 20	Center nose of device.
Test 3	4500	60	20[d]	540 ± 40	Alongside, midlength.
Test 4	4500	60	10-15[d]	540 ± 40	0-3 ft offset from center of nose of the device.

Notes:

[a]±200 lb.

[b]±2 degrees.

[c]From centerline of highway.

[d]From line of symmetry of device.

[e]For devices that produce fairly constant or slowly varying vehicle deceleration; an additional test at 30 mph (13.4 m/s) or less is recommended for staged devices, those devices that produce a sequence of individual vehicle deceleration pulses (i.e., "lumpy" device) and/or those devices comprised of massive components that are displaced during dynamic performance.

[f]Point on barrier where initial vehicle contact is made.

Metric Conversions: 1 lb. = 0.454 kg; 1 mph = 1.61 km/h; 1 ft-lb = 1.356 J; 1 ft = 0.305 m.

evaluate either the structural adequacy of the barrier or its impact severity and vehicle trajectory hazard. Generally, the structural adequacy of a longitudinal barrier is determined by impacting it with a 4500 lb (2040 kg) automobile at a 25 degree angle. The impact severity and vehicle trajectory hazard of a longitudinal barrier is determined by impacting it with a 2250 lb (1020 kg) automobile at a 15 degree angle.

Test 1 and 2 for crash cushions are designed to demonstrate the energy-absorbing capabilities of the cushion for both large and small cars. Test 3 is designed to evaluate the redirection capabilities of the cushion when impacted from the side. Test 4 evaluates the cushion for unsymmetric impacts. Detailed commentary on the basis of each test in Table II-B-2 is presented in NCHRP Report 153, together with suggested testing facility practices, data acquisition systems, and data reduction techniques.

Barrier systems chosen for inclusion in the guide are classified as either *operational*, *experimental*, or *research and development (R & D)* defined herein as follows. An *operational* system is one that has performed satisfactorily in full scale crash tests and has demonstrated satisfactory in-service performance. It must be noted that there is no widely accepted evaluation criteria whereby "satisfactory in-service performance" can be determined. In general, however, satisfactory performance can be established by documented evidence that the barrier is functioning as intended by the evaluation criteria presented herein. An *experimental* system is one that has performed satisfactorily in full-scale crash tests and promises satisfactory in-service performance.

An *R & D* system is one that is in the development stage and has had insufficient full-scale crash testing and in-service performance to be classified otherwise.

Omission of a barrier system does not necessarily imply that the system is non-operational. There are numerous traffic barrier systems on the roadways that have not been subjected to full-scale crash tests. However, it was not within the scope of this effort to evaluate and determine the status of these systems.

To the extent that pertinent information was available the barrier systems given in this guide were evaluated in terms of the NCHRP Report 153 criteria. However, prior to its publication in 1974, there were no unified test procedures for evaluating traffic barriers. As a consequence barriers have been tested at a wide range of impact conditions. Many longitudinal barriers have never been subjected to a 15 degree crash test. There have been considerable variations in the type and size of the test vehicles used, the type and location of photographic and electronic instrumentation used during the tests, and the manner in which the test data was reduced and evaluated.

Evaluation forms for the longitudinal barriers and the crash cushions have been designed to present the impact performance of each barrier in terms of the suggested criteria (e.g., see Table III-B-1 and Table IV-B-1). *The impact conditions shown on the forms are those which most nearly represent the recommended test conditions.* Although the data shown is indicative of the general performance of each barrier, *discretion must be used when comparing the performance of the different systems due to the differences in impact conditions described above.*

Although crash testing is definitely the recommended way to evaluate the impact performance of a traffic barrier, it may be necessary in certain instances to use other means. Scale model tests, pendulum tests, and computer aided math models are often used in the conceptual and design stage, and occasionally are used as the means of final evaluation. Of course, there is no substitute for the application of basic engineering principles throughout the design and test phases.

If a barrier must be designed and installed without evaluation by full scale tests, the design should adhere to the criteria outlined in Table II-B-1. A method of estimating impact loads on a longitudinal barrier is presented in the Appendix G of this guide. Methods are also presented in the Appendix D to aid the highway engineer in designing certain types of crash cushions.

It should be noted that most traffic barriers have been designed for automobiles weighing approximately 4500 lb (2040 kg) or less. Although the vehicle population is composed predominantly of automobiles, there is a need, in some cases, for barriers which can contain and/or redirect large trucks and heavy vehicles. Testing of prototype bridge rails to accomplish this is already underway. The Federal Highway Administration is sponsoring studies in this area, aimed at the development of design criteria and the development of bridge rails, median barriers, and roadside barriers to restrain heavy vehicles. The highway engineer should remain cognizant of research in this area, and, if conditions warrant, consider the installation of such barriers.

II-C. Maintenance Characteristics

Maintenance is an important factor to consider when selecting a traffic barrier. Repair requirements in terms of manpower, material and equipment for typical collisions, the future availability of parts and the normal maintenance requirements are items to consider. Another important consideration is the time maintenance crews must be exposed to dangerous traffic conditions to repair the barrier. Repairs can also disrupt the traffic flow which increases the potential for accidents.

A very limited amount of objective criteria exists from which to evaluate the maintenance characteristics of current traffic barriers. As a consequence, the maintenance guidelines presented herein are, for the most part, general in nature. If the barrier system under consideration is being used by other agencies, the designer should consult with these agencies to determine their in-service experience.

Agencies are encouraged to record and document maintenance experience with traffic barriers and to publish the data. Such data would be very beneficial to everyone responsible for the selection of efficient and cost-effective barrier systems.

III. ROADSIDE BARRIERS

A roadside barrier is a longitudinal system used to shield vehicles from hazards in the roadside. It may also be used to shield hazards other than opposing traffic in extensive areas between divided highways. It may occasionally be used to protect pedestrians and "bystanders" from vehicular traffic. It is the purpose of this chapter to delineate criteria pertinent to the various elements of design, including warrants, structural and safety characteristics of operational systems, maintenance characteristics of operational systems, a selection procedure, placement recommendations, and guidelines for upgrading substandard installations.

III-A. Warrants

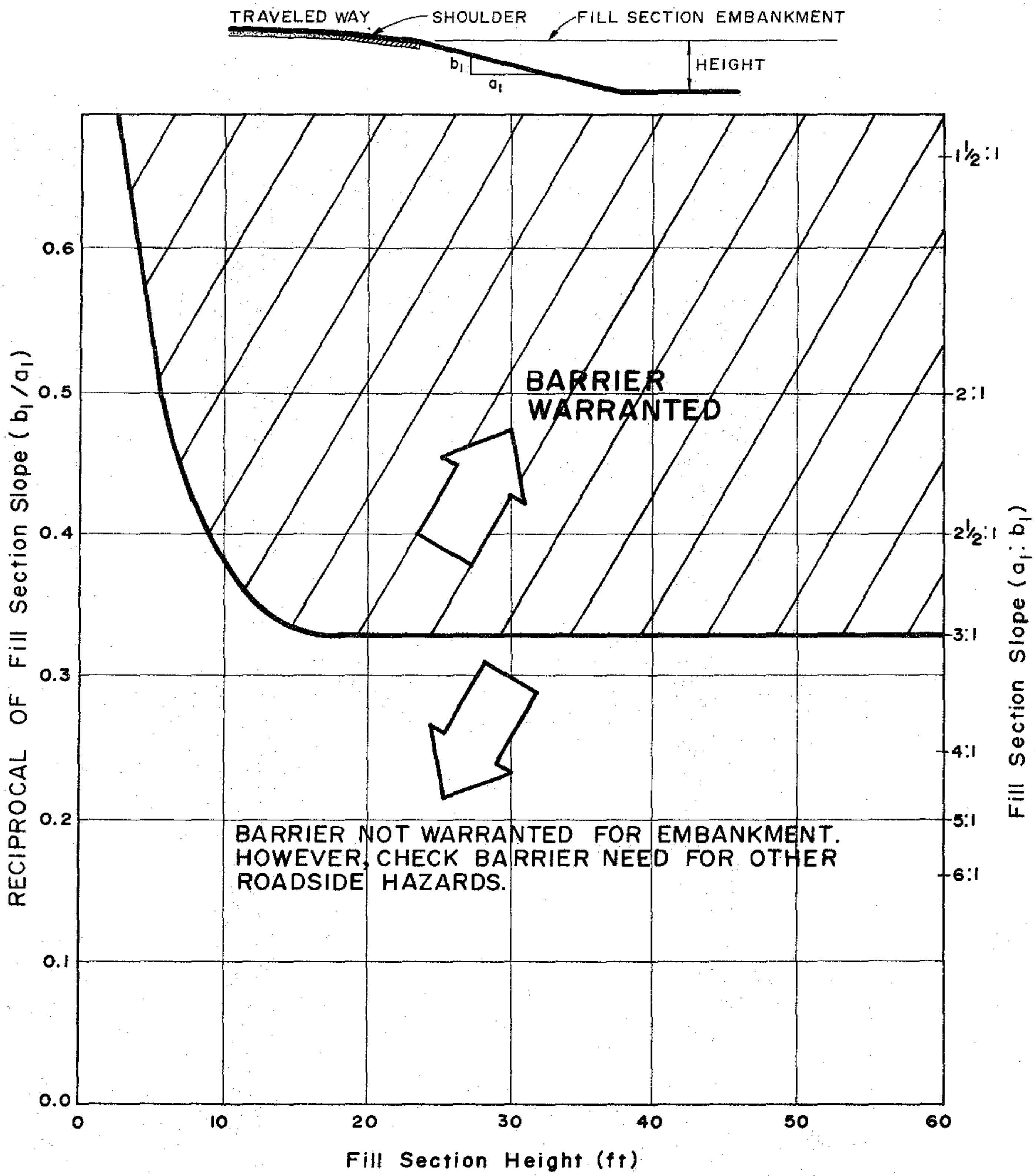
Highway hazards that may warrant shielding by a roadside barrier can be placed in one of two basic categories: embankments and roadside obstacles. Pedestrians or "innocent bystanders" may also warrant protection from vehicular traffic. The highway features contained in each of these categories are discussed in the following sections.

It is noted that these warrants apply primarily to roadways designed for vehicle speeds of approximately 50 mph (80.5 k/h) or greater. For roadways with design speeds less than 50 mph or roadways with very low volumes, the designer may consider amending these warrants. Such changes should be based on a careful evaluation of the existing conditions, and, preferably on documented criteria to support the changes. In this regard, the procedure presented in Chapter VII can be used to evaluate barrier needs as related to traffic conditions. This procedure is included as an alternate or optional approach to the establishment of barrier need.

III-A-1. Embankments

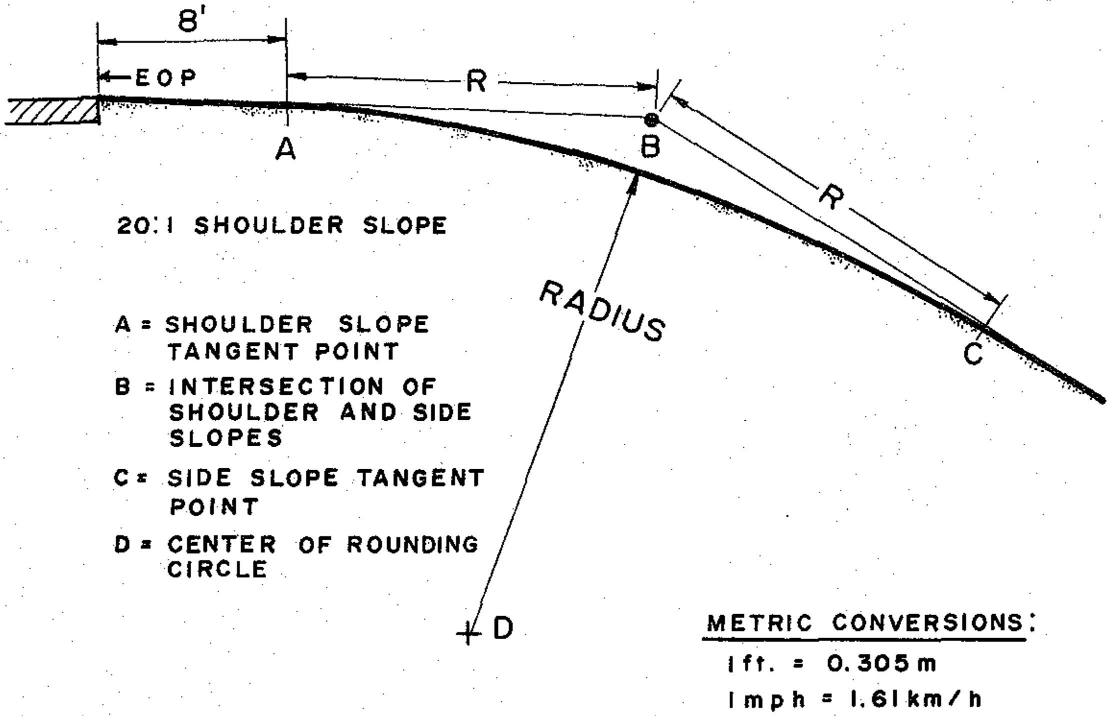
Height and slope of the embankment are the basic factors in determining barrier need for a fill section (an embankment that slopes downward). Warranting criteria for fill sections are shown in Figure III-A-1. The criteria are based on studies of the relative severity of encroachments on embankments versus impacts with roadside barriers (8, 9, 10). Embankments with slope and height combinations below the curve do not warrant protection. Obstacles on the slope may, however, warrant protection. The criteria in Section III-A-2 should be used in such cases. Embankments with slope and height combinations above the curve warrant protection.

Recent studies (11) have shown that rounding at the shoulder and the toe of an embankment can significantly reduce its hazard potential. Rounded slopes reduce the chances of an errant vehicle becoming airborne, thereby reducing the hazard of the encroachment and affording the driver more control over the vehicle. Figure III-A-2 illustrates the rounding geometry at the shoulder and it contains "optimum" rounding dimensions. Optimum rounding is arbitrarily defined as the minimum radius a standard automobile can negotiate without losing tire contact. It is dependent on the encroachment speed and angle, as well as the vehicle itself. The 25 degree values shown in Figure III-A-2 are considered *desirable* and the 15 degree values are considered *acceptable*.



METRIC CONVERSION:
1ft = .305m

Figure III A-1. Warrants For Fill Section Embankments.



SIDE SLOPE RATIO	ROUNDING (2R) FT	RADIUS FT.	LATERAL DISTANCE FROM EOP TO POINT~FT				ELEVATION OF POINT C FT BELOW EOP
			A	B	C	D	
DEPARTURE @ 60 MPH & 25 DEG.							
10:1	4.1*	81.8	8.0	10.0	12.0	3.9	0.7
6:1	9.4*	81.8	8.0	12.7	17.4	3.9	1.4
4:1	16.0	81.8	8.0	16.0	23.8	3.9	2.7
3:1	22.4	81.8	8.0	19.2	29.8	3.9	4.5
2:1	34.3	81.8	8.0	25.2	40.5	3.9	8.9
DEPARTURE @ 60 MPH & 15 DEG.							
10:1	2.0*	40.9	8.0	9.0	10.0	6.0	0.6
6:1	4.7*	40.9	8.0	10.4	12.7	6.0	0.9
4:1	8.0	40.9	8.0	12.0	15.9	6.0	1.6
3:1	11.2	40.9	8.0	13.6	18.9	6.0	2.5
2:1	17.2	40.9	8.0	16.6	24.3	6.0	4.7

*INDICATES ROUNDING IS LARGER THAN REQUIRED FOR OPTIMUM

Figure III-A-2. Dimensional Data for Optimum Rounding (11)

Rounding at the toe of the slope is also essential to minimize the hazard at the side slope to ground line hinge. Rounding values at the toe should equal those at the shoulder. Although unrounded slopes of 3:1 and flatter need not be shielded, *every effort should be made to round any slope as much as practical.* The added safety benefits of slope rounding will be ample justification.

III-A-2. Roadside Obstacles

Roadside obstacles are further classified as nontraversable hazards and fixed objects. These highway hazards account for over thirty percent of all highway fatalities each year. *Removal of these obstacles should be the first alternative considered.* If it is not feasible or possible to remove the hazard, then a barrier should be considered. *However, a barrier should be installed only if it is clear that the barrier offers the least hazard potential.*

Barrier warrants for roadside obstacles are a function of the nature of the obstacle and its distance from the edge of the traveled way. Figure III-A-3 shows a suggested criterion for determining the *clear distance* on fill and cut sections. Clear distance is defined as the minimum lateral distance measured with respect to the edge of the traveled way needed by the driver of an errant vehicle to either regain control and begin a return to the roadway or to slow the vehicle to a safe speed. The criterion in Figure III-A-3 is based on run-off-the road accident studies (7, 16) and research studies (10, 12, 144). It must be noted that the criterion is based on operating speeds of approximately 60 mph (96.54 km/h). For operating speeds below 60 mph,

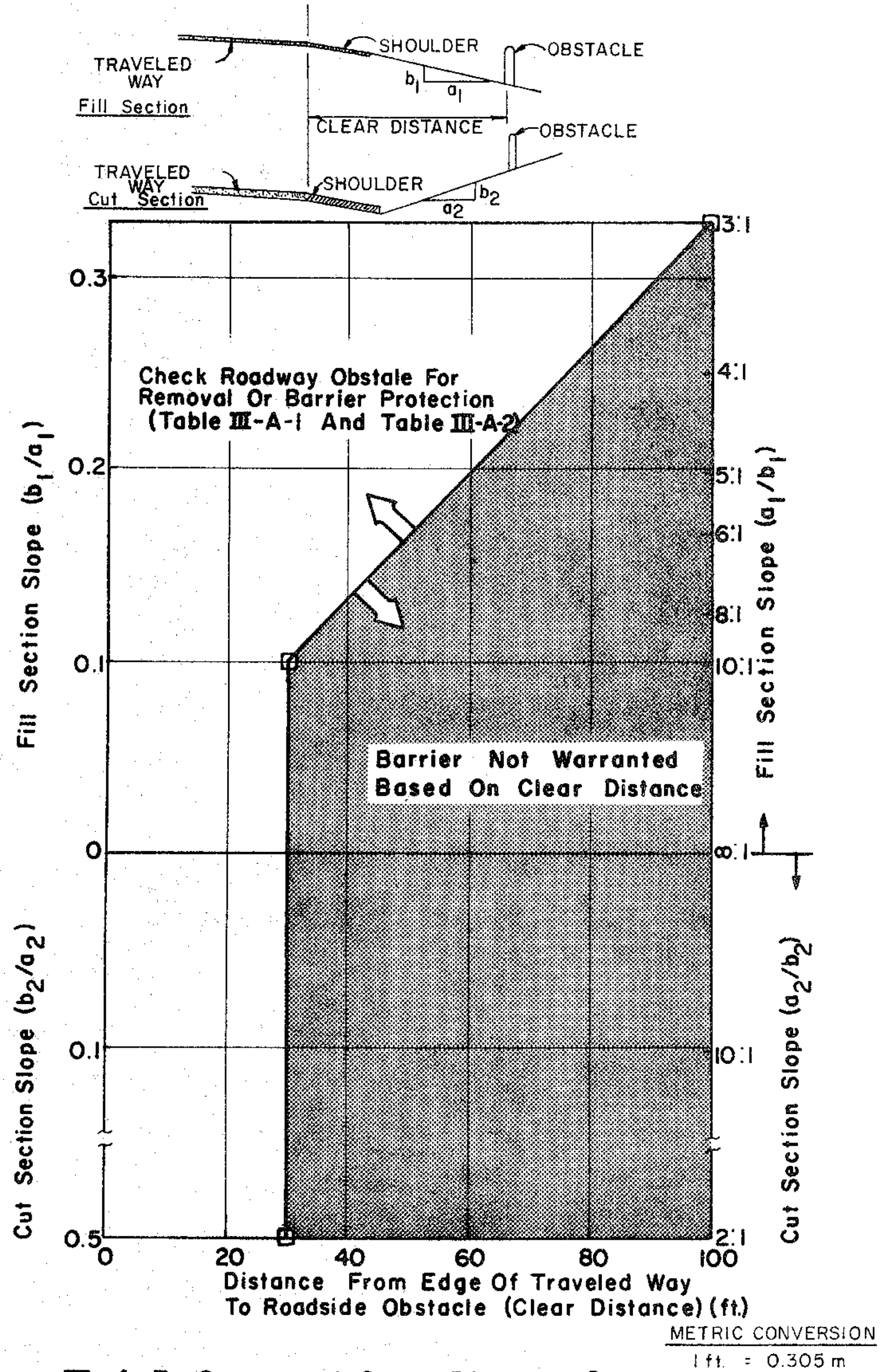


Figure III-A-3. Suggested Clear Distance Criterion For Roadside Obstacles smaller clear distances would be permissible. However, engineering judgment must be used in such cases due to an absence of objective criteria. Also, no appreciable slope rounding was used in the studies. Rounding will also reduce the clear distance required.

This procedure for use of Figure III-A-3 is as follows:

(a) First locate the point on the figure whose coordinates are the distance from the traveled way to the obstacle in question (horizontal axis) and the slope of the embankment (vertical axis).

(b) If this point lies below the line then protection is not warranted. If it lies above the curve then protection may be warranted, depending on the nature of the obstacle.

It is recognized that the suggested clear distance 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. It does, however, represent the present state of knowledge and it underlines the fact that flat, unobstructed roadsides are highly desirable.

Typical nontraversable hazards and appropriate barrier warrants are shown in Table III-A-1. Barrier need for rough rock cuts and large boulders is a matter of judgment by the highway engineer. Any non-traversable hazard that warrants shielding by a barrier should be removed. If this is not practical, a barrier should be provided.

Another common hazard on non-freeway facilities is a driveway or roadway or crossover which abuts a main roadway. If the main roadway

Table III-A-1. Warrants for Nontraversable Hazards

Nontraversable Hazard Within Clear Distance as Determined By Figure III-A-3	Traffic Barrier Required	
	Yes[1]	No
Rough rock cuts	X	
Large boulders	X	
Streams or permanent bodies of water less than 2 ft. in depth		X
Streams or permanent bodies of water more than 2 ft. in depth	X	
Shoulder drop-off with slope steeper than 1:1 and		
a) Height greater than 2 ft.	X	
b) Height less than 2 ft.		X

[1]All roadside obstacles within the clear distance should be removed if possible, otherwise provide barrier protection.

Metric Conversions

1 ft. = 0.3048 m

is in a fill section or has adjoining ditches of considerable depth, the driveway will of necessity also be on a fill. A culvert is often necessary under the driveway. However, a roadside barrier would not normally be used to shield the driveway due to the restrictions it would impose on the sight distance of users of the driveway. Barrier ends also pose special problems. *It is therefore highly desirable that the slope of the driveway embankment be as flat as possible, preferably 10:1 or flatter, to minimize the hazard potential to motorists on the main roadway. Sloping inlet and outlet culvert grates will also reduce the hazard of open culverts.*

Typical fixed objects and the appropriate warranting criteria are given in Table III-A-2. Current AASHTO specifications (15) state that satisfactory dynamic performance for breakaway supports is indicated when "the maximum change in momentum for a standard 2250 lb (1020 kg) vehicle, or its equivalent, striking a breakaway support at speeds from 20 mph (32 km/h) to 60 mph (97 km/h) does not exceed 1100 lb-sec (4893 N-sec), but desirably does not exceed 750 lb-sec (3336 N-sec)." As used by AASHTO (15), the term breakaway support ... "refers to all types of signs, luminaire and traffic signal supports that are designed to be safely displaced under vehicle impacts, whether the release mechanism is a slip plane, plastic hinges, fracture elements or a combination of these." While this criterion is objective, the ability of a given support to satisfy the criterion is not easily determined other than by full-scale tests. If analytical evaluation methods are used, they should include a consideration of the mass of the structure, its stiffness properties, the failure mechanism of the support,

Table III-A-2. Warrants for Fixed Objects

Fixed Objects Within Clear Distance as Determined by Figure III-A-3	Traffic Barrier Required	
	Yes	No
Sign, traffic signal, and luminaire supports[1]		
a) Breakaway or yielding design with linear impulse:[2]		
1) less than 1,100 lb-sec		X
2) greater than 1,100 lb-sec	X[3]	
b) Concrete base extending 6 in. or more above ground	X	
Fixed sign bridge supports	X	
Bridge piers and abutments at underpasses	X	
Retaining walls and culverts	X	
Trees with diameter greater than 6 in.	X	
Wood poles or posts with area greater than 50 in.[2]	X	

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

[2]See discussion in text.

[3]A judgement decision (see discussion in text).

<u>Metric Conversions:</u>
1 lb-sec = 4.45 N-sec
1 in = 0.0254 m

and the vehicle's characteristics. While the momentum criterion on breakaway supports represents the best available guidelines, its application to barrier warrants should be tempered with discretion. It is conceivable that a support that exceeds the 1100 lb-sec (4893 N-sec) momentum criterion may still not be as hazardous as a roadside barrier. Until more definitive data are available, barrier need for such supports must be based on engineering judgment. Also, installation of a roadside barrier greatly increases the target area for an errant vehicle, reduces the lateral clearance, and poses special problems at its ends. Such factors can be evaluated by the cost-effective procedure presented in Chapter VII.

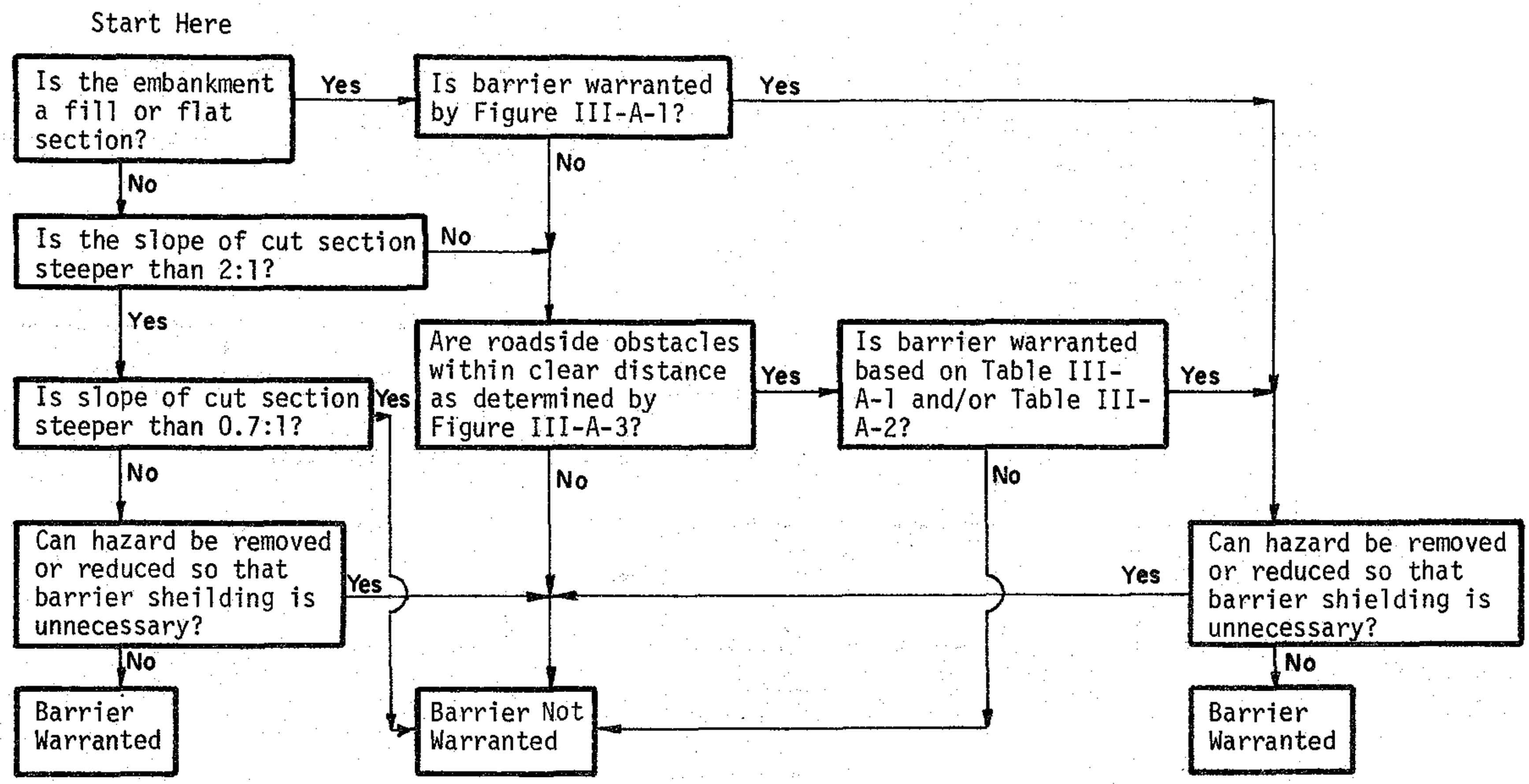
Fixed objects within the clear distance as determined by Figure III-A-3 that warrant barrier protection by Table III-A-2 should be removed. If removal is not practical or feasible, a barrier should be provided.

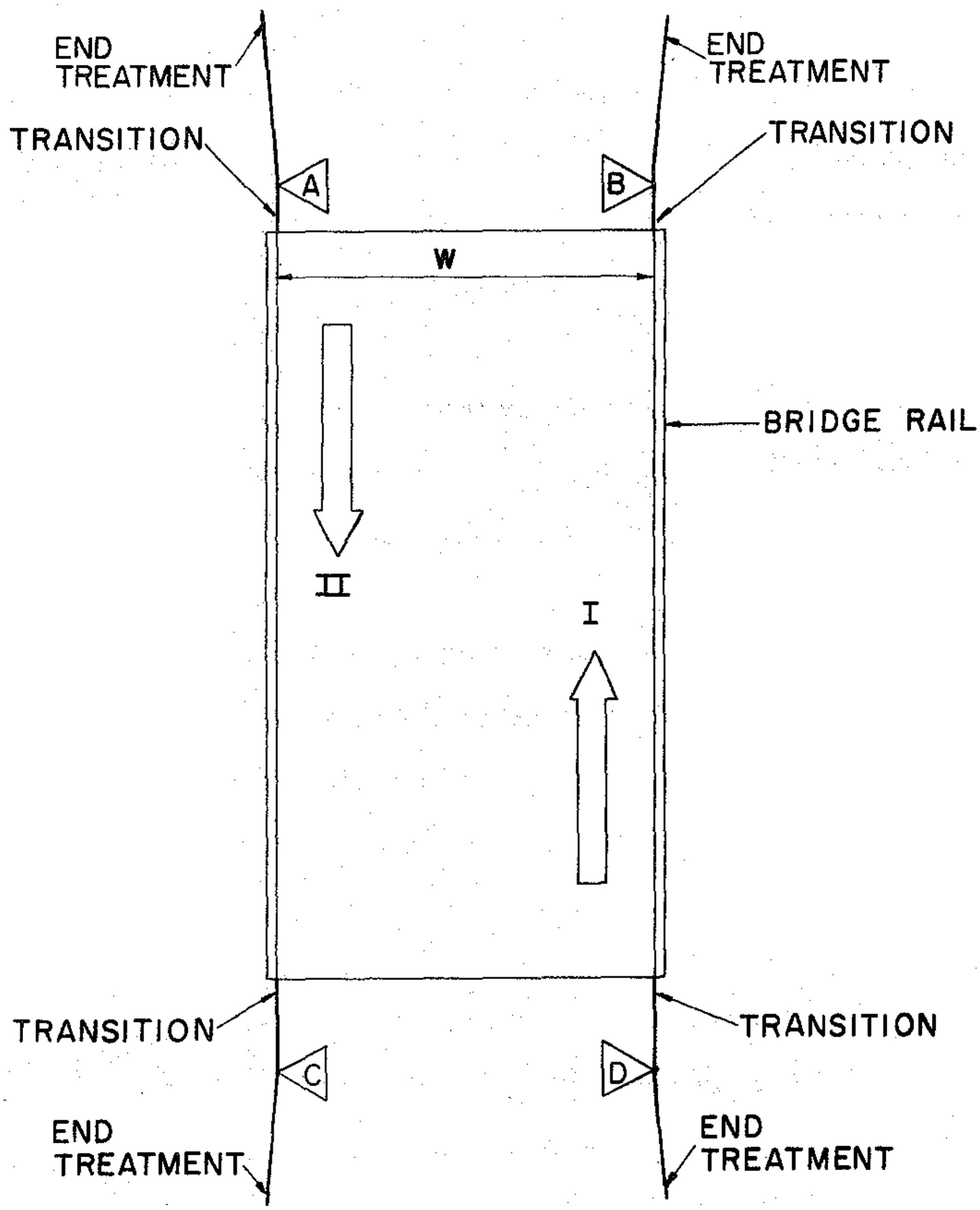
Figure III-A-4 outlines the procedure to follow to determine roadside barrier needs for fill and cut sections and roadside obstacles. The procedure should be followed for each roadside hazard until barrier need is established.

III-A-3. Bridge Rail Ends, Transitions, and End Treatments

Most bridge rail approach barrier systems are some type of roadside barrier. Figure III-A-5 summarizes the warrants for an approach barrier to a bridge. This criteria is again based on 30 ft (9.14 m) clear distance requirement for fixed hazards since the unprotected end of a bridge rail is considered a fixed object hazard. For twin

FIGURE III-A-4. Summary of Roadside Barrier Warrants





TRAFFIC DIRECTION	DISTANCE BETWEEN BRIDGE RAILS–W (ft.)	APPROACH BARRIER REQUIRED AT *
I AND II	≤ 60	A, B, C, D
I AND II	> 60	A, D
II ONLY	ALL WIDTHS	A, B
I ONLY	ALL WIDTHS	C, D

*Check roadside for other warranting features.

METRIC CONVERSION: 1 ft. = 0.305 m

Figure III-A-5. Bridge Approach Barrier Criteria

bridges, the length of the approach rail on the median side of each bridge should be of sufficient length to prevent an errant vehicle from impacting the bridge rail end of the other bridge. Lengths of need and flare rates for approach barriers are given in Section III-E.

If an approach barrier is warranted based on Figure III-A-5, an adequate transition section between the approach barrier and the bridge rail is warranted. If the end of the approach barrier terminates within the clear distance, a crashworthy end treatment is also warranted.

In general, a transition section is warranted when there is a significant change in the lateral strength or lateral stiffness of a roadside barrier. A crashworthy end treatment of a roadside barrier is warranted when the barrier terminates within the clear distance.

III-A-4. Bystanders, Pedestrians, and Cyclists

An area of concern to highway officials is what has been termed the "innocent bystander" problem. In most such cases, the conventional criteria presented in the previous sections cannot be used to establish barrier needs. For example, a major street, highway, or freeway may adjoin a school yard, but the boundaries are beyond the clear distance. Conventional criteria would not require that a barrier be installed. However, if there is any reasonable probability of an errant vehicle encroaching on the school yard, a barrier would be warranted. If possible, the barrier could be placed near the school boundary to minimize the hazard to the motorist. Reference should be made to Section III-E for lateral placement criteria. Special consideration should also be given to businesses and/or residences which are near the right of way.

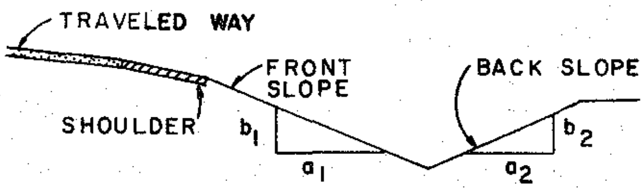
Pedestrians and cyclists are another area of concern to highway engineers. The most desirable solution to this problem is to physically separate them from vehicular traffic. Since this solution is not always practical, alternate means of protecting them is sometimes necessary.

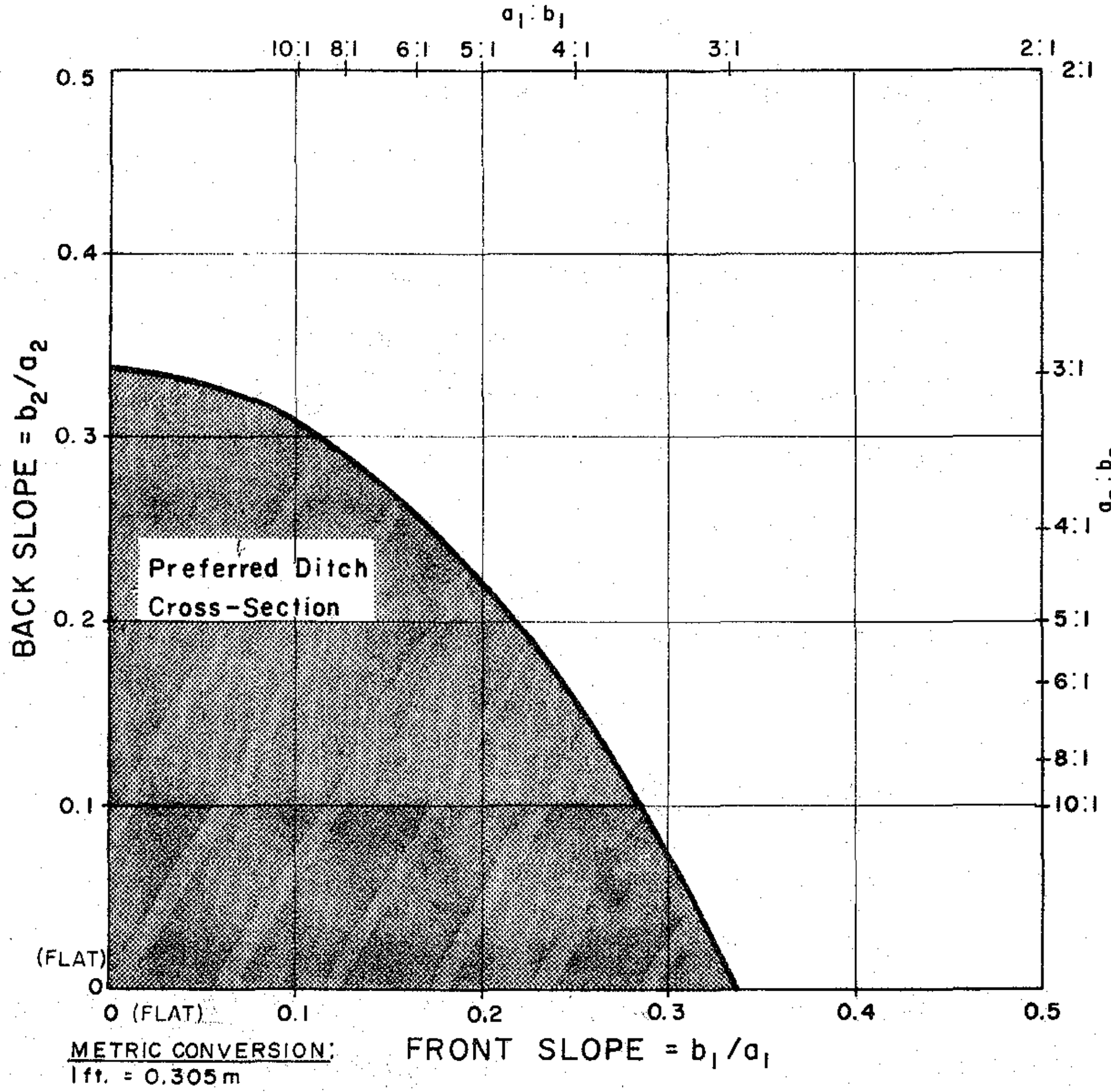
As in the case of bystander warrants, there is no objective criteria to draw on for pedestrian and cyclist barrier warrants. On low speed streets, a barrier curb will usually suffice to protect pedestrians and cyclists from vehicular traffic. However, at speeds in excess of 30 to 40 mph (48.3 to 64.4 km/h), a vehicle will mount the curb for relatively flat approach angles. Hence, when sidewalks or bicycle paths are near the traveled way of high speed facilities, some provision should be made for the safety of the pedestrians and the cyclists. If necessary, one of the roadside barriers presented in Section III-B should be installed. Proper consideration should be given to the deflection characteristics of the barrier in the lateral placement of the barrier.

III-A-5. Preferred Ditch Cross Sections

Although specific warrants for barrier protection of ditches do not exist, the designer should recognize their potential hazard. Ditches near the traveled way can be a significant hazard if their cross section cannot be easily traversed by an errant vehicle.

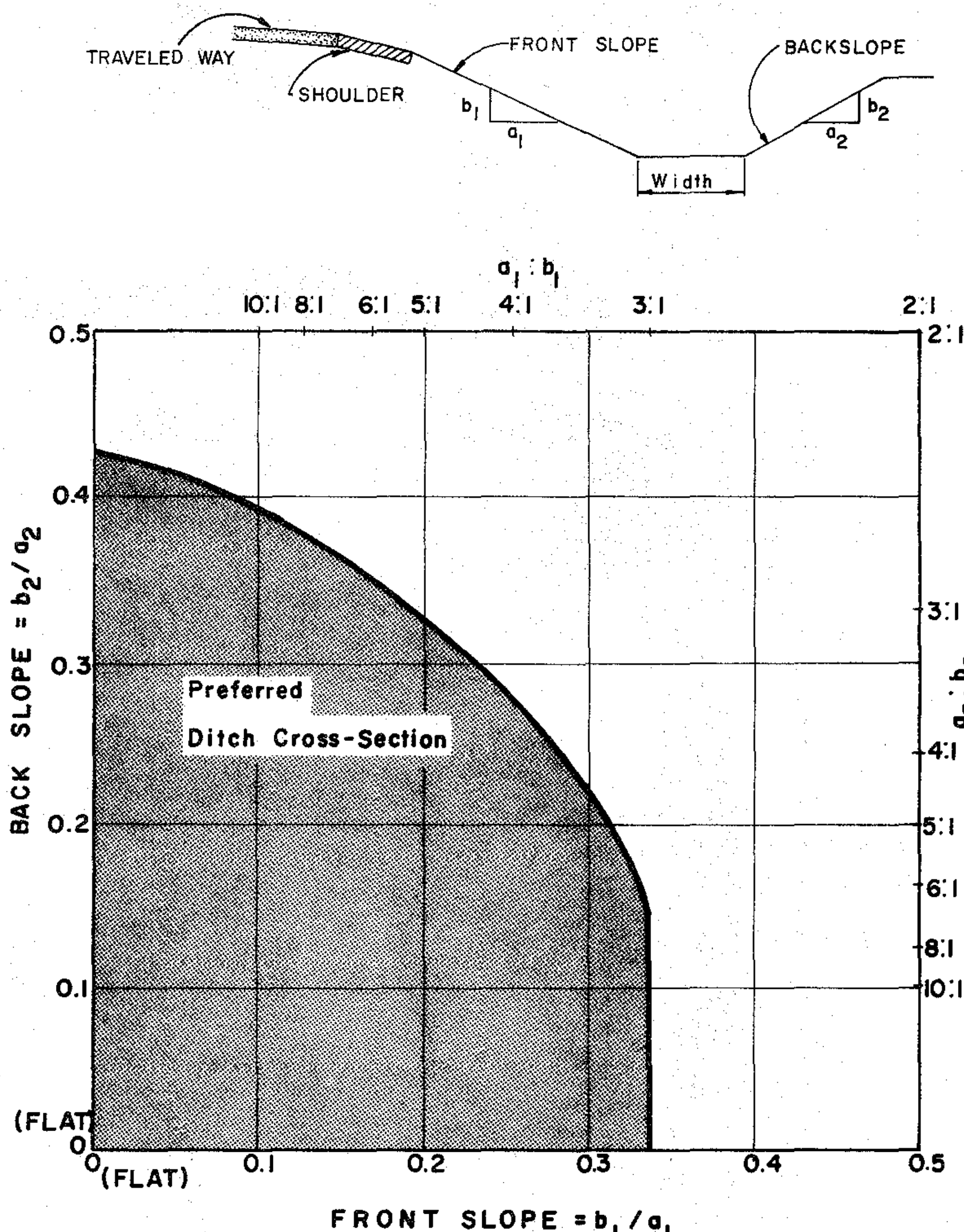
Figures III-A-6, III-A-7, and III-A-8 present preferable front slopes and back slopes for various ditch configurations (144). Ditch





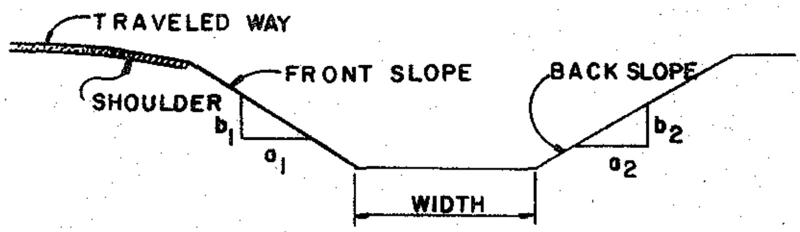
METRIC CONVERSION:
1ft. = 0.305m

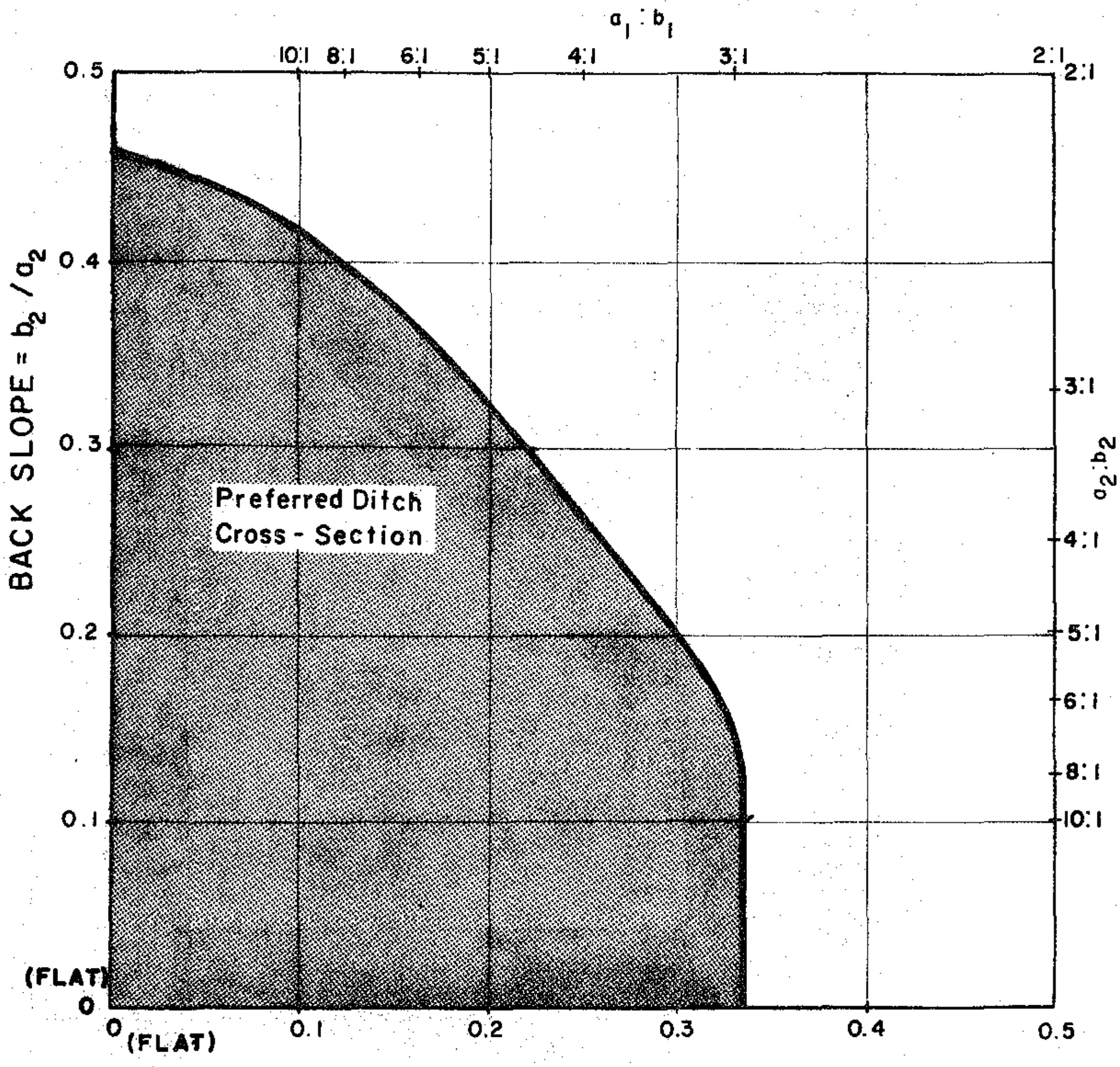
Figure III-A-6. Preferred Ditch Sections For:
(a) Vee Ditch; or
(b) Round Ditch, Bottom Width < 8 ft.; or
(c) Trapezoidal Ditch, Bottom Width < 4 ft.; or
(d) Rounded Trapezoidal Ditch, Bot. Wid. < 4 ft.



METRIC CONVERSION:
1ft. = 0.305m

Figure III-A-7. Preferred Ditch Sections For:
(a) Trapezoidal Ditch, Bottom Width = 4 ft. To 8 ft.; or
(b) Round Ditch, Bottom Width = 8 ft. to 12 ft.





METRIC CONVERSION:
1 ft. = 0.305 m

Figure III-A-8. Preferred Ditch Sections For:
(a) Trapezoidal Ditch, Width > 8 ft.; or
(b) Round Ditch, Width > 12 ft.; or
(c) Rounded Trapezoidal Ditch, Width > 4 ft.

sections which fall in the shaded region of each of the figures are considered to have a tolerable cross section. Tolerable implies that the occupants of an errant vehicle traversing the ditch would not likely experience serious injuries. Ditch sections which fall outside the shaded region are considered undesirable. If feasible, problem ditch sections may be flattened and/or rounded or internal drainage systems may be added.

III-A-6. Steep Grades

Heavy vehicles occasionally lose their brakes when going down long steep grades. Reference should be made to Section VI-A for a discussion of this problem and possible solution.

III-A-7. Example Problems

This section presents illustrative problems for determining barrier need at roadside hazards. Figure III-A-9 shows common roadside features that might warrant roadside barrier protection. Figure III-A-4 is used at each station or hazard in conjunction with the other appropriate figures and tables presented previously in this chapter. Note that a shoulder width of 12 feet (3.66 m) is assumed at each section in determining the clear distance.

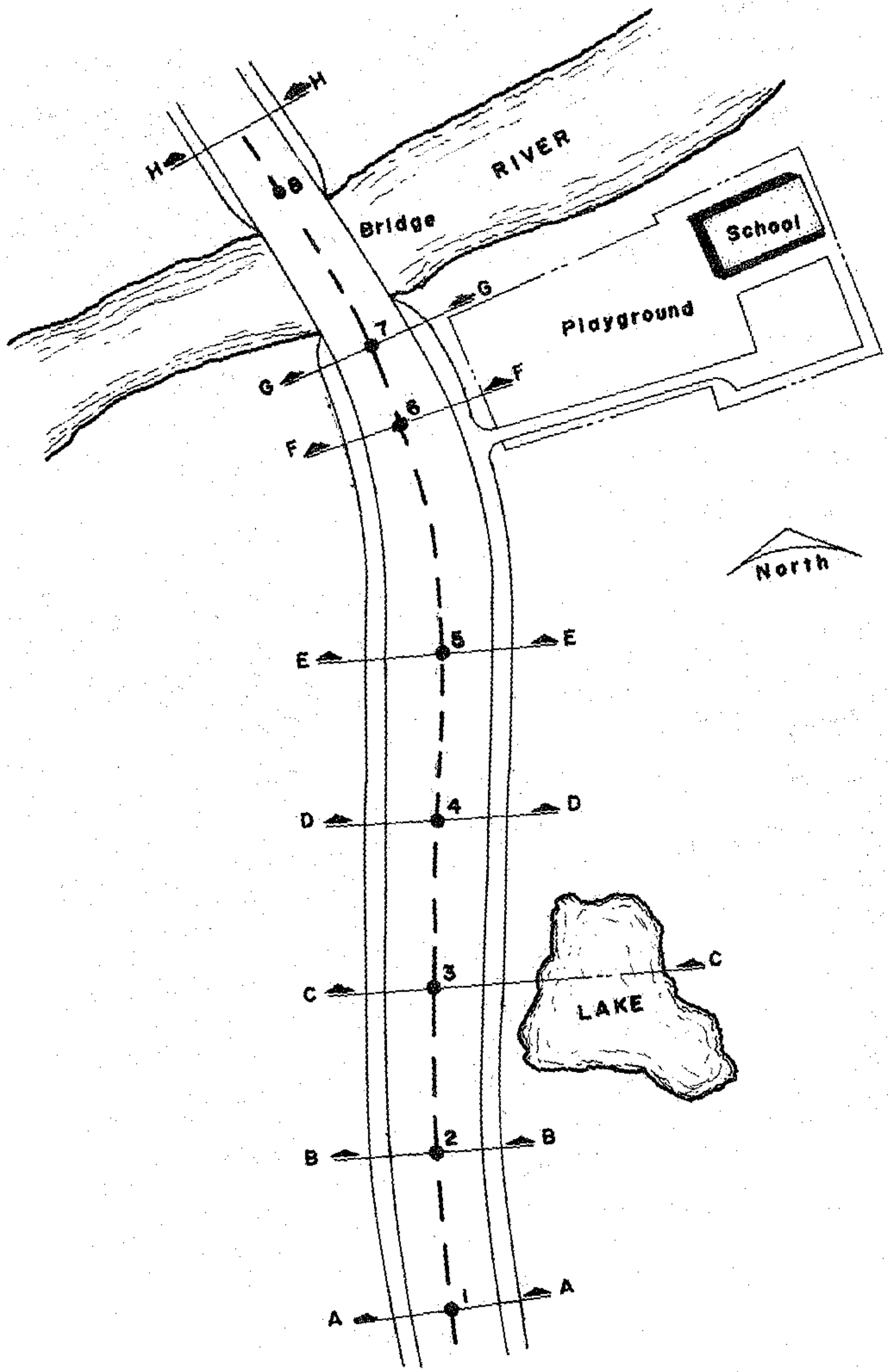


Figure III-A-9. Illustrative Example For Roadside Barrier Warrants.

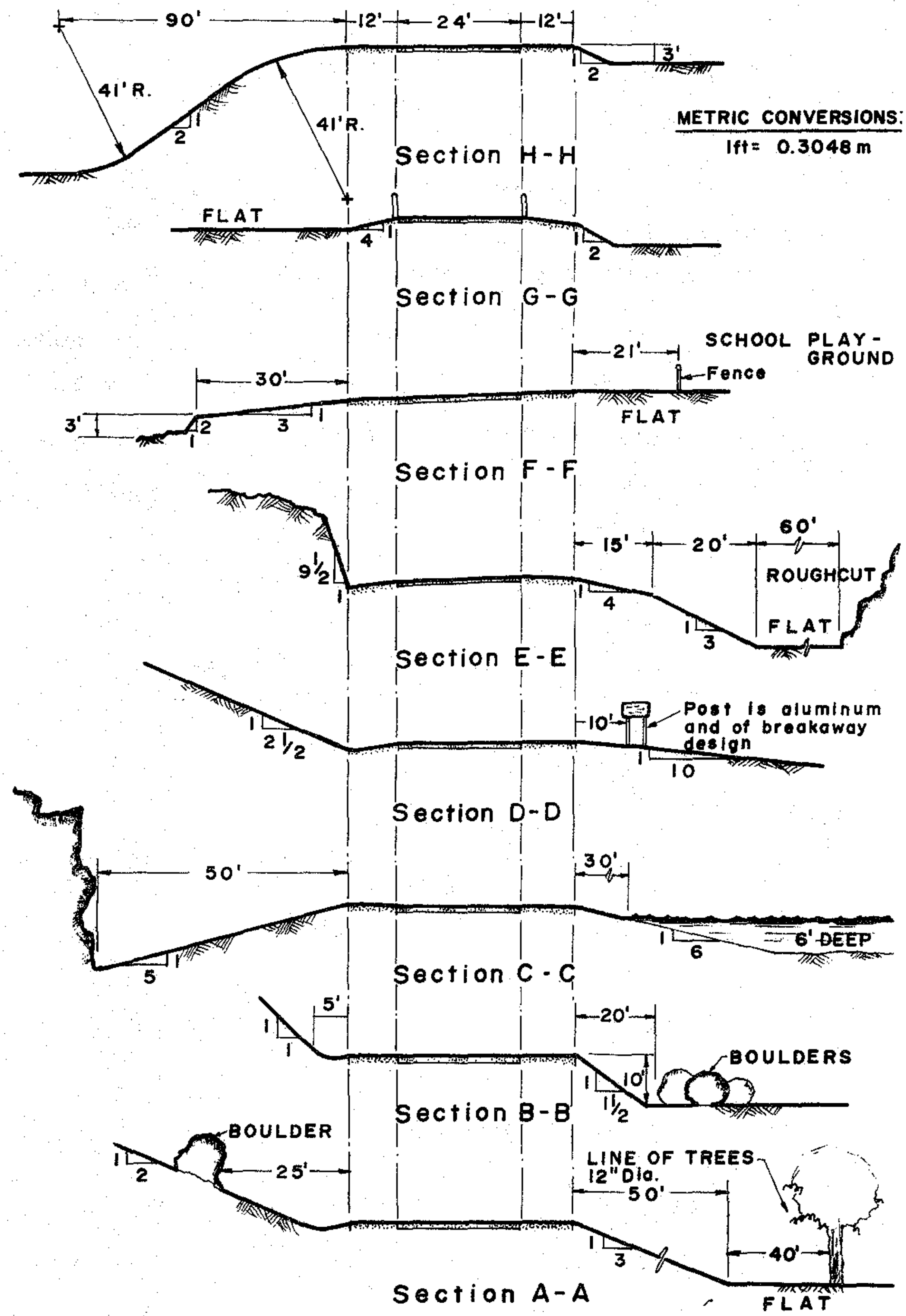


Figure III-A-9. Illustrative Example For Roadside
(Cont.) Barrier Warrants (Cross Sections)

Section A-A:

East Side of Roadway:

1) Fill section.

2) Slope not steeper than 3:1.

3) Clear distance criteria: For roadside hazards not located on the slope, a "weighted" average approach may be used to determine the average slope of the section from the edge of the shoulder to the roadside obstacle. For sections flatter than or equal to 10:1, a slope of 10:1 should be used. Average slope of the clear distance

$$(b_1/a_1)_{AVE} = \frac{(50 \text{ ft.})\ (0.333) + (40 \text{ ft.})\ (0.1)}{90 \text{ ft.}}$$

$$= 0.230$$

Enter Figure III-A-3 with $(b_1/a_1) = 0.230$ and clear distance = 102 ft. (31.1 m)

4) Barrier not warranted.

West Side of Roadway:

1) Cut section traversable.

2) Enter Figure III-A-3 with $(b_2/a_2) = 0.5$ and clear distance = 37 ft. (11.3 m)

3) Barrier not warranted.

Section B-B:

East Side of Roadway:

1) Fill section.

2) Slope is steeper than 3:1.

3) Enter Figure III-A-1 with fill height = 10 ft. (3.05 m) and $(b_1/a_1) = 0.667$. Barrier is warranted.

Solution: Flatten slope and/or remove or cover boulders. If this is not feasible, provide barrier.

West Side of Roadway:

1) Cut section traversable.

2) Barrier not warranted.

(Note: Back slopes greater than approximately 2:1 in cut sections should be avoided if possible.)

Section C-C:

East Side of Roadway:

1) Fill section.

2) Slope is not steeper than 3:1.

3) Enter Figure III-A-3 with $(b_1/a_1) = 0.167$ and clear distance = 42 ft. (12.8 m). Further check of obstacle is needed.

4) Check Table III-A-1 for permanent body of water with 6 ft. depth. Barrier is warranted.

Solution: Provide barrier protection.

West Side of Roadway:

1) Fill section.

2) Slope is not steeper than 3:1.

3) Enter Figure III-A-3 with $(b_1/a_1) = 0.2$ and clear distance = 62 ft. (18.9 m). Intersection of two points falls in region bordering further roadside obstacle check and barrier unwarranted.

Solution: Barrier not warranted unless frequency of accidents is high.

Section D-D:

East Side of Roadway:

1) Fill or flat section.

2) Slope is not steeper than 3:1.

3) Enter Figure III-A-3 with (b_1/a_1) = 0.1 and clear distance = 22 ft. (6.7 m). Further check of obstacle needed.

4) Check Table III-A-2 for sign supports.

5) Assuming breakaway design of support does not cause momentum change greater than 1100 lb-sec (4893 N-sec) barrier not warranted.

(Note: Move sign support outside 30 ft. clear distance if feasible.)

West Side of Roadway:

1) Cut section.

2) Slope is not steeper than 2:1.

3) No roadside obstacles to be checked.

4) Barrier not warranted.

Section E-E:

East Side of Roadway:

1) Fill section.

2) Average slope of fill section

$$(b_1/a_1)_{AVE} = \frac{(55\text{ ft.})\,(0.25) + (20\text{ ft.})\,(0.333)}{35\text{ ft.}}$$

$$= 0.30$$

Average slope is less than 3:1.

3) Average slope of clear distance

$$(b_1/a_1)_{AVE} = \frac{(15\text{ ft.})\ (0.25) + (20\text{ ft.})\ (0.333)}{95\text{ ft.}} +$$

$$\frac{(60\text{ ft.})\ (0.1)}{95\text{ ft.}} = 0.173$$

Enter Figure III-A-3 with $(b_1/a_1) = 0.173$ and clear distance = 107 ft. (32.6 m). No further check of rough rock cut needed.

4) Barrier not warranted.

West Side of Roadway:

Cut section not traversable. However, barrier would probably not be warranted if back slope surface is smooth and does not cause vehicle to pocket and/or overturn.

Section F-F:

East Side of Roadway:

1) Flat section.

2) Slope not steeper than 3:1.

3) Enter Figure III-A-3 with $(b_1/a_1) = 0.1$ and clear distance = 33 ft. (10.1 m).

4) Barrier not warranted by standard criteria, however, a playground near a high speed facility may need to be shielded. Need must be based on judgment. The driveway presents special problems. Reference should be made to the discussion in Section III-A-2.

West Side of Roadway:

1) Fill Section

2) Slope not steeper than 3:1.

3) Enter Figure III-A-3 with $(b_1/a_1) = 0.167$ and clear distance = 42 ft. (12.8 m). Further check of obstacle needed.

4) Check Table III-A-1 for drop-off of 3 ft. (0.91 m) at bottom of slope. Barrier warranted.

Solution: Fill in drop-off and taper to slope of 6:1 or flatter.

<u>Section G-G</u>:

East Side of Roadway:

1) By bridge approach barrier criteria in Figure III-A-5, an approach barrier system is warranted. An appropriate transition section and end treatment should also be provided with the approach rail. (See Section III-E-4 for discussion.)

West Side of Roadway:

1) Again, by bridge approach barrier criteria in Figure III-A-5, an approach barrier system is warranted. An appropriate transition section and end treatment should also be provided with the approach rail system. Note that at Station 8, bridge approach barrier with appropriate transition section and end treatment would also be warranted on the east and west side of the roadway, although this is not considered in this example. (See Section III-E-4 for discussion.)

Section H-H:

East Side of Roadway:

1) Fill section.

2) Slope is steeper than 3:1.

3) Enter Figure III-A-1 with $(b_1/a_1) = 0.5$ and fill height = 3 ft. (0.91 m). Height and slope of fill section does not warrant protection.

4) No roadside obstacle on or near fill section.

5) Barrier protection not warranted.

West Side of Roadway:

1) Fill section.

2) Slope is steeper than 3:1.

3) Slope is 2:1 and height is approximately 40 ft. (12.2 m). By Figure III-A-1, barrier is warranted. It should be noted, however, that the slope has optimum rounding (see discussion in Section III-A-1 and Figure III-A-2). Under some circumstances, such as low volume roadways or roadways with operating speeds below 60 mph (96.5 km/h) or favorable accident records, the highway engineer may choose not to provide a barrier for such a cross-section.

III-B. Structural and Safety Characteristics

It is the purpose of this section to present operational roadside barrier systems and to point out desirable structural and safety characteristics. The section is subdivided according to standard sections of roadside barriers, transitions, and end treatments for roadside barriers. Figure III-B-1 is an example to illustrate these three roadside barrier elements. In this example, the length of need is composed of a standard section and a transition. For embankment shielding, the length of need would only consist of the standard section. Length of need criteria is discussed in a subsequent section.

Structural and safety characteristics of operational systems within each of these three roadside barrier elements are presented on standard forms (e.g., Table III-B-1). Information on each form consists of the following:

(a) A *sketch* of the barrier and its basic dimensions.

(b) A *system* designation, used for convenience in referring to the barrier, consistent with standardized barrier notation (22, 23).

(c) *Barrier description* - This section contains a description of the main structural elements of the *as-tested* barrier and post spacing. *Prior to selection of a particular barrier system, the designer should obtain full details of the system through the references given on the form. Also, some of the systems have been standardized, in terms of hardware, and this should be considered in the selection process.* Identification of the standardized systems are given in the following sub-sections.

It has been shown that small variations in designs or in construction details can have adverse effects on the impact performance of barriers. *Thus, the design details should correspond to the as-tested details unless adequate justification exists for changing the design.*

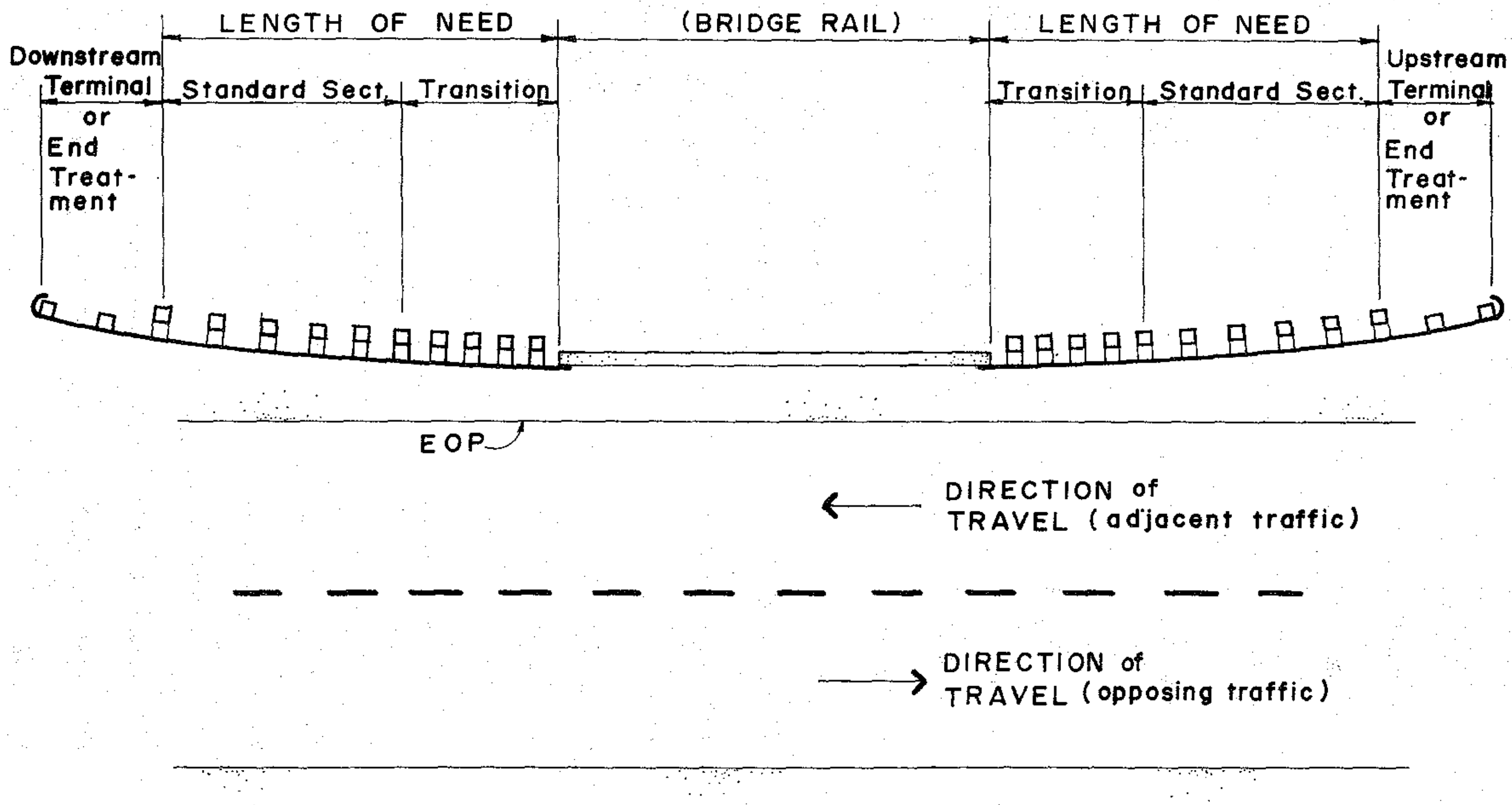


Figure III-B-1. Definition of Roadside Barrier Elements

(d) *Impact performance* - The contents of this part of the form are designed to allow the evaluation of each system in terms of the recommended evaluation criteria discussed in Section II-B. *However, before comparing the impact performance of the systems, reference should be made to the discussion in Section II-B concerning the absence of uniform test conditions.*

In many cases, the barrier was subjected to a series of crash tests. Appendix C contains a summary of all crash tests performed on each of the systems.

It is also to be emphasized that these crash tests were conducted under ideal conditions. The vehicle approached on a level surface, the posts were embedded in a firm to stiff soil, attention was given to erection details and the ends of the installation were anchored properly. *To the extent possible, the designer should evaluate the conditions under which the barrier will be installed in the field, i.e., typical soil conditions, the expertise required of the personnel who must install and maintain the barrier, and the sensitivity of the barrier to structural detail variations.*

(e) *Barrier damage* - A brief description of the barrier parts damaged during the test is given. These parts would have to be either repaired or replaced. Supplemental data in this area is given in Section III-C.

(f) *References* - The reference shown in the form contains the reported test data. However, Appendix C should be reviewed for other reported tests which may have been performed on the system. These references should be consulted for further structural details and for more in-depth reports on the crash tests.

(g) *Field performance data* - Documented field data that describes their in-service performance is available on some of the barriers. *The designer is encouraged to review these and any other field data during the selection process.*

(h) *Remarks* - General comments are given regarding the barrier's design and/or impact performance.

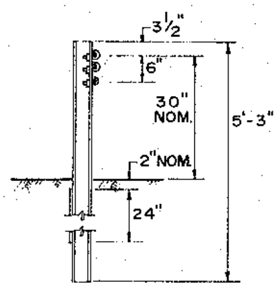
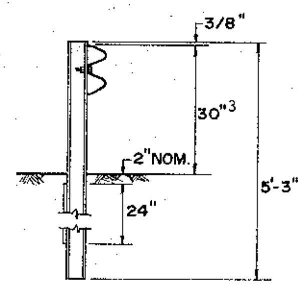
III-B-1. Standard Sections of Roadside Barriers

Table III-B-1 presents a summary of the structural and safety characteristics of current operational roadside barriers. Table III-B-2 contains a summary of the impact performance data on each of the operational systems. Before comparing the impact performance of the systems, reference should be made to the limitations of test methods discussed in Section II-B. Appendix B contains a summary of roadside barriers which appear promising but which do not have sufficient in-service use to be classified operational.

Although it is difficult to classify or categorize the performance of roadside barriers, they are usually denoted as either a *flexible* or a *semi-rigid* system. Flexible systems undergo considerable dynamic deflection upon impact and are generally more *forgiving* than the semi-rigid systems since they impose lower impact forces on the vehicle.

In selecting a roadside barrier, close attention must be given to its deflection characteristics. If the barrier can be placed a considerable distance from the hazard or hazards being protected, a

Table III-B-1. Operational Roadside Barrier Systems

Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg				
SYSTEM	G1 Cable Guardrail		G2 "W" Beam (Steel Weak Post)	
BARRIER DESCRIPTION				
POST SPACING	16' 0"		12' 6" Nominal	
POST TYPE	S3x5.7 steel		S3x5.7 steel	
BEAM TYPE	Three 3/4" diameter steel cables		Steel "W" section, 12 GA.	
OFFSET BRACKETS	------		------	
MOUNTINGS	5/16" diameter steel hook bolts		5/16" diameter steel bolt	
FOOTINGS	¼"x8"x24" steel plate welded to post		¼"x8"x24" steel plate welded to post	
IMPACT PERFORMANCE	**IMPACT ANGLE = 15°**	**IMPACT ANGLE = 25°**	**IMPACT ANGLE = 6°**	**IMPACT ANGLE = 27.8°**
IMPACT CONDITIONS	NO TEST			
Speed (mph)		44.0	57.0	59.2
Vehicle Weight (lb.)		3500	3500	4051
BARRIER				
Dynamic Deflection (ft.)		11.0	≈ 0	7.30
VEHICLE ACCLERATIONS (G's)[1]				
Lateral		UNAV	UNAV	3.80
Longitudinal		UNAV	UNAV	3.10
Total		6.10	1.00	UNAV
VEHICLE TRAJECTORY				
Exit Angle (deg.)		15	1	9
Roll Angle (deg.)		UNAV	0	≈20
Pitch Angle (deg.)		UNAV	0	≈10
BARRIER DAMAGE		6 posts damaged	12' of "W" section and 2 posts	UNAV
REFERENCES		17	17	18
FIELD PERFORMANCE DATA[2]	YES		YES	
REMARKS	Smooth redirection. System requires large recovery area due to large dynamic deflection. Limited crash test data.		In 27.8° test, vehicle was airborne for 50', however, smooth redirection and overall good barrier performance. Fairly large dynamic deflections.	

UNAV — unavailable

[1] **50 millisecond average unless otherwise noted**

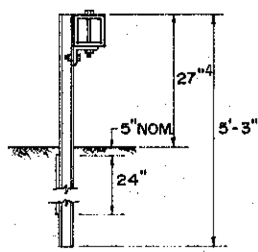
[2] **If available, see summary in Appendix A**

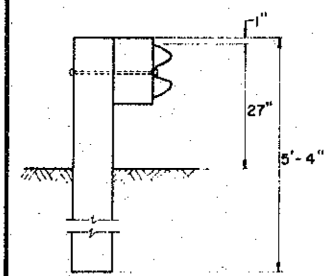
[3] Through studies (137) subsequent to the tests reported here, the State of New York has concluded that the W-beam performs better at a height of 33 inches.

Table III-B-1. Operational Roadside Barrier Systems (Continued)

Metric Conversions

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





SYSTEM	G3 Box Beam		G4(1W) Blocked-Out "W" Beam (Wood Post)	
BARRIER DESCRIPTION				
POST SPACING	6' 4"		6' 3"	
POST TYPE	S3x5.7 steel		8"x8" Douglas Fir	
BEAM TYPE	6"x6"x0.180" steel tube		Steel "W" section, 12 GA.	
OFFSET BRACKETS	L5"x3½"x¼" steel angle, 4½" long		8"x8"x14" Douglas Fir Block	
MOUNTINGS	3/8" dia. steel bolt (beam to angle)		5/8" diameter carriage bolts	
FOOTINGS	¼"x8"x24" steel plate welded to post		None	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 26°	IMPACT ANGLE = 15°	IMPACT ANGLE = 22.2°
IMPACT CONDITIONS				
Speed (mph)	NO TEST	57.7	NO TEST	60.1
Vehicle Weight (lb.)		4031		4123
BARRIER				
Dynamic Deflection (ft.)		4.80		2.80
VEHICLE ACCLERATIONS (G's)[1]				
Lateral		5.80		6.10
Longitudinal		2.80		3.00
Total		UNAV		UNAV
VEHICLE TRAJECTORY				
Exit Angle (deg.)		0.00		15
Roll Angle (deg.)		UNAV		UNAV
Pitch Angle (deg.)		UNAV		UNAV
BARRIER DAMAGE		UNAV		UNAV
REFERENCES		18		18
FIELD PERFORMANCE DATA[2]	YES		YES[3]	
REMARKS	Excellent redirection, vehicle came to rest parallel to the rail.		Smooth redirection. Southern yellow pine is acceptable alternate to Douglas Fir. See G4(2W) system for smaller post size.	

UNAV — unavailable

[1] 50 millisecond average unless otherwise noted

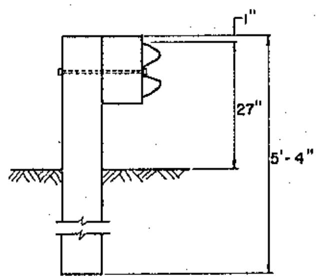
[2] If available, see summary in Appendix A

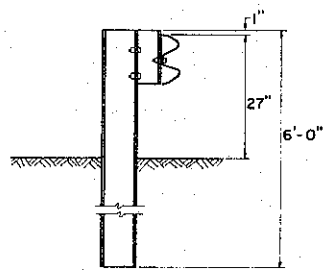
[3] Data for 6-inch block-out.

[4] Through studies (137) subsequent to the tests reported here, the State of New York has concluded that the box beam performs better at a height of 30 inches.

Table III-B-1. Operational Roadside Barrier Systems (Continued)

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





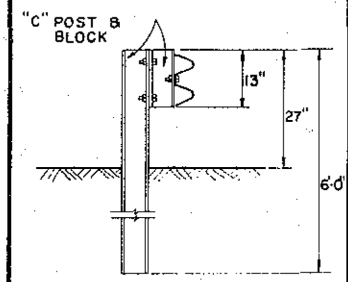
SYSTEM	G4(2W) Blocked-Out "W" Beam (Wood Post)		G4(1S) Blocked-Out "W" Beam (Steel Post)	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	 6' 3" 6" x 8" Douglas Fir Steel "W" section, 12 GA 6" x 8" x 14" Douglas Fir Block 5/8" diameter carriage bolts None		 6' 3" W6x8.5 steel post Steel "W" section, 12 GA W6x8.5x1' 2" long steel block[4] 5/8" diameter bolt None	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 24°	IMPACT ANGLE = 15°	IMPACT ANGLE = 25° (28.4°)
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	NO TEST	 68.0 4960	NO TEST	 66.0 (56.8) 4960 (3813)
BARRIER Dynamic Deflection (ft.)		2.33[3]		2.60 (4.05)
VEHICLE ACCLERATIONS (G's)[1] Lateral Longitudinal Total		 7.0 6.8 UNAV		 6.85 (6.60) 3.78 (3.90) UNAV (UNAV)
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)		 14 ≈15 UNAV		 16 (8) 0 (UNAV) 0 (UNAV)
BARRIER DAMAGE		25' of "W" section and 4 posts		25' of "W" section and 3 posts
REFERENCES		19		19, (18)
FIELD PERFORMANCE DATA[2]	NO		YES	
REMARKS	System is similar to G4(1W) except for smaller posts and block-out size. System performed well.		See text for explanation of differences in data shown for 25° and 28.4° tests. Smooth redirection.	

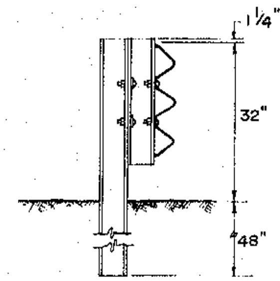
UNAV — unavailable
[1] 50 millisecond average unless otherwise noted
[2] If available, see summary in Appendix
[3] Maximum permanent deflection
[4] Tests show that a "W" section back-up plate, 1 ft. in length, must be placed behind rail elements at intermediate posts (non-splice posts).

Table III-B-1. Operational Roadside Barrier Systems (Continued)

Metric Conversions

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





SYSTEM	G4(2S) Blocked-Out "W" Beam (Steel "C" Posts)		G9 Blocked-Out "Thrie Beam" (Steel Post)	
BARRIER DESCRIPTION				
POST SPACING	6' 3"		6' 3"	
POST TYPE	4 1/3"x5 5/8"x3/16" "C" steel post		W6x8.5 steel	
BEAM TYPE	Steel "W" section, 12 GA		Thrie Beam, steel	
OFFSET BRACKETS	4 1/3" x5 5/8"x3/16" "C" steel post[3]		W6x8.5 and M14x17.2, steel	
MOUNTINGS	5/8" diameter bolt		2 5/8" diameter steel bolts	
FOOTINGS	None		UNAV	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 25°	IMPACT ANGLE = 15°	IMPACT ANGLE = 25°
IMPACT CONDITIONS				
Speed (mph)	NO TEST	59.0	59.1	56.4
Vehicle Weight (lb.)		4323	4500	4000
BARRIER				
Dynamic Deflection (ft.)		2.90	0.58	1.50
VEHICLE ACCLERATIONS (G's)[1]				
Lateral		6.80	4.10	7.90
Longitudinal		3.70	2.90	3.90
Total		UNAV	UNAV	UNAV
VEHICLE TRAJECTORY				
Exit Angle (deg.)		UNAV	Less than 10	15
Roll Angle (deg.)		less than 10	0	0
Pitch Angle (deg.)		0	0	0
BARRIER DAMAGE		25' of "W" section and 5 posts	12' 6" of thrie beam and 4 posts	12' 6" pf thrie beam and 4 posts
REFERENCES		20	21	21
FIELD PERFORMANCE DATA[2]	NO		NO	
REMARKS	Smooth redirection but with somewhat high exit angles (greater than 10°). Posts can be cold formed from steel sheets.		Smooth redirection. W6x8.5 block-out used in 15° test and M14x17.2 block-out was used in 25° test. Both systems performed well.	

UNAV — unavailable

[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix

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

Table III-B-2. Roadside Barrier Data Summary

System	Maximum Dynamic Deflection (ft.)[1]	Accelerations at 15° (G's)[2]			Accelerations at 25° (G's)[2]			Is Barrier Hardware Standardized?[3]
		Lateral	Longitudinal	Total	Lateral	Longitudinal	Total	
Flexible Systems								
G1	11.0	No Test	No Test	No Test	UNAV	UNAV	6.1	Yes
G2	7.3	UNAV	UNAV	1.0	3.8	3.1	UNAV	Yes
Semi-Rigid Systems								
G3	4.8	No Test	No Test	No Test	5.8	2.8	UNAV	Yes
G4(1W)	2.8	No Test	No Test	No Test	6.1	3.0	UNAV	Yes
G4(2W)	2.3[4]	No Test	No Test	No Test	7.0	6.8	UNAV	Yes[5]
G4(1S)	4.1	No Test	No Test	No Test	6.9	3.8	UNAV	Yes[5]
G4(2S)	2.9	No Test	No Test	No Test	6.8	3.7	UNAV	Yes[5]
G9	0.6	4.1	2.9	UNAV	7.9	3.9	UNAV	Yes[5]

UNAV - Unavailable

[1]Based on 25° impact.

[2]50 millisecond average.

[3]See reference 22, 23.

[4]Maximum permanent deflection.

Metric Conversion: 1 ft. = 0.305 m.

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

flexible barrier can be used. Conversely, semi-rigid barriers are necessary if the barrier-to-hazard distance is small. However, *short intermittent sections of two different types of roadside barriers are not recommended.* Such installations present problems at their terminals and at points where the two systems join (transition). *In general, short intermittent sections of any roadside barrier are undesirable. Gaps of less than 200 feet between barrier installations are to be avoided.*

Based on the test results shown in Table III-B-2, systems G1 and G2 are considered flexible barriers. In these systems, the resistance to impact is due in most part to the tensile forces developed in the cable (G1) or the W-beam (G2). The cable and the rail tear away from the support posts upon impact, the posts thus offering negligible resistance in the impact zone but are essential to control lateral deflection. Splices are designed to carry the full tensile strength of the cable (G1) or the rail (G2).

Systems G3 through G9 are considered semi-rigid barriers. In the G3 system, the resistance is achieved through the rail's combined flexure and tensile stiffness. The posts near the point of impact are designed to break or tear away, thereby distributing the impact force by beam action to adjacent posts. Systems G4(1W) through G9 resist impact through the combined tensile and flexural stiffness of the rail and the bending resistance of the posts. Note that the rail is blocked out from the posts in these systems to minimize vehicle snagging and to reduce the tendency for the vehicle to vault over the barrier. Block-outs are suggested for a "strong post" roadside barrier system.

Note that the rail heights range from 27 inches (0.69 m) to 32 inches (0.81 m), with 27 inches (0.69 m) as the most common height. Current roadside barrier heights have been established as a result of many years of research and field evaluations. Visibility or the ability to see over the barrier was one of the more important factors in early barrier height considerations. A minimum height of approximately 27 inches (0.69 m) is a necessary, but not sufficient, condition to insure proper barrier impact performance. The barrier must also be designed so that upon impact the rail remains essentially at its original mounting height. Note also that the post spacing for strong post systems, G4(1W) through G9, is 6.25 feet (1.91 m). Tests have shown that this spacing is needed for this type of system to minimize vehicle snagging or pocketing.

The degree to which the operational systems satisfy the recommended structural and safety criteria of Section II-B varies. All are considered to be structurally adequate, although some obviously deflect more than others. All do not satisfy the impact severity criteria, i.e., the maximum vehicle acceleration criteria. However, the acceleration criteria is tenuous and currently under review. Nonetheless, barriers which minimize impact forces should receive strong consideration. The barriers can only be evaluated in subjective terms with regard to the post crash vehicle trajectory hazard since there are little objective criteria. A vehicle rebounded back into the traffic lanes may present a hazard to other drivers. Ideally, a vehicle should redirect parallel to the barrier.

Two means of measuring post impact vehicle trajectory are the exit angle after impact and rebound distance (distance from the original roadside barrier line to the maximum outermost point which the vehicle travels during the post impact trajectory). Current vehicle trajectory hazard criteria states: "after impact, the vehicle trajectory and final stopping position shall intrude a minimum distance into adjacent traffic lanes." The "minimum distance" suggested in the above standards is a matter of judgment left to the design engineer. No maximum exit angle has been established since the rebound distance is considered a more meaningful trajectory parameter. However, since little data is available for rebound distance, exit angle is normally used as the indicator of trajectory hazard. An exit angle of 10° or less may be considered a non-hazardous post impact trajectory.

It is important to note that the performance of a roadside barrier is sensitive to a variety of conditions. The results of tests by two different agencies on system G4(1S) are a good example. For the 25° impact, two sets of data are shown in Table III-B-1 for this system. In one test, a 4960 lb (2250 kg) vehicle struck the system at 66 mph (106.3 km/hr) and caused a maximum dynamic deflection of 2.60 ft (0.79 m). In the other test a 3813 lb (1729 kg) vehicle struck the system at 56.8 mph (91.4 km/hr) and caused a maximum dynamic deflection of 4.05 ft (1.23 m). Thus, for the same barrier system impacted essentially at the same angle, the smaller, slower vehicle caused a much larger deflection than the heavier, faster vehicle. Differences in the response are attributed to three important parameters: the type of soil, the length of installation and the end treatment. The barrier system with the smaller deflection was considerably shorter, its ends had a positive anchorage system, and it was located in a much stiffer soil, thus creating a much stiffer overall system. Barriers installed in soft or yielding soil may require deeper embedment of the posts and/or closer post spacing.

Another example of barrier sensitivity to details again concerns the G4(1S) system. Note that a back-up plate is required between the rail and intermediate posts (non-splice posts). Without this plate, crash tests showed that the rail would tear and fail at the intermediate posts, and the impact performance was therefore unacceptable. Studies have been conducted to determine the sensitivity of roadside barriers to parameters such as rail tension, soil properties, and post strength and the reader is encouraged to review the results (18).

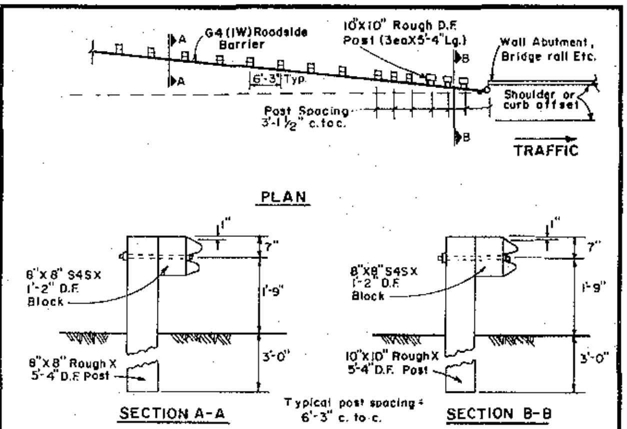
An effort has been made to standardize hardware for widely used traffic barriers (22, 23). Standardization is beneficial in terms of economy, improved availability of parts, readily available details and specifications, reduced repair time, and reduced inventory of replacement parts because of interchangeability of parts. Roadside barriers which have been standardized are so noted in the last column of Table III-B-2. The referenced standardized documents continue to be revised periodically and the designer should obtain the latest publications.

III-B-2. Transitions

Transition sections are necessary to provide continuity of protection when two different roadside barriers join, when a roadside barrier joins another barrier system (such as a bridge rail), or when a roadside barrier is attached to a rigid object (such as a bridge pier). The most common use of transition occurs between approach roadside barriers and bridge rail ends or bridge abutments.

Shown in Table III-B-3 are transition sections that are considered operational. Transition systems that are not considered operational but that have shown promising crash test results are presented in Appendix B.

Table III-B-3. Operational Roadside Barrier Transition Sections

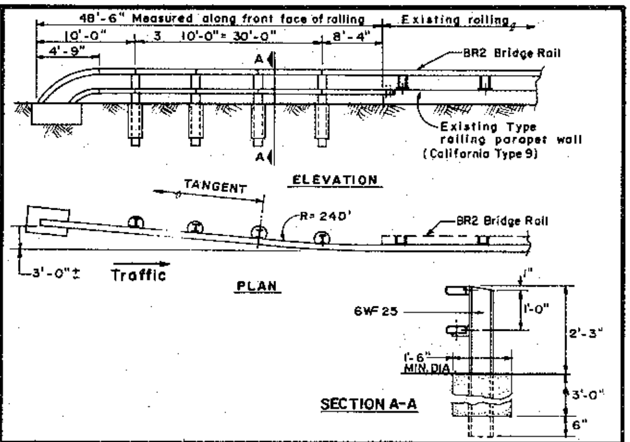


Metric Conversions
1 ft. = 0.305 m
1 in. = 25.4 mm
1 mph = 1.61 km/hr
1 lb. = 0.454 kg

SYSTEM	T1 G4(1W) Approach Rail to Concrete Parapet	
BARRIER DESCRIPTION	POST SPACING - as shown on sketch; POST TYPE - 8"x8" and 10"x10" Douglas Fir; BEAM TYPE - steel "W" section, 12 GA.; OFFSET BRACKETS - 8"x8" Douglas Fir block; MOUNTINGS - 1" diameter steel bolt; FOOTINGS - none.	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 25°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	NO TEST	 58.8 4297
BARRIER Dynamic Deflection (ft.)		 UNAV
VEHICLE ACCELERATIONS (G's)[1] Lateral Longitudinal Total		 19.0 8.8 UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)		 UNAV UNAV UNAV
BARRIER DAMAGE		UNAV
REFERENCES		18
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	Severe vehicle damage. System that was tested had no flare.	

UNAV = unavailable
[1] 50 millisecond average unless otherwise noted
[2] If available, see summary in Appendix A

Table III-B-3. Operational Roadside Barrier Transition Sections (Continued)

Metric Conversions 1 ft. = 0.305m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg		
SYSTEM	T2 Tubular Approach Rail to BR2 Bridge Rail	
BARRIER DESCRIPTION	POST SPACING - 10'10"; POST TYPE - W6x25, steel; BEAM TYPE - TS6"x2"x0.25" steel tubing; OFFSET BRACKETS - none; MOUNTINGS - two 3/4" diameter steel studs; FOOTINGS - 18" diameter, 36" concrete.	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 26°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	NO TEST	 60.0 4540
BARRIER Dynamic Deflection (ft.)		 0.23
VEHICLE ACCELERATIONS (G's)[1] Lateral Longitudinal Total		 UNAV UNAV UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)		 13 ≈5 ≈0
BARRIER DAMAGE		3 rail sections and 1 post
REFERENCES		24
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	Smooth redirection. Vehicle damage moderate with substantial sheet metal deformation.	

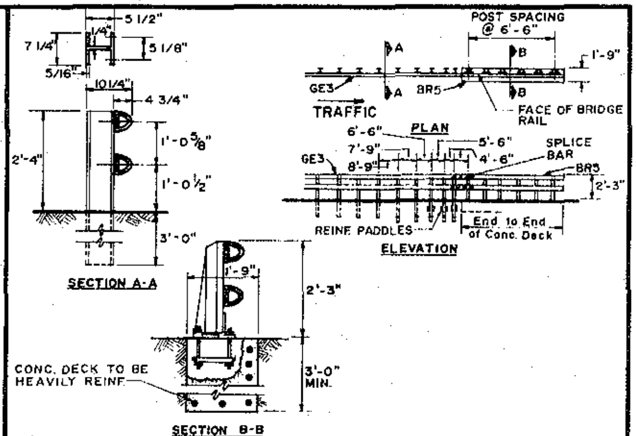
UNAV — unavailable

[1]50 millisecond average unless otherwise noted

[2]If available, see summary in Appendix A

Table III-B-3. Operational Roadside Barrier Transition Sections (Continued)

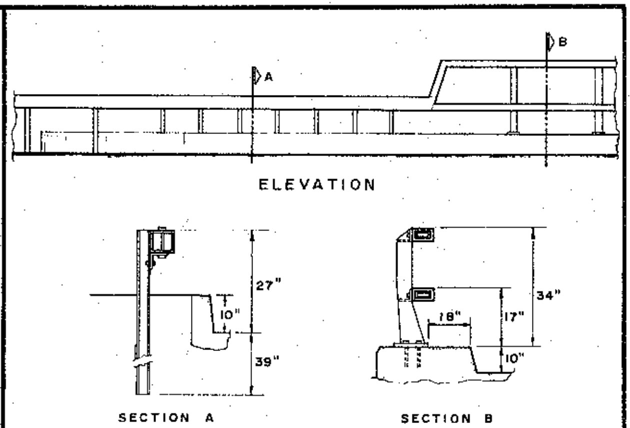
Metric Conversions
1 ft. = 0.305 m
1 in. = 25.4 mm
1 mph = 1.61 km/hr
1 lb. = 0.454 kg



SYSTEM	T3 GE3 Approach Rail to BR5 Bridge Rail	
BARRIER DESCRIPTION	POST SPACING - as shown on sketch; POST TYPE - 5½"x7¼" H section aluminum; BEAM TYPE - two standard aluminum extrusions; OFFSET BRACKETS - none; MOUNTINGS - standard hardware; FOOTINGS - none.	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 23°
IMPACT CONDITIONS		
Speed (mph)	NO TEST	58.0
Vehicle Weight (lb.)		3965
BARRIER		
Dynamic Deflection (ft.)		1.4
VEHICLE ACCELERATIONS (G's)[1]		
Lateral		7.8
Longitudinal		6.6
Total		UNAV
VEHICLE TRAJECTORY		
Exit Angle (deg.)		20
Roll Angle (deg.)		UNAV
Pitch Angle (deg.)		UNAV
BARRIER DAMAGE		2 sections of rail and 3 posts
REFERENCES		25
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	Some vehicle snagging. First post of bridge rail was taken out by impact.	

UNAV — unavailable
[1] 50 millisecond average unless otherwise noted
[2] If available, see summary in Appendix A

Table III-B-3. Operational Roadside Barrier Transition Sections (Continued)

Metric Conversions 1 ft. = 0.305m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg		
SYSTEM	T4 G3 Approach Rail to BR3 Bridge Rail	
BARRIER DESCRIPTION	POST SPACING - 4'0"; POST TYPE - S3 x 5.7 steel for approach rail, fabricated steel for bridge rail; BEAM TYPE - 6" x 6" x 0.188" steel tubing for approach rail, TS 5" x 3" x ¼" steel for bridge rail; OFFSET BRACKETS - L5" x 3½" x ¼" steel angle; MOUNTINGS - ½" and 5/16" diameter bolts; FOOTINGS - ¼" x 8" x 24" steel plate welded to post.	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 25°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb)	NO TEST	 54.0 3500
BARRIER Dynamic Deflection (ft.)		 4.6
VEHICLE ACCELERATIONS (G's)[1] Lateral Longitudinal Total		 UNAV UNAV 9.4
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)		 2 less than 10 0
BARRIER DAMAGE		5 posts damaged
REFERENCES		17
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	It is recommended that the curb not be used in this design.	

UNAV — unavailable
[1]50 millisecond average unless otherwise noted
[2]If available, see summary in Appendix C

Supporting crash test data for all transition sections is contained in Table C-5 of Appendix C.

Several comments are necessary with regard to the transitions shown.

(1) The T1 system is adaptable to other roadside barrier transition problems. See example in Section II-F-2.

(2) While the T2 transition itself is considered operational, means other than that shown should be sought to terminate the approach rail.

(3) The operational status of the T3 system should be "qualified" in that the GE3 approach barrier (described in Appendix B) is an experimental system.

It can be seen that more research, development, and testing of transition sections is needed. The problem is compounded by the existence of a large number of bridge rail types. Due to the lack of a wide range of operational transition sections, the highway engineer must often design and install transition sections without the benefit of crash tests. In such cases, the engineer should follow closely the guidelines presented herein.

Impact performance requirements of roadside transitions are essentially the same as those for the standard section of a roadside barrier. Special emphasis must be placed on the avoidance of designs which may cause vehicle snagging or excessive deflection of the transition. Such actions can lead to impact with the bridge end or other unacceptable results. Structural details of special importance are as follows:

(a) The approach rail-to-bridge rail splice should develop the full tensile and flexure strength of the approach rail.

(b) The approach rail-to-bridge rail or bridge parapet connection should be flared or sloped so that an errant vehicle from the opposing lane (of a two-way bridge) will not snag on the connection. In this regard, the standardized *terminal connector* (22), sometimes referred to as the "Michigan end shoe", is suggested for attaching approach W-beam rail to bridge parapets and to structurally compatible bridge rails. An example of the use of the terminal connector is shown in the TR2 system, Appendix B, Table B-10. Another effective rail-to-parapet connection can be achieved by providing a recessed area in the parapet wall to receive the rail. This is illustrated in Figure III-B-2. Other potential connections and transitions are shown in the last part of NCHRP 129 (39). Continuity can also be achieved by continuing the approach rail through the structure.

(c) Strong post systems must be used on transitions to rigid bridge rails or parapets or rigid objects. Such systems must be blocked-out to prevent vehicle snagging on the posts. However, block-outs alone may not be sufficient to prevent snagging at the section just upstream of the rigid bridge rail or parapet. A rub rail may be desirable in some designs using the standard W-beam or box beam. Rub rails are especially needed when the approach rail is terminated in a recessed area of the parapet. The rub rail should also be terminated in

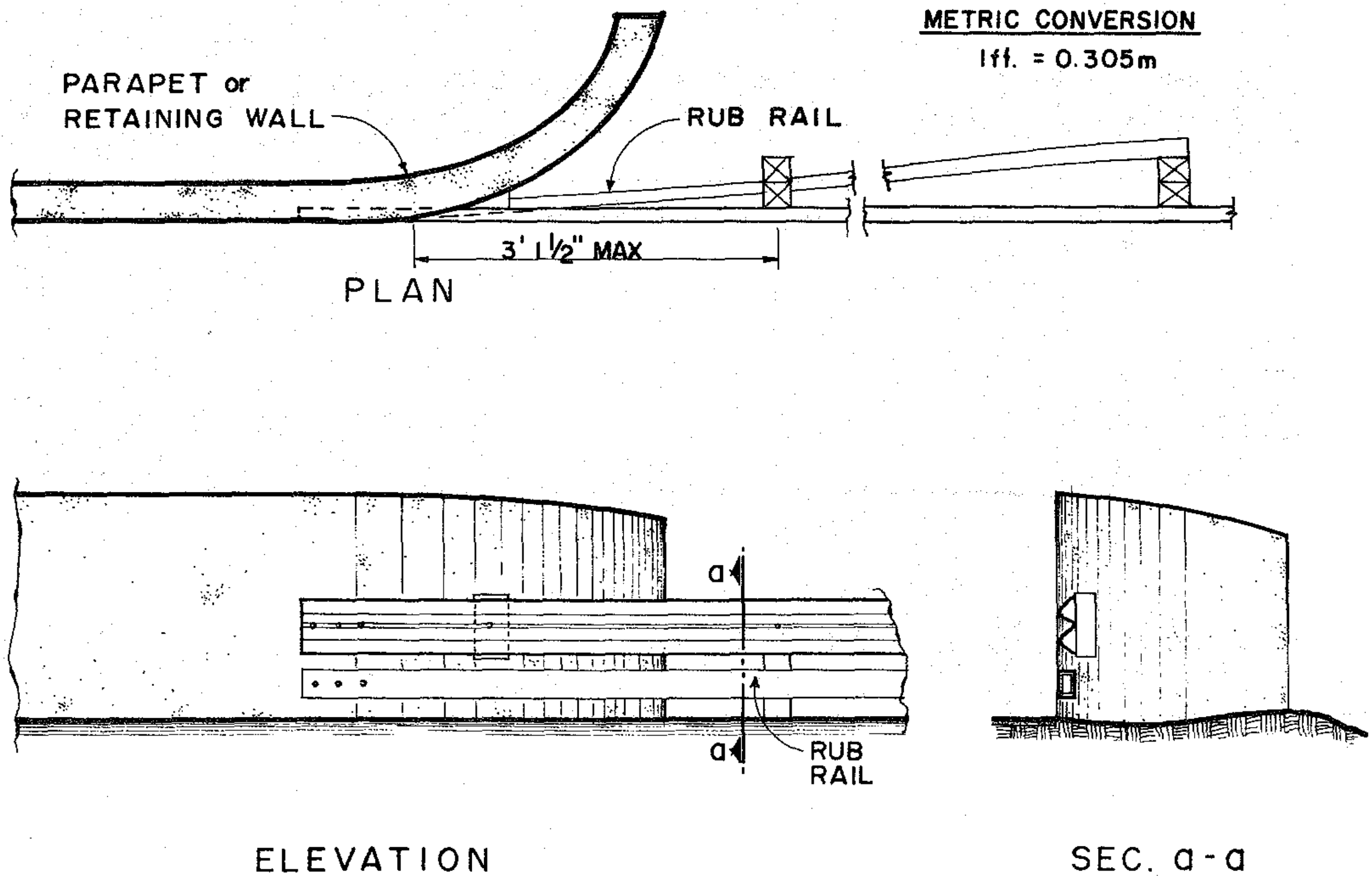


Figure III-B-2. A Suggested W-Beam to Parapet Connection the recessed area as illustrated in Figure III-B-2. The curved end of the parapet or retaining wall is desirable to further minimize the possibility of vehicle snagging. The designer is also encouraged to investigate the potential use of the thrie beam system (G9) for transition sections. Tests have shown that the thrie beam performs well as a transition rail (see TR4, Appendix B, Table B-10). Although there is no operational end treatment for the G9 system, solution to this limitation appears near.

(d) The length of the transition should be such that significant changes in the lateral stiffness do not occur within a short distance. It is suggested that the transition length be approximately 25 feet (7.6 m) at a minimum.

(e) The stiffness of the transition should increase smoothly and continuously from the weaker to the stronger system. This is usually accomplished by decreasing the post spacing and/or decreasing the post spacing and increasing the post size.

(f) The flare rate and lateral placement of a transition should adhere to the guidelines presented in Section III-E.

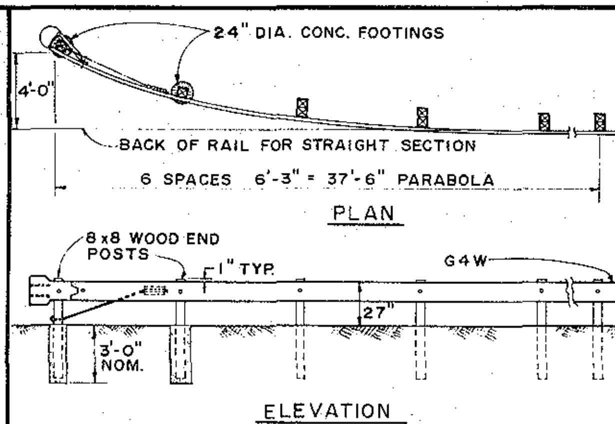
Design loads for roadside barriers are difficult to determine due to the number and complexity of variables involved. Nonetheless, the engineer is sometimes faced with the problem of designing a barrier element such as a transition section. NCHRP Report 115 (18) summarized available longitudinal barrier computer programs and analytical procedures used to investigate vehicle impacts, and presented an evaluation of each. The reader is encouraged to investigate these and other appropriate analytical models for possible application. As an aid in the design, a procedure for estimating the impact loads on a longitudinal barrier is presented in Appendix G. Although this procedure over-simplifies the actual vehicle-barrier interaction, it provides reasonable results and it is easy to use. In the absence of more accurate means, this procedure can be used.

III-B-3. End Treatment

An untreated end of a roadside barrier is extremely hazardous if impacted, since the beam of the system tends to penetrate the passenger compartment and will generally stop the vehicle abruptly. *A crashworthy end treatment is therefore recommended if the barrier terminates within the "clear distance".* As shown in Figure III-B-1, both an upstream terminal and a downstream terminal must be considered. The clear distance for the upstream terminal is dependent on the adjacent traffic and the clear distance for the downstream terminal is dependent on the opposing traffic. However, for most divided highways a crashworthy terminal for the downstream end would not be warranted. Reference should be made to Section III-E-4 for a further discussion of this subject.

To be crashworthy, the end treatment should not spear, vault, or roll the vehicle for head-on or "nose" impacts. Vehicle accelerations should not exceed the recommended limits. For impacts between the end and the standard section, the end treatment should have the same redirectional characteristics as the standard roadside barrier, which means that the end must be properly anchored. *The end treatment must be capable of developing the full tensile strength of the standard*

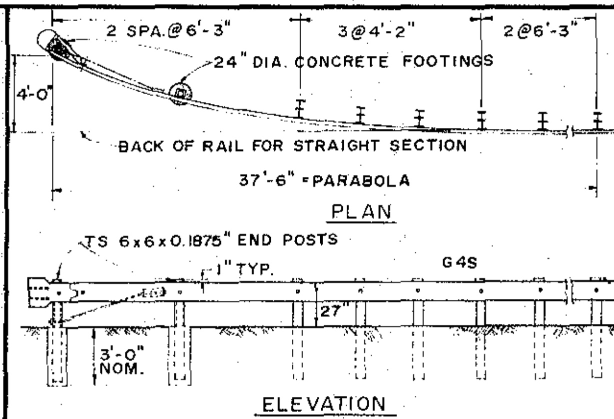
Table III-B-4. Operational Roadside Barrier End Treatments

Metric Conversions 1 ft. = 0.305m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg		
SYSTEM	GETI Breakaway Cable Terminal (Wood Post)	
BARRIER DESCRIPTION	TYPICAL POST - 8"x8" Douglas Fir; TERMINAL POSTS - 8"x8" Douglas Fir with 2 3/8" diameter hole through neutral axis; ANCHORAGE - Cable assembly (see sketch); FOOTING - 24" diameter, 36" deep concrete for terminal posts, other posts require none; BEAM TYPE - steel "W" section, 12 GA.; OFFSET BRACKETS - 8"x8" Douglas Fir block; MOUNTING - 5/8" diameter steel bolt.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	60.7	62.0
Angle (deg.)	0	27
Vehicle Weight (lb.)	3800	3900
BARRIER		
Deceleration Distance (ft.)	UNAV	3.3[3]
VEHICLE ACCELERATIONS (G's)[1]		
Lateral	1.5	3.4
Longitudinal	9.2	7.2
Total	UNAV	UNAV
VEHICLE TRAJECTORY		
Exit Angle (deg.)	Behind rail	≈30
Roll Angle (deg.)	UNAV	≈0
Pitch Angle (deg.)	UNAV	≈0
BARRIER DAMAGE	20' of "W" section and 2 end posts	20' of "W" section and 3 posts
REFERENCES	26	26
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	This system was tested with the G4(1W) system. Details of end posts, anchorage and footings are critical. Tests indicate that flare sections operate better than tangent sections. Although not documented by crash tests, it could be adapted for use with the G4(2W) system.	

UNAV — unavailable
[1]50 millisecond average unless otherwise noted
[2]If available, see summary in Appendix A
[3]Maximum dynamic deflection

Table III-B-4. Operational Roadside Barrier End Treatments (Continued)

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



SYSTEM	GET2 Breakaway Cable Terminal (Steel Post)	
BARRIER DESCRIPTION	TYPICAL POST - W6x8.5 steel; TERMINAL POSTS - TS6"x6"x0.1875" steel breakaway design; ANCHORAGE - Cable assembly (see sketch); FOOTING - 24" diameter, 36" deep concrete for terminal posts, other require none; BEAM TYPE - steel "W" section, 12 GA.; OFFSET BRACKETS - W6x8.5 steel; MOUNTING - 5/8" diameter steel bolt.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	62.0	58.0
Angle (deg.)	0	24
Vehicle Weight (lb.)	4423	4202
BARRIER		
Deceleration Distance (ft.)	UNAV	≈4.0[3]
VEHICLE ACCELERATIONS (G's)[1]		
Lateral	2.4	5.6
Longitudinal	9.0	8.2
Total	UNAV	UNAV
VEHICLE TRAJECTORY		
Exit Angle (deg.)	Behind rail	≈30
Roll Angle (deg.)	≈0	11
Pitch Angle (deg.)	≈0	≈0
BARRIER DAMAGE	25' of "W" section, 2 end posts and 2 W6x8.5 posts	25' of "W" section and 5 W6x8.5 posts
REFERENCES	27	27
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	This system was tested with the G4(1S) system. Details of end posts, anchorage system and footings are critical. Tests indicate that flare sections operate better than tangent sections. Although not documented by crash tests, it could be adapted for use with the G4(2S) and the G2 systems.	

UNAV — unavailable
[1]50 millisecond average unless otherwise noted
[2]If available, see summary in Appendix A
[3]Maximum dynamic deflection

rail element, whether a crashworthy end treatment is warranted or not.

Shown in Table III-B-4 are the two operational end treatments. Both systems are similar with the exception of the type of support post and the breakaway mechanism. As indicated on the form, the GET1 system is designed for terminating the G4(1W) roadside barrier but it could be adapted for use with the G4(2W) system. Similarly, the GET2 system is designed for the G4(1S) and G4(2S) systems but it could be adapted for use with the G2 system. In both of these systems, the "length of need" (see Section III-E) can be considered to begin at the third post from the end. It should be noted that at the time of this writing further refinements and modifications are being made to the GET1 and GET2 systems. The reader should contact the NCHRP for information on these developments. Table C-6 in Appendix C contains a summary of all crash test data available for end treatments. Although not shown, an inertia type crash cushion (see Section VI-B) could also be used to shield an untreated barrier end.

If possible, terminating and anchoring the roadside barrier in a backslope provides an excellent end treatment. In such cases, the approach rail should not violate the placement recommendations made in Sections III-B-3 and III-B-4.

III-C. Maintenance Characteristics

Table III-C-1 contains a number of maintenance factors which should be considered before selecting a roadside barrier system. The factors are grouped in one of four categories: collision maintenance, routine maintenance, environmental conditions, and material and storage requirements.

TABLE III-C-1. Maintenance Factors Influencing Roadside Barrier Selection

CATEGORY	CONSIDERATIONS
A. Collision Maintenance	1. Typical crew size 2. Typical man-hours to repair (exposure) 3. Typical barrier damage 4. Special equipment 5. Ability of rail to be repaired or straightened 6. Salvage value 7. Level of working knowledge
B. Routine Maintenance	1. Cleaning and painting 2. Mowing and clearing vegetation
C. Environmental Conditions	1. Snow or sand drifting 2. Snow or sand removal 3. Weathering or corrosion due to environment or chemical effects
D. Material and Storage Requirements	1. Dependence on a number of parts 2. Availability of parts 3. Storage facilities required

Collision maintenance concerns the activities required as a result of vehicle impacts. Such activities should play an important role in the selection of a barrier system since the majority of maintenance costs are usually due to collision repairs.

The number of impacts that will occur over any given length of barrier will depend on a number of factors, such as traffic volume, roadway alignment, distance barrier is off traveled way, etc. Chapter VII describes a method by which an estimate of the number of impacts can be made. It may be assumed, however, that the number of impacts is independent of the barrier selected, provided the lateral placement is the same for all systems considered. This assumption implies that delineation by a roadside barrier has negligible effect on impact frequency, something which has yet to be substantiated.

The extent of barrier damage for given impact conditions will depend on the strength of the barrier. Where available, the tables in Section B of this chapter give the barrier damage as a result of a crash test for specific impact conditions. To supplement these data, a gross survey was made of several states to determine typical collision repair values experienced. Table III-C-2 summarizes the available field data. It should be remembered that these are average values needed to repair a damaged section and not average values based on all hits. Many hits are only brushes and cause no appreciable barrier damage.

Information in Table III-C-2 was taken from both urban and rural areas. However, the data did not permit a differentiation between the two. It is speculated that the majority of the impacts with roadside barriers occur in urban areas where traffic densities are high. More

Table III-C-2. Collision Repair Data for Roadside Barriers.[1]

System	Typical Crew Size	Typical Material Repaired or Replaced: Rail (ft.)	Typical Material Repaired or Replaced: Posts	Average Refurbishment Time (Man-Hours/Foot of Rail)
G1-Cable Guardrail	UNAV	112	8	0.30
G2-W-Beam on Steel Weak Posts	UNAV	45	4	0.33
G3-Box Beam	5-6	32	5	0.92
G4(1W)- Blocked Out W-Beam on Wood Posts	4	35	4	0.35
G4(1S)-Blocked Out W-Beam on Steel Posts	3-4	38	4-5	0.32

[1]No data available for G4(2W), G4(2S), and G9 systems.

manpower is usually needed for traffic control purposes in urban areas than rural areas. In this regard, the hazard to both the motorists and the crew during repairs should be a major concern. Operating speeds for the roadways are unknown but it is probable that the data came primarily from high speed facilities.

Another important consideration in collision maintenance is the ability of the rail element, and possibly the post, to be straightened or repaired. Savings may be realized if the rail can be straightened. For example, one state reports that it straightens W-beam for less than 10 percent of its original cost. In some cases, the rail will be damaged beyond repair. In such cases, the salvage value of the rail is an important consideration.

The degree of expertise or the level of working knowledge of the system by the repair crew should be considered. Some systems require greater attention to details than others. A proven system installed or maintained improperly can be of little value.

Two items of consideration are listed under the routine maintenance category. In most cases, however, there would not be appreciable differences in these maintenance tasks for the operational systems.

Environmental factors may be important to consider in the selection process. Barriers with considerable frontage area may contribute to drifting of snow and sand. Snow plow operators should be cautioned against running the blade next to the face of roadside barriers. Experience has shown that this will tear the rail, loosen mounting hardware and loosen posts. Snow loads piled on top of the barrier may also cause damage as the snow settles and consolidates.

Before selecting a barrier system, an effort should be made to determine the future availability of the materials needed and their storage requirements. The need for the stocking of spare parts increases as a function of the number of parts in the barrier. In this regard, strong consideration should be given to use of barrier systems whose hardware has been standardized (22, 23). Reference should be made to Section III-B-1 for further information about standardization.

III-D. Selection Guidelines

Once it has been determined that a barrier system is warranted, a selection must be made. Although the process is complicated by the number of variables and the lack of objective criteria, there are guidelines which should be followed. In general, the most desirable system is one that offers the best protection at the least cost, and is consistent with the given constraints. Table III-D-1 presents eight items which should be considered before a selection is made. Although these items are not necessarily listed in order of importance, the deflection, strength, and safety requirements should never be compromised.

Section B of this chapter discusses the deflection, strength, and safety aspects of roadside barriers. It also presents the deflection, strength, and safety characteristics of the operational roadside barriers.

Maintenance factors which should influence barrier selection are discussed in Section C of this chapter. Available maintenance data on the operational systems are also presented there. A special point of interest in maintenance concerns the availability of replacement parts. Recent shortages in some barrier hardware has pointed to the need for

Table III-D-1. Selection Criteria For Roadside Barriers

ITEM	CONSIDERATIONS
A. Deflection	1. Space available behind barrier must be adequate to permit dynamic deflection of barriers.
B. Strength and Safety	1. System should contain and re-direct vehicle at design conditions.
	2. System should be least hazardous available, consistent with costs and other considerations.
C. Maintenance	1. Collision maintenance.
	2. Routine maintenance.
	3. Environmental conditions.
D. Compatibility	1. Can system be transitioned to other barrier systems?
	2. Can system be terminated properly?
E. Costs	1. Initial costs.
	2. Maintenance costs.
	3. Accident costs to motorist.
F. Field Experience	1. Documented evidence of barrier's performance in the field.
G. Aesthetics	1. Barrier should have a pleasing appearance.
H. Promising New Designs	1. It may be desirable to install new systems on an experimental basis.

advance planning and alternate hardware. Before selecting a system, material suppliers should give some assurance of future availability. Reference should be made to the discussion of standardization in Section III-B-1.

Compatibility is a very important item that should be considered in the selection process. Two major deficiencies of many roadside barriers are the absence of crashworthy transitions to other barriers (usually bridge rails), and the absence of crashworthy end or terminal treatments. Section B of this chapter addresses these problems and presents the operational transitions and terminal designs.

Initial costs and future maintenance costs in particular should be carefully evaluated. As a general rule, the initial cost of a system increases as a rigidity or strength increases but the maintenance costs usually decrease with increased strength. Also, the degree of hazard the barrier poses to the motorist may increase as the rigidity increases. Consideration should be given to the costs incurred by the motorist as a result of collision with the barrier. Both damage costs to the vehicle and injury costs to the occupants need to be evaluated for a typical collision. The decision may ultimately involve the question of what level of protection the state or agency is able to provide. The procedure presented in Chapter VII should provide a means with which to approach this question.

Item F in Table III-D-1 concerns field experience. There is no substitute for documented proof of a barrier's field performance. In this regard, the impact performance data for each operational system as presented in Section B of this chapter indicates the availability of field data. If none exists, the state or states which developed and/or implemented the system should be contacted for data and their views and comments.

With regard to aesthetics, the barrier should have a pleasing appearance. In scenic areas, it may be appropriate to select a barrier which allows the motorist the largest field of view possible. However, under no circumstances should aesthetics justify a compromise in the crashworthiness of the selection.

Many of the experimental systems included in Appendix B exhibit excellent impact performance characteristics. The designer should give serious consideration to the installation of some of these barriers, at least on an experimental basis. The performance of the barrier should be monitored and if proven satisfactory it may be installed on a permanent basis.

III-E. Placement Recommendations

Major factors to consider in the lateral placement of a roadside barrier are:

(1) uniform clearance and distance between barrier and hazard being shielded;

(2) effects of terrain between edge of traveled way and the barrier on the errant vehicle's trajectory;

(3) probability of impact with barrier as a function of its distance off the traveled way;

(4) flare rate and length of need of transitions and approach barriers; and

(5) slow moving vehicles on the shoulder of the roadway.

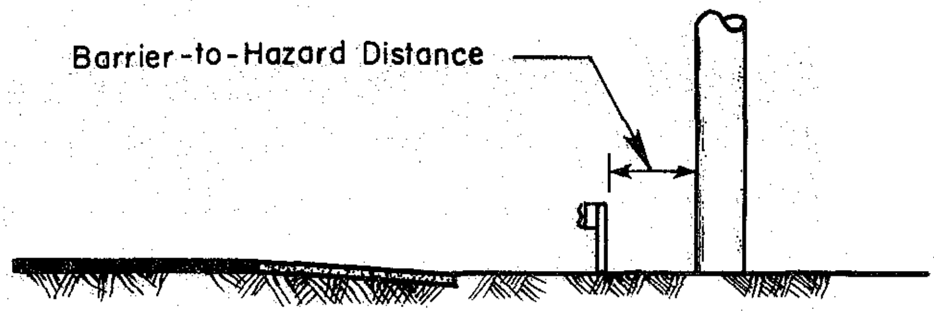
A discussion of each of these factors and the available criteria related thereto follows.

III-E-1. Uniform Clearance and Distance Between Barrier and Hazard

A highly desirable characteristic of any roadway is that it have shoulders of constant width, whether it is in a cut, fill, or on a structure. Uniform clearance to bridge rails or parapets, retaining walls, abutments, and roadside barriers is also desirable, especially in urban areas where there is a preponderance of such elements. Such an alignment of these elements enhances highway safety by reducing driver reaction and concerns for those objects and by reducing the probability of vehicle snagging. However, care must be exercised to insure proper transition designs where the roadside barrier connects with one of these other features. Care must also be exercised to insure a proper barrier-to-hazard distance, as discussed in subsequent paragraphs.

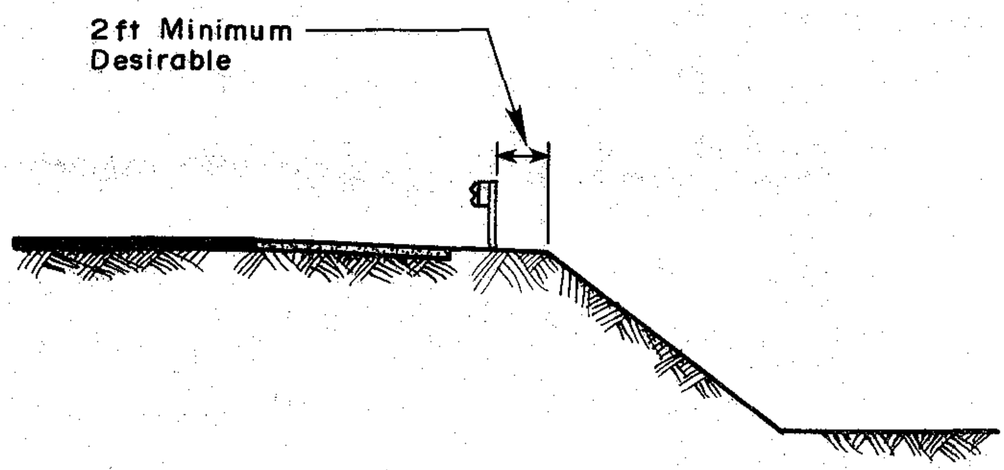
Where a roadside barrier is needed to shield an isolated hazard, adherence to the uniform clearance criteria is not essential. It is more important in such cases that the barrier be located as far from the traveled way as conditions permit (see Section III-E-2). However, *gaps less than approximately 200 feet (61 m) between barrier installations are to be avoided*. In such cases, the barrier should be continued at a constant distance from the traveled way until all hazards are shielded.

The amount a barrier will deflect upon impact is a critical factor in its placement, especially if the hazard being shielded is a rigid object. Figure III-E-1 illustrates the two basic types of roadside



(a) Rigid Object Protection

METRIC CONVERSION:
1ft = 0.305 m



(b) Embankment Protection

FIGURE III-E-1 Barrier-to-Hazard Distance for Roadside Protection

configurations of concern. If the hazard being shielded is a rigid object, the barrier-to-hazard distance should be sufficient to avoid snagging by the vehicle on the rigid object. If the hazard is a drop off or a steep embankment, the barrier-to-hazard distance should be sufficient to prevent the wheels from dropping and thus causing the vehicle to roll excessively. However, limited test results (17) indicate that the barrier-to-hazard distance for embankments is not as critical as it is for rigid objects. A 2 ft (0.61 m) minimum distance is desirable as shown in Figure III-E-1 (b). This minimum distance is also needed to insure adequate lateral soil resistance for the posts during impact.

Deflection characteristics for the operational roadside systems are given in Section B of this chapter and in Appendix B for the experimental systems. *The barrier-to-hazard distance for rigid objects should not be less than the dynamic deflection of the barrier for impact by a full-size automobile at impact conditions of approximately 25 degrees and 60 mph (96.5 km/hr).*

In some cases, the available space between the barrier and the hazard may not be adequate. In such cases, the barrier should be stiffened in the area of the hazard. This will involve a transition section, usually flared. The designer should refer to Section III-B-2 for structural design criteria and to Section III-E-4 for flare rate criteria.

III-E-2. Probability of Impact

As a general rule, a roadside barrier should be placed as far from the traveled way as conditions permit. As such, the probability of impact will be minimized. However, the lateral placement should not violate the requirements of Sections III-E-1, III-E-3, and III-E-4 of this chapter.

III-E-3. Terrain Effects

Terrain conditions between the traveled way and the barrier can have significant effects on the barrier's impact performance. Curbs and sloped roadsides are two prominent features which deserve special attention. A vehicle which traverses one of these features prior to impact may go over the barrier or submarine under the barrier or snag on its support posts. Research studies have provided considerable insight regarding the dynamic behavior of an automobile upon traversing a curb or a slope. Automobile orientation (translation and angular position) as a function of distance off the traveled way is now known for a number of curbs and slopes for various encroachment conditions (speed and angle of vehicle). Thus, the impact position of a car relative to a given barrier, placed at a given lateral distance from the traveled way, is now known for a variety of conditions. Background data, upon which the criteria in this section are based, are presented and discussed in Appendix F.

Curbs - In general, it has been found that curbs offer no safety benefits on high-speed roadways from the standpoint of vehicle behavior following impact. *It is therefore suggested that a curb, either used alone or when placed in front of a roadside barrier, not be used for purposes of redirecting errant vehicles.* Although curbs may improve delineation and drainage, it is suggested that other methods can be used to achieve these functions.

If special conditions require the use of a curb and if a roadside barrier is to be placed behind the curb, the reader should refer to the data in Appendix F for lateral placement guidelines. As a general rule, if the barrier face is within approximately 9 inches (0.23 m) of the curb's face, a vehicle, traveling at approximately 60 mph (96.5 km/hr), will not likely vault the barrier. However, if the top of the rail is approximately 27 inches (0.69 m) above the top of the curb, impacts with the rail can be expected to occur at lower than normal impact heights. This will occur since the vehicle will not undergo appreciable lifting before contact with the barrier occurs. In effect, the height of the rail exceeds its normal mounting height by the height of the curb. For such mountings, a rub rail should be placed between 15 to 20 inches (0.38 to 0.51 m) above the top of the curb.

Slopes - *As a general rule, a roadside barrier should not be placed on the embankment if the angle* α*, in Figure III-E-2, is greater than approximately 6 degrees.* For non-superelevated sections and a shoulder slope of 20:1, α of approximately 6 degrees is equivalent to a 10:1 embankment slope.

All of the roadside barrier systems presented in this guide were designed and tested for level terrain conditions only. If placed on slopes steeper than 10:1, studies have shown that for certain encroachment conditions, an errant vehicle could go over the present roadside barriers or impact them at an undesirable position.

In some special cases, it may be desirable to place the barrier on a slope steeper than 10:1. For example, where large fills are required, "barn top" or "barn roof" sections are sometimes provided,

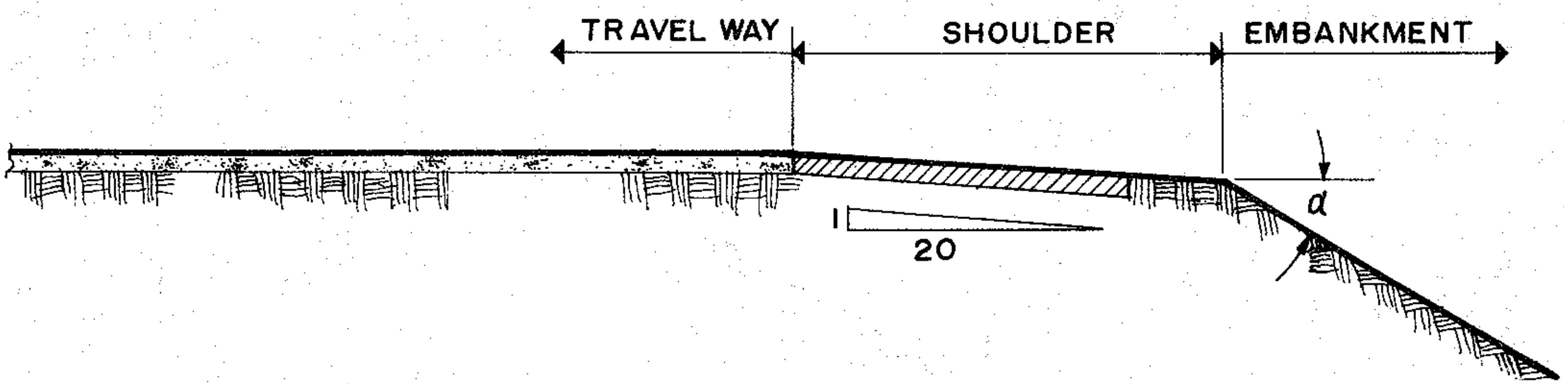


Figure III-E-2. Roadside Slope Definition as shown in Figure III-E-3. *As a general rule, a barrier may be placed on a 6:1 or flatter slope provided it is more than 12 feet (3.66 m) from the shoulder hinge point.*

As discussed in Section III-A-1, slope rounding enhances the ability of a driver to maintain control of an errant vehicle and it reduces the potential for the vehicle to become airborne. When the shoulder-to-embankment hinge has "optimum" rounding, as defined in Figure III-A-2, it may be desirable to place the barrier on the embankment, provided the slope is no steeper than 6:1.

III-E-4. Flare Rate and Length of Need

Figure III-E-4 illustrates the variables of interest in the layout of an approach barrier to shield an *area of concern*. Length of need is equal to the length of the area of concern parallel to the roadway, plus the length of the approach barrier on the upstream side (and downstream side if needed).

Ends of roadside barriers should be flared where possible. The function of the flare is threefold: (1) to locate the barrier and its terminal as far from the traveled way as is feasible, (2) to redirect an errant vehicle without serious injuries to the occupants, and (3) to minimize a driver's reaction to a hazard near the traveled way. With regard to the latter function, it has been shown (3) that an object (or barrier) which appears close to the traveled way may cause a driver to shift laterally, slow down, or both. Such reactions are undesirable. The flare should therefore be such that a driver does not perceive the barrier as a hazard.

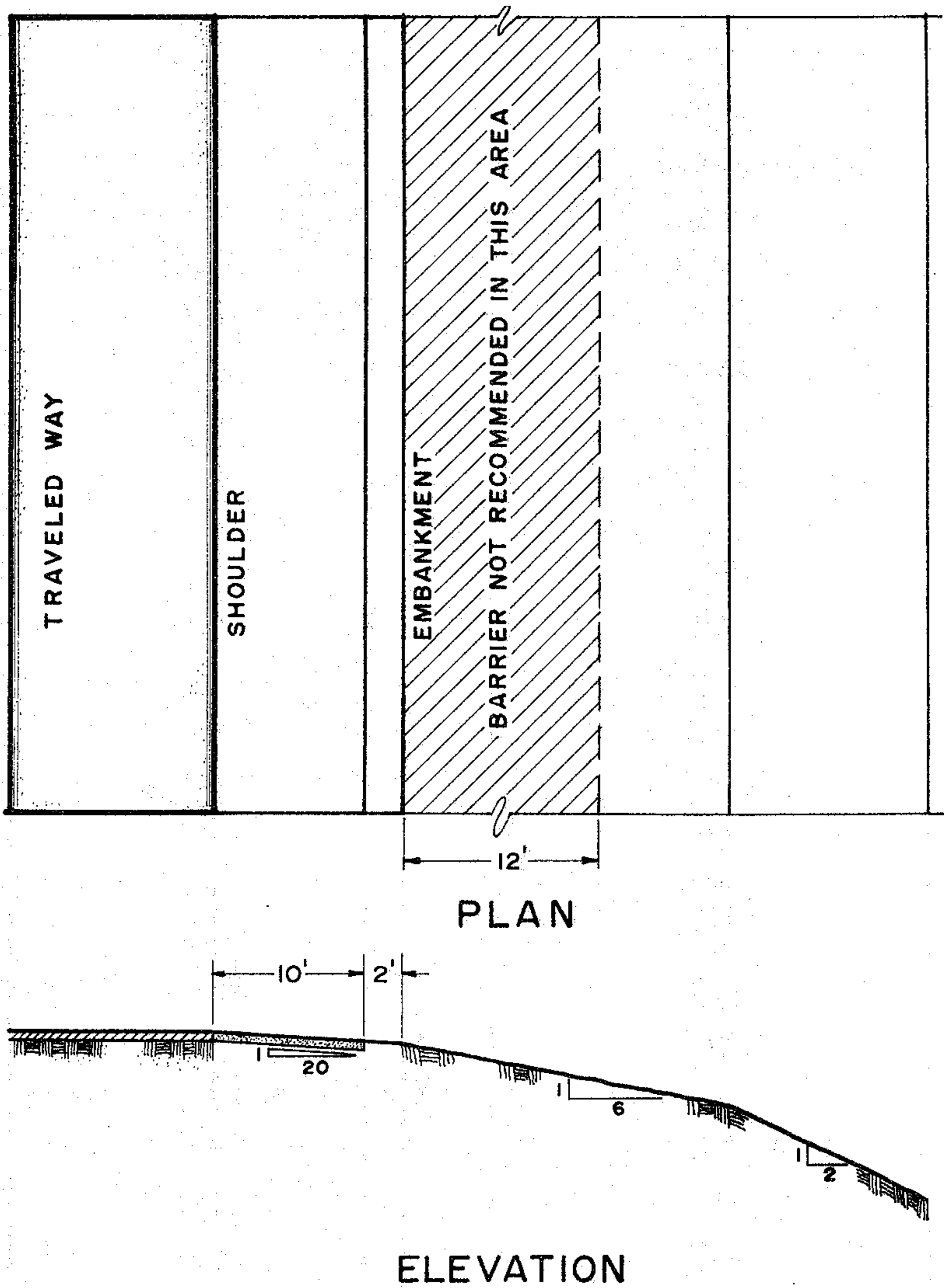


FIGURE III-E-3. Roadside Barrier Location on Typical Barn Top Section.

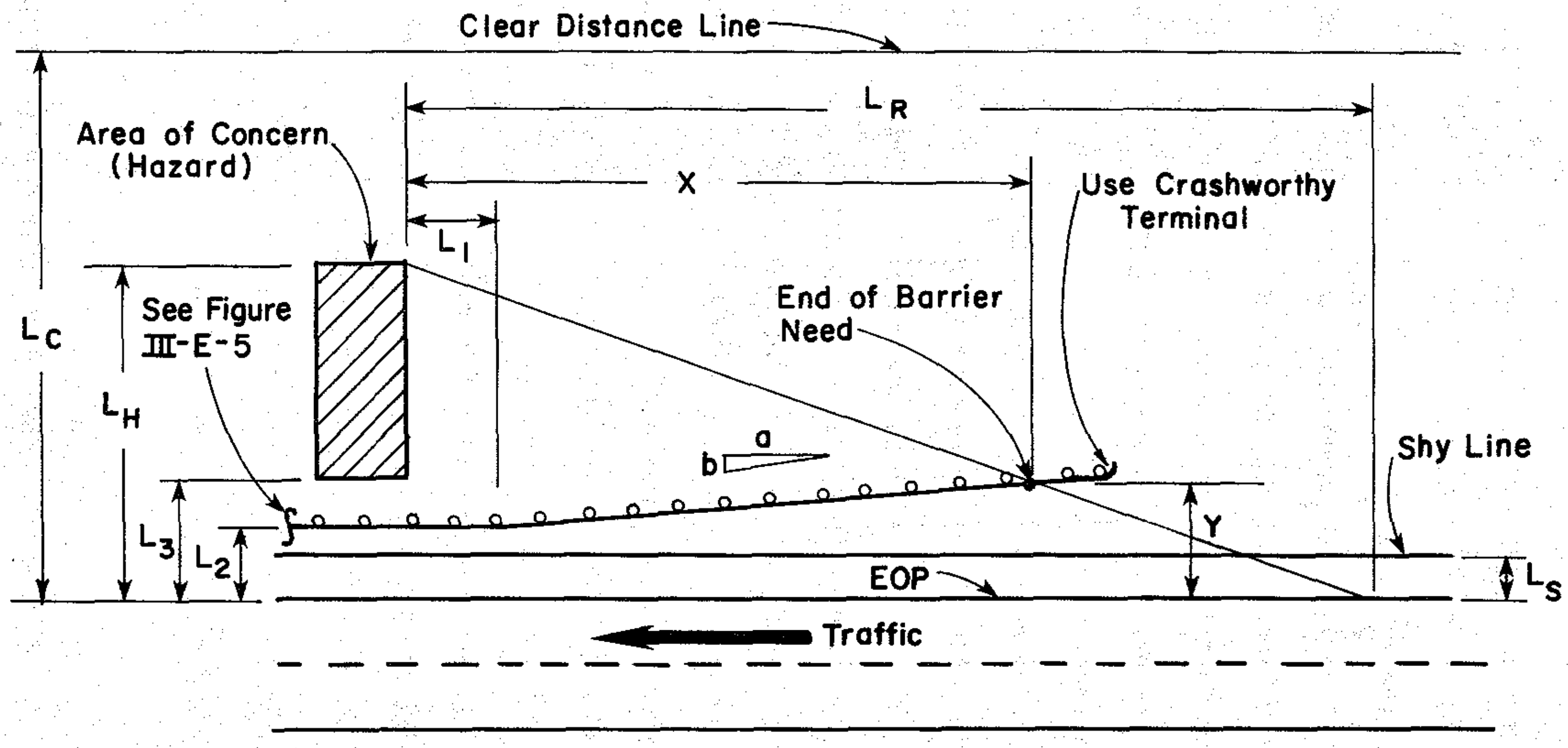


FIGURE III-E-4. Approach Barrier Layout Variables

If the flare rate is too steep, functions 2 and 3 may not be satisfied and if it is too flat functions 1 and 3 may not be satisfied. A compromise must therefore be made.

Table III-E-1 contains the suggested runout length (L_R), flare rate (a:b), and shy line offset (L_S) as a function of ADT and design speed. Shy line offset is defined as a distance beyond which a roadside object will not be perceived by a driver (143). In other words, a driver will not react to an object beyond the shy line offset. *If possible, the roadside barrier should be placed beyond the shy line offset.* Values in Table III-E-1 were determined from an evaluation of previous studies (16, 3, 41, 143) and engineering judgment.

For roadways with operating speeds of approximately 60 mph (96.5 km/h), clear distance (L_C) can be determined from Figure III-E-3. Clear distance criteria for roadways with lower operating speeds have not been established. In the absence of more objective data, the clear distances given in Figure III-E-3 may be reduced proportionally to the reduction in the runout length given in Table III-E-1, i.e., reductions below a design speed of 60 mph (96.5 km/h). For example, the required clear distance for a 6:1 slope on a 40 mph (64.4 km/h) facility with an ADT of 5000 would be computed as follows:

$$\frac{L_C \text{ (at 40 mph)}}{L_C \text{ (at 60 mph)}} = \frac{L_R \text{ (at 40 mph)}}{L_R \text{ (at 60 mph)}}$$

where

L_C(at 60 mph) = 50 ft (15.2 m), from Figure III-A-3;

L_R(at 40 mph) = 220 ft (67.1 m), from Table III-E-1; and

Table III-E-1. Design Parameters for Roadside Barrier Layout

	Traffic Volume (ADT)					
	Over 6000	2000-6000	800-2000	Under 800		
Operating Speed (mph)	Runout Length L_R(ft)	Runout Length L_R(ft)	Runout Length L_R(ft)	Runout Length L_R(ft)	Shy Line Offset (ft)	Flare Rate (a:b)
70	480	440	400	360	10.0	25:1
60	400	360	330	300	8.0	20:1
50	320	290	260	240	6.5	16:1
40	240	220	200	180	5.0	14:1

<u>Metric Conversions:</u>

1 ft = 0.305 m
1 mph = 1.61 km/h

L_R(at 60 mph) = 360 ft (109.7 m), from Table III-E-1.

Thus

$$\frac{L_C \text{ (at 40 mph)}}{50} = \frac{220}{360}$$

or

$$L_C \text{ (at 40 mph)} = 30.6 \text{ ft } (9.3 \text{ m}).$$

To determine the position (see Figure III-E-4) of the end of need, the following equations apply:

$$X = \frac{L_H + \left(\frac{b}{a}\right)\left(L_1\right) - \left(L_2\right)}{\left(\frac{b}{a}\right) + \left(\frac{L_H}{L_R}\right)} \qquad \text{(III-E-1)}$$

$$Y = L_H - \left(\frac{L_H}{L_R}\right)(X) \qquad \text{(III-E-2)}$$

where,

L_H = distance from edge of traveled way, commonly referred to as edge of pavement (EOP), to the lateral extent of the hazard. Note that L_H should never exceed the "clear distance" (L_C);

$\frac{b}{a}$ = slope of flare (see Figure III-E-4);

L_1 = length of tangent section of barrier upstream from hazard. When the approach barrier connects with a bridge parapet or bridge rail, a tangent section, consisting of a transition section, is commonly used;

L_2 = distance from EOP to tangent section of barrier; and

L_R = runout length (see Figure III-E-4).

Note that the distance (L_3-L_2) should satisfy the criteria of Section III-E-1.

Coordinates X and Y will locate the end of need for the approach barrier, however, *to terminate the barrier properly, some type of crashworthy end treatment should be used.* If the end treatment permits the vehicle to penetrate (such as the ET1 or ET2 design described in Section III-B-3), the end treatment should extend upstream from the point defined by X and Y. A vehicle should be redirected for contacts downstream of the point defined by X and Y. If the approach barrier is in a cut section, it is desirable to terminate the barrier by anchoring it in the back slope.

A parabolic layout of the flared section may also be used. If so, the maximum slope of the curve should not exceed the suggested slopes (flare rates) given in Table III-E-1.

It is noted that the flare rate of the end treatment or terminal is permitted to exceed the suggested flare rates provided such rates are essential for proper impact performance (as is the case for the ET1 and ET2 systems).

Figure III-E-5 illustrates the layout variables of an approach barrier for opposing traffic. The length of need and the end of the barrier are determined by use of Equations III-E-1 and III-E-2, together with the suggested values in Table III-E-1. However, note that all of the lateral dimensions are with respect to the edge of the traveled way of the opposing traffic. If there is a two-way divided roadway, the

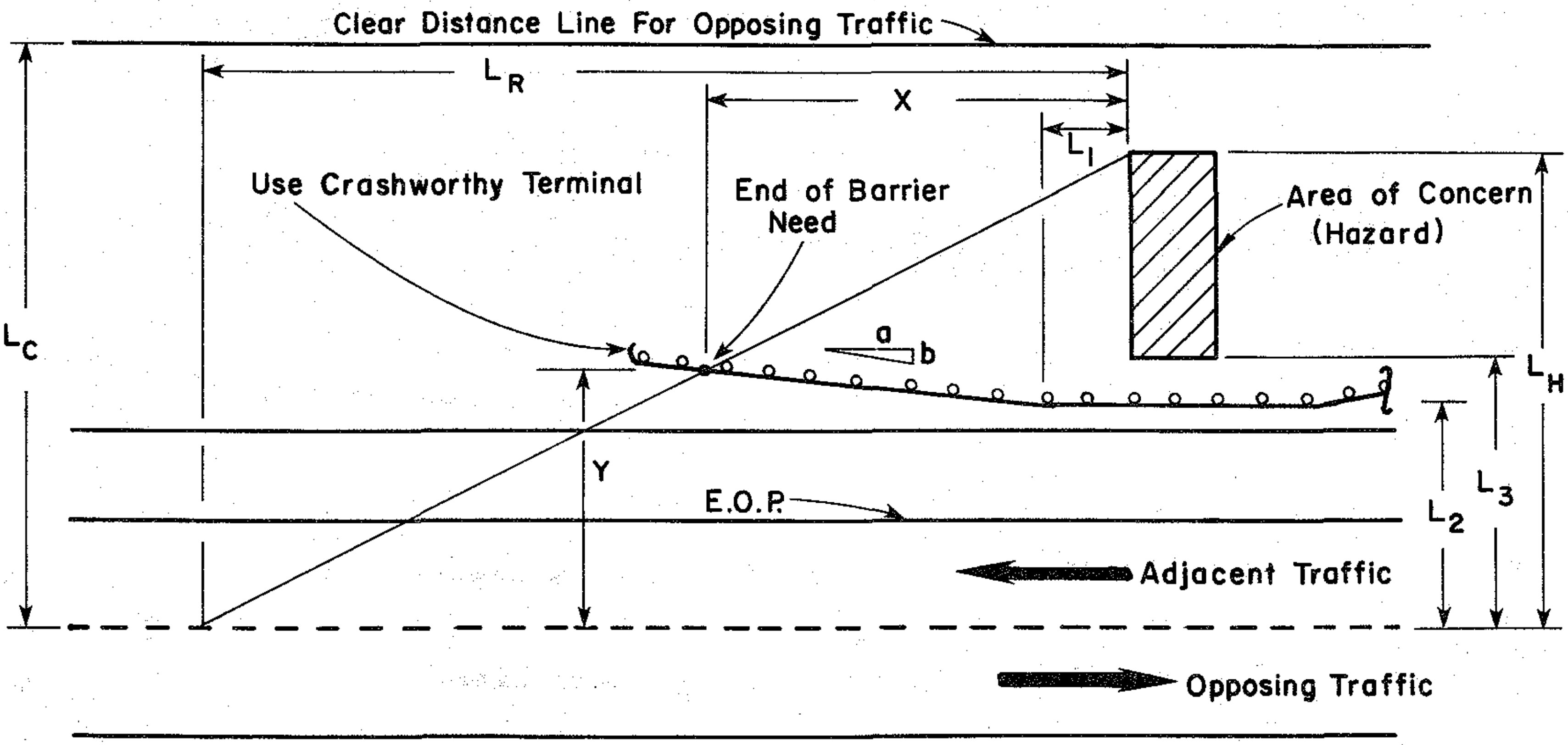


FIGURE III-E-5. Approach Barrier Layout For Opposing Traffic edge of the traveled way for the opposing traffic would be the EOP on the median side. There are three ranges of L_C which deserve special attention for an approach barrier for opposing traffic:

(1) $L_3 < L_C \leq L_H$ In this case use $L_H = L_C$.

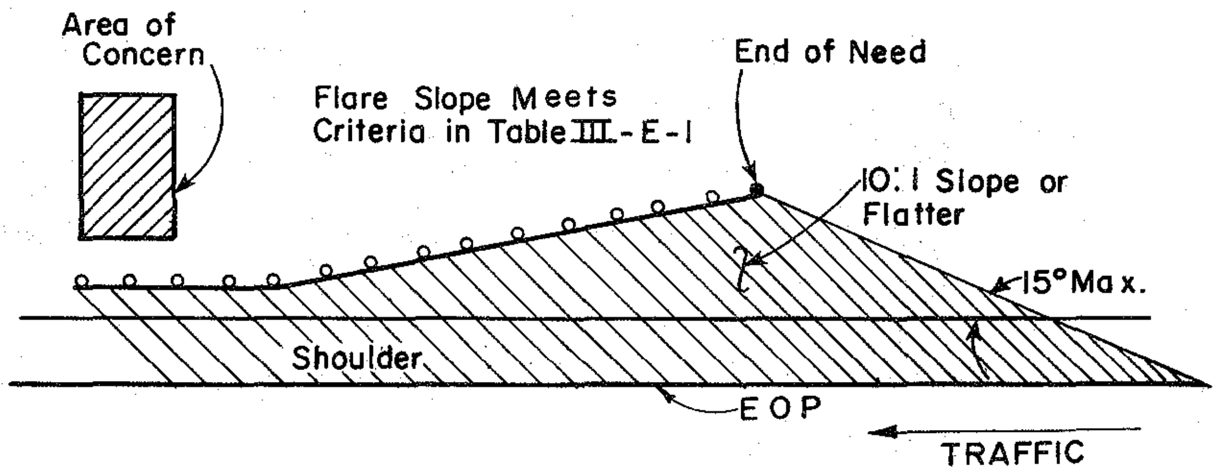
(2) $L_2 < L_C \leq L_3$ In this case, no approach barrier is needed (i.e., X = 0), but a crashworthy terminal is suggested.

(3) $L_C \leq L_2$ In this case, no approach barrier is needed and no crashworthy terminal is needed.

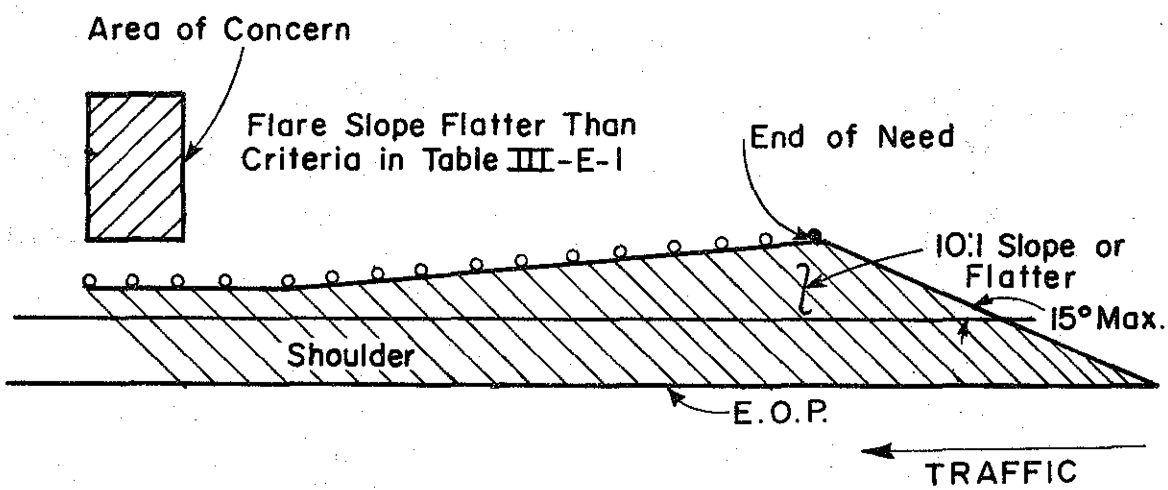
The lateral placement of the approach rail should also satisfy the criteria on embankment slopes in Section III-E-3. If the existing slope is greater than 10:1, it is suggested that fill be provided to flatten the slope to a 10:1, as illustrated in part A of Figure III-E-6. An acceptable alternative is to flatten the slope of the flare so that the embankment slope criteria is not violated, as illustrated in part B of Figure III-E-6. Note that in the latter alternative, a slightly longer length of approach barrier would be needed. In some cases, it may be necessary to have no flare at all on the approach barrier.

III-E-5. Slow Moving Vehicles

In some areas, there is a significant number of slow moving vehicles, primarily farm machinery, that travel on the shoulder of the roadway. In these areas, *consideration should be given to placing the barrier at a lateral distance that will allow slow moving vehicles to travel on the shoulder without obstructing the normal traffic, provided the placement does not compromise the impact performance of the barrier.*



(A) Desirable



(B) Acceptable

FIGURE III-E-6. Suggested Roadside Slopes For Approach Barriers

III-F. Upgrading Substandard Systems

III-F-1. Guidelines

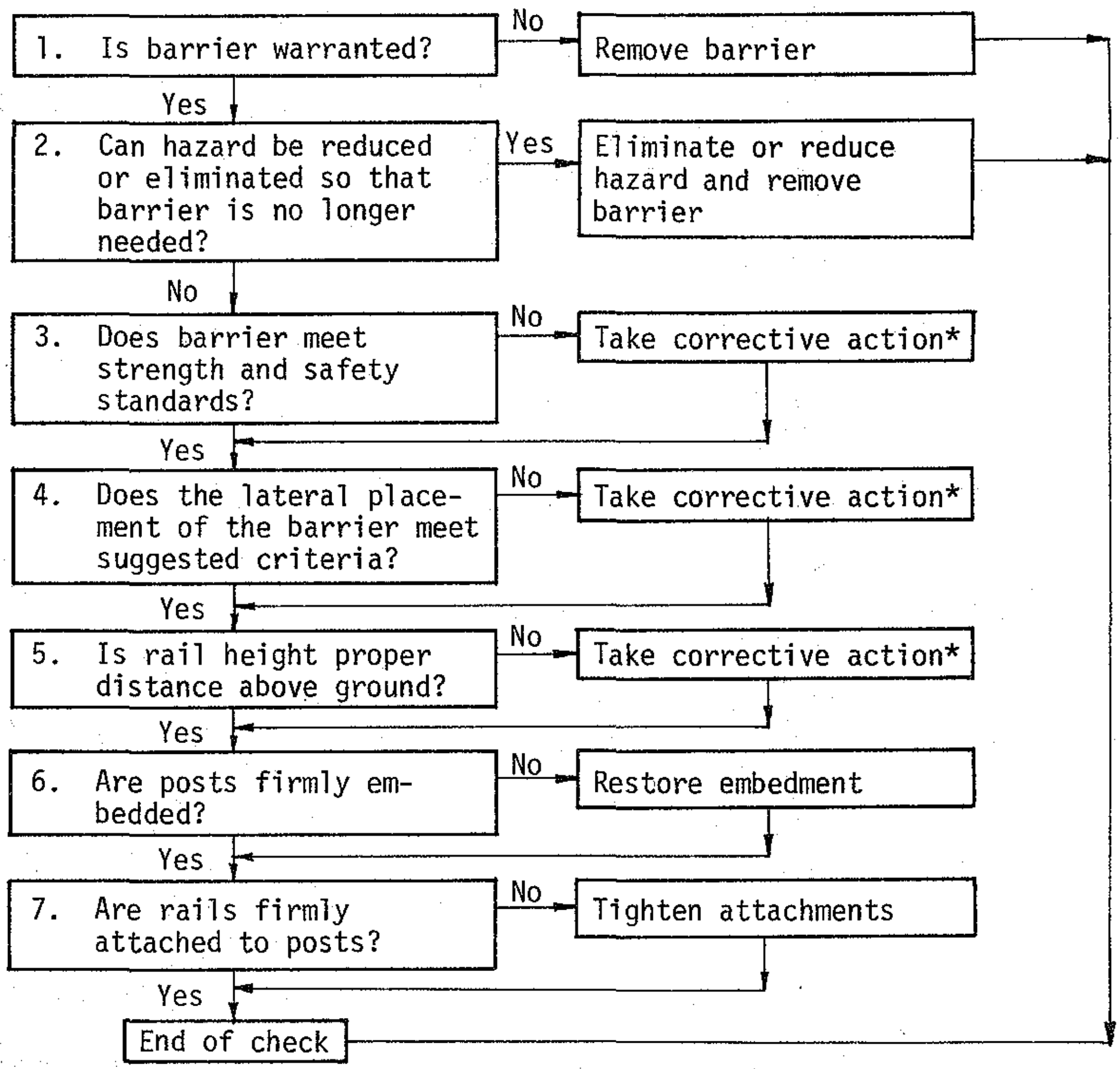
Some existing roadside barriers are not necessary while others are substandard and will not meet suggested performance levels. Substandard barriers usually fall into one of two categories, namely, those that have structural inadequacies and those that are improperly located.

Figure III-F-1 presents an inspection procedure designed to identify unnecessary or substandard barriers. It is suggested that this inspection be conducted on a regularly scheduled basis. *Personnel performing this inspection should stay abreast of current traffic barrier standards and guidelines as well as promising new research findings.*

With regard to item 3, the criteria presented in Section III-B should be used where possible to evaluate existing systems. Of course, there is no substitute for field data or accident records to evaluate the performance of a system. *If a barrier system is judged substandard, it is suggested that the barrier either be modified to conform to an operational system, or be replaced by an operational system.* It is recognized that this action is not always feasible and other remedial action must be taken. Table III-F-1 lists common structural inadequacies that occur and the suggested remedial action. If the upgraded system does not conform to an operational system, crash tests are suggested to verify the design, especially if substantial use of the system is planned.

The criteria given in Section III-E should be used to evaluate the adequacy of the lateral placement of existing barriers. If the barrier is placed on an embankment, in a depressed median etc., it may not

Figure III-F-1. Inspection Procedure for Existing Roadside Barriers



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*See text for discussion

Table III-F-1. Structural Inadequacies of Roadside Barriers

INADEQUACY	REMEDIAL ACTION
Transition Section	
·No rail continuity	·Attach to adjoining system to provide axial and flexure strength. May need new rail.
·Post too weak	·Increase post size or build up existing post.
·Post spacing too large	·Reduce post spacing to prevent pocketing or snagging of vehicle.
·No block out or rub rail	·Install block out and/or rub rail to prevent snagging by tires.
Terminal	
·Nonconforming end treatment	·Flare and anchor end of barrier in back slope if possible. ·Install crashworthy end treatment, such as ET1 system described in Section III-B-3.
Longitudinal Section	
·Post spacing too large	·Post spacing for W-beam rail should not be greater than approximately 6'3" (1.9 m) for high speed facilities.
·No block out or rub rail for strong post systems	·Install block out and/or rub rail to prevent snagging by tires. Use of Thrie Beam (see G6 system described in Section III-B-1 will eliminate need for rub rail.
·Too close to rigid object	·Move barrier to proper distance, or stiffen section near rigid object.

function properly. If improperly located, corrective measures should be considered. If necessary, the barrier can be moved near the shoulder's edge or returned to a position in which the approach terrain to the barrier is no steeper than the criteria suggest. Another possible solution would be to provide fill material to the lateral distance desired and place the barrier on the fill. Steep flare rates for approach and transition sections should be flattened to conform to the suggested criteria.

With regard to item 5 of Figure III-F-1, the rail height of an operational system should be approximately equal to the original design height of the system. In any case, it is suggested that the barrier be approximately 27 inches (0.69 m) above the ground or greater.

In some cases, the effective rail height will be decreased due to an accumulation of dirt, pavement overlays, etc. Of course, dirt should be removed if feasible to return the barrier to its correct height. If necessary and if the length and strength of the post and foundation permits, the rail can be raised an appropriate amount. If not, it may be necessary to install taller posts with added strength and deeper embedment to accommodate the increased rail height.

Items 6 and 7 of Figure III-F-1 can be accomplished by maintenance personnel.

III-F-2. Example Problem

The following example will illustrate how the guidelines in Section F can be applied to upgrade an installation.

Given: Figure III-F-2 shows a roadside barrier installation in which the design is substandard and the layout does not meet the suggested criteria. The design speed is 60 mph (96.5 k/h) and the ADT is 5,000. The problems with this installation are as follows:

a. Flare rate too steep.

b. No end treatment for exposed rail.

c. Barrier not structurally adequate since it is not anchored and it is too close to the pier for the post spacing.

d. No protection for the opposing traffic.

Required: Upgrade this installation according to the criteria and and guidelines contained herein.

Solution: From Table III-E-1,

L_R = 360 ft (109.7 m)

L_S = 8.0 ft (2.4 m);

a:b = 20:1

To determine the end of need for the approach barrier for the "adjacent" traffic, Equations III-E-1 and III-E-2 are used with the following values (refer to Figures III-A-3 and III-E-4):

L_C = 30 ft (9.1 m);

L_H = 15 ft (4.6 m);

L_1 = 0.0 (no tangent section); and

L_2 = 11.3 ft (3.4 m).

Due to the limited space between the edge of the shoulder and the pier, the barrier must be stiffened in the area of the pier. The dynamic

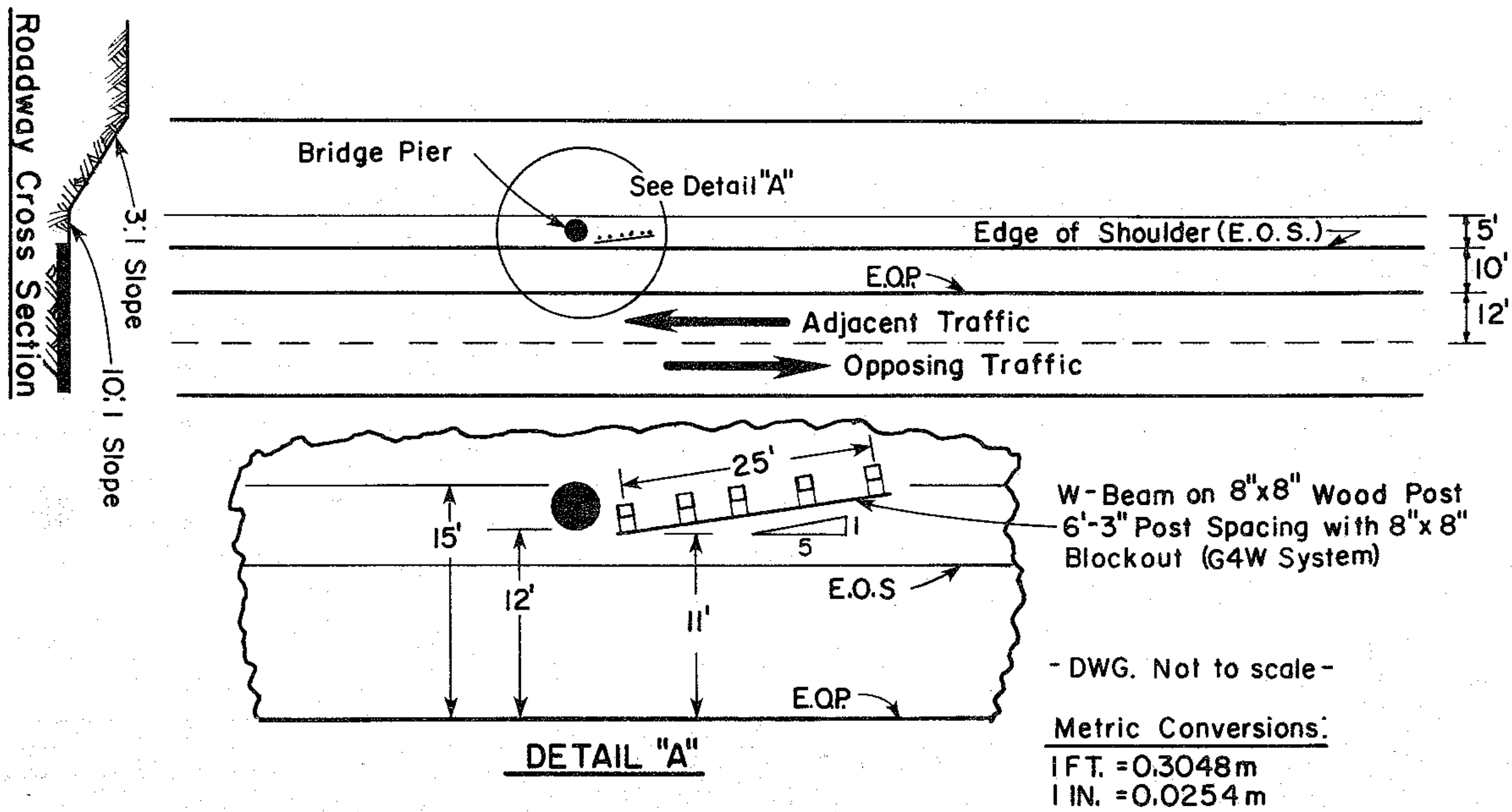


FIGURE III-F-2. Example of Substandard Design and Layout of Approach Barrier deflection of the G4(1W) system is 2.8 feet (0.85 m). Thus, the W-beam rail will be attached to the pier but blocked out by an 8 inch (0.2 m) by 8 inch (0.2 m) wood block. From Equations III-E-1 and III-E-2,

$X = 40.4$ ft (12.3 m), and

$Y = 13.3$ ft (4.1 m).

To determine the end of need for the approach barrier for the "opposing" traffic, Equations III-E-1 and III-E-2 are used with the following values (refer to Figures III-A-3 and III-E-4):

$L_C = 30$ ft (9.1 m)

$L_H = 27$ ft (8.2 m)

$L_1 = 0.0$ ft; and

$L_2 = 23.3$ ft (7.1 m).

Note that an approach rail for the opposing traffic is needed since L_H is less than L_C. Thus,

$X = 29.6$ ft (9.0 m) and

$Y = 24.8$ ft (7.6 m).

The suggested design and layout is shown in Figure III-F-3. Note that a T1 transition is suggested for the area near the pier and a G4(1W) system for the remainder of the barrier. Also note that an ET1 end treatment is suggested to terminate both ends of the barriers or some crashworthy end treatment. As an alternate end treatment, the barrier could be extended, at the given flare rate, to the back slope and anchored there. This would require considerably more barrier but it would eliminate the possibility of an end impact with the barrier. If anchored in the back slope, the guidelines of Section III-B-3 should be followed.

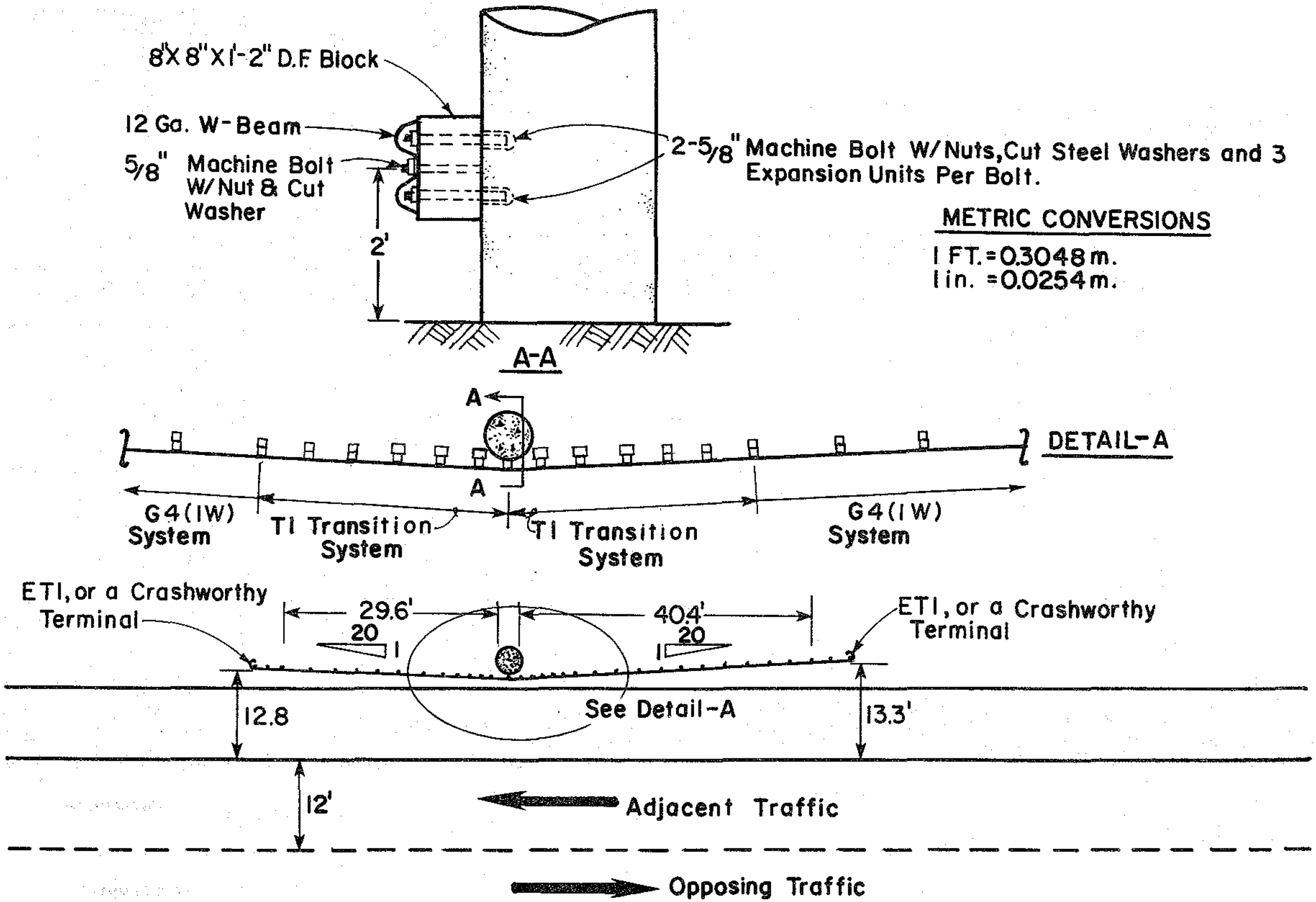


FIGURE III-F-3. Suggested Design and Layout for Example Problem

It is emphasized that the suggested design shown in this example is not unique. There are other designs which would serve the intended purpose. However, proven systems should be used as was done in this example to upgrade substandard systems where possible.

IV. MEDIAN BARRIERS

A median barrier is a longitudinal system used to prevent an errant vehicle from crossing the portion of a divided highway separating the traveled ways for traffic in opposite directions. It is the purpose of this chapter to delineate the criteria pertinent to the various elements of median barrier design, including warrants, structural and safety characteristics of operational systems, maintenance characteristics of operational systems, selection guidelines, placement recommendations, and guidelines for upgrading substandard installations. Figure IV-A-1 illustrates the three basic median barrier elements, namely, the standard section, the transition section and the end treatment.

IV-A. Warrants

IV-A-1. Standard Section

Figure IV-A-2 presents the suggested warrants for median barriers on high speed, controlled access roadways which have relatively flat, unobstructed medians. This criteria is based on an evaluation of median crossover accidents (28), research studies (29), and on the combined judgment of the Task Force which assisted in the preparation of this guide (30).

As indicated in Figure IV-A-2, median barriers are warranted for combinations of average daily traffic (ADT) and median widths that fall within the dotted area. At low ADT's, the probability of a vehicle crossing the median is relatively low. Thus, for ADT's less than 20,000 and median widths within the optional area of the figure, a

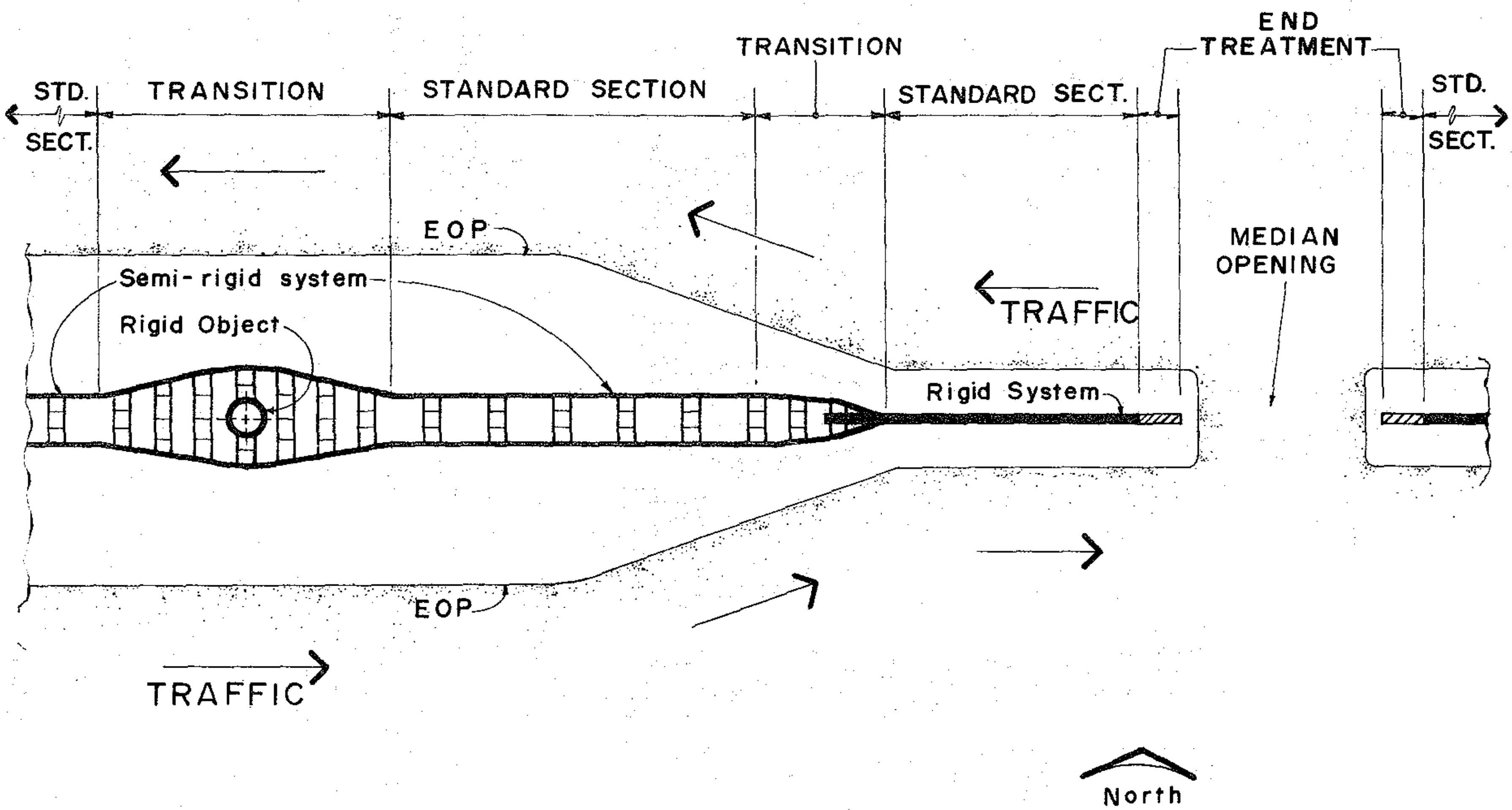


Figure IV-A-1. Definition of Median Barrier Elements

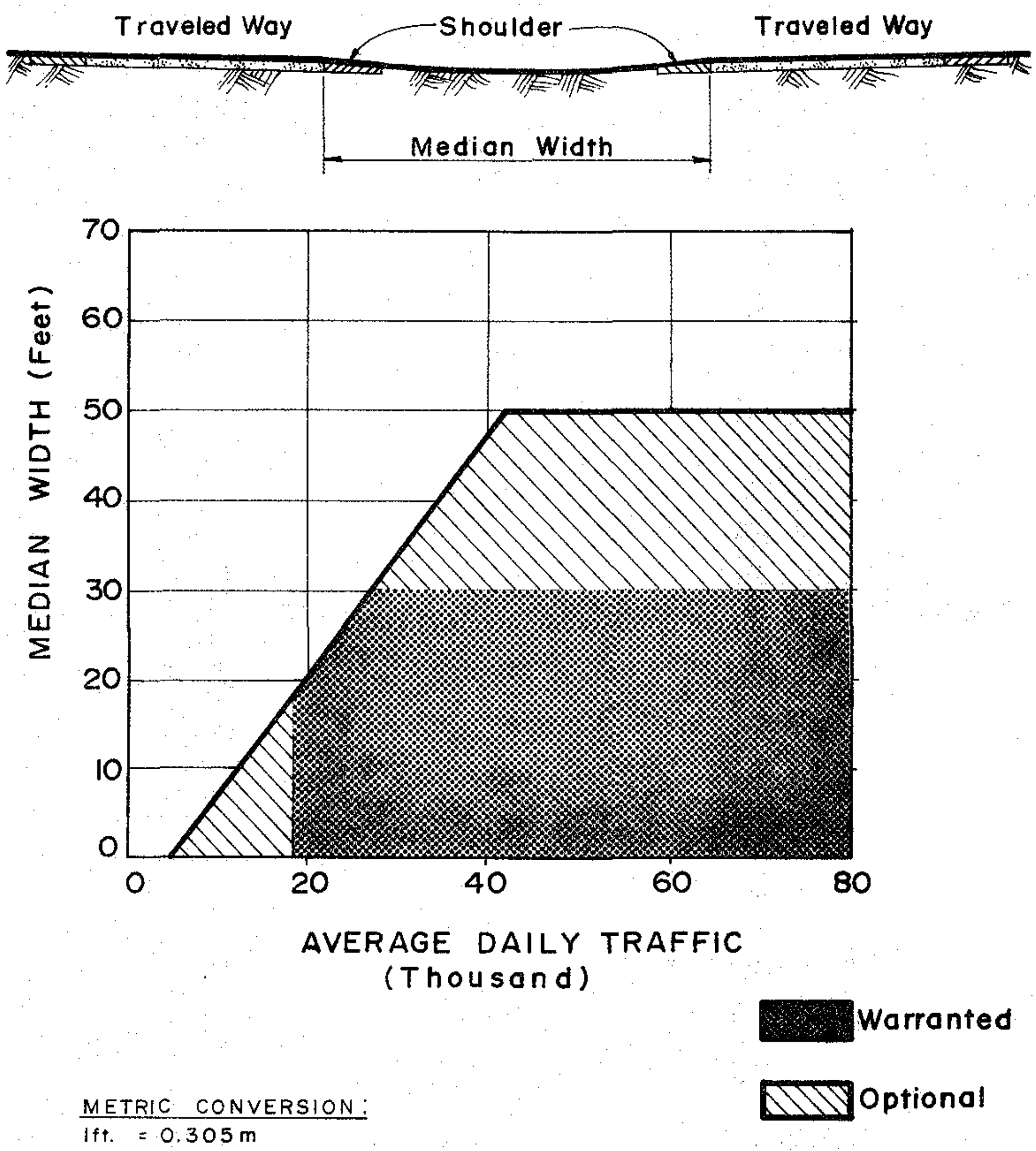


Figure IV-A-2. Median Barrier Warrants

barrier is warranted only if there has been a history of high rate of across-the-median accidents. For new roadways, an estimate of the potential for crossover accidents should be made for median widths falling within the optional areas. Likewise for relatively wide medians, the probability of a vehicle crossing the medians is also relatively low. Thus, for median widths greater than 30 ft (9.1 m) and within the optional area of the figure, a barrier may or may not be warranted, depending on the across-the-median accident history. Medians that are wider than 50 ft (15.24 cm) do not warrant a barrier unless there is an adverse history of across-the-median accidents. It should be noted that after a warranted median barrier is installed, accident severity will decrease, however, accident frequency will generally increase since the space available for return-to-the-road maneuvers is decreased.

Special consideration should be given to barrier needs for medians separating traveled ways at different elevations. The ability of an errant driver leaving the higher elevated roadway to return to the road or to stop diminishes as the difference in elevation increases. Thus, the potential for cross-over, head-on accidents increases. For such sections, it is suggested that the clear distance criterion given in Figure III-A-3 be used as a guideline for establishing barrier need.

Careful consideration should be given to the installation of median barriers on multilane expressways or other roadways with partial control of access. Problems are created at each intersection or median cross-over since the median barrier must be terminated at these points. An evaluation of the number of crossovers, accident history, alignment, sight distance, design speed, traffic volume, and median width should be made prior to non-freeway installations.

IV-A-2. Transition

Median barrier transition sections are warranted when it becomes necessary to connect median barriers of differing lateral stiffness. In general, a median barrier transition section is needed when there is a significant change in the lateral strength of the barrier. Another example is median barriers which must also shield fixed objects in a narrow median. In such cases, the median barrier is usually flared so that it encompasses the rigid object (for example, see TR5 system, Table B-10, Appendix B).

Rigid objects in wide medians which separate the traveled ways for traffic in opposite direction require special attention, i.e., medians of sufficient width which do not warrant a continuous median barrier. If the hazard warrants shielding for travel in one direction only, the criteria of Chapter III applies. If shielding is warranted for both directions of travel, the placement recommendations of Section IV-E should be followed.

IV-A-3. End Treatment

An untreated median barrier terminal is essentially a fixed-object hazard to the motorist. Therefore, *for freeways, a crashworthy end treatment is warranted if the median barrier is terminated within the clear distance.*

Emergency median openings in median barriers are to be minimized to avoid the end treatment problem. Highway engineers should work closely with law enforcement officials and other emergency vehicle officials in this regard. Emergency openings should never be installed for maintenance purposes.

IV-B. Structural and Safety Characteristics

This section presents operational median barrier systems and points out their desirable structural and safety characteristics. It is subdivided according to standard sections of median barriers, transitions, and end treatments.

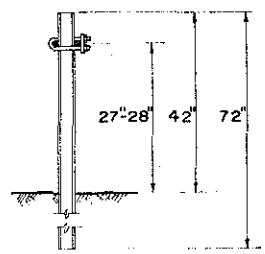
Structural and safety characteristics of operational systems within each of these three median barrier elements are presented on standard forms (e.g., see Table IV-B-1). The information consists of a sketch, a system designation, barrier description, impact performance, barrier damage, references, field performance data, and remarks. *Reference should be made to the introduction of Section III-B for a discussion of each of these items.* It is noted that the evaluation criteria for a median barrier is essentially the same as that for a roadside barrier, since both are longitudinal barriers whose functions are similar.

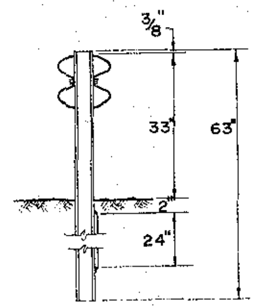
IV-B-1. Standard Sections of Median Barriers

Table IV-B-1 presents a summary of the structural and safety characteristics of current operational median barriers. Table IV-B-2 contains a summary of the impact performance data on each of the operational systems. Unfortunately, acceleration data are unavailable for several of the systems. Most of these systems were developed and tested prior to the establishment of the standard test procedures. Appendix B contains a summary of median barriers which appear promising but which do not have sufficient in-service use to be classified operational.

Table IV-B-1. Operational Median Barrier Systems

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

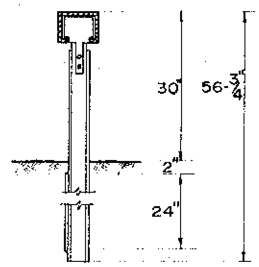
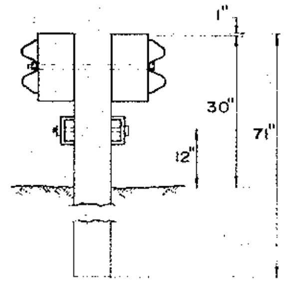




SYSTEM	MB1 Cable		MB2 "W" Section (Steel Weak Post)	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	 8' 0" H2-¼"x4.1" Two 3/4" diameter steel cables ------ ½" diameter steel "U" bolt Varied		 12' 6" S3x5.7 Two steel "W" sections None 5/16" bolts 8"x¼"x24" steel plate welded to post	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 25°	IMPACT ANGLE = 15°	IMPACT ANGLE = 25°
IMPACT CONDITIONS				
Speed (mph)	NO TEST	87.0	NO TEST	56.0
Vehicle Weight (lb.)		4300		3680
BARRIER				
Dynamic Deflection (ft.)		17.0		7.00
VEHICLE ACCLERATIONS (G's)[1]				
Lateral		UNAV		UNAV
Longitudinal		UNAV		UNAV
Total		UNAV		UNAV
VEHICLE TRAJECTORY				
Exit Angle (deg.)		UNAV		UNAV
Roll Angle (deg.)		UNAV		UNAV
Pitch Angle (deg.)		UNAV		UNAV
BARRIER DAMAGE		UNAV		UNAV
REFERENCES		138		1
FIELD PERFORMANCE DATA[2]	YES		YES	
REMARKS	Barrier suitable for wide flat medians.		System suitable for wide medians.	

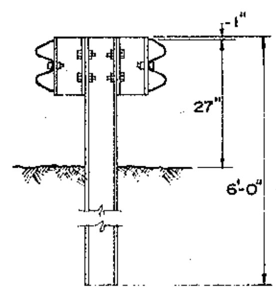
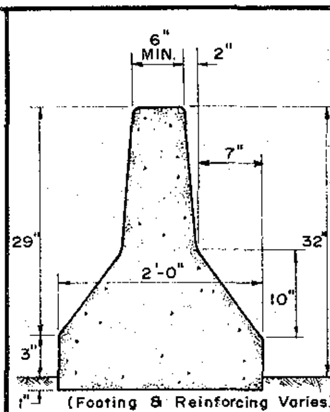
UNAV — unavailable
[1] 50 millisecond average unless otherwise noted
[2] If available, see summary in Appendix A

Table IV-B-1. Operational Median Barrier Systems (Continued)

Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg				
SYSTEM	MB3 Box Beam		MB4W Blocked-Out "W" Beam (Wood Posts)	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	6' 0" S3x5.7 8"x6"x¼" steel tube None Steel paddles 8"x¼"x24" steel plate welded to post		6' 3" 8"x8" Douglas Fir [3] Two "W" section, two C6x8.2 rubrails Two 8"x8"x14" Douglas Fir Blocks [4] 5/8" diameter bolts None	
IMPACT PERFORMANCE	IMPACT ANGLE =10°	IMPACT ANGLE =25°	IMPACT ANGLE =15°	IMPACT ANGLE =25°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	 49.0 4540	 56.0 3500	NO TEST	 69.0 4570
BARRIER Dynamic Deflection (ft.)	 0.75	 5.50		 ≈2.00
VEHICLE ACCLERATIONS (G's)[1] Lateral Longitudinal Total	 UNAV UNAV UNAV	 UNAV UNAV 5.30		 UNAV UNAV UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)	 3 0 0	 9 ≈5 ≈5		 15 UNAV UNAV
BARRIER DAMAGE	3 posts only.	30' of steel tube beam and 10 posts.		UNAV
REFERENCES	14	17		140
FIELD PERFORMANCE DATA[2]	YES		YES	
REMARKS	System suitable for wide medians.		Southern yellow pine is acceptable alternate for Douglas Fir. A "W" beam centered at 10" above grade is an acceptable alternate rubrail.	

UNAV — unavailable
[1] 50 millisecond average unless otherwise noted
[2] If available, see summary in Appendix A
[3] 6" x 8" post acceptable alternate based on G4(2W) test results.
[4] 6" x 8" x 14" block acceptable based on G4(2W) test results.

Table IV-B-1. Operational Median Barrier Systems (Continued)

Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg				
SYSTEM	MB4S Blocked-Out "W" Beam (Steel Posts)		MB5 Concrete Median Barrier	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	6' 3" W6X8.5[3] Two steel "W" sections Two W6X8.5[4] 5/8" diameter steel bolts None		Continuously poured, reinforced, sloped face, concrete section. Barrier can be anchored by dowels or an asphalt key. See text for further details of various configurations tested.	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 25°	IMPACT ANGLE = 15°	IMPACT ANGLE = 25°
IMPACT CONDITIONS				
Speed (mph)	67.0	NO TEST	60.7	62.4
Vehicle Weight (lb.)	3500		4210	4000
BARRIER				
Dynamic Deflection (ft.)	1.50		0.00	0.00
VEHICLE ACCLERATIONS (G's)[1]				
Lateral	UNAV		6.00	9.00
Longitudinal	UNAV		5.00	7.00
Total	5.70		UNAV	UNAV
VEHICLE TRAJECTORY				
Exit Angle (deg.)	9		11.5	7
Roll Angle (deg.)	0		≈25	≈35
Pitch Angle (deg.)	0		≈10	≈20
BARRIER DAMAGE	25' of "W" section and 2 posts.		None	None
REFERENCES	17		31	31
FIELD PERFORMANCE DATA[2]	YES		YES	
REMARKS			Good redirection for impact angles of 15° or less. At larger impact angles vehicle roll and pitch may become critical. Recommended use on narrow medians, retaining walls, rock cuts, etc. Several modified versions have been tested, see text.	

UNAV — unavailable

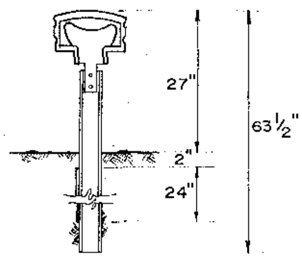
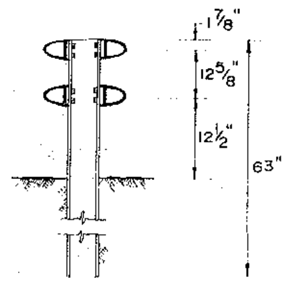
[1] **50 millisecond average unless otherwise noted**

[2] **If available, see summary in Appendix** A

[3] 4 1/3" x 5 5/8" x 3/16" "C" steel post acceptable based on G4(2S) test results.

[4] 4 1/3" x 5 5/8" x 3/16" "C" steel blockout acceptable based on G4(2S) test results.

Table IV-B-1. Operational Median Barrier Systems (Continued)

Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg				
SYSTEM	MB 7 Aluminum Strong Beam		MB 8 Aluminum Balanced Beam	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	6' 3" Aluminum I or steel S3x5.7 Aluminum extrusions None Steel or aluminum paddles 8"x3/16"x24" steel or aluminum plate		12' 6" 5½"x7¼" H section aluminum 5½"x7¼" H section aluminum Four standard aluminum extrusions None Standard Hardware None	
IMPACT PERFORMANCE	IMPACT ANGLE =15°	IMPACT ANGLE =26.6°	IMPACT ANGLE =7°	IMPACT ANGLE = 25°
IMPACT CONDITIONS				
Speed (mph)	53.0	62.7	51.0	56.0
Vehicle Weight (lb.)	4000	4057	4000	4000
BARRIER				
Dynamic Deflection (ft.)	1.50	7.20	UNAV	UNAV
VEHICLE ACCLERATIONS (G's)[1]				
Lateral	UNAV	4.10	0.70	4.0[3]
Longitudinal	UNAV	3.70	1.00	9.0[3]
Total	UNAV	UNAV	UNAV	UNAV
VEHICLE TRAJECTORY				
Exit Angle (deg.)	UNAV	UNAV	4	≈0
Roll Angle (deg.)	UNAV	UNAV	UNAV	UNAV
Pitch Angle (deg.)	UNAV	UNAV	UNAV	UNAV
BARRIER DAMAGE	UNAV	UNAV	UNAV	UNAV
REFERENCES	1	1	1	1
FIELD PERFORMANCE DATA[2]	NO		NO	
REMARKS				

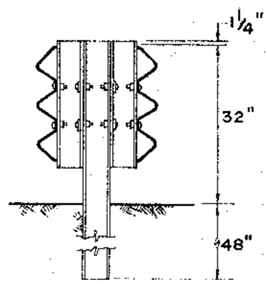
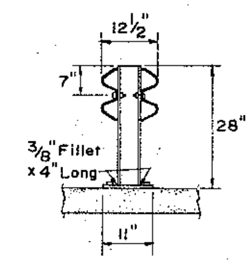
UNAV — unavailable

[1]50 millisecond average unless otherwise noted

[2]If available, see summary in Appendix A

[3]From mechanical peak-g accelerometer

Table IV-B-1. Operational Median Barrier Systems (Continued)

Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg				
SYSTEM	MB 9 Blocked-Out Thrie Beam (Steel Post)		MB 10 Metal Beam Guard Fence (Steel "Breakaway" Post)	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	 6' 3" W6x8.5 Two Thrie Beams W6x8.5 5/8" diameter steel bolts UNAV		 6' 3" W6x8.5 steel Two steel "W" sections None 5/8" diameter bolt 7"x11"x5/8" steel plate	
IMPACT PERFORMANCE	IMPACT ANGLE = 17°	IMPACT ANGLE = 25°	IMPACT ANGLE = 14.7°	IMPACT ANGLE = 25°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	 54.1 2200	 66.1 4500	 63.4 4200	 57.3 3640
BARRIER Dynamic Deflection (ft.)	 0.33	 3.17	 1.00	 1.50
VEHICLE ACCLERATIONS (G's)[1] Lateral Longitudinal Total	 5.30 2.00 UNAV	 6.30 6.60 UNAV	 6.30 4.30 UNAV	 UNAV 10.0 UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)	 ≈2.0 0 0	 less than 10 0 0	 3.8 0 0	 19.7 less than 10 less than 10
BARRIER DAMAGE	None	25' of thrie beam and 3 posts.	50' of "W" section and 3 posts	50' of "W" section and 3 posts.
REFERENCES	21	21	32	31
FIELD PERFORMANCE DATA[2]	NO		NO	
REMARKS	Provides smooth redirection. Rub-rail not needed. Chance of vehicle snagging on post is minimal.		Good redirection. Some wheel snagging occurred in 25° test, but was not severe. Fillet weld at base is 3/8" weld along outside edge of flange only. This is critical for shearing at low impact energies.	

UNAV — unavailable

[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A

Table IV-B-2. Median Barrier Data Summary

System	Maximum Dynamic Deflection (ft.)[1]	Accelerations at 15° (G's)[2]			Accelerations at 25° (G's)[2]			Is Barrier Hardware Standardized?[3]
		Lateral	Longitudinal	Total	Lateral	Longitudinal	Total	
Flexible Systems								
MB1	17.0	No Test	No Test	No Test	UNAV	UNAV	UNAV	Yes
MB2	7.0	No Test	No Test	No Test	UNAV	UNAV	UNAV	Yes
Semi-Rigid Systems								
MB3	5.5	UNAV	UNAV	UNAV	UNAV	UNAV	5.3	Yes
MB4W	≈2.0	No Test	No Test	No Test	UNAV	UNAV	UNAV	Yes
MB4S	1.5[4]	UNAV	UNAV	5.7	7.1	7.6	UNAV	Yes
MB7	7.2	UNAV	UNAV	UNAV	4.1	3.7	UNAV	Yes
MB8	UNAV	0.7	1.0	UNAV	4.0[5]	9.0[5]	UNAV	Yes
MB9	3.2	5.3	2.0	UNAV	6.3	6.6	UNAV	Yes[6]
MB10	1.5	6.3	4.3	UNAV	UNAV	10.0	UNAV	No
Rigid System								
MB5	0.0	6.0	5.0	UNAV	9.0	7.0	UNAV	Yes

UNAV - Unavailable

Metric Conversion: 1 ft = 0.305 m.

[1]Based on 25° impact unless otherwise noted.
[2]50 millisecond average unless otherwise noted.
[3]See reference 22, 23.
[4]Based on 15° impact data.
[5]Peak acceleration.
[6]To be included in a revised edition of references 22, 23.

Although it is difficult to classify or categorize the performance of median barriers, they are usually denoted as one of three types: *flexible, semi-rigid,* or *rigid.* Flexible systems undergo considerable dynamic deflection upon impact and are generally more *forgiving* than the semi-rigid or the rigid systems since they impose lower impact forces on the vehicle.

Based on the test results shown in Table IV-B-2, systems MB1 and MB2 are considered to be flexible barriers. In these systems, the resistance to impact is due in most part to the tensile force developed in the cable (MB1) or the W-beam (MB2). The cable and the rail tear away from the support posts upon impact, the posts thus offering negligible resistance in the impact zone. However, posts outside the impact zone provide resistance essential to control the deflection to an acceptable limit. Splices are designed to carry the full tensile strength of the cable (MB1) or the rail (MB2).

Systems MB3 through MB4S and systems MB7 through MB10 are considered semi-rigid barriers. In the MB3 and the MB7 systems, the resistance is achieved through the rail's combined flexure and tensile stiffness. The posts near the point of impact are designed to break or tear away, thereby distributing the impact force by beam action to adjacent posts. The remaining semi-rigid systems resist impact through the combined tensile and flexural stiffness of the rail and the bending resistance of the posts. In the MB10 system, the posts are designed to breakaway at the base at a relatively low impact force, about 5,000 pounds (22,240 N). Note that the rail is blocked out from the support post in the "strong post" systems, with the exception of the MB8 and MB10 systems. Block-outs in these systems minimize the potential for vehicle snagging on the posts and reduce the tendency for the vehicle to vault over the rail. Additional protection against snagging is provided in the MB4W by the rub rail.

The MB5 system or the Concrete Median Barrier (CMB) is the only operational rigid median barrier. However, variations in the footing and reinforcing of the MB5 have been tested and proven adequate. These variations are summarized in Table IV-B-3. A continuously poured, post tensioned MB5 system has also been tested but has not received sufficient in-service experience to be classified as operational (see MBE2 system, Table B-3, Appendix B).

A considerable amount of interest has been shown in precast segments for the MB5 system, and some crash tests have been performed. Reference should be made to systems MBE1 and MBE3, Table B-3, Appendix B, for promising precast barriers. As of this writing, these systems have not received ample in-service experience to be classified as operational. To date, there has been no general agreement as to the minimum lengths permitted in precast segments, the connection details, the anchorage details, and the amount of reinforcing needed for handling and/or impact performance.

It is also to be noted that current research (57) indicates that the impact performance of the MB5 system can be improved by slight changes to its shape. Reference should be made to the MBE4 system (known as Configuration F), Table B-3, Appendix B, for the suggested new shape. The MB5 shape is shown on the drawing as a dotted line. The reader should keep abreast of these and other median barrier developments.

Table IV-B-3. Variations in the Continuous Concrete Median Barrier Design (MB5)

Barrier Configuration	Length of Barrier Tested(ft.)	Reinforced?	Description of Reinforcing	Description of Footing	Reference
A	150	Yes	8 - #5 continuous, grade 60, reinforcing bars.	System placed on grade. 1 in. layer of hot mix asphalt placed at base of barrier to provide lateral restraint.	31
B	160(poured in 20 ft. segments)	No	None	Base of system (unreinforced concrete) is extended 10 in. below grade.	14
C	97	Yes	1 - #4, continuous, reinforcing bar. Additional reinforcing is provided by 3/4 in. diameter cable from existing lowered cable barrier.	System is placed on grade over existing lowered cable barrier. Footing of existing barrier provides lateral restraint.	33

Note: 1 ft. = 0.305 m; 1 in. = 25.4 mm

Note that the rail heights range from 27 inches (0.69 m) to 33 inches (0.84 m). A minimum height of approximately 27 inches (0.69 m) is a necessary, but not sufficient, condition to insure proper barrier impact performance. The barrier must also be designed so that upon impact the rail remains essentially at its original mounting height. Note also that the post spacing for "strong post" systems is 6.25 feet (1.91 m) with the exception of the MB8 system. Tests have shown that this spacing is needed for this type of system to minimize vehicle snagging or pocketing.

Current research indicates that the most desirable height of the MB5 system is 32 inches (0.81 m). This height has been reached after carefully evaluating factors such as vehicle redirection, sight distance, structural stability of the barrier, and the psychological effect of barrier height on driver reaction. Unless sufficient justification exists, variations in this height are to be avoided.

The degree to which the operational systems satisfy the recommended structural and safety criteria of Section II-B varies. All are considered to be structurally adequate, although some obviously deflect more than others. Although all do not satisfy the impact severity criteria, the acceleration criteria is tenuous and currently under review. *Nonetheless, median barriers which minimize impact forces should receive strong consideration.* With regard to the vehicle trajectory hazard, it is desirable that the vehicle be redirected parallel to the barrier. An exit angle of 10^{o} or less may be considered a non-hazardous post impact trajectory.

The designer should be aware of the impact performance sensitivity of median barriers to a number of conditions. These include soil conditions, length of installation, type of end anchorage and rail tension, post spacing and post size. Some of these parameters have been investigated and the reader is encouraged to review the results (18).

An effort has been made to standardize hardware for widely used traffic barriers (22, 23). Standardization is beneficial in terms of economy, improved availability of parts, readily available details and specifications, reduced repair time, and reduced inventory of replacement parts because of interchangeability of parts. Median barriers which have been standardized are so noted in the last column of Table IV-B-2. The referenced standardized documents continue to be revised periodically and the designer should obtain the latest publications.

Shown in Table IV-B-4 are the types of median barriers recommended for the given median widths. The primary consideration in establishing these guidelines was safety, both to the motorist and the maintenance personnel who must repair damaged barriers. Each barrier type exhibits characteristics which make it more desirable for a given median condition than the others. These characteristics are as follows.

Rigid Systems - The MB5 system (often referred to as the CMB) is the only operational rigid barrier. It does not deflect upon impact and it therefore dissipates a negligible amount of the vehicle's impact energy. At shallow impact angles, which is characteristic of impact in narrow medians, the MB5 system will redirect the vehicle with little or no damage to the vehicle. At higher impact angles, major damage to

Table IV-B-4. Suggested Median Barriers[1] as Related to Median Width

Median Width	Suggested Barrier
Up to 18 feet	Rigid or Semi-Rigid[2]
18 to 30 feet	Rigid, Semi-Rigid, or Flexible[3]
30 to 50 feet	Semi-Rigid or Flexible

[1]If warranted by Figure IV-A-2.

[2]Semi-rigid system with dynamic deflection greater than one-half of median width not acceptable.

[3]MB1 system not acceptable.

Metric Conversion: 1 ft = 0.3048 m

the vehicle can be expected, together with the probability of occupant injuries. It has been shown that the MB5 system can safely redirect a tractor-trailer truck at a moderate impact speed and impact angle (85). On impact, this barrier suffers little or no damage and hence requires little maintenance. This has an added benefit as traffic is not disrupted by extensive maintenance operations and the maintenance forces are not exposed to the hazard of large volumes of relatively high-speed traffic.

Semi-Rigid Systems - Some of these systems are practically rigid while others are quite flexible. Each system, however, will dissipate some of the impact energy through yielding of the rail and post elements and the soil in some cases. For this reason, the semi-rigid systems are more forgiving than the MB5 system and thus reduce the probability of injury, at least for the high speed-high angle impact. Most of the semi-rigid barrier systems can sustain minor impacts without requiring immediate and extensive restoration work. As noted in Table IV-B-4, a semi-rigid system with a dynamic deflection greater than one-half of the median width (assuming barrier in the middle of the median) is not acceptable.

Flexible Systems - The flexible barrier is more "forgiving" than the other types of barriers. However, its deflection characteristics are such that it can only be used in relatively wide medians. It functions primarily by containing rather than redirecting the vehicle. Even minor impacts usually require some restoration work.

It is important to point out that the height of the cable in the MB1 system is critical. If its height is above approximately 28 inches

(0.71 m), small cars submarine under it. If its height is less than approximately 27 inches (0.69 m), large cars can vault over it. *The MB1 should therefore not be used in medians with significant terrain irregularities.*

IV-B-2. Transitions

Median barrier transition sections are needed between adjoining median barriers of significant differences in lateral stiffness, between a median barrier and another type of barrier, such as a bridge rail, or when a median barrier must be stiffened to shield fixed objects in the median such as a continuous illumination system. Reference should be made to Figure IV-A-1 for examples of median barrier transitions.

Unfortunately, there are no operational median barrier transition sections to report. A system (TR5) has been developed and tested for transitioning the MB10 system around luminaire poles in the median, and is described in Table B-10, Appendix B. It is likely this system will become operational in the near future.

Until operational median barrier transitions are developed, the engineer may have to design and install transition sections without the benefit of crash test evaluations. In such cases, the design guidelines presented herein should be followed closely.

Impact performance requirements of median barrier transitions are essentially the same as those for the standard median barrier section. Special emphasis must be placed on the avoidance of designs which may cause vehicle snagging or excessive deflection of the transition. Structural details of special importance are as follows.

(a) All rail splices should be capable of developing the full tensile and flexure strength of the weaker rail. Examples are the MB1 to the MB4W, or the MB4W to the MB5.

(b) A flared or sloped connection should be used when it can snag an errant vehicle. With reference to Figure IV-A-1, such a connection would be needed on the north side of the semi-rigid-to-rigid transition. In this regard, the standardized *terminal connector* (22) (sometimes referred to as the "Michigan end shoe") is suggested for attaching approach W-beam rail to the MB5 system or parapets, and to structurally compatible rails. An example of the use of the terminal connector is shown in the TR2 system, Appendix B, Table B-10. Another effective rail-to-parapet connection can be achieved by providing a recessed area in the parapet wall to receive the rail. This is illustrated in Figure III-B-2. Other potential connections and transitions are shown in the last part of NCHRP 129 (39).

(c) Strong post median barrier systems must be used on transitions to the MB5 system or to bridge rails or parapets or rigid objects. Such systems should be blocked out to prevent vehicle snagging on the posts. However, block-outs alone may not be sufficient to prevent snagging at the section just upstream of the rigid system or obstacle. A rub rail may be desirable in some designs using the standard W-beam or box beam (see rub rail on MB4W system). Rub rails are especially needed when the approach rail is terminated in a recessed area of the parapet. The rub rail should also be terminated in the recessed area as illustrated in Figure III-B-2. The designer is also encouraged to investigate the potential use of the thrie-beam system (MB9) for transition sections. Tests have shown that the thrie beam performs well as a transition rail (see TR4, Appendix B, Table B-10).

(d) The length of the transition should be such that significant changes in the lateral stiffness do not occur within a short distance. It is suggested that the transition length be at a minimum approximately 25 feet.

(e) The stiffness of the transition should increase smoothly and continuously from the weaker to the stronger system. This is usually accomplished by decreasing the post spacing and/or decreasing the post spacing and increasing the post size.

(f) The flare rate of the transition should adhere to the guidelines presented in Section IV-B.

The engineer is sometimes faced with the problem of designing a barrier element such as a transition section. NCHRP Report 115 (18) summarized available longitudinal barrier computer programs and analytical procedures used to investigate a barrier's impact performance, and presented an evaluation of each. The reader is encouraged to investigate these and other computer programs for possible implementation. A procedure for estimating the impact loads on a longitudinal barrier is presented in Appendix G. Although this procedure over-simplifies the actual vehicle-barrier interaction, it provides reasonable results and it is easy to use. In the absence of more accurate means, this procedure can be used.

IV-B-3. End Treatment

An untreated end of a median barrier is extremely hazardous. Impact with the untreated end of a metal beam type system may result in the beam penetrating the passenger compartment as well as an abrupt stop. Impact with the untreated end of the MB5 system will result in untolerable impact forces. A crashworthy end treatment for a median barrier is essential if the barrier is terminated within the clear distance of travel from either direction.

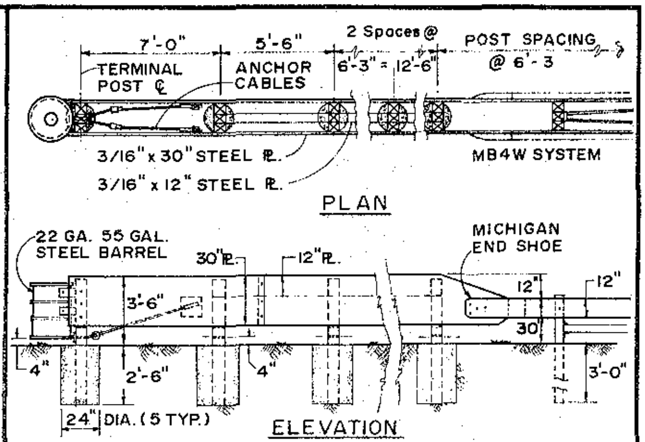
To be crashworthy, the end treatment should not spear, vault, or roll the vehicle for head-on or "nose" impacts. Vehicle accelerations should not exceed the recommended limits. For impacts between the end and the standard section, the end treatment should have the same redirectional characteristics as the standard median barrier which means that the end must be properly anchored. *The end treatment must thus be capable of developing the full tensile strength of the standard rail element, whether a crashworthy end treatment is warranted or not.*

Shown in Table IV-B-5 are the three operational median barrier end treatments. The MBET1 was tested with the MB4W system but could probably be adapted to any of the systems using the W-beam. With some modifications it could also be adapted to the MB5 system. The *remarks* of the MBET2 system discuss its adaptability to other systems. The MBET3 system is ideally suited for the MB9 system, as well as the MB5 system.

If adequate space is available at the median barrier terminal, a crash cushion can also serve as an effective end treatment. Reference should be made to Chapter VI for crash cushion details.

Table IV-B-5. Operational Median Barrier
End Treatments

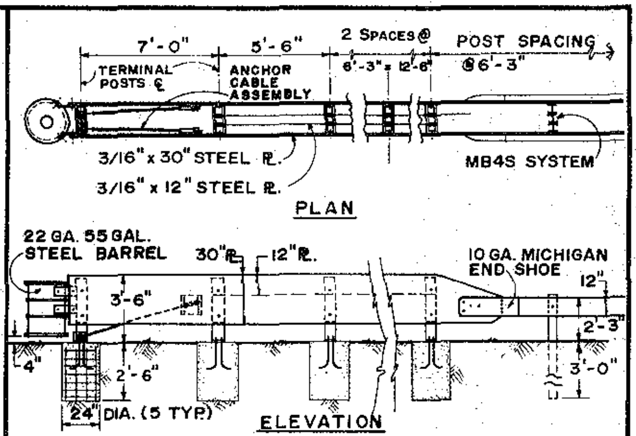
Metric Conversions
1 ft. = 0.305 m
1 in. = 25.4 mm
1 mph = 1.61 km/hr
1 lb. = 0.454 kg



SYSTEM	MBETI Median Barrier Breakaway Cable Terminal (Wood Post)	
BARRIER DESCRIPTION	TYPICAL POST - 8"x8" Douglas Fir; TERMINAL POST - 6"x8" Southern Pine with 2 3/8" diameter hole drilled through neutral axis; ANCHORAGE - Cable assembly (see sketch); FOOTING - 24" diameter, 30" deep concrete for terminal posts, other posts require none; TYPICAL RAIL - steel "W" section, 12 GA.; TERMINAL RAIL - 3/16"x30" steel plate; OFFSET BRACKETS - 6"x8" Southern Pine block.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		NO TEST
Speed (mph)	64.8	
Angle (deg.)	1.2	
Vehicle Weight (lb.)	3900	
BARRIER		
Deceleration Distance (ft.)	22.0	
VEHICLE ACCELERATIONS (G's)[1]		
Lateral	5.0	
Longitudinal	11.6	
Total	UNAV	
VEHICLE TRAJECTORY		
Exit Angle (deg.)	Behind rail	
Roll Angle (deg.)	≈0	
Pitch Angle (deg.)	≈0	
BARRIER DAMAGE	Entire terminal rail and 4 terminal posts	
REFERENCES	27	
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	System was tested with MB4W system. Details of the end posts, anchorage and footings are critical.	

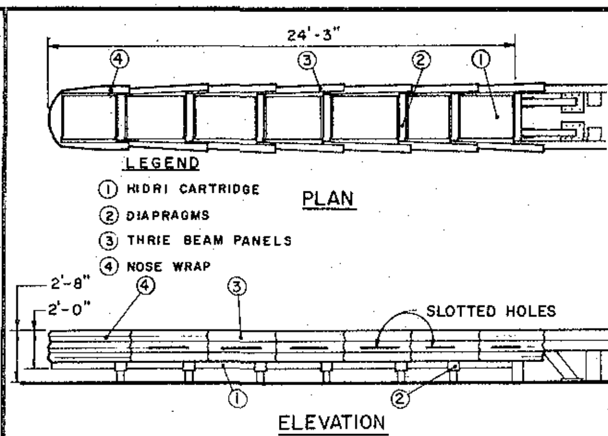
UNAV — unavailable
[1]50 millisecond average unless otherwise noted
[2]If available, see summary in Appendix A

Table IV-B-5. Operational Median Barrier End Treatments (Continued)

Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg		
SYSTEM	MBET2 Median Barrier Breakaway Cable Terminal (Steel Post)	
BARRIER DESCRIPTION	TYPICAL POST - W6x8.5 steel; TERMINAL POST - TS6"x6"x0.1875" steel breakaway design; ANCHORAGE - Cable assembly (see sketch); FOOTING - 24" diameter, 30" deep concrete for terminal posts, other posts require none; TYPICAL RAIL - steel "W" section, 12 GA.; TERMINAL RAIL - 3/16"x30" steel plate; OFFSET BRACKETS - 6"x6" steel blocks.	
IMPACT PERFORMANCE	**HEAD ON IMPACT**	**SIDE IMPACT**
IMPACT CONDITIONS Speed (mph) Angle (deg.) Vehicle Weight (lb.)	 58 0 4500	 62 26 4500
BARRIER Deceleration Distance (ft.)	 ≈25	 5.3[4]
VEHICLE ACCELERATIONS (G's)[1] Lateral Longitudinal Total	 3.0 9.7 UNAV	 6.5 6.0 UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)	 NOAP[3] UNAV ≈15	 ≈0 ≈10 ≈20
BARRIER DAMAGE	Entire terminal rail and 5 terminal posts	12' of terminal rail and 20' of typical rail, 4 terminal posts and 4 typical posts
REFERENCES	27	27
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	This system was tested with the MB4S system. Other documented tests have been conducted with the MB3 and MB4S systems but with the terminal posts (TS6"x6"x0.1875" and W6x8.5) welded to a base plate at grade. See Appendix C. Although not documented by crash tests, this system could also be adapted for use with the MB2 and MB5 systems.	

UNAV — unavailable
[1] 50 millisecond average unless otherwise noted
[2] If available, see summary in Appendix A
[3] NOAP - not applicable
[4] Maximum dynamic deflection

Table IV-B-5. Operational Median Barrier End Treatments (Continued)

Metric Conversions 1 ft. = 0.305m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg		
SYSTEM	MBET3	
BARRIER DESCRIPTION	Hi-dri cell cartridges used in conjunction with telescoping steel thrie beam fender panels.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	62.0	63.0
Angle (deg.)	0	20
Vehicle Weight (lb.)	Pontiac Sedan	1968 Buick LeSabre
BARRIER		
Deceleration Distance (ft.)	UNAV	UNAV
VEHICLE ACCELERATIONS (G's)[1]		
Lateral	UNAV[3]	8.0[3]
Longitudinal	15.0[3]	5.0[3]
Total	UNAV	UNAV
VEHICLE TRAJECTORY		
Exit Angle (deg.)	UNAV	8
Roll Angle (deg.)	less than 10	0
Pitch Angle (deg.)	less than 10	0
BARRIER DAMAGE	Hi-dri cell cartridges destroyed. Thrie beam not damaged.	None
REFERENCES	34	34
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	Vehicle yawed 48° in head-on test. Slight barrier damage reported in all tests.	

UNAV — unavailable

[1]50 millisecond average unless otherwise noted

[2]If available, see summary in Appendix A

[3]Peak acceleration

Emergency openings in median barriers are to be avoided if possible. When necessary, the opening should be designed so as not to require a crash attenuating end treatment. If the median is of sufficient width, a design similar to that shown in Figure IV-B-1 is suggested for semi-rigid and rigid systems. Note that

$$W = 2a + d \sin \theta \qquad \text{(IV-B-1)}$$

As an example, assume

$a = 2$ ft (0.61 m),

$d = 8$ ft (2.4 m), and

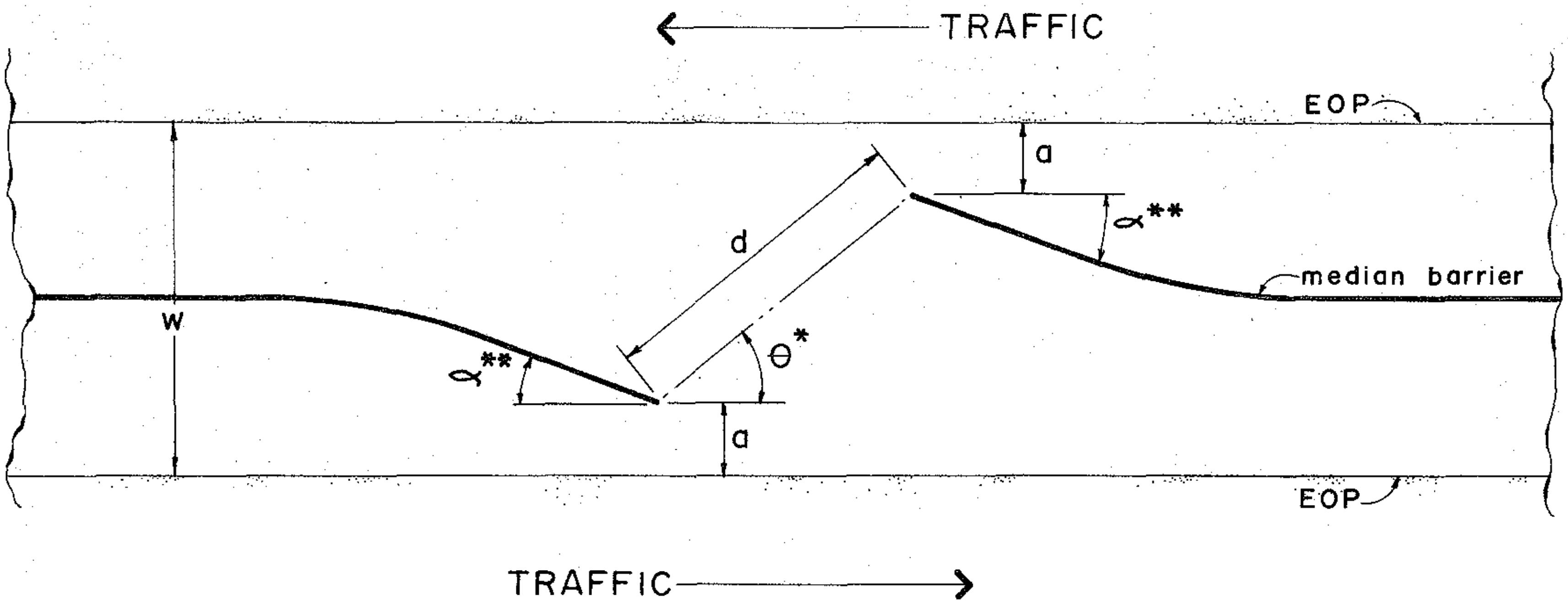
$\theta = 25$ degrees

Thus

$W = 7.4$ ft (2.3 m)

Or, if an opening of 8 feet (2.4 m) is of sufficient width, such a design will suffice for median widths in excess of 7.4 ft (2.3 m). It is desirable that θ be as large as possible, but it is essential that it be no less than 25 degrees. A gate could be placed across the opening if problems arise with unauthorized crossings. Careful consideration must be given to the terminal design to insure proper anchorage for the semi-rigid systems. The terminal must also be capable of redirecting impacts at or near the end of the terminal. The flare rate of the terminal section should adhere to criteria given in Section III-E-4.

Other designs have been used for emergency openings. These have included W-beam barriers with quick release bolts and nuts, load binder cable release mechanisms for the cable barrier and a steel plated gate for the MB5 system which has the barrier's shape when closed and opens by rolling the plates down flush with the pavement. These systems, however, have not been evaluated by crash tests.



* Θ must be ≥ 25 degrees.

** The flare rate of the terminal section should not exceed the flare rates suggested in Section III-E-4 (Table III-E-1).

Figure IV-B-1. Suggested Emergency Opening Design for Semi-Rigid or Rigid Systems

IV-C. Maintenance Characteristics

Section III-C contains a discussion of the maintenance factors to consider before selecting a *roadside* barrier. Those factors are essentially the same ones that should be considered before selecting a *median* barrier. *The reader should therefore refer to Section III-C and Table III-C-1.* There are, however, some differences in maintenance considerations between the two types of barriers and these are discussed below.

The extent of median barrier damage for a given set of impact conditions will depend on the strength of the barrier. Where available, the tables in Section B of this chapter give the barrier damage as a result of a crash test for specific impact conditions. To supplement these data, a gross survey was made of several states to determine typical collision repair values experienced in the field. Table IV-C-1 summarizes the available field data. It should be remembered that these are average values needed to repair a damaged section and not average values based on all hits. Many hits are only brushes and cause no appreciable barrier damage.

Information in Table IV-C-1 was taken from both urban and rural areas. However, the data did not permit a differentiation between the two. It is speculated that the majority of the impacts with roadside barriers occur in urban areas where traffic densities are high. More manpower is usually needed for traffic control purposes in urban areas than rural areas. In this regard, the hazard to both the motorists and the crew during repairs should be a major concern. Operating speeds for the roadways are unknown but it is probable that the data came primarily from high speed facilities.

Table IV-C-1. Collision Repair Data for Median Barriers.

System	Typical Crew Size	Typical Material Repaired or Replaced		Average Refurbishment Time (Man-Hours/Foot of Rail)
		Rail (ft.)	Posts	
MB1-Cable Barrier[a]	3-4	75	8	0.10
MB1-Cable Barrier[b]	3-4	75	8	0.13
MB1-Cable Barrier[c]	3-4	75	8	0.055
MB1-Cable Barrier[d]	3-4	75	8	0.083
MB2-W-Beam on Steel Weak Posts	3-4	53	4-5	0.32
MB3-Box Beam	UNAV	36	4	0.61
MB4W-Blocked Out W-Beam on Wood Posts	4-5	25	4	0.36

[a]Post in asphalt, with glare screen
[b]Post in PCC, with glare screen
[c]Post in asphalt, without glare screen
[d]Post in PCC, without glare screen

Metric Conversion: 1 ft = 0.305 m

Table IV-C-1. Collision Repair Data for Median Barriers. (Continued)

System	Typical Crew Size	Typical Material Repaired or Replaced		Average Refurbishment Time (Man-Hours/Foot of Rail)
		Rail (ft.)	Posts	
MB4S-Blocked Out W-Beam on Steel Posts	4-5	57	4-5	0.36
MB5-Concrete Median Barriers	4-5	UNAV	Not Applicable	3.50
MB7-Aluminum Strong Beam[e]	4	66	11	0.48
MB7-Aluminum Strong Beam[f]	4-6	66	11	0.73
MB8-Aluminum Balanced Beam	-------------------NO DATA AVAILABLE------------------------			
MB9-Blocked Out Thrie Beam	-------------------NO DATA AVAILABLE------------------------			
MB10-W-Beam on Steel Breakaway Posts	5-7	56	2	0.59

[e]Summer conditions (data from a north central area)

[f]Winter conditions (data from a north central area)

<u>Metric Conversion</u>: 1 ft = 0.305 m

It must be noted that the relatively high refurbishment time for the MB5 system can be misleading. Although the typical length of barrier repaired was unavailable, it is widely known that the MB5 system requires far less maintenance than any other longitudinal barrier.

With regard to environmental factors, questions have arisen about the potential of snow drifting on the MB5 system and the MB6 system, due to their large frontal area. At this time, there is no documented evidence that these barriers cause any more drifting than other barriers. However, an effort should be made to determine if such a problem exists before installing these barriers on roadways with high snowfalls.

IV-D. Selection Guidelines

Once it has been determined that a median barrier is warranted, a selection must be made. Although the process is complicated by the number of variables and the lack of objective criteria, there are guidelines which should be followed. In general, the most desirable system is one that offers the best protection at the least cost and is consistent with the given constraints. Table IV-D-1 presents nine items which should be considered before a selection is made.

The first item in the selection process is to determine the type of median barrier recommended for the given median width. This is done by use of Table IV-B-4. Then a selection must be made from the available barriers within the type recommended, i.e., rigid, semi-rigid, or flexible. In this regard, the designer must give careful consideration to the deflection characteristics as well as the safety aspects of the available barriers. Detailed discussions of these characteristics are given in Section B.

Table IV-D-1. Selection Criteria for Median Barriers

Item	Consideration
A. Median Width and Deflection	1. Criteria in Table IV-B-4 should be used.
	2. Dynamic deflection of barrier should not be greater than one-half of median width.
	3. Cable barrier should be placed on flat medians.
B. Strength and Safety	1. System should contain and redirect vehicle at design conditions.
	2. System should be least hazardous available, consistent with costs and other considerations.
C. Maintenance	1. Collision maintenance.
	2. Routine maintenance.
	3. Environmental conditions.
D. Compatibility	1. Can system be transitioned to other barrier systems?
	2. Can system be terminated properly?
E. Costs	1. Initial costs.
	2. Maintenance costs.
	3. Accident costs to motorists.
F. Field Experience	1. Documented evidence of barrier's performance in the field.
G. Aesthetics	1. Barrier should have pleasing appearance.
H. Promising New Design	1. It may be desirable to install new systems on an experimental basis.

Maintenance factors which should influence median barrier selection are discussed in Section C of this chapter. Available maintenance data on the operational systems are also presented there. A special point of interest in maintenance concerns the availability of replacement parts, as well as their interchangeability and acceptable alternates. Recent shortages in some barrier hardware has pointed to the need for advance planning and alternate hardware. Before selecting a system material suppliers should give some assurance of future availability. Reference should be made to the discussion of standardization in Section IV-B-1.

Compatibility is a very important item that should be considered in the selection process. Two major deficiencies of many median barriers are the absence of crashworthy transitions and the absence of crashworthy end or terminal treatments. In selecting a median barrier, strong consideration should be given to its adaptability to operational transitions and end treatments. Sections IV-B-2 and IV-B-3 address these problems and present the operational transitions and end treatments.

Initial costs and future maintenance costs of each candidate median barrier should be carefully evaluated. As a general rule, the initial cost of a system increases as the rigidity or strength increases, but the maintenance costs usually decrease with increased strength. Consideration should also be given to the costs incurred by the motorist as a result of collision with the barrier. Both damage costs to the vehicle and injury costs to the occupants need to be evaluated for a typical collision. The decision may ultimately involve the question of what level of protection the state or agency is able to provide. The procedure presented in Chapter VII should provide a means with which to approach this question.

Item F in Table IV-D-1 concerns the field experience. There is no substitute for documented evidence of a barrier's field performance. In this regard, the evaluation forms for each operational system, presented in Section B of this chapter, indicate the availability of field data. If none exists, the state or agency which developed and implemented the system should be contacted for data and their views and comments.

With regard to aesthetics, the barrier should have a pleasing appearance. However, under no circumstances should aesthetics justify a compromise in the crashworthiness of the selection.

Many of the experimental systems included in Appendix B exhibit excellent impact performance characteristics. The designer should give serious consideration to the installation of some of the barriers, at least on an experimental basis. The performance of the barrier should be monitored, and if proven satisfactory, it may be installed on a permanent basis.

IV-E. Placement Recommendations

Major factors to consider in the lateral placement of a median barrier are the effects of the terrain between the edge of the traveled way and the barrier on the errant vehicle's trajectory, and the flare rate of transition sections. Another factor of concern is rigid objects in the median.

A discussion of these factors and the available criteria related thereto follows.

IV-E-1. Terrain Effects

Terrain conditions between the traveled way and the barrier can have significant effects on the barrier's impact performance. Curbs and sloped medians (including superelevated sections) are two prominent features which deserve special attention. A vehicle which traverses one of these features prior to impact may go over the barrier or submarine under the barrier or snag on its support posts. Research studies have provided considerable insight regarding the dynamic behavior of an automobile upon traversing these features. Automobile orientation (translation and angular position) as a function of distance off the traveled way is now known for a number of curbs and slopes for various encroachment conditions (speed and angle of vehicle). Thus, the impact position of a car relative to a given barrier, placed at a given lateral distance from the traveled way, is now known for a variety of conditions. Background data, upon which the criteria in this section are based, are presented and discussed in Appendix F.

Curbs - In general, it has been found that curbs offer no safety benefits on high-speed roadways from the standpoint of vehicle behavior following impact. *It is therefore suggested that a curb, either when used alone or when placed in front of a median barrier, not be used for purposes of redirecting errant vehicles.* Although curbs may improve delineation and drainage, it is suggested that other methods can be used to achieve these functions.

If special conditions require the use of a curb and if a median barrier is to be placed behind the curb, the reader should refer to the data in Appendix F for lateral placement guidelines. As a general rule, if the barrier face is within approximately 9 inches (0.23 m) of the curb's face, a vehicle, traveling at approximately 60 mph (96.5 km/hr), will not likely vault the barrier. However, if the top of the rail is approximately 27 inches (0.69 m) or higher above the top of the curb, impacts with the rail can be expected to occur at lower than normal impact heights. This will occur since the vehicle will not undergo appreciable lifting before contact with the barrier occurs. In effect, the height of the rail exceeds its normal mounting height by the height of the curb. For such mountings, a rub rail should be placed between 15 to 20 inches (0.38 to 0.51 m) above the top of the curb.

Sloped Medians - *The most desirable median is one that is relatively flat (slopes less than 10:1) and free of rigid objects.* If warranted, the barrier can then be placed at the center of the median. When these conditions cannot be met, placement guidelines are necessary.

Figure IV-E-1 shows three basic median sections for which placement guidelines are presented. *In each section, it is assumed that a median barrier is warranted by the criteria in Section IV-A.* Section I applies to depressed medians or medians with a ditch section. Section II applies to stepped medians or medians that separate travel ways with significant differences in elevation, and Section III applies to raised medians, or median berms. The criteria assumes that no appreciable slope rounding exists. As discussed in Section III-A-1 slope rounding affords the driver more control of an errant vehicle since it reduces the potential for the vehicle to become airborne. *It is therefore desirable that sharp breaks or hinges in median slopes be rounded.*

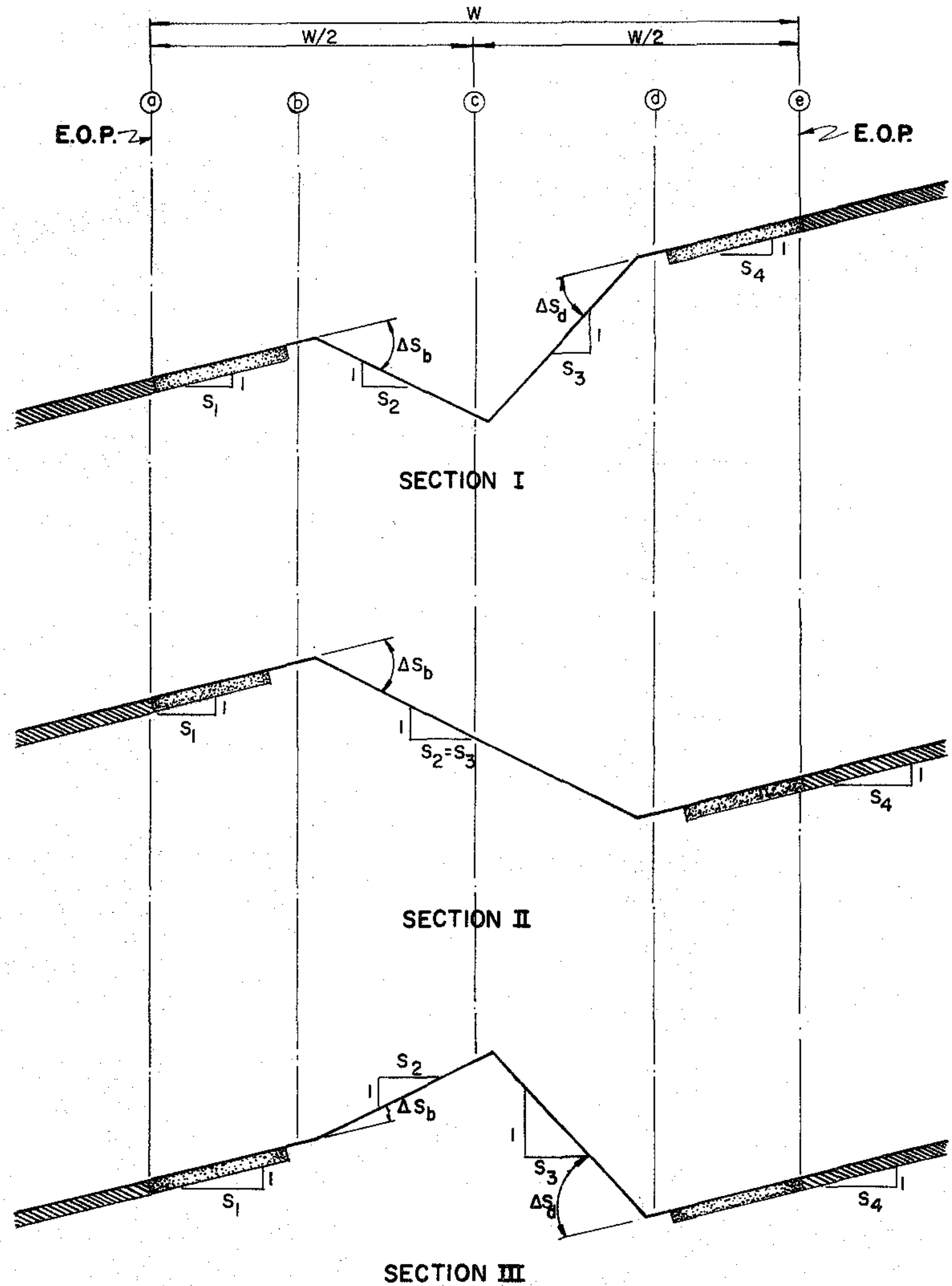


Figure IV-E-1. Definitions of Median Sections

Section I - The slopes and the ditch section should first be checked by the criteria in Section III-A to determine if a roadside barrier is warranted. If both slopes require protection, a *roadside barrier* should be placed near the shoulder on each side of the median ("b" and "d"). If only one slope requires protection, e.g., S_3, a *median barrier* should be placed at "d". In this situation, a rigid or semi-rigid barrier is suggested, and a rub rail should be installed on the ditch side of the barrier.

If neither slope requires protection but ΔS_b or ΔS_d is greater than approximately 6 degrees, a *median barrier* should be placed on the side with the larger ΔS. For example, if

$$\Delta S_b = 12^\circ, \text{ and}$$

$$\Delta S_d = 10^\circ,$$

the barrier would be placed at "b". A rigid or semi-rigid system is suggested in this situation.

If ΔS_b and ΔS_d are both less than approximately 6 degrees, a *median barrier* should be placed at or near the center of the median (at "c"). Any type of median barrier can be used, provided its dynamic deflection is not greater than W/2.

Section II - If ΔS_b is greater than approximately 6 degrees, a *median barrier* should be placed at "b". If the slope is not traversable (rough rock cut, etc.) a *roadside barrier* should be placed at "b" and "d". It is not unusual for this section to have a retaining wall at "d". If so, it is suggested that the base of the wall be contoured to the exterior shape of the MB5 system.

If ΔS_b is less than approximately 6 degrees, a *median barrier* should be placed at or near the center of the median.

Section III - Placement criteria for median barriers on this cross-section are not clearly defined. Research has shown that such a cross-section, if high enough and wide enough, can itself redirect vehicles (see MBR2 system, Table B-4, Appendix B).

As a general rule, if the cross-section itself is inadequate for redirecting errant vehicles, i.e., the slopes are relatively flat, a semi-rigid *median barrier* should be placed at the apex of the cross-section.

If the slopes are not traversable (rough rock cut, etc.), a *road-side barrier* should be placed at "b" and "d". If retaining walls are used at "b" and "d", it is recommended that the base of the wall be contoured to the exterior shape of the MB5 system. Guidelines for the orientation of the MB5 shape on superelevated sections is as shown in Figure IV-E-2.

When a median barrier is warranted, it is desirable that the same barrier be used throughout the length of need, and that the barrier be placed in the middle of a flat median. However, it may be necessary to deviate from this policy in some cases. For example, the median in Section I of Figure IV-E-1 may require a barrier on both sides of the median. If a median barrier is warranted upstream and downstream from the section, it is suggested that the median barrier be "split" so that continuity is maintained. This is illustrated in Figure IV-E-3. Most of the operational median barriers can be split this way, especially the W-beam types and the MB5 system. It involves a transition on both ends

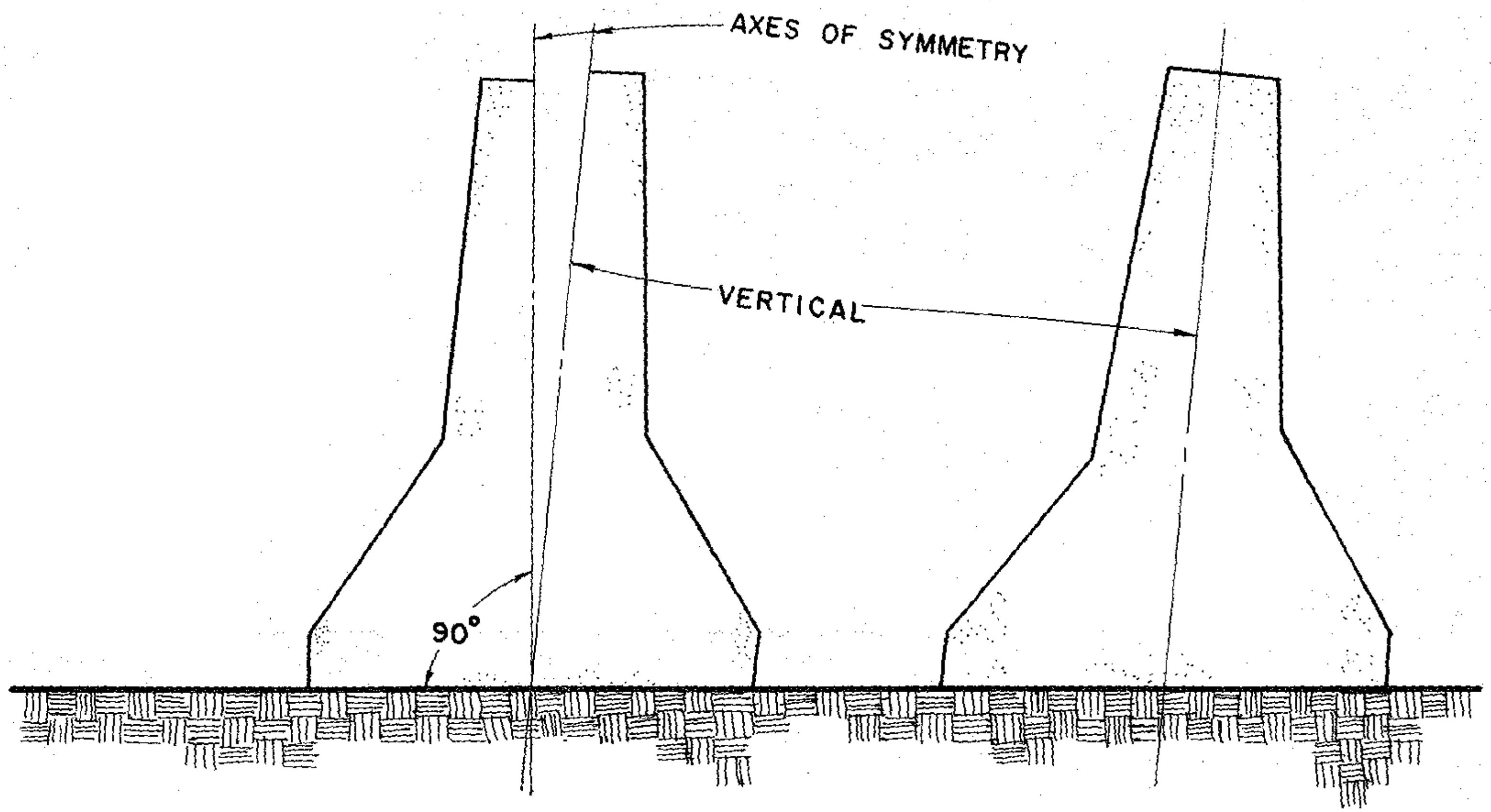
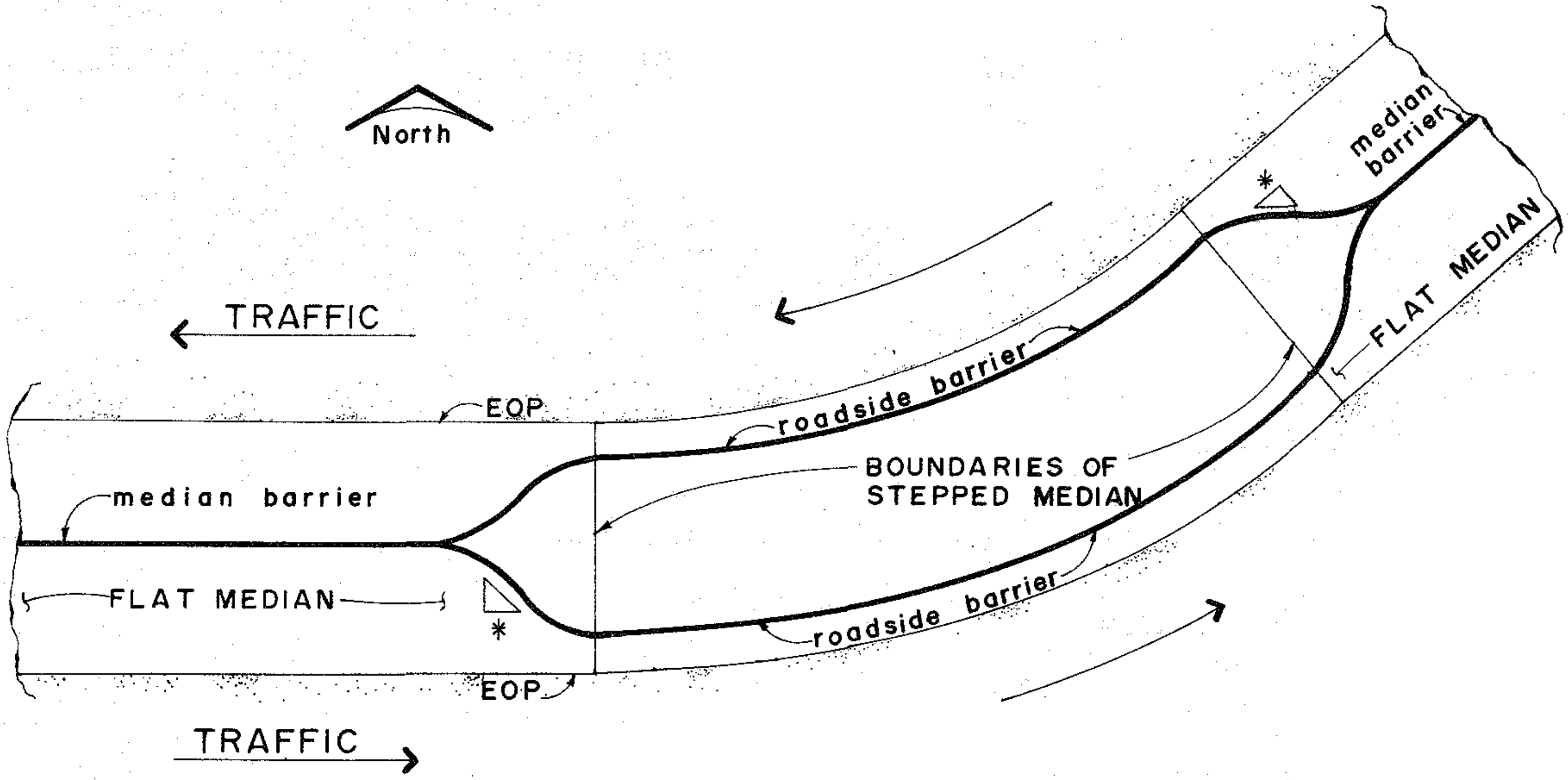


Figure IV-E-2. Suggested Orientation of MB5 Shape on Superelevated Sections.



*Flare rate should not exceed suggested limits (Section III-E-4).

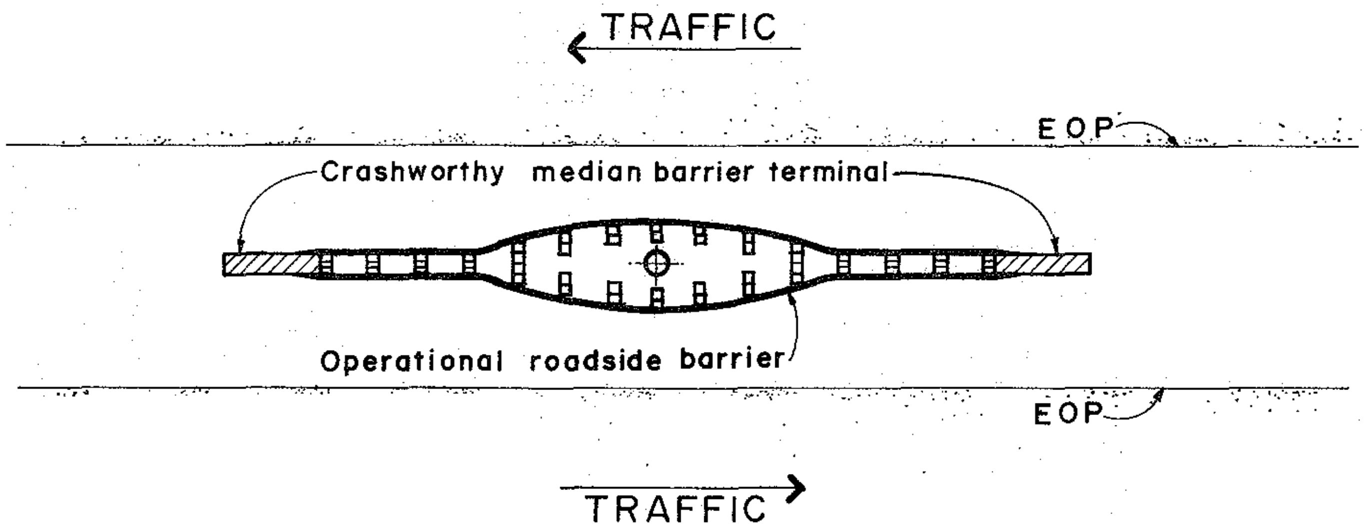
Figure IV-E-3. Example of Median Barrier Placement at Superelevated Section and a compatible operational roadside barrier at the superelevated section. It is noted that although a rigid roadside barrier similar to the MB5 system has not been tested, such a system will obviously perform the same as the MB5 as long as it is structurally adequate. In other words, the impact performance of the MB5 *shape* has been clearly established.

A layout similar to that of Figure IV-E-3 is also suggested where depressed medians require barriers on both sides of the median, or at the approach to a divided structure.

IV-E-2. Flare Rate

When it becomes necessary to flare a median barrier, such as at a rigid object in a median, divided structures, etc., the flare rate should not significantly increase the hazard potential of the barrier. The flare rates given in Table III-E-1 for roadside barriers apply to median barriers also. Reference should be made to Figure III-E-4 for parameter definitions.

Another special layout problem concerns medians whose widths are such that a median barrier is not warranted but that have a rigid object which warrants shielding. Typical examples are bridge piers and an overhead sign support structure. If shielding is necessary for one direction of travel only, or if the object is in a depressed median and shielding from either or both directions of travel is necessary, the criteria of Chapter III should be used. If shielding for both directions of travel is necessary and if the median is flat (side slopes less than approximately 6 degrees), two means of protection are suggested. In the first case, the designer should investigate the possible use of crash cushions to shield the object (see Section VI-F). The second suggestion is illustrated in



NOTE: Designer should also investigate use of crash cushion to shield hazard.

Figure IV-E-4. Suggested Layout for Shielding of Rigid Object in Median

Figure IV-E-4. If semi-rigid systems are used, the barrier-to-hazard distance should be greater than the dynamic deflection of the barrier (see Table III-B-1). If the MB5 shape is used, the barrier can be placed adjacent to the hazard, as shown in Figure IV-E-4. However, the MB5 system should be used with discretion if the distance from the EOP to the barrier is greater than approximately 15 feet (4.6 m).

IV-F. Upgrading Substandard Systems

Some existing median barriers are not necessary while others are substandard and will not meet suggested performance levels. Substandard barriers usually fall into one of two categories, namely, those that have structural inadequacies and those that are improperly located.

Figure III-F-1 of Chapter III presents an inspection procedure designed to identify unnecessary or substandard *roadside* barriers. *The same inspection procedure should be followed for median barriers, and it is suggested that it be conducted on a regularly scheduled basis. Personnel performing this inspection should stay abreast of current traffic barrier standards and guidelines, as well as promising new research findings.*

With regard to item 3 of Figure III-F-1, the criteria presented in Section IV-B should be used where possible to evaluate existing systems. Of course, there is no substitute for field data or accident records to evaluate the performance of a system. *If a barrier system is judged substandard, it is suggested that the barrier either be modified to conform to an operational system, or be replaced by an operational system.* It is recognized that this action is not always feasible and other remedial action must be taken. Table III-F-1 of Chapter III lists common structural inadequacies that occur and the suggested remedial action. If the upgraded system does not conform to an operational system, crash tests are suggested to verify the design, especially if substantial use of the system is planned.

The criteria given in Section IV-E should be used to evaluate the adequacy of the lateral placement of existing barriers. If the barrier is placed in a depressed median or a median with surface irregularities, it may not function properly. If improperly located, corrective measures should be considered. If necessary, the barrier can be moved near the shoulder's edge, or returned to a position in which the approach terrain to the barrier is no steeper than the criteria suggest. Another possible solution would be to extend the shoulder to the lateral distance desired, and place the barrier on the shoulder. Steep flare rates for approach and transition sections should be flattened to conform to the suggested criteria.

With regard to item 5 of Figure III-F-1, the rail height of an operational system should be approximately equal to the original design height of the system. In any case, it is suggested that the barrier be approximately 27 inches (0.69 m) above the ground or greater. The cable in the MB1 system should not be less than 27 inches (0.69 m) and not greater than approximately 28 inches (0.71 m).

In some cases, the effective rail height will be decreased due to an accumulation of dirt, pavement overlays, etc. Of course, dirt should be removed if feasible to return the barrier to its correct height.

If necessary and if the length and strength of the post and foundation permits, the rail can be raised an appropriate amount. If not, it may be necessary to install taller posts with added strength and deeper embedment to accommodate the increased rail height.

Items 6 and 7 of Figure III-F-1 can be accomplished by maintenance personnel.

V. BRIDGE RAILS

A bridge rail is a longitudinal barrier whose primary function is to prevent an errant vehicle from going over the side of the bridge structure. Metal rails and concrete parapets are the most common types of bridge rails. It is the purpose of this chapter to delineate the criteria pertinent to the various elements of bridge rail design, including warrants, structural and safety characteristics of operational systems, maintenance characteristics of operational systems, selection guidelines, placement recommendations, and guidelines for upgrading substandard installations.

Information in this chapter is intended as supplement and not as a replacement to existing AASHTO design criteria and specifications for highway bridges, including bridge rails (86, 87).

V-A. Warrants

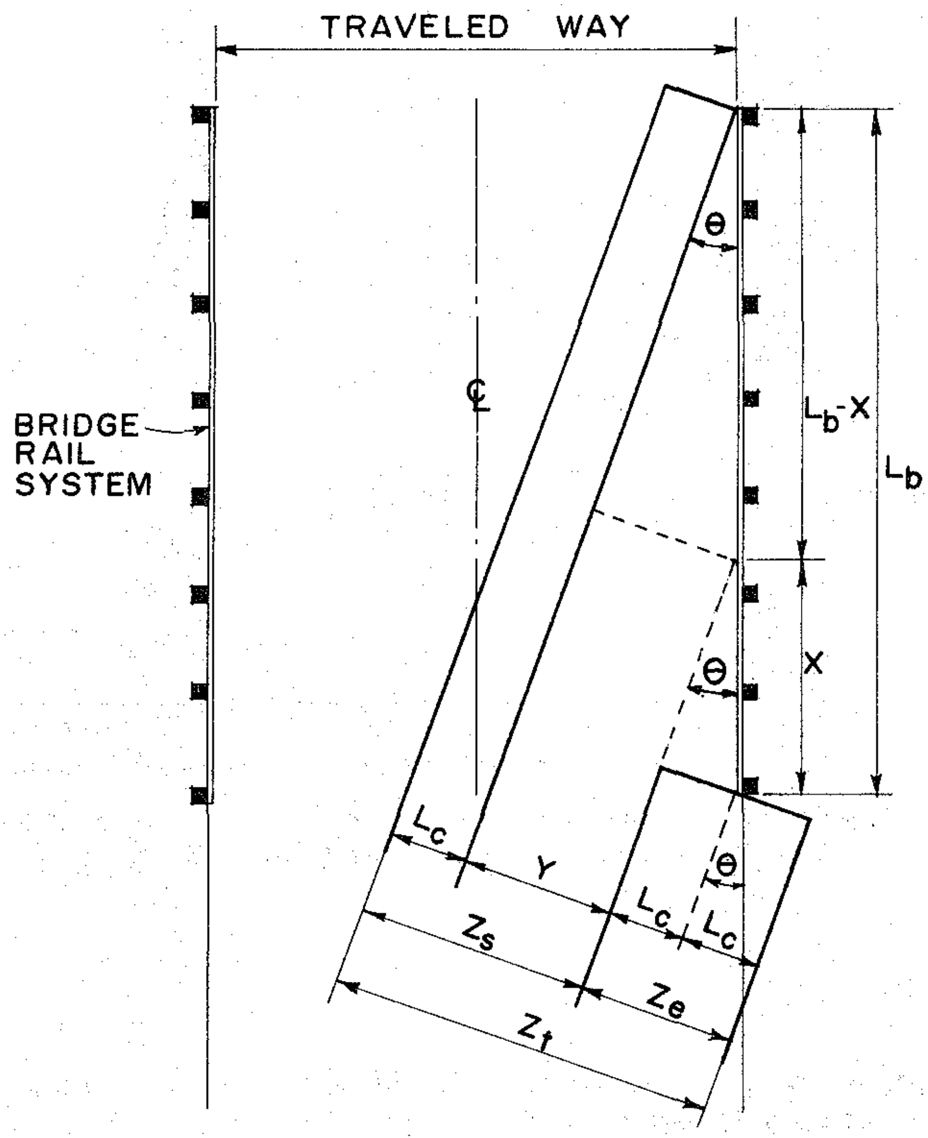
Current criteria suggest that bridge rails should be installed on all bridge structures. However, the view is now held by some highway engineers that this criteria is too restrictive and in some cases has resulted in the unnecessary use of bridge rails. A possible example of this would be their use on a short structure that spans a shallow stream or drainage area on a low volume rural roadway. Many such structures do not have an approach roadside barrier to shield the bridge rail end. It is likely that the exposed end of the rigid bridge rail is more hazardous to the motorist than would be the stream or drainage area. Judgment must therefore be used to determine if the overall hazard of the bridge rail and the approach roadside barrier necessary to shield the bridge rail end is less hazardous than the roadside condition being shielded. Warrants for barriers to shield culverts can be established from the criteria in Section III-A. If warranted, a *roadside barrier* will probably suffice for shielding culvert openings.

When the bridge also serves pedestrians and/or cyclists, a barrier to shield them from the traveled way may be warranted. In addition, a *pedestrian rail* at the bridge's edge may also be warranted. If necessary, a "fence" should be placed on the side of the bridge to prevent pedestrians from throwing hazardous objects on a roadway below. The need for pedestrian and/or cyclist railing should be predicated on an evaluation of the density and operating speed of the vehicles and the number of pedestrians and/or cyclists using the bridge.

Exposed bridge rail ends or parapet walls are to be avoided. In most designs, an approach roadside barrier with a smooth transition to the bridge barrier is warranted. Chapter III contains warrants for approach barriers, operational transitions and roadside barrier end treatments and placement recommendations.

Reports of accidents in which vehicles collided with barriers on and near bridges were examined, and factors causing the accidents were studied (36). It was reported (36) that "from 1967 to 1969, California and Texas experienced a notable decrease -- from 52 to 13 percent and 57 to 25 percent, respectively -- in the proportion of single-vehicle accidents occurring at the ends of bridge rails or parapets. This probably reflects the emphasis placed on smooth transitions."

Figure V-A-1 is included to further illustrate the need for shielding a bridge rail end. It can be shown that of all possible impacts with the bridge rail for a vehicle leaving the traveled way at an angle θ, the probability, P, of impacting the end of the rail is given by



where: L_b = length of bridge

L_c = effective width of car

θ = angle of encroachment

$Z_e = 2L_c$ = zone in which vehicle would impact end of bridge rail.

Z_s = zone in which vehicle would impact side of bridge rail.

Z_t = zone of all vehicle impacts with bridge rail.

Figure V-A-1. Model for Predicting Percentage of Bridge Rail End Impacts.

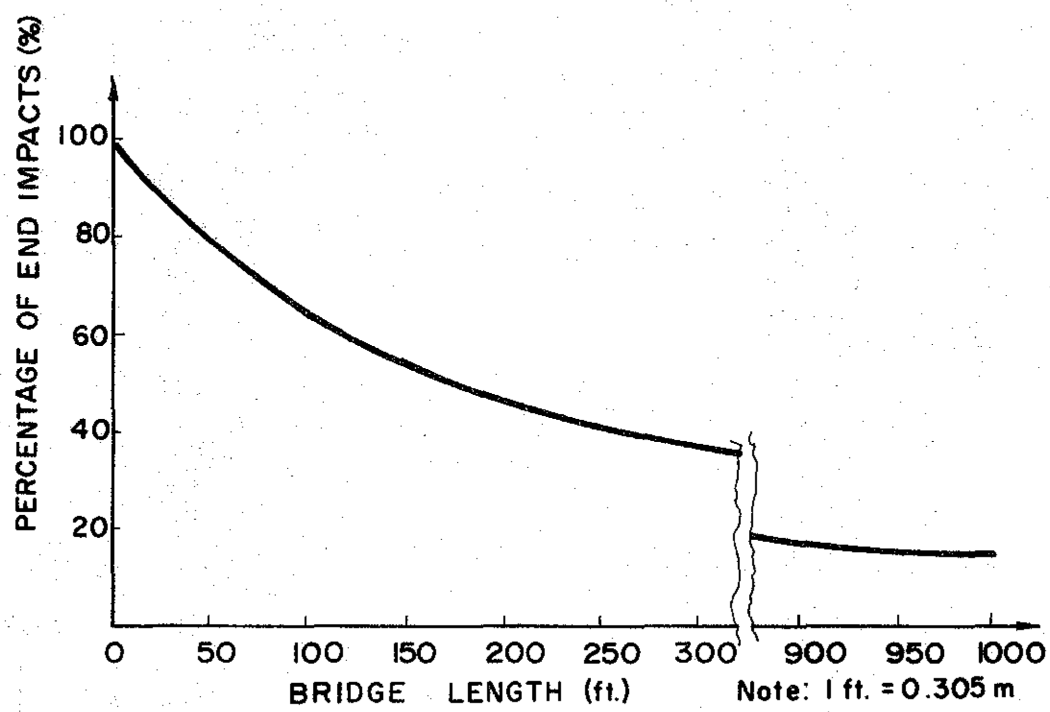


Figure V-A-2. Percentage End Impacts vs. Bridge Length For $\theta = 5°$ And $L_c = 96$ in.

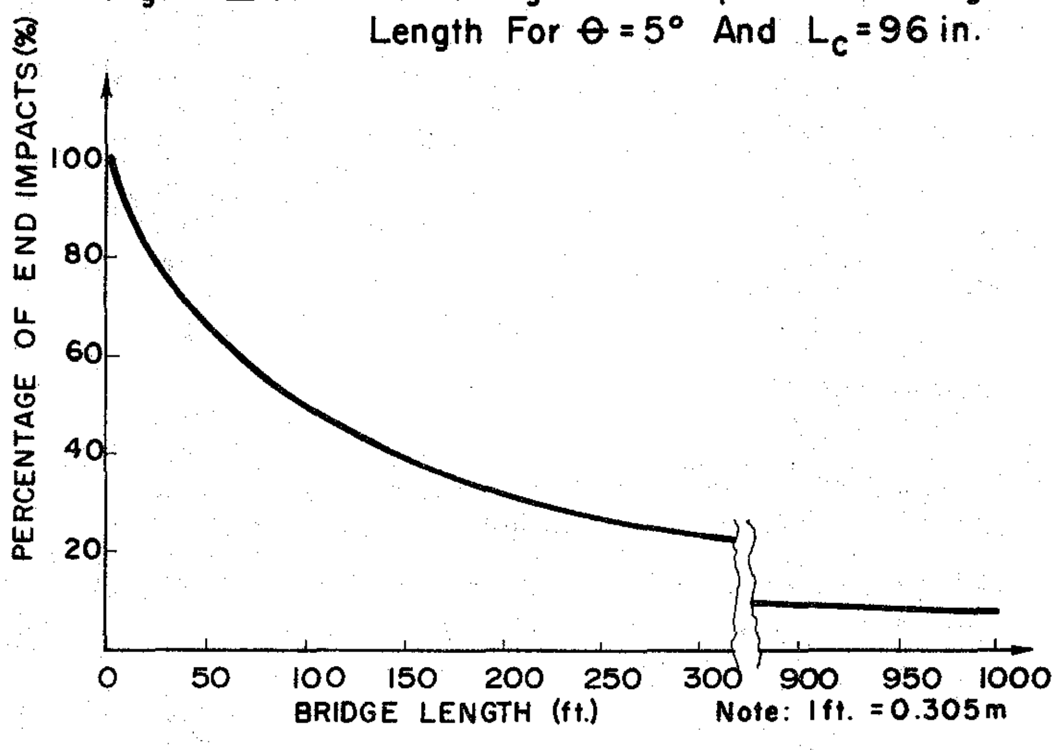


Figure V-A-3. Percentage End Impacts vs. Bridge Length For $\theta = 10°$ And $L_c = 96$ in.

$$P = \frac{2L_c}{L_b \text{ Sin } \theta + 2L_c} \times 100\% \qquad \text{(V-A-1)}$$

Figures V-A-2 and V-A-3 show this probability as a function of bridge length for encroachment angles of 5 degrees and 10 degrees. Most errant vehicles leave the traveled way at angles less than about 13 degrees. The effective width of the vehicle of 92 inches (2.3 m) is assumed to represent an automobile in a partial skid.

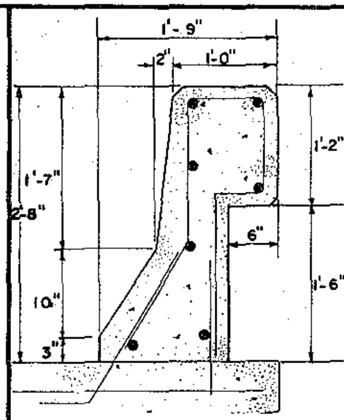
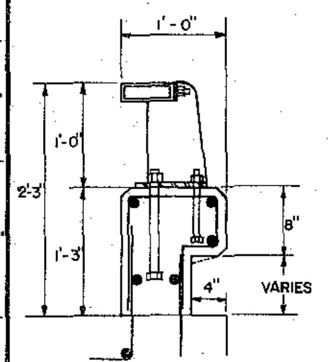
Consider, for example, 10 degree encroachments for a bridge length of 100 feet (30.5 m). It is predicted that of all impacts with the rail, approximately 50 percent would impact the bridge end if no approach rail were used.

V-B. Structural and Safety Characteristics

This section presents operational bridge rail systems and points out desirable structural and safety characteristics.

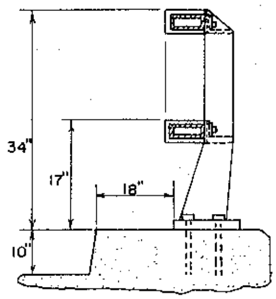
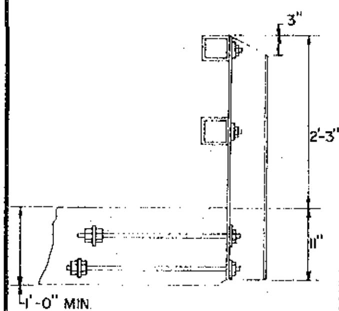
Structural and safety characteristics of operational bridge rail systems are presented in Table V-B-1. The information on each barrier consists of a sketch, a system designation, barrier description, impact performance, barrier damage, references, field performance data, and remarks. *Reference should be made to the introduction of Section III-B for a discussion of each of these items.* All of these barriers, with the exception of the BR1 system have been crash tested. The BR1 is considered operational since its *shape* has been evaluated through crash tests (same face as MB5), and its strength satisfies the AASHTO specifications (86, 87). Note that the BR4 system was designed for use on secondary roadways with maximum bridge widths of 32 feet (9.75 m). Appendix B contains a summary of bridge rails which appear promising but

Table V-B-1. Operational Bridge Rail Systems

Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg				
SYSTEM	BR1		BR2	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	Continuously poured, reinforced, sloped face concrete section. Shape of system similar to MB5 (Chapter IV). Barrier anchored to bridge deck with appropriate reinforcing steel.		10' 0" Fabricated steel plates TS 6"x2"x¼" tubing (steel) None Two 3/4" diameter steel bolts Concrete parapet	
IMPACT PERFORMANCE	**IMPACT ANGLE = 15°**	**IMPACT ANGLE = 25°**	**IMPACT ANGLE = 15°**	**IMPACT ANGLE = 26°**
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	NO TEST (See remarks below)	NO TEST (See remarks below)	NO TEST	57.0 4540
BARRIER Dynamic Deflection (ft.)				0.42[3]
VEHICLE ACCLERATIONS (G's)[1] Lateral Longitudinal Total				UNAV UNAV UNAV
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)				6 0 ≈5
BARRIER DAMAGE				20' of rail section and 1 post. Some concrete spalling on parapet at posts.
REFERENCES				24
FIELD PERFORMANCE DATA[2]	NO		NO	
REMARKS	Safety aspects of barrier shape have been evaluated by full scale crash tests (see MB5, Chapter IV). Structural adequacy has not been evaluated by crash tests (see more discussion in text).		Some vehicle snagging on posts. Vehicle damage relatively severe.	

UNAV — unavailable
[1] **50 millisecond average unless otherwise noted**
[2] **If available, see summary in Appendix A**
[3] Permanent set in barrier

Table V-B-1. Operational Bridge Rail Systems (Continued)

	BR3		BR4	
Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg				
SYSTEM	BR3		BR4	
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	 8' 9" Fabricated steel Two TS 5"x3"x¼" steel None UNAV Bridge deck		 6' 3"[3] WF6x25 steel Two TS 3½"x3½"x0.25" (Steel) None 3/4" diameter steel stud bolts Bridge deck	
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 25°	IMPACT ANGLE = 12°	IMPACT ANGLE = 25°
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	NO TEST	 55.0 3500	 64.0 4550	NO TEST
BARRIER Dynamic Deflection (ft.)		 0	 0.21	
VEHICLE ACCLERATIONS (G's)[1] Lateral Longitudinal Total		 UNAV UNAV 12.3	 9.0 4.7 UNAV	
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)		 1 ≈0 ≈0	 3 5 0	
BARRIER DAMAGE		Slight.	15' of rail section and 3 posts.	
REFERENCES		17	38	
FIELD PERFORMANCE DATA[2]	NO		NO	
REMARKS	Tested with 10" curb. Curb severely damaged the steering. Subsequent studies have shown that curb should not be used.		This bridge rail was designed for use on secondary highways with maximum bridge widths of 32 ft.	

UNAV — unavailable

[1]50 millisecond average unless otherwise noted

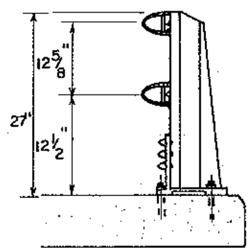
[2]If available, see summary in Appendix A

[3]Test results indicate 8' 0" post spacing is optimum although as-tested systems used 6' 3" and 9' 4½" spacing.

Table V-B-1. Operational Bridge Rail Systems (Continued)

Metric Conversions

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



SYSTEM	BR5			
BARRIER DESCRIPTION POST SPACING POST TYPE BEAM TYPE OFFSET BRACKETS MOUNTINGS FOOTINGS	 6' 6" Fabricated aluminum Two aluminum extrusions None UNAV Bridge deck			
IMPACT PERFORMANCE	IMPACT ANGLE = 15°	IMPACT ANGLE = 27°	IMPACT ANGLE =	IMPACT ANGLE =
IMPACT CONDITIONS Speed (mph) Vehicle Weight (lb.)	 NO TEST	 58.0 1956 Plymouth		
BARRIER Dynamic Deflection (ft.)		 1.4		
VEHICLE ACCLERATIONS (G's)[1] Lateral Longitudinal Total		 UNAV UNAV UNAV		
VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)		 ≈0 UNAV UNAV		
BARRIER DAMAGE		UNAV.		
REFERENCES		1		
FIELD PERFORMANCE DATA[2]	NO			
REMARKS	This system is similar to many state standards.			

UNAV — unavailable
[1] 50 millisecond average unless otherwise noted
[2] If available, see summary in Appendix A

which do not have sufficient in-service use to be classified operational.

Table V-B-2 presents a summary of the impact performance data on each of the operational systems. Unfortunately, acceleration data was unavailable for several of the systems. Most of these systems were developed and tested prior to the establishment of standard test procedures.

Evaluation criteria for the impact performance of a bridge rail are given in Table II-B-1 (longitudinal barrier). Recommended crash tests to evaluate bridge rails, and other longitudinal barriers, are given in Table II-B-2.

Omission of an existing bridge rail system is not meant to imply that the system is non-operational. Many bridge rails have been designed and installed which meet AASHTO bridge specifications (86, 87). It was decided, however, that only those bridge rails that have been evaluated through crash tests would be considered for inclusion in the guide. Inclusion of all bridge rail designs which meet the AASHTO bridge specifications was beyond the scope of this guide. *Although not required, it is desirable that new bridge rail designs (as well as other new traffic barrier systems) be evaluated by crash tests.*

The degree to which the operational systems satisfy the recommended structural and safety criteria of Section II-B varies. All are considered to be structurally adequate. Although all do not satisfy the impact severity criteria, the acceleration criteria is tenuous and currently under review. Nonetheless, *barriers which minimize impact forces should receive strong consideration.* With regard to the vehicle trajectory hazard, it is desirable that the vehicle be redirected parallel to the

Table V-B-2. Bridge Rail Crash Data Summary

System	Maximum Dynamic Deflection (ft.)[1]	Accelerations at 15° (G's)[2]			Accelerations at 25° (G's)[2]			Is Barrier Hardware Standardized?[3]
		Lateral	Longitudinal	Total	Lateral	Longitudinal	Total	
BR1[4]	No Test	No Test	No Test	No Test	No Test	No Test	No Test	No
BR2	0.42[5]	No Test	No Test	No Test	UNAV	UNAV	UNAV	Yes
BR3	≈0.00	No Test	No Test	No Test	UNAV	UNAV	12.3	Yes
BR4	0.21[6]	9.0	4.7	UNAV	No Test	No Test	No Test	No
BR5	1.40	No Test	No Test	No Test	UNAV	UNAV	UNAV	Yes

UNAV - Unavailable.

[1] Based on 25° impact unless otherwise noted.

[2] 50 millisecond average unless otherwise noted.

[3] See reference 22, 23.

[4] Although no tests have been conducted on this system, barrier and vehicle performance would be similar to MB5 (Chapter IV).

[5] Permanent set in barrier.

[6] Based on 12° impact.

Note: 1 ft. = 0.305 m

barrier. An exit angle of 10^0 or less may be considered a non-hazardous post impact trajectory.

Note that the rail heights range from 27 inches (0.69 m) to 34 inches (0.84 m). Barrier heights have been established as a result of many years of research and field evaluations. Visibility or the ability to see over the barrier was one of the more important factors in early barrier height consideration. A minimum height of approximately 27 inches (0.69 m) is a necessary, but not sufficient, condition to insure proper barrier impact performance.

Current research indicates that the most desirable height of the BR1 system is 32 inches (0.81 m). This height has been reached after carefully evaluating factors such as vehicle redirection, sight distance, and the psychological effect of barrier height on driver reaction. Unless sufficient justification exists, variations in this height are to be avoided.

A 10 inch (0.25 m) curb is shown in front of the BR3 barrier, since this was the as-tested configuration of the barrier. However, as discussed in Section V-E, *curbs in front of barriers are to be avoided where possible.*

The designer should be aware of the impact performance sensitivity of bridge rails to a number of factors. These include post spacing, rail height, post size, rail tension, and end anchorage. Some of these parameters have been investigated and the reader is encouraged to review the results (18).

An effort has been made to standardize hardware for widely used traffic barriers (22, 23). Standardization is beneficial in terms of economy, improved availability of parts, readily available details and specifications, reduced repair time, and reduced inventory of replacement parts because of interchangeability of parts. Bridge rails which have been standardized are so noted in the last column of Table V-B-2. The referenced standardized documents continue to be revised periodically and the designer should obtain the latest publications.

Where a *pedestrian* rail is to be provided in addition to the *traffic* bridge rail, reference should be made to the AASHTO specifications (86, 87) for its design requirements. Placement guidelines for traffic and pedestrian rails are discussed in Section V-E.

Current design criteria for bridge rails, as well as other traffic barriers, relates primarily to standard size automobiles. However, it may be desirable in certain situations to install bridge rails which can contain and redirect heavy vehicles, such as large busses and trucks. Bridge structures which span roadways or which are near businesses should be given careful evaluation, especially if the bridge carries significant heavy vehicle traffic. With regard to heavy vehicle containment, the BRE3 system shown in Table B-5, Appendix B, is a very promising barrier. Crash tests have shown that it can safely contain and redirect both automobiles and heavy vehicles. The BR1, although not designed specifically for heavy vehicles, offers promise in this area also.

On the other hand, there is an awareness that the structural requirements presented herein for bridge rails, and other longitudinal barriers, may be too stringent on certain roadways. For example, bridges in recreational areas such as state and federal parks often carry low traffic volumes at greatly reduced speeds. It seems reasonable that such bridge rails need not be designed to the specifications for high speed-high volume roadways. Once again, however, the lack of objective criteria precludes the presentation of specific guidelines. The engineer must once again rely on his best judgment. An NCHRP study is planned which will focus on the need and design of traffic barriers for roadways with lower levels of service. The designer should stay abreast of developments in this area.

V-C. Maintenance Characteristics

Section III-C contains a discussion of the maintenance factors to consider before selecting a *roadside* barrier. Those factors are essentially the same ones that should be considered before selecting a bridge rail. *The reader should therefore refer to Section III-C and Table III-C-1.*

The extent of bridge rail damage for a given set of impact conditions will depend on the strength and shape of the barrier. Where available, Table V-B-1 gives the barrier damage as a result of a crash test for the operational barriers. Efforts to supplement the crash test damage data with field data were unsuccessful. The large number of different bridge rail types in use within each state makes it difficult to determine typical damage data for a specific bridge rail design. Potential damage to the bridge deck as a result of vehicle impacts should also be evaluated in selecting a bridge rail system.

An environmental factor to consider in barrier selection is its potential for creating snow drifts. At this time, there is no evidence that a particular barrier causes more drifting than other barriers. However, an effort should be made to determine if such a problem exists before installing a barrier on roadways with high snowfalls. Also, the barrier should not impede the flow of rainfall from the traveled way.

V-D. Selection Guidelines

Table V-D-1 presents eight items which should be considered in selecting a bridge rail. Although these items are not necessarily listed in order of importance, the strength and safety requirements should never be compromised.

Section B of this chapter discusses the desirable strength and safety aspects of a bridge rail. It also presents the deflection, strength, and safety characteristics of operational bridge rails. If the bridge rail is to be placed between traffic and pedestrians, it should not deflect or permit vehicle structure protrusions into the sidewalk area.

Maintenance factors which should influence barrier selection are discussed in Section C of this chapter. Available maintenance data on the operational systems are also discussed there. A special point of interest in maintenance concerns the availability of replacement parts. Recent shortages in some barrier hardware has pointed to the need for advance planning and alternate hardware. Before selecting a system, material suppliers should give some assurance of future availability. Reference should be made to the discussion of standardization in Section V-B.

Compatibility is a very important item that should be considered in the selection process. A major deficiency of many bridge rail systems is the absence of a crashworthy transition section to the roadside barrier.

Table V-D-1. Selection Considerations for Bridge Rails

ITEM	CONSIDERATIONS
A. Strength and Safety	1. System should contain and redirect vehicles at design at design conditions.
	2. Deflection should not exceed specified amount.
B. Compatibility	1. Can system be transitioned to other barrier systems?
C. Maintenance	1. Collision maintenance.
	2. Routine maintenance.
	3. Environmental conditions.
D. Costs	1. Initial costs.
	2. Maintenance costs.
	3. Accident costs to motorist.
E. Field Experience	1. Documented evidence of barrier's performance in the field.
F. Aesthetics	1. Barrier should have a pleasing appearance.
G. Promising New Designs	1. It may be desirable to install new systems on an experimental basis.

Incompatibility of bridge rails with approach roadside barriers is attributed in large part to the proliferation of bridge rail types. Highway engineers should strive to standardize bridge rail designs with an eye toward compatible approach rail-to-bridge designs. Section III-B addresses these problems and presents the operational transitions and terminal designs.

Initial costs and future maintenance costs in particular should be carefully evaluated. As a general rule, the initial cost of a system increases as the rigidity or strength increases, but the maintenance costs usually decrease with increased strength. Consideration should be given to the costs incurred by the motorist as a result of collision with the barrier. Both damage costs to the vehicle and injury costs to the occupants need to be evaluated for a typical collision. The decision may ultimately involve the question of what level of protection the state or agency is able to provide. The procedure presented in Chapter VII should provide a means with which to approach this question.

Item E in Table V-D-1 concerns field experience. There is no substitute for documented proof of a barrier's field performance. In this regard, the impact performance data for each operational system, presented in Section B of this chapter, indicates the availability of field data. If none exists, the state or states which developed and implemented the system should be contacted for data and their views and comments.

With regard to aesthetics, the barrier should have a pleasing appearance. In scenic areas, it may be appropriate to select a barrier which allows the motorist the largest field of view possible. However, aesthetic considerations should not be used to justify a compromise in the crashworthiness of the selection.

Many of the experimental systems included in Appendix B exhibit excellent impact performance characteristics. The designer should give serious consideration to the installation of some of these barriers, at least on an experimental basis. The performance of the barrier should be monitored, and if proven satisfactory, it may be installed on a permanent basis.

V-E. Placement Recommendations

A desirable feature of a bridge structure is that it provide a full continuous shoulder so that the uniform clearance to roadside elements is maintained (see discussion in Section III-E-1). It is also desirable that the bridge rail be placed beyond the *shy distance* (see discussion in Section III-E-4).

If possible, curbs in front of the bridge rail and other barriers are to be avoided (see discussion in Section III-E-3). For speeds less than 40 mph (64.4 km/hr), a barrier curb provides marginal protection for pedestrians. If used for this purpose, it is desirable that the sidewalk be offset from the curb as far as feasible to minimize the possibility of pedestrian accidents.

If pedestrian protection is warranted, consideration should be given to placing the bridge rail between the traffic and the sidewalk. A hand rail (and protective fence if necessary) would be needed at the outer edge of the sidewalk. It is desirable that the sidewalk not compromise the uniform clearance concept discussed previously. To avoid such a compromise, it may be possible to cantilever the sidewalk off the edge of the bridge deck.

V-F. Upgrading Substandard Systems

It has been estimated that 67 percent of all bridge rails do not conform to current safety performance standards and another 25 percent are considered marginal (36). Obviously, a major effort is needed to upgrade a large number of bridge rails.

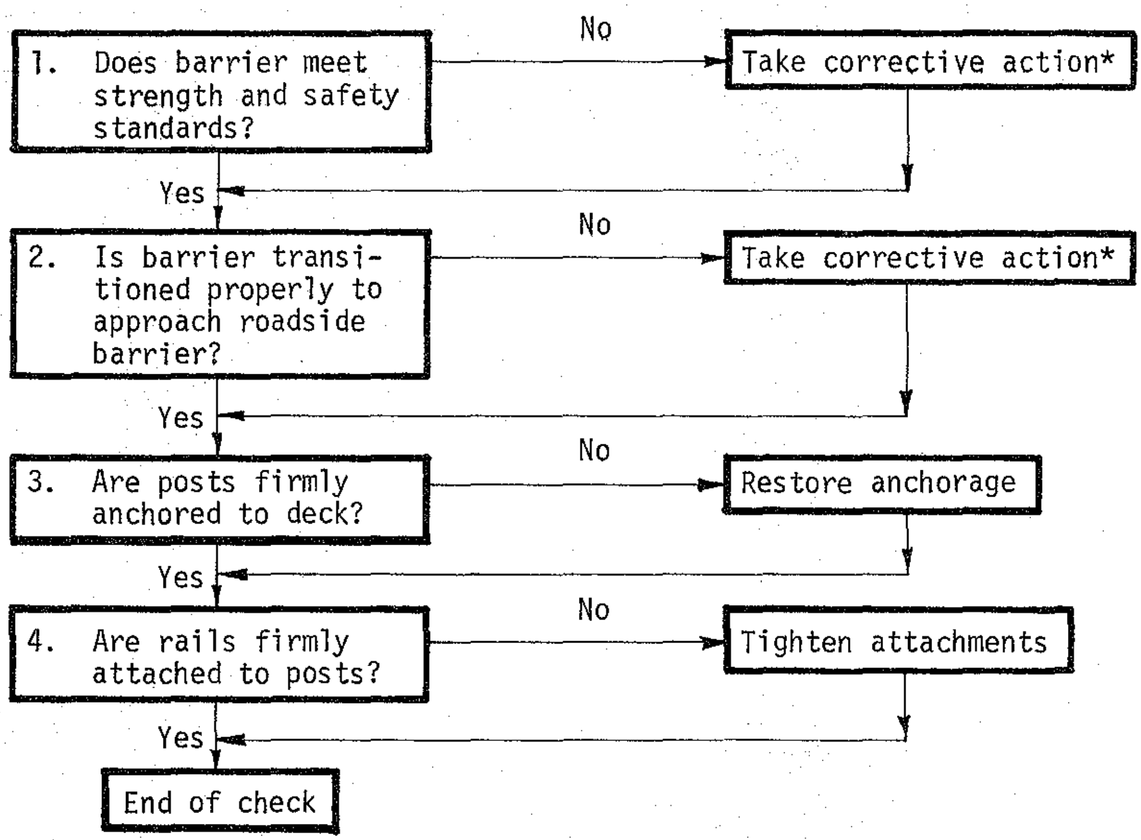
V-F-1. Guidelines

Figure V-F-1 presents an inspection procedure designed to identify substandard bridge rail installations. It is suggested that this inspection be conducted on a regularly scheduled basis. *Personnel performing this inspection should stay abreast of current traffic barrier standards and guidelines, as well as promising new research findings.*

With regard to item 1, current AASHTO specifications (86, 87) and the guidelines presented herein should be used to evaluate the structural adequacy and safety aspects of bridge rails. Of course, there is no substitute for field data or accident records to evaluate the performance of a system. *If a barrier installation is substandard, it is suggested that the barrier either be modified to conform to an operational system, or be replaced by an operational system.* Suggested methods of upgrading are discussed later in this section. If neither of these actions is feasible, the designer should insure that the upgraded system conforms to the aforementioned standards and guidelines. Crash tests are recommended for the final evaluation of such a system, especially if substantial use of the system is planned.

Table V-F-1 lists elements of bridge rail design which should be

Figure V-F-1. Inspection Procedure for Existing Bridge Rails



* See text for discussion

Table V-F-1. Conformance Checks for Bridge Rails

Item	Appropriate Criteria
I. Conformance with AASHTO Bridge Specifications	Applicable AASHTO Paragraph Number
A. Geometry	
1. Curb	
(a) Width	1.1.8[1]
(b) Height	1.1.8[1]
2. Rail Position	
(a) Top Rail	1.1.9A[2]
(b) Spacing	1.1.9A[2]
B. Railing Features	
1. Continuity of Face	1.1.9A[2]
2. Post Set Back	1.1.9A[2]
3. Structural Continuity	1.1.9A[2]
4. Anchorage	1.1.9A[2]
5. Joints	1.1.9A[2]
C. Mechanical Properties	
1. Materials	
(a) Rail	1.1.9A[2]
(b) Post	1.1.9A[2]
(c) Parapet	1.1.9A[2]
2. Stresses	
(a) Rail	1.1.9A[2]
(b) Post	1.1.9A[2]
(c) Parapet	1.1.9A[2]
(d) Anchor Bolts	1.1.9A[2]
II. General Impact Performance[3]	
A. Structural Adequacy	Item I, Table II-B-1
B. Impact Severity	Item II, Table II-B-1
C. Vehicle Trajectory Hazard	Item III, Table II-B-1

[1]See reference 86.

[2]See reference 87.

[3]Unless crash test or accident data available, this must be evaluated subjectively.

checked for conformance to specifications and guidelines. *Nonconformance with the strength (stress) requirements of the rail and post was found to be a prime reason many bridge rails are substandard (88).* It was also found (88) that many bridge rails are marginal or nonconforming with respect to the evaluation criteria given in Table II-B-1.

Another area which demands close attention is the bridge rail ends. Appropriate criteria for approach barriers and transitions sections is given in Sections III-B-2 and III-E-4.

V-F-2. Suggested Upgrading Designs

A recent study (88) developed conceptual modifications to upgrade certain types of bridge rails. Three concepts were formulated: (a) a collapsing ring bridge rail system, (b) a concrete safety shape, and (c) a thrie beam offset from backup structure with deforming cylinders. These concepts are illustrated in Figure V-F-2. *It must be emphasized that these are only concepts, whose details and impact evaluation are to be determined.*

A variation of the thrie beam system has been developed and tested, for possible use in upgrading concrete baluster bridge rails (62) (BRR4 system in Table B-6 of Appendix B). The designer should keep abreast of these and other efforts to upgrade barrier systems.

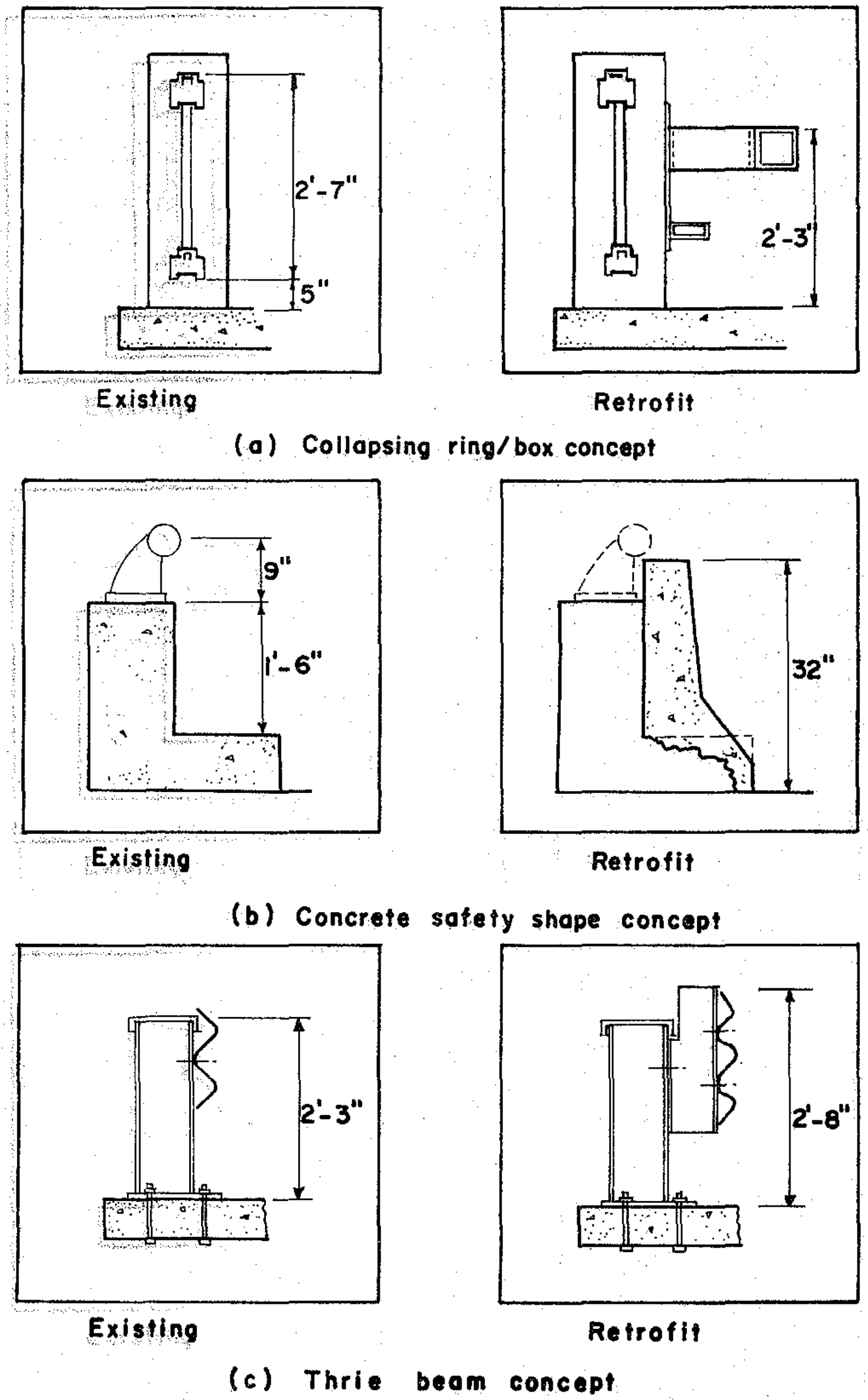


Figure V-F-2. Possible Retrofit Concepts for Bridge Rails (88)

VI. CRASH CUSHIONS

Crash cushions are protective systems which prevent errant vehicles from impacting hazards by either smoothly decelerating the vehicle to a stop when hit head-on, or by redirecting it away from the hazard for glancing impacts. These barriers are used to shield rigid objects or hazardous conditions that cannot be removed, relocated, or made breakaway. Before the development of crash cushions, many of these objects could not be shielded at all, and others could only be partially shielded by roadside barriers. The relatively low cost and potentially high safety payoff offered by crash cushions justifies national emphasis on their installation.

This chapter delineates criteria pertinent to the various elements of design, including warrants, structural and safety characteristics of operational systems, maintenance characteristics of operational systems, selection guidelines and placement and site considerations. It is noted that the Federal Highway Administration has published a report to assist the designer choose the best type of cushion for the particular location under consideration (13). It also presents crash cushion design procedures. The reader is encouraged to supplement the contents of this chapter with the FHWA document.

VI-A. Warrants

Crash cushions have proven to be a cost-effective and safe means of shielding rigid objects. Their use is therefore warranted to shield rigid objects within the clear distance that cannot be removed or shielded by more cost-effective means. Studies indicate that crash cushions are considerably more cost effective than conventional longitudinal barriers in many instances (see example in Section VII-C-3). Chapter VII presents an alternate procedure that can be used to determine crash cushion warrants. It provides the designer with a means with which to evaluate the effectiveness of various types of barrier protection in terms of initial costs, maintenance costs, and accident costs to the motorist. Specific policies have been established by the FHWA concerning crash cushion need and installation on Federal-Aid construction (40, 97).

The most common application of a crash cushion is in the ramp exit gore wherein practical design for the site calls for a bridge rail end in the gore. Where site conditions permit, a crash cushion should also be considered as an alternate to a roadside barrier for shielding rigid objects such as bridge piers, overhead sign supports, abutments, and retaining wall ends. Crash cushions may also be used to shield roadside and median barrier terminals. Examples and placement recommendations are given in Section VI-F.

Since limited resources may preclude the shielding of all rigid objects, a priority system should be established for crash cushion installation. In the absence of a more definitive procedure, the following equation may be used to establish priority:

$$RF = \frac{(1 + NOA) \times ADT \times S}{10{,}000}$$

where

RF = ranking factor;

NOA = number of accidents at the site over a given period of time (the same period should be used for all sites);

ADT = average daily volume of traffic; and

S = operating speed of roadway.

Locations with the higher ranking number are considered the most hazardous and should be the first to receive crash cushion protection. If other procedures are used, they should always include a consideration of each site's accident history.

Long steep downgrades present a unique type of problem with regard to traffic barriers. Loss of brakes on a vehicle on such a grade quickly produces a hazardous condition to its driver and to other motorists. Where such problems exist, special consideration should be given to the installation of a roadside decelerating device. An experimental device which shows considerable promise is the *gravel bed attenuator* (CR4) shown in Table B-8, Appendix B. Some states have installed similar systems and the results are very encouraging.

Another special condition for which crash cushions are warranted concerns the protection of maintenance personnel, and the motorist, during maintenance operations. It has been shown that a portable crash cushion can be used effectively to provide this type of protection (98). Further studies have been made to establish recommended design configurations (99). Also, a portable "truck mounted attenuator" is being developed and marketed commercially (100).

A crash cushion or a vehicle arresting device may also be warranted at the end of a dead-end street or beyond a "T" intersection. Need should be based on an evaluation of the probability and consequence of an errant driver going beyond the intersection.

VI-B. Structural and Safety Characteristics

This section presents the operational crash cushions and summarizes desirable structural and safety characteristics of a crash cushion. Also discussed are the different crash cushion design concepts.

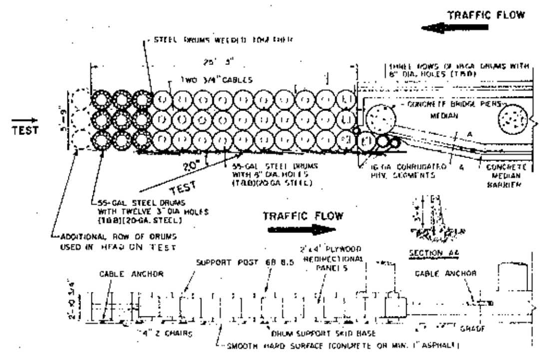
Shown in Table VI-B-1 are the operational crash cushions. Information on each system consists of a sketch, a system designation, barrier description, impact performance, barrier damage, references, field performance data and remarks. *Reference should be made to the introduction of Section III-B for a discussion of each of these items.* It is noted that the particular configurations shown in each sketch represent the as-tested configurations and are not necessarily typical installations. Each system can be designed for a wide range of performance requirements.

Table VI-B-2 summarizes the impact performance data of the six operational systems. *Although the values in Table VI-B-2 are indicative of the general performance of each barrier, discretion must be used in comparing each system based on these data.* First, as can be seen in Table VI-B-1, the impact conditions were not consistent. This problem should be remedied in the future due to the publication of standard test procedures (4). Secondly, the as-tested designs would not all necessarily be used for the same site conditions. Design and functional characteristics will be discussed in subsequent paragraphs.

As indicated in Table VI-B-2, none of the crash cushions have been standardized. Also note that all of the operational crash cushions are patented with the exception of the steel drum system.

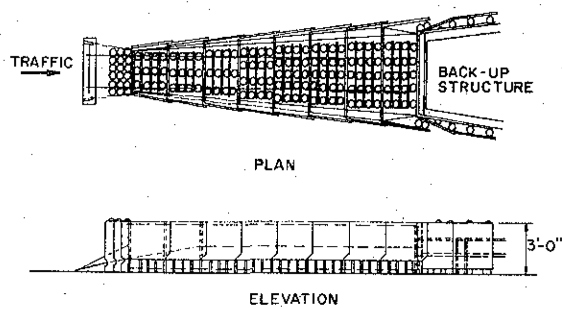
Recommended structural and safety criteria for crash cushions is

Table VI-B-1. Operational Crash Cushion Systems

Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg		
SYSTEM	C1 Steel Drums	
BARRIER DESCRIPTION	55 gallon tight head drum arranged in modular clusters, fender panels or "fish scales" fastened to sides for side impact redirection. 3/4" cable used to secure drums for side impacts. "U" bolt chairs used to ensure uniform sliding of drums.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	55.8	56.7
Angle	0	20
Vehicle Weight (lb.)	1790	4150
BARRIER		
Dynamic Deflection (ft.)	11.3	1.25
VEHICLE ACCELERATIONS (G's)[1]		
Lateral	UNAV	4.0[4]
Longitudinal	9.2[3]	3.9[4]
Total	UNAV	UNAV
VEHICLE TRAJECTORY		
Exit Angle (deg.)	NOAP	≈20
Roll Angle (deg.)	0	≈10
Pitch Angle (deg.)	0	≈ 5
BARRIER DAMAGE	Most of cushion damaged.	Moderate barrier damage
REFERENCES	42	42
FIELD PERFORMANCE DATA[2]	YES	
REMARKS	Good performance at head-on and side impacts. Recent accident surveys indicate that elimination of the fender panels may be desirable (see text).	

UNAV — unavailable
[1]50 millisecond average unless otherwise noted
[2]If available, see summary in Appendix
[3]Averaged over 0.257 sec.
[4]Averaged over 0.27 sec.

Table VI-B-1. Operational Crash Cushion Systems (Continued)

Metric Conversions 1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg		
SYSTEM	C2 Hi-Dro Cell Sandwich	
BARRIER DESCRIPTION	6" diameter, 42" long polyvinyl chloride plastic cells filled with water. Fender panels (fish scales) are provided for re-direction.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	61.8	57.0
Angle (deg.)	0	9.0
Vehicle Weight (lb.)	4690	4760
BARRIER		
Deceleration Distance (ft.)	18.0	UNAV
VEHICLE ACCELERATIONS (G's)[1]		
Lateral	UNAV	5.2
Longitudinal	9.8	8.4
Total	UNAV	UNAV
VEHICLE TRAJECTORY		
Exit Angle (deg.)	NOAP	less than 10
Roll Angle (deg.)	0	0
Pitch Angle (deg.)	less than 10	0
BARRIER DAMAGE	Slight permanent damage	Several fender panels and 5 cells
REFERENCES	43	43
FIELD PERFORMANCE DATA[2]	YES	
REMARKS	Barrier performs well for head-on and side impacts.	

UNAV — unavailable, NOAP - not applicable

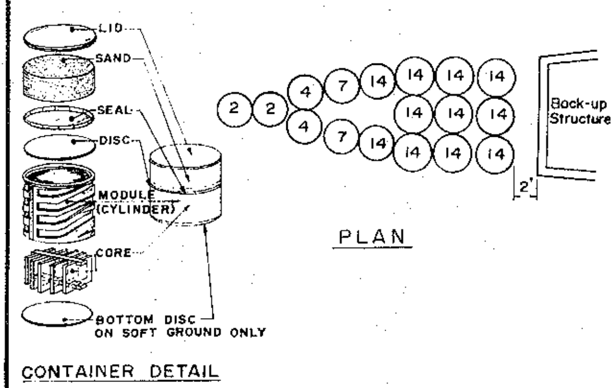
[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A

Table VI-B-1. Operational Crash Cushion Systems (Continued)

Metric Conversions

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



SYSTEM	C3 Fitch Inertial Barrier	
BARRIER DESCRIPTION	Specially manufactured plastic containers (36" in diameter and height) filled with sand. Standard weights are 200, 400, 700, 1400 and 2100 lb. Volume and density of sand may vary.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	59.0	57.0
Angle (deg)	0	15
Vehicle Weight (lb.)	1940	4770
BARRIER		
Deceleration Distance (ft)	19.0	UNAV
VEHICLE ACCELERATIONS (G's)[1]		
Lateral	UNAV	UNAV
Longitudinal	8.7	7.9
Total	UNAV	UNAV
VEHICLE TRAJECTORY		
Exit Angle (deg.)	NOAP	No redirection
Roll Angle (deg.)	0	0
Pitch Angle (deg.)	15	≈10
BARRIER DAMAGE	14 of 17 barrels either damaged or destroyed.	15 of 17 barrels were either damaged or destroyed
REFERENCES	44	44
FIELD PERFORMANCE DATA[2]	YES	
REMARKS	Good performance for head-on and side impact tests. No redirection capabilities with this type of barrier.	

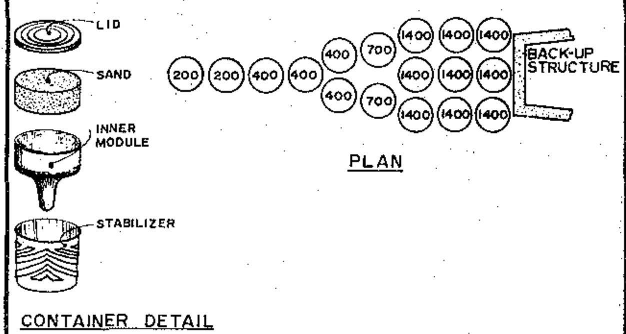
UNAV – unavailable, NOAP - not applicable

[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A

Table VI-B-1. Operational Crash Cushion Systems (Continued)

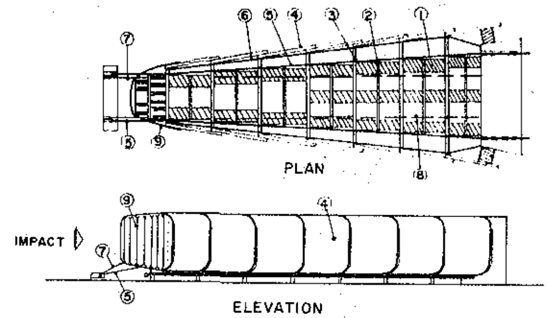
Metric Conversions	
1 ft. = 0.305 m	
1 in. = 25.4 mm	
1 mph = 1.61 km/hr	
1 lb. = 0.454 kg	



SYSTEM	C4 Energite Inertial Barrier	
BARRIER DESCRIPTION	Specially manufactured plastic containers filled with sand. Standard size of container is 36" diameter top, 32" diameter base and 35 3/4" height. Standard weights of modules are 200, 400, 700 and 1400 lb.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	58.4	59.3
Angle (deg.)	0	10
Vehicle Weight (lb.)	4490	4430
BARRIER		
Deceleration Distance (ft.)	35.0	46.0
VEHICLE ACCELERATIONS (G's)[1]		
Lateral	UNAV	6.0[3]
Longitudinal	3.3[3]	8.0[3]
Total	UNAV	UNAV
VEHICLE TRAJECTORY		
Exit Angle (deg.)	NOAP	No redirection
Roll Angle (deg.)	less than 10	0
Pitch Angle (deg.)	less than 10	0
BARRIER DAMAGE	All barrels were damaged extensively	All barrels were damaged extensively
REFERENCES	45	45
FIELD PERFORMANCE DATA[2]	NO	
REMARKS	Good performance for head-on and side impact tests. No redirection capabilities with this type of barrier.	

UNAV — unavailable, NOAP - not applicable
[1] 50 millisecond average unless otherwise noted
[2] If available, see summary in Appendix A
[3] Acceleration calculated from stopping distance

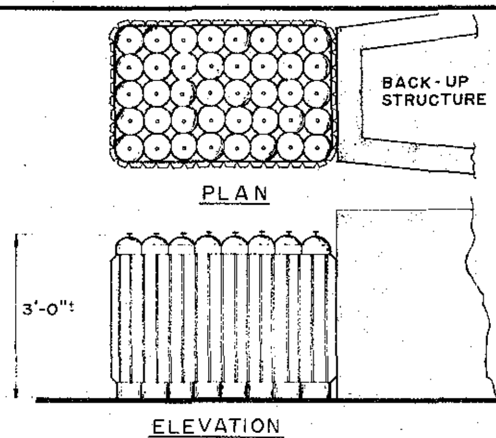
Table VI-B-1. Operational Crash Cushion Systems (Continued)

Metric Conversions	
1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg	 — LEGEND — 1 HELICELL CARTRIDGE 4 FENDER PANELS 7 SECONDARY CABLES 2 DIAPHRAMS (CARTRIDGE) 5 RESTRAINING CABLES 8 SLIDE STRAPS 3 DIAPHRAMS (UNIT) 6 PULL OUT CABLES 9 BELTING

SYSTEM	C5 Hi-Dri Cell Sandwich	
BARRIER DESCRIPTION	Heli-cell cartridges are arranged in a cluster along with fender panels (fish scales) to provide capabilities for head-on and side impacts.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS		
Speed (mph)	56.0	60.0
Angle (deg.)	0	20
Vehicle Weight (lb.)	3700	4000
BARRIER		
Deceleration Distance (ft.)	14.5	UNAV
VEHICLE ACCELERATIONS (G's)[1]		
Lateral	UNAV	4.5[3]
Longitudinal	7.2[3]	4.0[3]
Total	UNAV	UNAV
VEHICLE TRAJECTORY		
Exit Angle (deg.)	NOAP	9
Roll Angle (deg.)	0	UNAV
Pitch Angle (deg.)	UNAV	UNAV
BARRIER DAMAGE	UNAV	UNAV
REFERENCES	46	47
FIELD PERFORMANCE DATA[2]	YES	
REMARKS	Barrier performs well for head-on and side impacts.	

UNAV — unavailable, NOAP - not applicable
[1]50 millisecond average unless otherwise noted
[2]If available, see summary in Appendix A
[3]Acceleration calculated from stopping distance

Table VI-B-1. Operational Crash Cushion Systems (Continued)

Metric Conversions 1 ft. = 0.305m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb. = 0.454 kg		
SYSTEM	C6 Hi-Dro Cell Cluster	
BARRIER DESCRIPTION	6" diameter, 42" long polyvinyl chloride plastic cells arranged in a cluster and filled with water.	
IMPACT PERFORMANCE	HEAD ON IMPACT	SIDE IMPACT
IMPACT CONDITIONS Speed (mph) Angle (deg.) Vehicle Weight (lb.) BARRIER Deceleration Distance (ft.) VEHICLE ACCELERATIONS (G's)[1] Lateral Longitudinal Total VEHICLE TRAJECTORY Exit Angle (deg.) Roll Angle (deg.) Pitch Angle (deg.)	NO TEST	NO TEST
BARRIER DAMAGE		
REFERENCES		
FIELD PERFORMANCE DATA[2]	YES	
REMARKS	This system is considered operational for speeds less than 45 mph based on tests of the C2 system. It should be used at hazards with limited space available for barrier protection and low vehicle speeds.	

UNAV — unavailable
[1]50 millisecond average unless otherwise noted
[2]If available, see summary in Appendix A

Table VI-B-2. Crash Cushion Crash Data Summary

System	Deceleration Distance (ft.)[1]	Accelerations for Head-On Impacts (G's)[2]			Accelerations for Side Impacts (G's)[2,3]			Is Barrier Hardware Standardized?
		Lateral	Longitudinal	Total	Lateral	Longitudinal	Total	
C1	11.3	UNAV	9.2[5, 10]	UNAV	4.0[6]	3.9[6]	UNAV	No
C2	18.0	UNAV	9.8	UNAV	5.2[7]	8.4[7]	UNAV	No[4]
C3	19.0	UNAV	8.7[10]	UNAV	UNAV	7.9[8]	UNAV	No[4]
C4	35.0	UNAV	3.3	UNAV	6.0[5]	8.0[5]	UNAV	No[4]
C5	14.5	UNAV	7.2[5]	UNAV	4.5[5]	4.0[5]	UNAV	No[4]
C6[9]	No Test	No Test	No Test	No Test	No Test	No Test	No Test	No[4]

UNAV - Unavailable.

[1] Based on head-on impact.

[2] 50 millisecond average unless otherwise noted.

[3] Based on 20° impact unless otherwise noted.

[4] Patented or proprietory system.

[5] Average acceleration calculated from stopping distance.

[6] Averaged over 0.27 sec.

[7] Based on 9° impact.

[8] Based on 15° impact.

[9] Although no tests have been conducted on this system, it is considered operational (for speeds under 45 mph) based on the tests of the C2 system.

[10] Test conducted with small car.

Note: 1 ft. = 0.305 m

given in Table II-B-1. The degree to which the operational systems satisfy these criteria is discussed below.

VI-B-1. Steel Drums (C1)

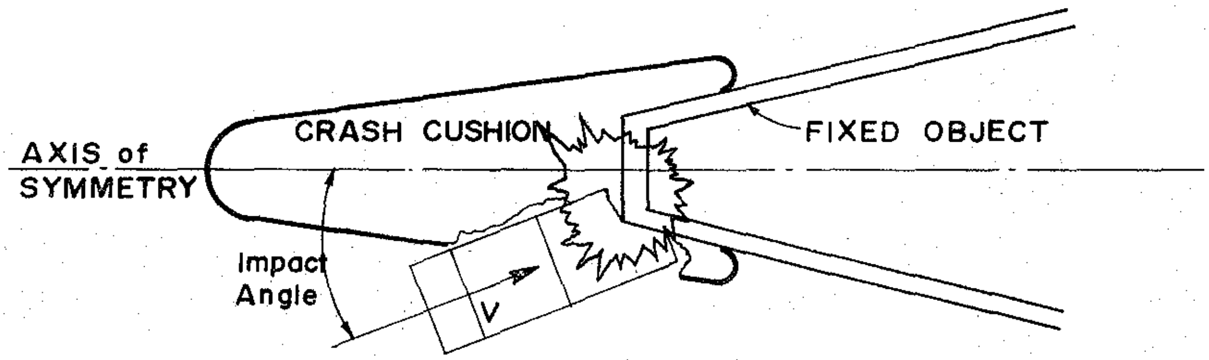
This system, sometimes referred to as the "Texas Barrels", dissipates the kinetic energy of the impacting vehicle primarily through the plastic deformation or crushing of the steel drums. The cushion is designed so that the resultant force at the vehicle-barrier interface is applied at a height approximately equal to the vertical position of the center of gravity of a standard size vehicle. The drums are restrained vertically and laterally by steel cables, but are free to move to the rear during impact. A rigid back-up structure (usually the rigid object being shielded) is necessary at the rear of the cushion. The drums are either bolted or welded together. As a consequence, there are no loose elements, fragments or other debris following an impact. It is desirable that the cushion be placed on a level concrete or asphalt pad to facilitate free movement of the U-bolt support chairs during impact.

The cushion is composed of 55 gallon, 20 gauge steel tight-head drums. Each drum has an 8 inch (0.2 m) diameter hole centered in the top and bottom. A "softer nose" can be achieved by placing drums with 12 - 3 inch (0.08 m) diameter holes around the periphery of the top and bottom, at the front of the cushion (as shown in Table VI-B-1). The soft nose cushion produces a smaller initial decelerating force than would be obtained in a cushion with 8 inch (0.20 m) diameter hole leading drums. While the soft nose is desirable, acceptable performance can be achieved without it.

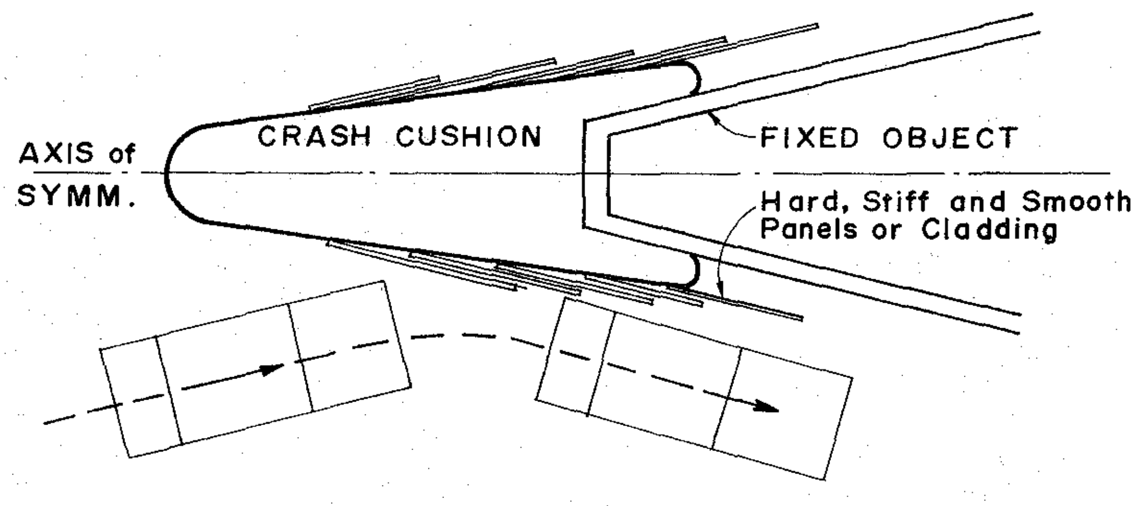
The decelerating force produced by the steel drum cushion is dependent primarily on the amount of crush or deformation of the cushion and is independent of the rate of crush. Barrier inertia forces are negligible. The length of the cushion and the number and orientation of the drums needed is a function of the range of kinetic energy to be dissipated. Usually, the barrier is designed to safely stop both small vehicles, 2250 lb, (1021 kg) and large vehicles, 4500 lb, (2043 kg) at a given design speed. Once the kinetic energy ranges have been established, the design is achieved through an iterative process. The two major constraints are that the barrier must dissipate the energy within a given stopping distance and it must do so without producing excessive decelerations. As a consequence, design of the front portion of the barrier is usually dictated by the small vehicle requirements, and the design of the remainder of the barrier is usually dictated by the large vehicle requirements. The C1 system can be designed to meet the recommended dynamic performance criteria with regard to direct-on impacts (see item II-B of Table II-B-1) for a wide range of design conditions. Further design aids for the steel drum system are given in Appendix D and in an FHWA publication (13).

The steel drum system is one of three operational systems designed to redirect a vehicle if hit from the side, i.e., for side impacts it functions essentially as a longitudinal barrier. In the C1 system, this is achieved through plywood "fish scales" or fender panels attached to the side of the barrier. This is illustrated in Figure VI-B-1. Impact in the "transition zone" can result in an impact with the fixed object if redirection panels are not provided.

Although the *concept* of redirection for crash cushions is sound,



(a) Potential impact with fixed object without redirection panels.



(b) Redirection with side panels.

Figure VI-B-1. Illustration of Side Impacts in Transition Zone the cost-effectiveness of redirection panels is currently being reviewed (99). Statistics from the referenced report indicate that transition zone impacts, with the steel drum system without side panels, may not be of sufficient frequency to warrant the added cost of the panels. Conclusions, however, cannot be drawn at this writing as to the cost-effectiveness of side panels on the steel drum system. Regardless, it is probable that their use will be warranted for certain conditions, for example, where alignment increases the potential for side impacts or where there is a record of side impact accidents. The designer should stay abreast of future developments in this area.

In summary, the steel drum crash cushion can be designed to satisfy all of the recommended dynamic performance criteria, as listed in Table II-B-1, for a wide range of design conditions.

VI-B-2. Hi-Dro Cell Sandwich (C2)

This system dissipates the kinetic energy of the impacting vehicle by the discharge of water from plastic filled tubes through orifices in the tubes, and by the transfer of momentum (movement of the water mass). It is a patented device and is manufactured and distributed by Energy Absorption Systems, Inc. (100). Standard installations, detailed design guides and installation procedures are available from the manufacturer. *The interested designer should consult with the manufacturer to determine availability of designs and insure proper selection and installation.*

The cushion is designed so that the resultant force at the vehicle-barrier interface is applied at a height approximately equal to the vertical position of the center of gravity of a standard size vehicle.

It is composed of 6 inch (0.15 m) diameter, 42 inch (1.07 m) polyvinyl plastic cells filled with water. These cells are arranged in clusters or bays to make up the cushion for a given set of design conditions. A rigid back-up structure (usually the rigid object being shielded) is necessary at the rear of the cushion. The cells are restrained vertically and laterally by steel cables, but are free to move to the rear during impact. As a consequence, there are no loose elements, fragments or other debris following an impact. However, water on the roadway may increase the potential for accidents by reducing the skid resistance of the pavement, especially if it freezes. It is desirable that the cushion be placed on a level concrete or asphalt pad to facilitate its movement during impact.

The decelerating force produced by the hi-dro cell system is dependent on the depth of vehicle penetration and on the rate of deformation of the cells, i.e., the force is velocity dependent. Upon head-on impact the nose cluster is directly contacted. As the vehicle penetrates the crash cushion, the nose cluster cartridges are compressed. There are no diaphrams in the nose cluster therefore all of the force of the vehicle is located at the bumper; this makes the nose cluster reaction relatively soft.

As the vehicle penetrates further into the cushion it exerts force on the first bay of cartridges which contains diaphrams that distribute the force over all of the cartridges uniformly thereby causing the crash cushion system to resist the force of the impacting vehicle. Further penetration activates the remaining bays of cartridges which bring the vehicle to a stop.

Energy dissipation with this crash cushion system is a complex interaction of events since several things are happening at varying rates during the impact. The three most predominant things to consider are:

1. Fluid is being forced up through orifices at varying pressure.
2. The mass of the cushion is being moved at varying velocities and accelerations.
3. The mass of the system changes as it is compressed because of the loss of fluid.

Some energy is also dissipated as the cushion slides along the supporting surface and as the different parts of the system are deformed.

Because of this complex reaction of an impacted hi-dro cell system, a simplified design procedure is not available. This system has been extensively tested and a mathematical model has been developed enabling the manufacturer to develop standard bay arrangements which will suit most typical crash cushion requirements.

The hi-dro cell system is one of three operational systems designed to redirect a vehicle if hit from the side i.e., for side impacts it functions essentially as a longitudinal barrier. Redirection is achieved through fender panels attached to the side of the barrier. This is illustrated in Figure VI-B-1. Impact in the "transition zone" can result in an impact with the fixed object if redirection panels are not provided.

In summary, the hi-dro cell sandwich cushion can be designed to satisfy all of the recommended dynamic performance criteria, as listed in Table II-B-1, for a wide range of design conditions.

VI-B-3. Sand Filled Plastic Barrels (C3 and C4)

These systems dissipate the kinetic energy of the impacting vehicle by a transfer of the vehicle's momentum to the mass of the cushion. Both systems consist of an array of plastic containers filled with varying weights of sand. The C3 system is patented and is manufactured and distributed by FIBCO, Inc. (101). The C4 system is also patented and is manufactured and distributed by Energy Absorption Systems, Inc. (100). Although the two systems differ in the container details, both function essentially the same. Standard installation layout details, design guides, and installation procedures are available from the manufacturers. *The interested designer should consult with the manufacturer to determine availability of designs and to insure proper selection and installation.*

These cushions are designed so that the resultant force at the vehicle-barrier interface is applied at a height approximately equal to the vertical position of the center of gravity of a standard size vehicle. Note that a back-up device is not required for either system since the force that the vehicle exerts on the crash cushion units is not transmitted through the cushion. Also note that neither crash cushion system is designed to redirect vehicles upon side-on impacts. Careful consideration must therefore be given to the placement of the units in the transition zone between the barrier and the fixed object. Figure VI-B-2 shows a suggested layout for the last three exterior modules in an inertial barrier. While this layout will not accomodate all side impacts at the recommended acceleration levels, it is considered an acceptable compromise for many sites.

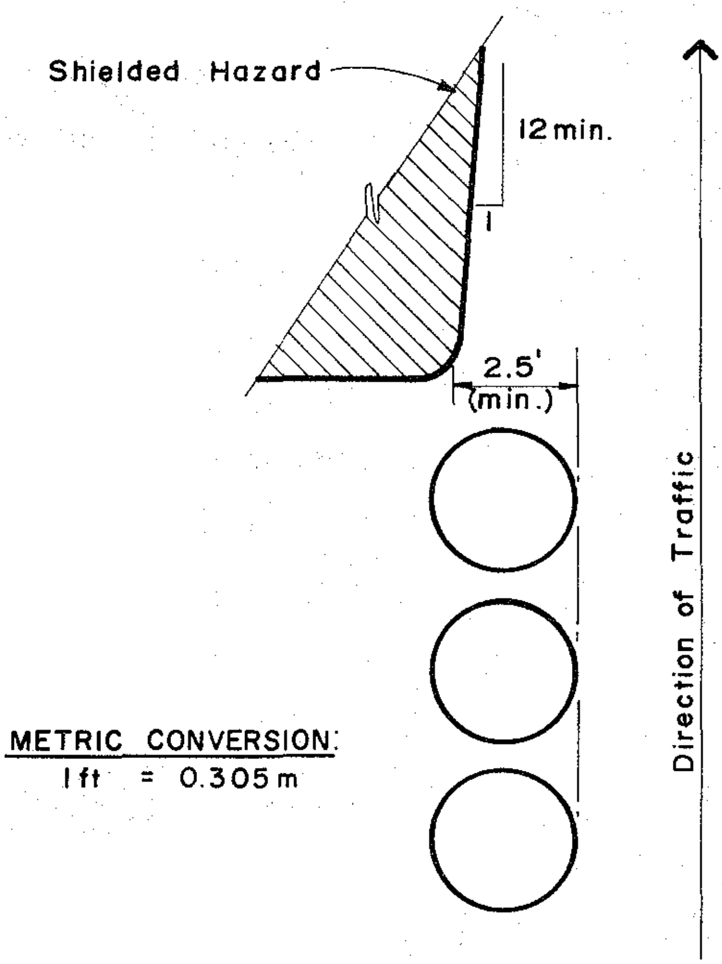


Figure VI-B-2. Suggested Layout for Last Three Exterior Modules in an Internal Barrier

Both of these systems generate debris upon impact, consisting of sand and remnants of the plastic barrels. As such, there is a potential danger to other motorists. If the cushion is on a structure, the debris may fall into traffic lanes below. However, at this writing, there is no documented evidence that these characteristics are a significant liability to inertial barriers.

Design of an inertial barrier system is relatively simple and straightforward. By use of the law of conservation of momentum, the barrier is designed to incrementally reduce the vehicle's impact velocity from module to module (or from a row of modules to the succeeding row of modules). To obtain a constant change in velocity, or a constant decelerating force, as the vehicle impacts each successive container, the containers must increase in weight as they get closer to the hazard.

Theoretically, the vehicle cannot be stopped completely by this principle. Practically, it is usually adequate to design this type of crash cushion to reduce the vehicle speed to 10 mph after the final container is impacted. At this point, the remaining vehicle kinetic energy is dissipated by friction in the sand as the vehicle "bulldozes" into the final containers. Design aids and examples of their application are given in Appendix D. The designer should also refer to an FHWA publication (13) for design procedures and examples.

Standard sizes and weights of available modules for each of the systems are given in the "barrier description" on Table VI-B-1. Sand heights and center of gravity data of modules for both systems is given in Table VI-B-3. Note that the height of the center of gravity of the

Table VI-B-3. Center of Gravity Data for Inertial System Modules

Module Weight (lb)	FITCH INERTIAL SYSTEM			ENERGITE INERTIAL SYSTEM		
	Core Height (in.)	Sand Depth (in.)	Height of Center of Gravity (in.)	Wine Glass Core*	Sand Depth (in.)	Height of Center of Gravity (in.)
200	20.5	3.5	22.5	A	28.0	24.0
400	20.5	7.0	24.5	A	31.5	26.0
700	16.5	12.0	23.0	B	32.5	24.5
1400	11.5	24.0	24.0	C	36.0	22.0
2100	0	26.0	18.0	NOT AVAILABLE		

*Energite designations

METRIC CONVERSIONS: 1 in. = 0.0254 m

1 lb = 0.454 kg

2100 lb (953 kg) module is 18 inches (0.46 m) above the ground, a height which is lower than the center of gravity of most standard size automobiles. It is placed at the rear of the array to completely stop the slowed vehicle before it impacts the rigid object. Head-on tests at 60 mph (96.5 km/h) have shown that the 2100 lb (953 kg) module can perform this function effectively. However, its impact performance during transition zone or shallow angle side impacts is questionable due to its relatively low center of gravity. The 2100 lb (953 kg) module should therefore be used with discretion and if space permits, consideration should be given to the use of a smaller module.

The width of the back row of modules should always be greater than the width of the fixed object. This will soften the impacts of those vehicles striking the rear portion of the barrier at an angle and provide some deceleration prior to striking the fixed object. The barrier modules should be set back from the traffic lanes to minimize the number of casual vehicular contacts with the barrier and the amount of debris thrown into the traveled way when an impact does occur. Also, space should be left behind the last row of modules so the sand and debris will not be confined and produce a ramping effect on the vehicle. It is suggested that this space be one foot (0.3 m) to two feet (0.6 m).

When fixed objects are more than 6 feet (1.8 m) wide, extra longitudinal rows of modules may be added to the barrier. The first few modules in each of these rows should be no more than 3 feet (0.9 m) apart (clear dimension) in the lateral direction. Then impacting vehicles, most of which have a width of about 6 feet (1.8 m), will displace approximately the same mass of sand whether they hit one longitudinal row of modules head-on or carry away one-half of each row on either side. Depending on available space, modules may be separated by any distance in the longitudinal direction. Extra distance may lower the deceleration rates.

The standard containers have been sized to hold the standard weights based on sand density of 100 lb/cu ft. A significant variation in sand density actually used could have some effect on the performance of the crash cushion.

Care must be exercised in selecting the modules in an inertial system so that the small car will not be subjected to undesirable decelerating forces. For example, a 2000 pound (908 kg) vehicle impacting a 400 pound (182 kg) module at 60 mph (96.5 km/hr) will be slowed to 50 mph (80.5 km/hr) with a 12.2 g deceleration. *Whenever stopping distance permits, it is suggested that 200 pound (91 kg) modules be used on the nose of inertial barriers exposed to high speed traffic.*

In summary, the inertial barriers (systems C3 and C4) can be designed to satisfy the recommended dynamic performance criteria, as listed in Table II-B-1, for a wide range of design conditions. Although debris is produced upon impact for both systems, it is not considered a significant limitation. Neither of the two systems is designed to redirect if impacted from the side.

VI-B-4. Hi-Dri Cell Sandwich (C5)

This system dissipates the kinetic energy of the impacting vehicle through the crush of the lightweight concrete components and through the transfer of momentum (movement of cushion mass). It is a patented device, manufactured and distributed by Energy Absorption Systems, Inc. (100). Standard installations, detailed design guides, and installation procedures are available from the manufacturer. *The interested designer should consult with the manufacturer to determine availability of designs, appropriate selections, and installation procedures.*

The cushion is designed so that the resultant force at the vehicle-barrier interface is applied at a height approximately equal to the vertical position of the center of gravity of a standard size vehicle. The energy absorbing elements of this system are 7 inch (0.18 m) diameter cylindrical cells made of lightweight concrete. The cell has a hole in its center and steel wire wound around the outside. Each cell is wrapped with a weatherproof covering to keep water out and to prevent pieces of concrete from being scattered about during impact.

The hi-dri cells are installed in bays very similar to the hi-dro cell bays as discussed in Section VI-B-2. Side panels, diaphragms, cables, and some of the hardware are the same as used in the hi-dro cell sandwich crash cushion. This cushion is one of three operational systems designed to redirect a vehicle if hit from the side. Redirection is achieved through the fender panels attached to the side of the barrier. This is illustrated in Figure VI-B-1. It also generates minimal debris upon impact. A rigid back-up structure (usually the rigid object being shielded) is required at the rear of the cushion.

Upon impact, the lightweight concrete cells crush. The void in the center of the cell fills with concrete pieces as the cell is compressed. Then the concrete is forced outward between the steel wires.

This action converts the kinetic energy of the impacting vehicle into work. Simultaneously, other actions are taking place that absorb the KE of the impacting vehicle. These are:

1. The mass of the crash cushion is being moved.
2. The crash cushion parts are being dragged along the pavement surface.
3. The parts of the crash cushion are being physically deformed.

Because of the complex reaction of an impacted hi-dri cell sandwich crash cushion, a simplified rational design procedure does not appear to be feasible. This system has been extensively tested and a mathematical model has been developed enabling the manufacturer to develop standard bay arrangements which will suit most typical crash cushion requirements.

In summary, the hi-dri cell sandwich system can be designed to satisfy the recommended impact performance criteria, as listed in Table II-B-1, for a wide range of design conditions.

VI-B-5. Hi-Dro Cell Cluster (C6)

This system functions along the same principle as the hi-dro cell sandwich cushion discussed in Section VI-B-2. It is also a patented device and is manufactured and distributed by Energy Absorption, Inc. (100). Standard installations, detailed design guides, and installation procedures are available from the manufacturer. *The interested designer should consult the manufacturer to determine availability of designs, appropriate selections, and installation procedures.*

Its application is limited to roadways with design speeds of 45 mph

(72.4 km/hr) or less. It can be used where there are space limitations and it can be arranged in various patterns to fit the object to be protected. Typical applications are to shield gore walls, bridge abutments, traffic control devices, toll booths, etc.

A back-up structure is required at the rear of the cushion. It has minimal redirection capabilities when impacted from the side. There is no debris, with exception of water, produced upon impact.

Design aids for this system are relatively straightforward and easy to use. These aids are included in Appendix D.

In summary, the hi-dro cell cluster system can be designed to shield various rigid objects when the design speeds are 45 mph (72.4 km/hr) or less. It has no redirection capabilities. Negligible debris is produced upon impact.

VI-B-6. Summary

All of the operational crash cushions, with the exception of the hi-dro cell cluster, can be designed to satisfy the recommended impact performance criteria of Table II-B-1 for a wide range of design conditions. The hi-dro cell cluster cushion is limited to roadways with a design speed of 45 mph (72.4 km/hr) or less. Table VI-B-4 summarizes the structural and safety characteristics of the operational systems.

Although not mentioned in the preceding discussion, the vehicle itself will deform and dissipate some of the kinetic energy. However, each cushion should be designed to dissipate the vehicle's total kinetic energy. Any vehicle crush that occurs will then be an added safety factor.

Table VI-B-4. Summary of Structural and Safety Characteristics of Crash Cushions

Item	Steel Drums (C1)	Hi-Dro Cell Sandwich (C2)	Fitch Inertial (C3)	Energite Inertial (C4)	Hi-Dri Cell Sandwich (C5)	Hi-Dro Cell Cluster (C6)
1. Tolerable accelerations?	Yes[1]	Yes[1]	Yes[1]	Yes[1]	Yes[1]	Yes[2]
2. Redirection capabilities?	Yes	Yes	No	No	Yes	No
3. Back-up structure required?	Yes	Yes	No	No	Yes	Yes
4. Debris produced upon impact?	No	No[3]	Yes	Yes	No	No[3]
5. Anchorage required?	Yes	Yes	No	No	Yes	Yes

[1] For any reasonable design speed.

[2] For a speed of 45 mph (72.4k/h) or less.

[3] Except water. Water on the roadway can increase the potential for accidents by reducing skid resistance of pavement, especially if it freezes.

Finally, there are several promising crash cushion systems which at present are not considered operational. Reference should be made to Table B-7 and B-8 of Appendix B for a summary of these systems. Three of these systems need further discussion. First, the CE3 system of Table B-7 has been installed on an experimental basis to prevent an errant vehicle from entering the opening between twin structures and at a ferry landing. It also has potential for use at the end of a dead-end street or beyond a "T" intersection. Second, the CR1 system of Table B-8 has performed very well in crash tests and has the potential for reuse without significant repairs after each hit. Third, the CR3 system of Table B-8 offers promise as a crash cushion that is compatible with the standard W-beam roadside or median barrier.

It is likely that some of these experimental systems will become operational in the near future. The designer may wish to install one of these systems on a trial basis. If so, the system should be monitored for its in-service performance.

VI-C. Maintenance Characteristics

Since all of the operational systems can be designed to meet the recommended impact performance criteria for a wide range of design conditions, the maintenance characteristics of the barriers can and should play a very important role in the selection process. To aid the designer, an attempt has been made to summarize the pertinent maintenance characteristics of each crash cushion. The data is presented in Table VI-C-1. The data in the table was obtained from state maintenance records where available. However, as can be seen, some of the data is based on

Table VI-C-1. Maintenance Characteristics of Operational Crash Cushions

Maintenance Requirement	Steel Barrel Cushion	Hy-Dro Cushion	Fitch Barrier	Energite System	Hy-Dri Cell
I. Collision Maintenance					
A. Manpower and Equipment					
1. Crew Size	6 men	6 men	5 men	UNAV	UNAV
2. Expertise required	welding	hardware training	very little	very little	UNAV
3. Special equipment	flat-bed truck, welding equipment	water truck, maintenance truck, pick-up	loader, maintenance truck	loader, maintenance truck	UNAV
B. Collision aftermath					
1. Immediate removal of scattered debris, water, anti-freeze needed?	no	yes, anti-freeze[1]	yes, sand and plastic	yes, sand and plastic	no
2. Immediate problem created?	no	yes[2]	yes, debris	yes, debris	no
3. Lane closure necessary?	yes, to repair	yes, to repair	yes, clean and repair	yes, clean and repair	yes, to repair
C. Restoration					
1. Overall difficulty	above average	average[3]	average	average	average[3]
2. Any salvageable hardware?	yes	usually	very little	very little	usually
3. Energy absorption unit reusable?	usually not	usually	no	no	usually
D. Considerable maintenance due to the nuisance hit?	no	no	yes	yes	no
E. Disposal of debris a problem?	yes	no	yes	yes	yes
F. Average exposure time per hit (man-hours)	34	13	10	UNAV	UNAV

[1]certain types of anti-freeze

[2]only if "oil slick" develops from anti-freeze or water freezes

[3]"average", assuming most of hardware reusable

Table VI-C-1. Maintenance Characteristics of Operational Crash Cushions (Continued)

Maintenance Requirement	Steel Barrel Cushion	Hy-Dro Cushion	Fitch Barrier	Energite System	Hy-Dri Cell
II. Regular Maintenance					
A. General condition checks					
1. Cushion in position?	no	no	yes	yes	no
2. Vandalism damage?	no	yes	yes	yes	no
3. Hardware and cables intact?	yes	yes	no	no	yes
4. Nuisance hit?	yes	yes	yes	yes	yes
5. Water level and anti-freeze quantity adequate?	no	yes	no	no	no
B. Painting, cleaning, and other treatments to assure adequate appearance/performance needed?	yes, paint and clean	yes, paint and clean	yes, clean	yes, clean	yes, paint and clean
C. Weathering/corrosion problem due to environmental/chemical effects?	yes, salt corrosion may be a problem	yes	yes	yes	UNAV
III. Material Storage and/or Availability Requirements					
A. Dry sand stock pile necessary?	no	no	yes	yes	no
B. Modules/barrels for replacement?	yes, 55 gallon drums	yes, cells enough to replace damaged	yes, Fitch Modules	yes, Energite Modules	yes, vermiculite cell replacement
C. Water supply and anti-freeze?	no	yes	no	no	no
D. Hardware and connections for assembly?	yes	yes	no	no	yes
E. Paint and/or aesthetic coverings for appearance/performance?	if desired	if desired	if desired	if desired	if desired

subjective evaluations. Figures given in the table are based on average values of several agencies, and should be used as "indicators" or "ball-park" estimations. The three major categories given in the table are discussed below.

VI-C-1. Collision Maintenance

Special consideration should be given to this phase of crash cushion maintenance since it will require the most effort and expenditure. Careful evaluation of items I-A, I-C, and I-F are suggested since these items have a large influence on the maintenance costs. The latter item is also significant in terms of the hazard the maintenance crew is subjected to while repairing the barrier and the disruption of normal traffic flow.

When a particular site has a relatively high frequency of accidents, consideration should be given to the installation of a reusable crash cushion. Hardware in the hi-dro cell (C2) and the hi-dri cell (C5) sandwich systems is reusable for many impact conditions (head-on impacts by automobiles traveling at 60 mph (96.5 km/hr) or less). Of course, water must be added to the C2 system and the damaged cartridges must be replaced in the C5 system. A cushion with redirection panels may be appropriate for sites with a high frequency of brush hits (or nuisance hits), or where the potential for such hits exists.

VI-C-2. Regular Maintenance

In general, the operational systems require relatively little regular or routine maintenance. However, *periodic maintenance checks should* *be performed to accomplish the appropriate checks outlined in II-A.* Several instances of vandalism have been reported with the sand inertial barriers. It is more prevalent where pedestrians have access to the roadside. Item II-A-5 is a particularly critical item for the hi-dro systems. For minor impacts, the hi-dro cell cluster system and the nose of the hi-dro cell sandwich system can return to its original position and thus appear outwardly that it had not been hit. However, with each impact, water can be lost, thereby diminishing its crash attenuating capabilities for the next hit. Checks are also needed to determine if leaks or evaporation has occurred. *Damages to any of the systems which diminish their original crash attenuating capabilities should be repaired immediately.*

Some cracking problems have occurred in the past with polyethylene plastic containers used in the sand inertial systems. These problems have been attributed in part to the effects of actinic radiation, vibrations (when placed on a structure), salt if mixed with the sand, and to earlier design problems with the container. The manufacturer reports that these problems have been solved through improved designs.

VI-C-3. Material Storage

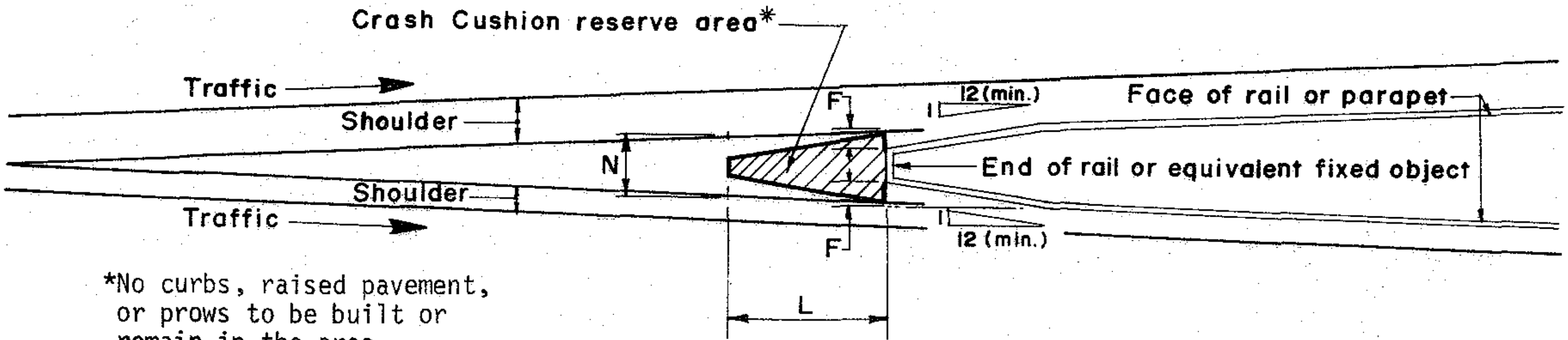
It will be necessary to store a certain amount of hardware and supplies for each of the operational systems. The point to be emphasized is that *a sufficient stockpile of parts must be maintained to avoid delays in restoring a damaged barrier.* Availability of parts and delivery times should be considered before selecting a system.

In summary, the criteria in Table VI-C-1 should be used as guidelines in evaluating the maintenance characteristics of the operational crash cushions. However, *the designer is urged to seek out supplemental data from agencies using the different crash cushions. There is no substitute for documented evidence of a barrier's in-service performance.*

VI-D. Site Considerations

VI-D-1. New Roadways

It has been recommended that space be reserved on all new construction for potential crash cushion installations (40). These recommendations are presented in Table VI-D-1. Under the "minimum" column, the "restricted conditions" represent the absolute minimums and should only be considered where there are extremely tight geometric controls. The "unrestricted conditions" represent the minimum for all projects except for those sites where it can be shown that the increased cost for accomodating these dimensions, as opposed to those for restricted conditions, will be unreasonable. The "preferred" values should be considered optimum. There is no intention to imply that if space is provided in accordance with these dimensions that the space will be fully occupied by a crash cushion device. The reason for proposing these dimensions is so that if experience shows that devices should be designed for greater ranges of vehicle weights and/or for lower deceleration forces there will be space available for installation of such devices in the future. In the meantime, the unoccupied reserve crash cushion space will provide valuable additional recovery area.



*No curbs, raised pavement, or prows to be built or remain in the area surrounding or occupied by the crash cushion.

Design Speed on Mainline (m.p.h.)	Dimensions for Crash Cushion Reserve Area (Feet)								
	Minimum						Preferred		
	Restricted Conditions			Unrestricted Conditions					
	N	L	F	N	L	F	N	L	F
30	6	8	2	8	11	3	12	17	4
50	6	17	2	8	25	3	12	33	4
70	6	28	2	8	45	3	12	55	4
80	6	35	2	8	55	3	12	70	4

Table VI-D-1. Reserve Area for Gores

It is suggested that considerations be given, at the design stage of new projects, to the use of crash cushions at other locations also. These would be hazardous sites that could not be avoided in the project. Examples are bridge piers, overhead sign supports, and other non-avoidable rigid objects. These sites could be designed to facilitate the installation of a crash cushion.

VI-D-2. Existing Roadways

The selection of a crash cushion for some existing roadways may be dictated by site conditions. The following factors should be considered in the selection.

Dimensions of object or hazard to be shielded - The width of the object or hazard is an important factor. While the C1, C2, and C5 crash cushions can be designed for a range of object widths, they are not normally used to shield relatively wide objects. The C1 is usually limited to widths of approximately 12 feet (3.7 m) and the C2 and C5 systems are usually limited to widths of approximately 7.5 feet (2.3 m). Inertial barriers are more adaptable to the wider objects.

Structural details of object to be shielded - Systems C1, C2, C5, and C6 require a back-up structure that is capable of withstanding the impact forces. If the object being shielded is structurally inadequate, provisions will have to be made to support or restrain the barrier during impact if these systems are used. Site preparations on existing structures can be extensive. This usually involves removing a concrete gore nose. In some instances, bridge railing ends are revised and a concrete wall or backstop is built. A backstop or secondary barrier is suggested for inertial crash cushions where the vehicle could penetrate the cushion and plunge down a slope.

Space available for crash cushion - Two dimensions must be considered with regard to the available space. These are the length ("L" in Figure VI-D-1) over which the barrier can be placed, and the distance on either side of the barrier to the hazard ("F" in Figure VI-D-1). While the length is important in the design of each barrier, all of the operational systems (excluding C6) will perform in a similar manner for a given length of installation if designed properly, at least for reasonable vehicle speeds and weights.

As shown in Figure VI-B-2, the suggested minimum distance "F" for inertial crash cushions is 2.5 feet (0.8 m). Where this cannot be accomplished, a cushion with redirectional capabilities should be strongly considered. Care must be exercised, however, with the fendering systems to insure that a structurally adequate transition is used between the cushion and the object it shields. Snag points are not acceptable. If the cushion requires special anchorage, it will have to be provided in the available space.

Physical conditions of the available space - The following site conditions should be considered:

1. the presence of a curb which could affect the performance of the crash cushion;
2. the existing surface material and condition thereof;
3. the longitudinal and transverse slope of the crash cushion area;
4. expected low temperature since several of the systems are sensitive to below freezing temperatures;

5. high wind and/or abnormal vibration conditions; and
6. the existence of construction or expansion joints in the crash cushion area.

Reference should be made to Section VI-F for more discussion of items 1 and 3. With regard to item 2, it is desirable that all of the systems be placed on a concrete or asphalt surface, but it is essential for the steel drums, hi-dro cell sandwich, and the hi-dri cell sandwich. This permits the systems to slide back with uniform response during an impact. In the case of the inertial crash cushions, the paved surface provides uniform support for the modules. In addition, it provides a surface on which the pattern and weights of the modules can be marked. This helps maintenance forces in subsequent restorations after impacts. The following comments are offered with regard to items 4 and 5:

a. If the hi-dro cell sandwich or cluster crash cushion is proposed for a location that is subject to prolonged freezing temperatures, an anti-freeze treatment will be necessary for the water.
b. Plowed snow might infiltrate an array of sand filled barrels but have less effect on barriers with the side fender panels. The effects of falling, drifting, or blowing snow can be minimized with a cover of some type of flexible material. Of course, snow should be completely cleared away from all crash cushions.
c. When the hi-dro cell sandwich or cluster crash cushion is installed where extremely hot weather is prevalent, extra consideration of water loss due to evaporation is needed. A thin

layer of mineral oil on top of the water will provide added protection against evaporation loss.

d. Sand filled barrels may be less desirable in high wind areas because barrier debris can be scattered, i.e., barrel pieces, core pieces, and sand.

With regard to item 6, special design accomodations may be necessary for those systems that require anchorage.

VI-E. Selection Guidelines

The number and complexity of factors which enter the selection process for crash cushions preclude the development of a simple selection procedure. As has been alluded to in the previous sections, each operational system has its own unique physical and functional characteristics. In some cases, one crash cushion will stand out as the most appropriate, while in other cases two or more crash cushions may be considered essentially equal in performance. Listed as discussed below are factors which should be evaluated before making a selection. It is suggested that these factors be evaluated in the order given, although they are not necessarily listed in order of importance.

It is assumed, at this point, that a crash cushion is warranted and that a selection must be made. As an aid to the guidelines presented in this section, the designer should also consider the application of the cost-effective selection procedure presented in Chapter VII.

1. Site considerations - The first item to evaluate is the site conditions. Factors to evaluate include dimension of object being shielded, structural characteristics of object being shielded, available space for cushion, and physical condition of site. Reference should be made to Section VI-D for a discussion of all the factors related thereto. In many cases, the site conditions will establish the type of barrier needed.

2. *Structural and safety characteristics of candidate systems* - If more than one system can be used, the designer should carefully evaluate the structural and safety characteristics of each candidate system. These include factors such as impact decelerations, redirection capabilities, anchorage requirements, debris produced by impact, and back-up structure requirements. It is desirable that the most crashworthy system be installed. Reference should be made to Section VI-B for a discussion of the structural and safety characteristics of the operational systems. Table A-3 of Appendix A summarizes crash cushion accident data.

3. *Maintenance characteristics and aesthetic appeal* - Not too infrequently the most appropriate barrier will still not be evident after evaluating items 1 and 2 above. The maintenance characteristics of each barrier may therefore play an important role in the selection. Section VI-C identifies the pertinent facts and provides guidelines to aid in evaluating the maintenance and aesthetic characteristics of the operational systems.

4. *Costs* - Limited cost data has indicated that some crash cushions are more expensive than others. This variation in cost can readily be seen in the components which go to make up the systems and the installation effort required. The designer should, if other design factors for the site under consideration have not indicated the one best crash cushion, employ engineering economics so as to arrive at the least expensive system

over the estimated life of the system. The economic factors to be considered are intial cost, maintenance costs, vehicle damage and occupant injury costs, time value of money, life of the system, and salvage value. The procedure described in Chapter VII can be used to evaluate these factors.

The initial cost indications shown below are based on a very few installations. Each State should determine local costs for each of the approved systems. Limited initial and maintenance cost data are given in Table A-3 of Appendix A.

System	Low Initial Costs	Moderate Initial Costs	High Initial Costs
C1 - Steel Drums		√	
C2 - Hi-Dro Cell Sandwich			√
C3 - Fitch Inertial	√		
C4 - Energite Inertial	√		
C5 - Hi-Dri Cell Sandwich			√
C6 - Hi-Dro Cell Cluster		√	

Reference should be made to Section VI-C and Table VI-C-1 to aid in estimating maintenance costs and salvage values. All of the approved systems will produce damage to impacting vehicles whether hit on the nose or on the side. Experience does not indicate that one system is better than the other in this respect. Naturally, the higher the impact speed-the higher the degree of damage. Field experience has shown that most vehicles which impact crash cushions are driven away.

VI-F. Placement Recommendations

It must be recognized that all of the crash cushions were designed and tested for relatively level terrain conditions. Adverse and unacceptable performance can be expected if the barrier is placed on or behind certain terrain conditions. *It is highly desirable that the crash cushion be placed on a relatively flat surface (5 percent slope or less preferrable) and that there be no appurtenances bewteen the traveled way and the barrier.*

Two prominent roadside features which the designer must often contend with are curbs and slopes. Tests and computer simulations have shown that both of these features can cause an errant vehicle to rise above the terrain and become airborne and reach undesirable roll and pitch angles. For new projects, curbs should not be built where crash cushions are to be installed. Existing curbs where cushions are to be installed should be removed if feasible, in particular those that are higher than approximately 4 inches (0.1 m).

For roadside or median installations, it is desirable that the shoulder be extended to provide a relatively flat appraoch area to the cushion. A more detailed discussion of the effects of curbs and slopes on barrier performance is given in Section III-E-3. Also, Appendix F contains a summary of vehicle trajectory data for various slopes and curb sizes and types.

Unanchored crash cushions (C3 and C4), when placed on elevated gores, may walk or crack due to vibration of the structure. However, at this writing there is no clear pattern of such occurrences. Manufacturers should assure the adequacy of their design in this regard.

Hazardous gore areas have received the greatest attention with regard to crash cushion installations. It cannot be refuted that these areas have a higher potential for serious accidents than any other area of similar size along the roadway. Treatment of these areas should be given top priority. It now appears, however, that other areas, which heretofore had been shielded by conventional roadside barriers, can best be shielded, *cost effectively,* by crash cushions. Reference should be made to Example 2 of Section VII-C for an illustration of this.

Figure VI-E-1 shows examples of median and roadside hazards which can be shielded either totally or partially by crash cushions. The approach areas should be flat and have no appurtenances between the traveled way and the cushion. If these conditions do not exist and cannot be provided, a roadside barrier placed near the shoulder is the recommended system. Selection of the barrier angle, Θ, should be based on the probable impact angle of encroaching vehicles. Impact angles will be dependent in most part on operating speeds, roadway alignment, and lateral distance from the traveled way to the cushion. For most roadside conditions, an angle of approximately 10 degrees or less is suggested.

All of the operational crash cushions can probably be adapted to shield rigid objects such as those shown in Figure VI-E-1. However, with the possible exception of the median barrier end treatments (see Table IV-B-5), the inertial barriers are more easily adapted to shield rigid objects than others. First, they do not require a back-up structure. Secondly, if exposed, the rear part of a non-inertial barrier system may itself be a significant hazard. Such problems would arise for median

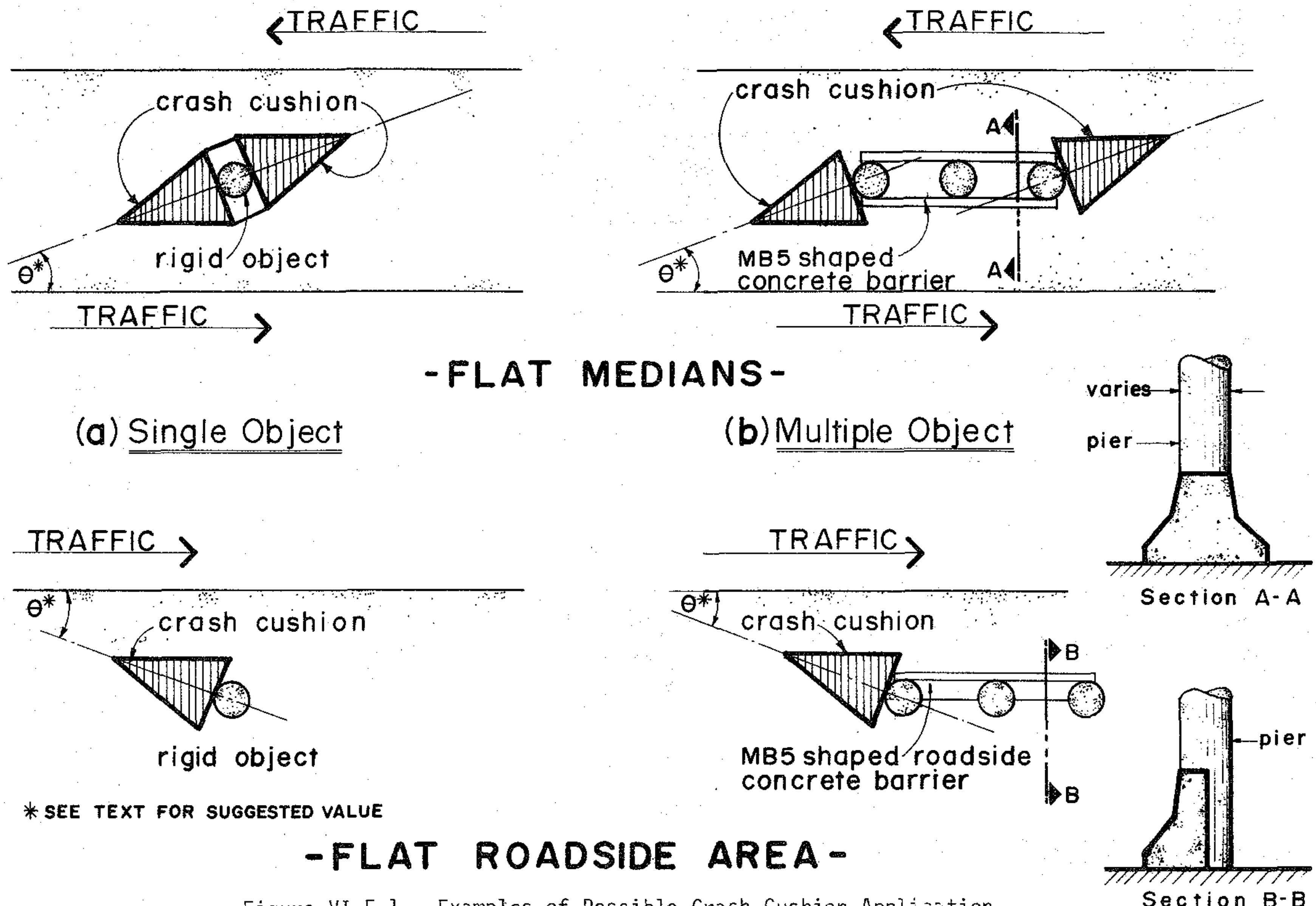


Figure VI-E-1. Examples of Possible Crash Cushion Application on the Roadside or in the Median installations. It is likely, however, that the non-inertial systems could be adapted by careful design of transition and attachment details.

VII. A COST-EFFECTIVE SELECTION PROCEDURE

VII-A. 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.

1. Obstacles which may be removed should be eliminated.
2. Obstacles which may not be removed should be relocated laterally or in a more protected location.
3. Obstacles which may not be moved should be reduced in impact severity. Breakaway devices and flattened side slopes offer such an improvement.
4. 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 is 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 would normally be cost effective only on low volume and/or low speed facilities, or where the probability of accidents is low. With regard to item 2, the procedure allows 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 will allow one to objectively establish priorities for the options at a given site. Although not presented, the procedure can be extended to establish priorities for a roadway system, either on a local, regional or statewide basis. Such a procedure can be found in the literature (102, 103, 141).

VII-B. Development, Assumptions and Limitations

Although certain assumptions were essential to the development of the cost-effective procedure, it reflects a rational approximation based on existing technology. Generally, the formulation of the procedure parallels closely other cost-effective selection techniques (102, 103, 141). The procedure is structured around an accident prediction technique used to estimate the frequency at which a roadside object or hazard will be struck over a given period of time. For an in-depth discussion of the basis for the procedure, its assumptions and limitations, the reader may refer to the citations given above. Specific limitations and assumptions are listed and discussed below.

Generality and flexibility have been preserved in the procedure presented herein. This allows the user to incorporate new data as it becomes available and to make subjective adjustments as deemed necessary.

Limitations which exist in the procedure relate primarily to the data needed to implement it. In this regard, the following observations are made:

1. *Encroachment frequency* - Frequency of accidents with roadside objects is closely related to the nature and frequency of vehicle encroachments from the traveled way. *Encroachment data presented herein is based on observations conducted on relatively flat medians along tangent sections of multi-lane facilities (16).* Studies are needed to determine the effects of vertical and horizontal alignment, roadway width and number of lanes, operating speed, and other variables on the encroachment frequency. Recent studies with regard to encroachments on secondary roadways has increased the state of knowledge in this area (142).

2. *Encroachment speed* - Encroachment speed is not considered directly in the model. Indirectly, effects of encroachment speed can be accounted for by adjusting the anticipated relative severity of the impact with the roadside object or hazard. Also, the speed of an errant vehicle will generally diminish with lateral movement on the roadside, i.e., the driver will usually be stopping the vehicle, or it will be slowed due to skidding. Again, the effects of such speed reductions can be accounted for by adjustments in the relative severity of the object as a function of its offset distance. However, there is no data to indicate how speed and lateral movement of an errant vehicle are related. Roadside slopes or ditches would also be a factor in such a relationship, as discussed below. *Suggested severity ratings for roadside objects are included herein. These apply to high speed facilities and are based on assumed impacts at high speeds, approximately 60 mph (96.5 km/hr).*

3. *Roadside slopes* - Recent studies have shown that the ability to return an errant vehicle to the traveled way after encroaching on an embankment decreases as the slope of the embankment increases. Results of these studies are reflected in the "clear distance" criteria suggested in Figure III-A-3. However, at this time, there is no field or accident data to describe the statistical distribution of the lateral movement of errant vehicles on embankments. Data used to develop the cost-effective procedure are based on observations

of encroachments on relatively flat medians (16).

4. *Directional split - It is assumed that the directional split is 50/50 with respect to average daily traffic.*

Whenever alternate data is available, it may be used as input at the discretion of the designer. By providing this option to the user, the model assumes a general format as opposed to being strictly dependent on existing technology relative to the current state of the art.

VII-C. 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 word "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 (feet),
   L = horizontal length of the roadside obstacle (feet), and
   W = width of the roadside obstacle (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_f (vehicle encroachments per mile per year), from Figure VII-C-1. Figure VII-C-1 was obtained from data discussed previously (16). Other available

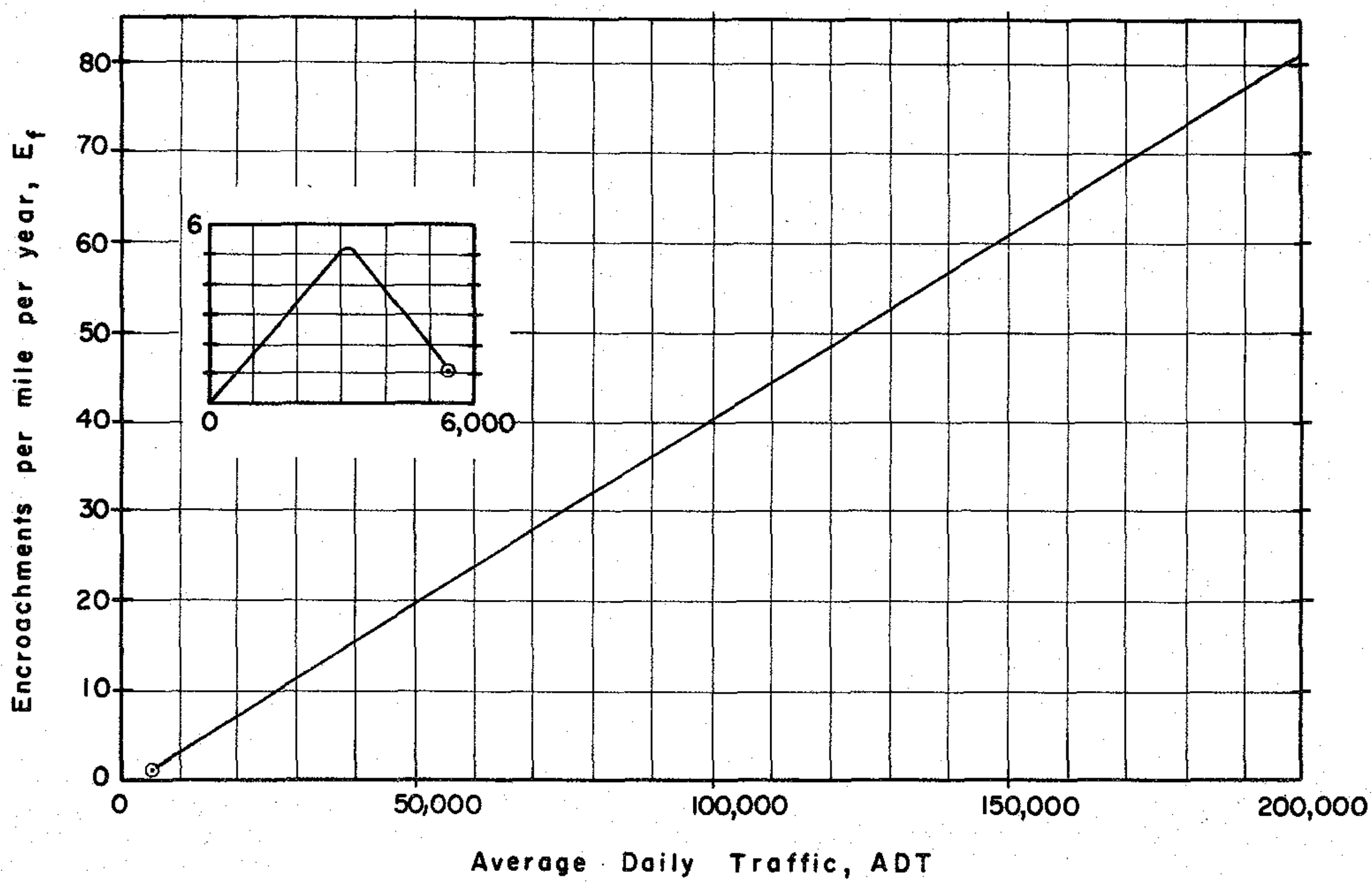


Figure VII-C-1. Encroachment Frequency

data or 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 nomographs given in Figures VII-C-2 and VII-C-3 (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.

    a. Locate and mark the encroachment frequency, E_f, on vertical axis 1 .

    b. On horizontal axis 2 locate the lateral placement, A, and construct a vertical reference line the full height of the graph.

    c. Locate and mark the point where the lateral placement reference line intersects the width, W, curve in consideration.

    d. Project a line to the right from the point determined in (c) to vertical axis 3 and mark the point of intersection.

    e. Locate and mark the point where the lateral placement reference line intersects the length, L, curve in consideration.

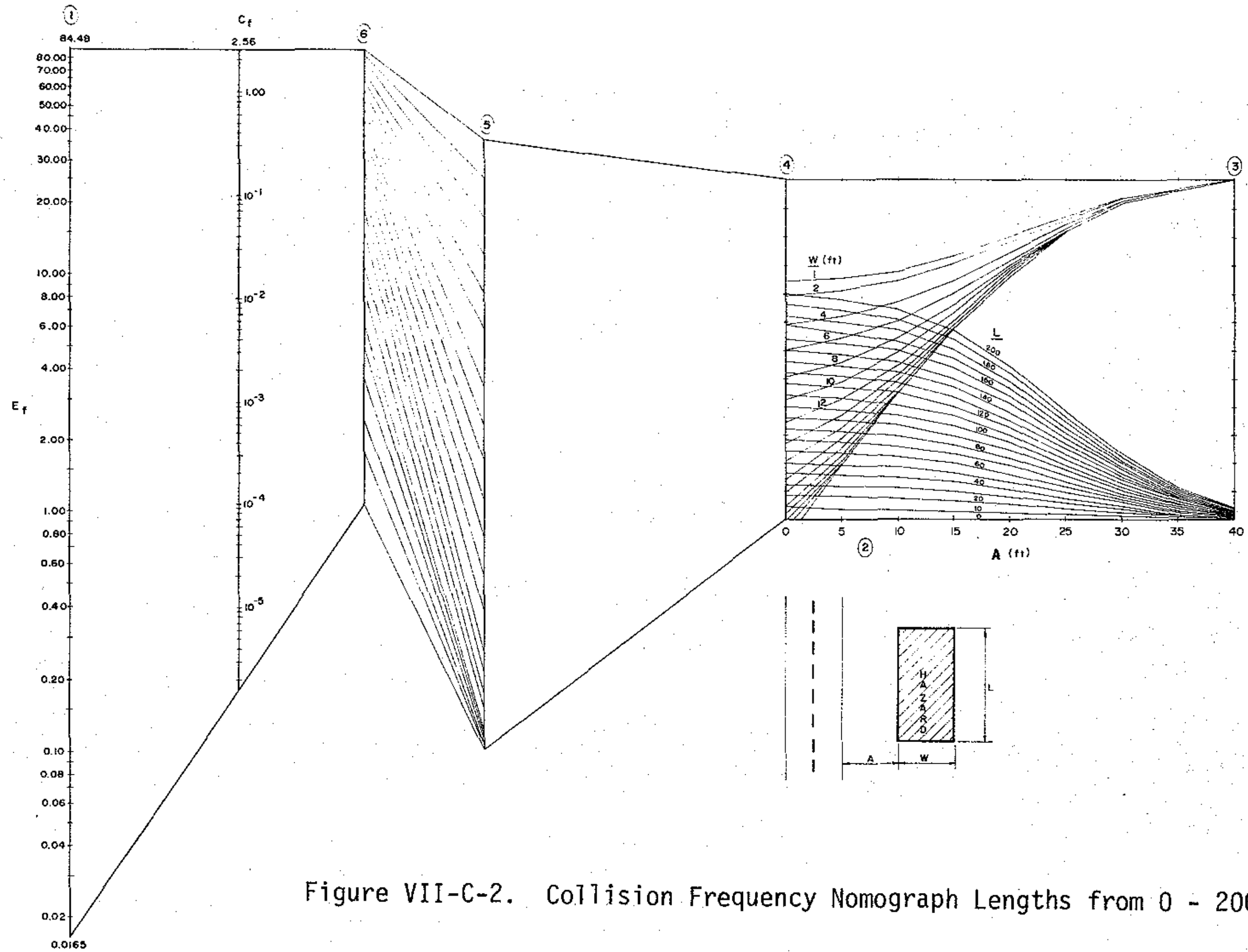


Figure VII-C-2. Collision Frequency Nomograph Lengths from 0 - 200 Feet

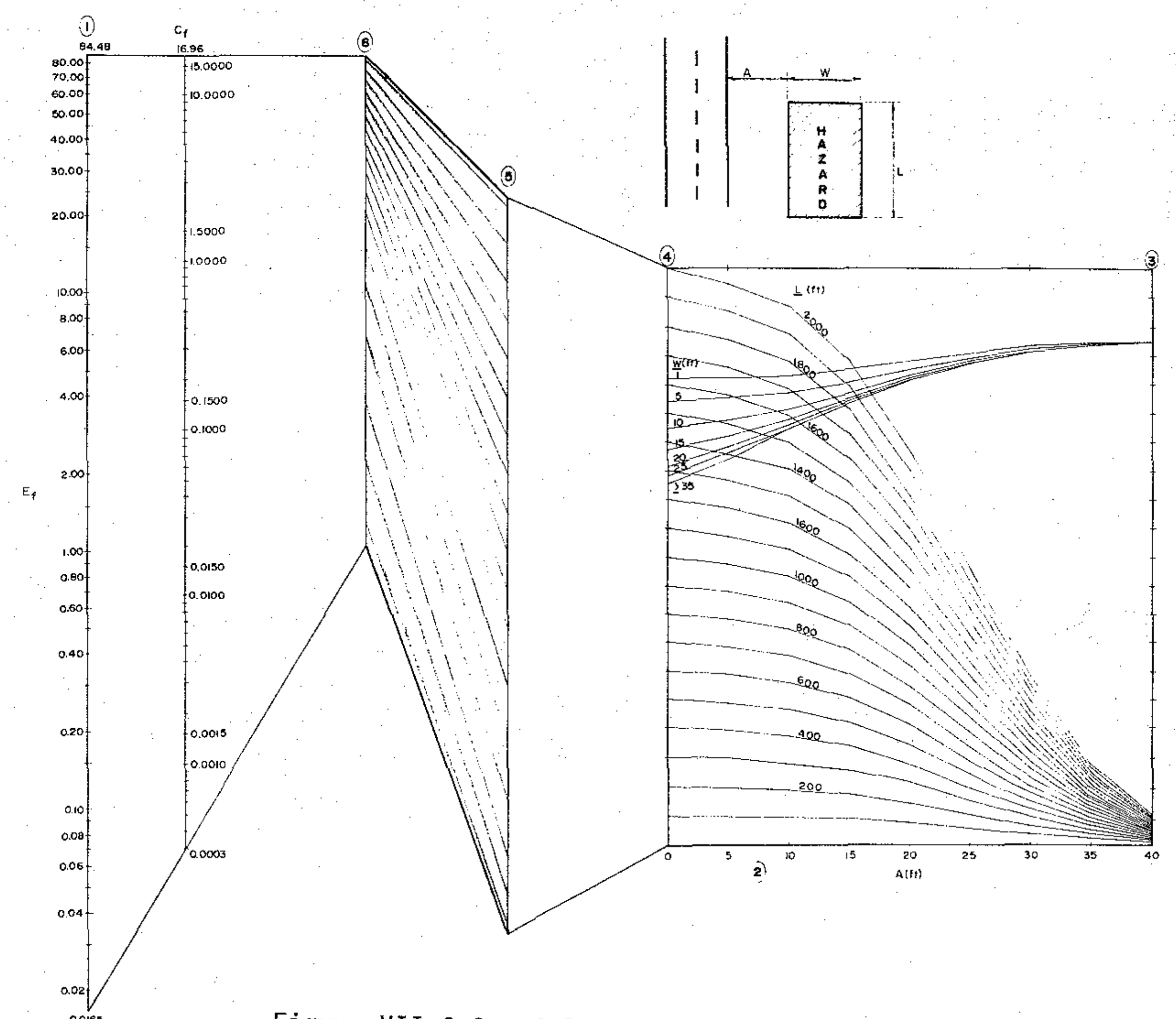


Figure VII-C-3. Collision Frequency Nomograph Lengths from 200 - 2000 Feet

f. Project a line to the left from the point determined in (e) to the vertical axis 4 and mark the point of intersection.

g. 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.

h. From the point determined in (g) construct a line to vertical axis 6 keeping approximately parallel to guidelines. Mark the point of intersection.

i. 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 VII-C-4. 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 (102). Mathematically, the collision frequency is given in the expression below.

$$C_f = \frac{E_f}{10,560} \left[L \cdot P\,[Y \geq A] + 31.4 \cdot P\,[Y \geq A + 3] + 5.14 \sum_{J=1}^{W} P\,[Y \geq A + 6 + \frac{2J - 1}{2}] \right]$$

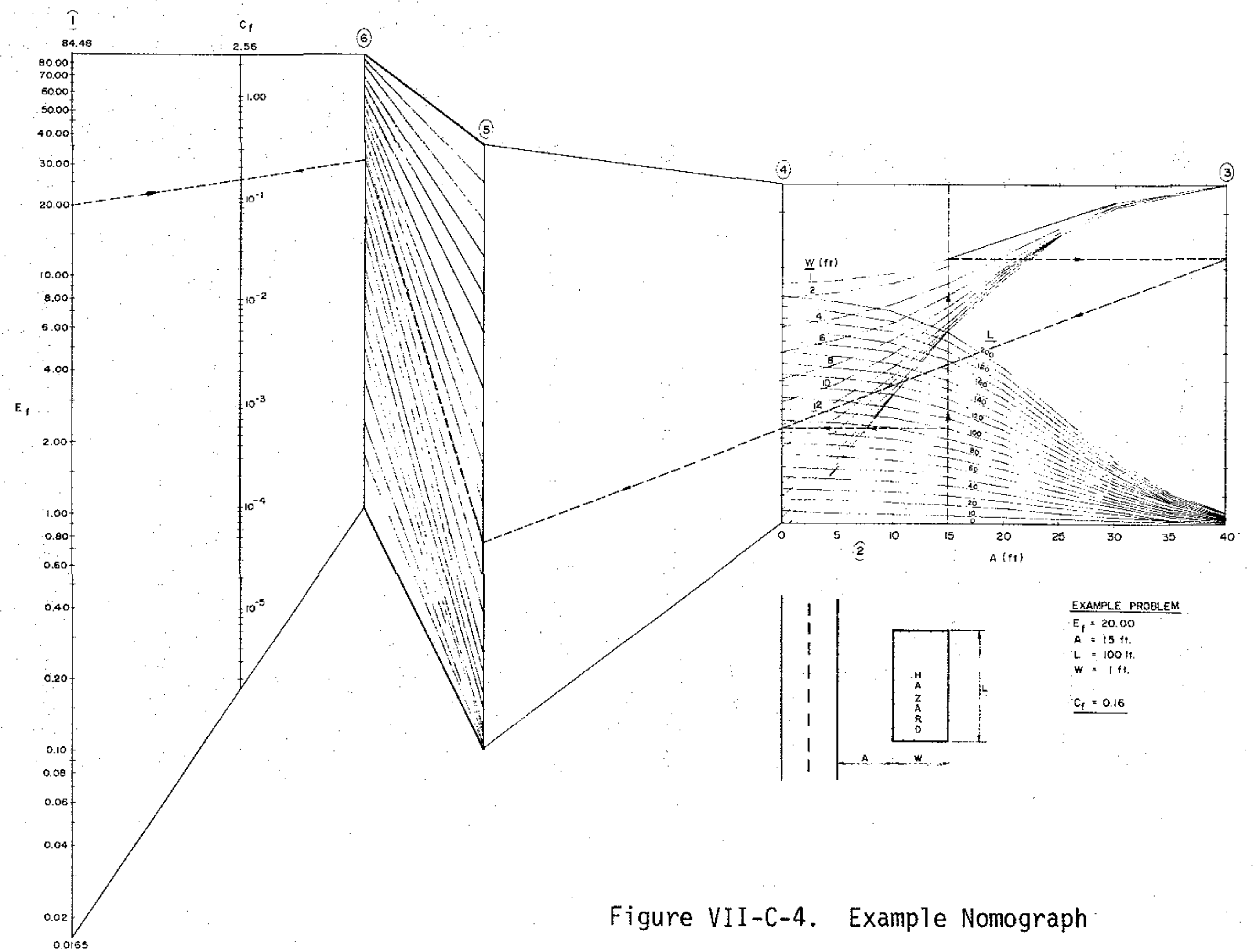


Figure VII-C-4. Example Nomograph

where,

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

and,

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

$P[Y \geq \ldots]$ = probability of a vehicle lateral displacement greater than some value. These probabilities may be taken from Figure VII-C-5 (102); and

J = the number of obstacle-width increments used in the summation.

This equation may be implemented directly into the cost analysis or used as a double-check for the collision frequency nomographs.

5. Assign a severity index to the obstacle of concern. It is suggested that the index be chosen on a scale of 0 to 10 according to the criteria given in Table VII-C-1 (103). 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 VII-C-6 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. A set of indices for a number of

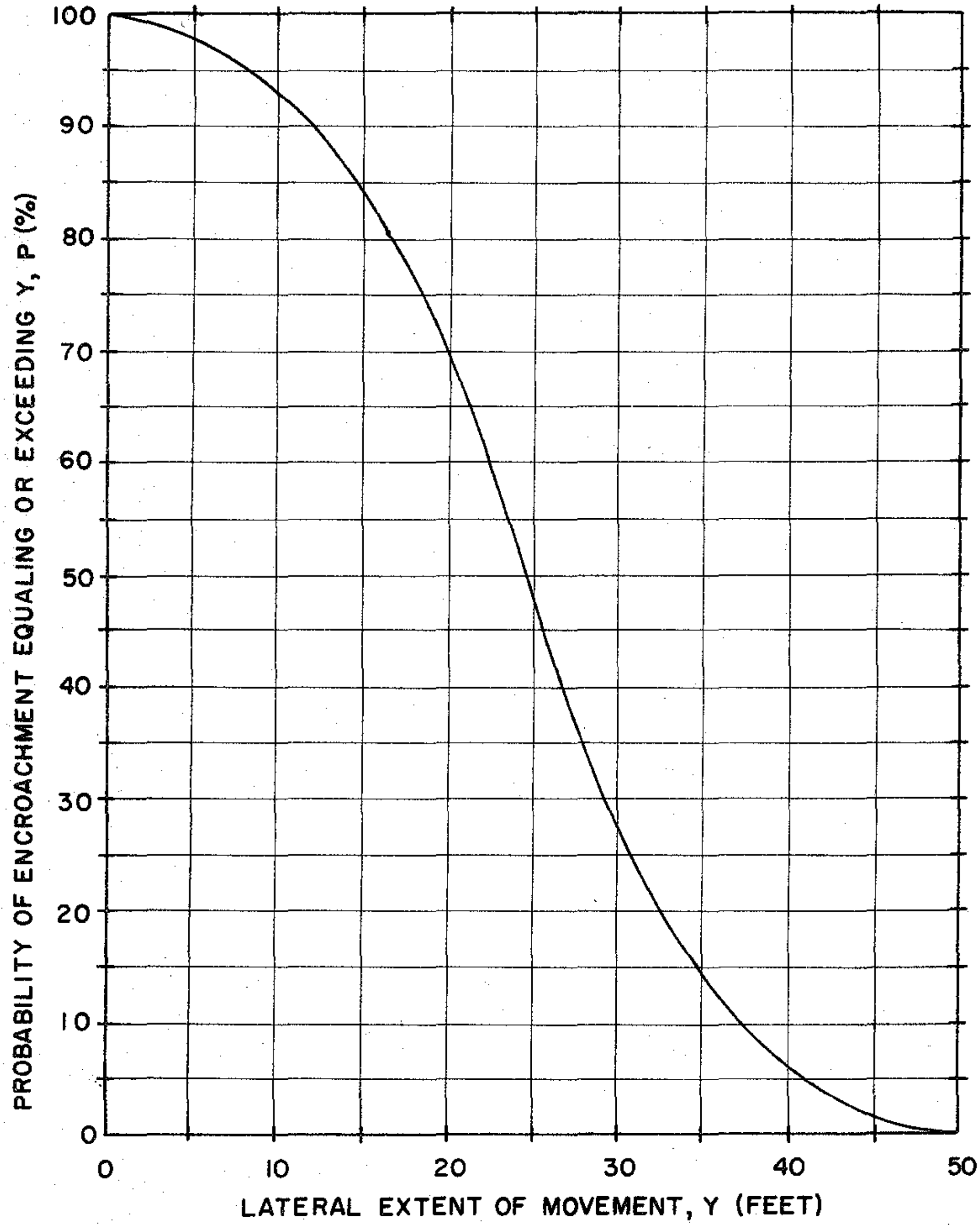


Figure VII-C-5. Lateral Displacement Distribution

Table VII-C-1. Severity Index and Accident Cost

Severity Index	% PDO Accidents*	% Injury Accidents	% Fatal Accidents	Total Accident Cost
0	100	0	0	$ 700
1	85	15	0	2,095
2	70	30	0	3,490
3	55	45	0	4,885
4	40	59	1	8,180
5	30	65	5	16,710
6	20	68	12	30,940
7	10	60	30	66,070
8	0	40	60	124,000
9	0	21	79	160,000
10	0	5	95	190,000

*PDO refers to those accidents where property damage only is involved.

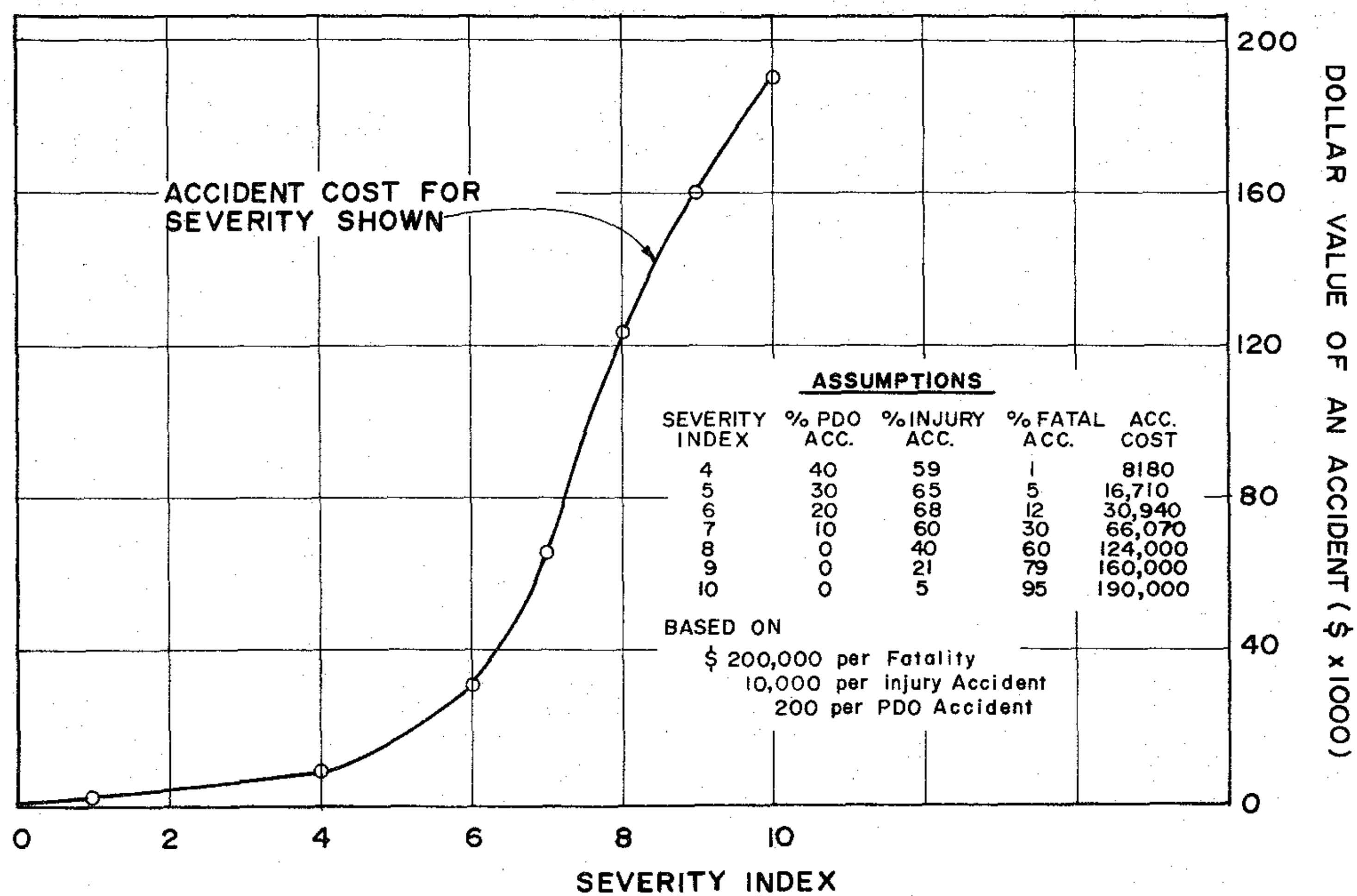


Figure VII-C-6. Average Occupant Injury and Vehicle Damage Costs roadside obstacles has been developed (<u>103</u>), see Tables E-1 and E-2 of Appendix E, and may be used for guidelines in the absence of more definitive data.

6. Determine the intial 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 VII-C-1 or Figure VII-C-6 may be used to determine C_{OVD} in the absence of more definitive data.
10. Determine the useful life, T, of the obstacle (years).
11. Determine the economic present worth factors, K_T and K_J, for the useful life, T, and a current interest rate from Tables VII-C-2 and VII-C-3.
12. Estimate the expected salvage value of the obstacle, C_S, at the end of its useful life (future dollars).

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
1.0	1.000	0.990	0.980	0.971	0.962	0.952	0.943	0.935	0.926	0.917	0.909
2.0	2.000	1.970	1.941	1.913	1.886	1.859	1.833	1.808	1.783	1.759	1.736
3.0	3.000	2.941	2.884	2.829	2.775	2.723	2.673	2.624	2.577	2.531	2.487
4.0	4.000	3.902	3.808	3.717	3.630	3.546	3.465	3.387	3.312	3.240	3.170
5.0	5.000	4.853	4.713	4.580	4.452	4.329	4.212	4.100	3.993	3.890	3.791
6.0	6.000	5.795	5.601	5.417	5.242	5.076	4.917	4.767	4.623	4.486	4.355
7.0	7.000	6.728	6.472	6.230	6.002	5.786	5.582	5.389	5.206	5.033	4.868
8.0	8.000	7.651	7.325	7.020	6.733	6.463	6.210	5.971	5.747	5.535	5.335
9.0	9.000	8.565	8.162	7.786	7.435	7.108	6.802	6.515	6.247	5.995	5.759
10.0	10.000	9.471	8.982	8.530	8.111	7.722	7.360	7.024	6.710	6.418	6.145
11.0	11.000	10.367	9.787	9.253	8.760	8.306	7.887	7.499	7.139	6.805	6.495
12.0	12.000	11.254	10.575	9.954	9.385	8.863	8.384	7.943	7.536	7.161	6.814
13.0	13.000	12.133	11.348	10.635	9.986	9.393	8.853	8.358	7.904	7.487	7.103
14.0	14.000	13.003	12.106	11.296	10.563	9.899	9.295	8.745	8.244	7.786	7.367
15.0	15.000	13.864	12.849	11.938	11.118	10.380	9.712	9.108	8.559	8.061	7.606
16.0	16.000	14.717	13.577	12.561	11.652	10.838	10.106	9.447	8.851	8.313	7.824
17.0	17.000	15.561	14.292	13.166	12.166	11.274	10.477	9.763	9.122	8.544	8.022
18.0	18.000	16.397	14.992	13.753	12.659	11.689	10.828	10.059	9.372	8.756	8.201
19.0	19.000	17.225	15.678	14.324	13.134	12.085	11.158	10.336	9.604	8.950	8.365
20.0	20.000	18.044	16.351	14.877	13.590	12.462	11.470	10.594	9.818	9.129	8.514
21.0	21.000	18.856	17.011	15.415	14.029	12.821	11.764	10.836	10.017	9.292	8.649
22.0	22.000	19.659	17.658	15.937	14.451	13.163	12.042	11.061	10.201	9.442	8.772
23.0	23.000	20.454	18.292	16.443	14.857	13.488	12.303	11.272	10.371	9.580	8.883
24.0	24.000	21.242	18.914	16.935	15.247	13.799	12.550	11.469	10.529	9.707	8.985
25.0	25.000	22.022	19.523	17.413	15.622	14.094	12.783	11.654	10.675	9.823	9.077
26.0	26.000	22.794	20.121	17.877	15.983	14.375	13.003	11.826	10.810	9.929	9.161
27.0	27.000	23.558	20.706	18.327	16.330	14.643	13.210	11.987	10.935	10.027	9.237
28.0	28.000	24.315	21.281	18.764	16.663	14.898	13.406	12.137	11.051	10.116	9.307
29.0	29.000	25.064	21.844	19.188	16.984	15.141	13.591	12.278	11.158	10.198	9.370
30.0	30.000	25.806	22.396	19.600	17.292	15.372	13.765	12.409	11.258	10.274	9.427

Table VII-C-2. Values of K_T

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
1.0	1.0000	0.9901	0.9804	0.9709	0.9615	0.9524	0.9434	0.9346	0.9259	0.9174	0.9091
2.0	1.0000	0.9803	0.9612	0.9426	0.9246	0.9070	0.8900	0.8734	0.8573	0.8417	0.8264
3.0	1.0000	0.9706	0.9423	0.9151	0.8890	0.8638	0.8396	0.8163	0.7938	0.7722	0.7513
4.0	1.0000	0.9610	0.9238	0.8885	0.8548	0.8227	0.7921	0.7629	0.7350	0.7084	0.6830
5.0	1.0000	0.9515	0.9057	0.8626	0.8219	0.7835	0.7473	0.7130	0.6806	0.6499	0.6209
6.0	1.0000	0.9420	0.8880	0.8375	0.7903	0.7462	0.7050	0.6663	0.6302	0.5963	0.5645
7.0	1.0000	0.9327	0.8706	0.8131	0.7599	0.7107	0.6651	0.6227	0.5835	0.5470	0.5132
8.0	1.0000	0.9235	0.8535	0.7894	0.7307	0.6768	0.6274	0.5820	0.5403	0.5019	0.4665
9.0	1.0000	0.9143	0.8368	0.7664	0.7026	0.6446	0.5919	0.5439	0.5002	0.4604	0.4241
10.0	1.0000	0.9053	0.8203	0.7441	0.6756	0.6139	0.5584	0.5083	0.4632	0.4224	0.3855
11.0	1.0000	0.8963	0.8043	0.7224	0.6496	0.5847	0.5268	0.4751	0.4289	0.3875	0.3505
12.0	1.0000	0.8874	0.7885	0.7014	0.6246	0.5568	0.4970	0.4440	0.3971	0.3555	0.3186
13.0	1.0000	0.8787	0.7730	0.6810	0.6006	0.5303	0.4688	0.4150	0.3677	0.3262	0.2897
14.0	1.0000	0.8700	0.7579	0.6611	0.5775	0.5051	0.4423	0.3878	0.3405	0.2992	0.2633
15.0	1.0000	0.8613	0.7430	0.6419	0.5553	0.4810	0.4173	0.3624	0.3152	0.2745	0.2394
16.0	1.0000	0.8528	0.7284	0.6232	0.5339	0.4581	0.3936	0.3387	0.2919	0.2519	0.2176
17.0	1.0000	0.8444	0.7142	0.6050	0.5134	0.4363	0.3714	0.3166	0.2703	0.2311	0.1978
18.0	1.0000	0.8360	0.7002	0.5874	0.4936	0.4155	0.3503	0.2959	0.2502	0.2120	0.1799
19.0	1.0000	0.8277	0.6864	0.5703	0.4746	0.3957	0.3305	0.2765	0.2317	0.1945	0.1635
20.0	1.0000	0.8195	0.6730	0.5537	0.4564	0.3769	0.3118	0.2584	0.2145	0.1784	0.1486
21.0	1.0000	0.8114	0.6598	0.5375	0.4388	0.3589	0.2942	0.2415	0.1987	0.1637	0.1351
22.0	1.0000	0.8034	0.6468	0.5219	0.4220	0.3418	0.2775	0.2257	0.1839	0.1502	0.1228
23.0	1.0000	0.7954	0.6342	0.5067	0.4057	0.3256	0.2618	0.2109	0.1703	0.1378	0.1117
24.0	1.0000	0.7876	0.6217	0.4919	0.3901	0.3101	0.2470	0.1971	0.1577	0.1264	0.1015
25.0	1.0000	0.7798	0.6095	0.4776	0.3751	0.2953	0.2330	0.1842	0.1460	0.1160	0.0923
26.0	1.0000	0.7720	0.5976	0.4637	0.3607	0.2812	0.2198	0.1722	0.1352	0.1064	0.0839
27.0	1.0000	0.7644	0.5859	0.4502	0.3468	0.2678	0.2074	0.1609	0.1252	0.0976	0.0763
28.0	1.0000	0.7568	0.5744	0.4371	0.3335	0.2551	0.1956	0.1504	0.1159	0.0895	0.0693
29.0	1.0000	0.7493	0.5631	0.4243	0.3207	0.2529	0.1846	0.1406	0.1073	0.0822	0.0630
30.0	1.0000	0.7419	0.5521	0.4120	0.3083	0.2314	0.1741	0.1314	0.0994	0.0754	0.0573

Table VII-C-3. Values of K_J

13. Calculate the total present worth cost, C_T, from the following equation:

$$C_T = C_I + C_D\ (C_f)(K_T) + C_M\ (K_T) + C_{OVD}\ (C_f)(K_T) - C_S\ (K_J)$$

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

$$C_{TD} = C_I + C_D\ (C_f)(K_T) + C_M\ (K_T) - C_S\ (K_J)$$

These total present worth 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. This weighting scheme provides some insight as to where the greatest return in safety may be realized.

Summary of Variable Definitions

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

L = horizontal length of the roadside obstacle (feet)

W = width of the roadside obstacle (feet)

ADT = average daily traffic (vehicles per day, two-way)

E_f = encroachment frequency (encroachments per mile per year)

C_f = collision frequency (accidents per year)

SI = severity index

C_I = initial cost of the obstacle (present dollars)

C_C = 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_T = total present worth cost associated with the obstacle

C_{TD} = total present worth direct cost associated with the obstacle

T = useful life of the obstacle (years)

K_T, K_J = economic factors for some current interest rate

VII-C-1. Example 1 - Roadside Slopes

In the first example, it is desired that criteria be established to indicate when it is cost-effective, in terms of ADT and sideslope, to shield an embankment. It is assumed that an operating speed of approximately 60 mph (96.5 km/hr) exists. The general geometry of the roadside is illustrated in Figure VII-C-7. For purposes of analysis, both the average daily traffic, ADT, and the roadside slope will be considered as variables. *Values assigned to the 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.

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 III-E. By making these calculations, the flared sections were found to exhibit the following general geometry:

1. the average offset equals 15.115 ft (4.6 m),
2. the horizontal length of the flared sections equals 255.73 ft (78.0m),

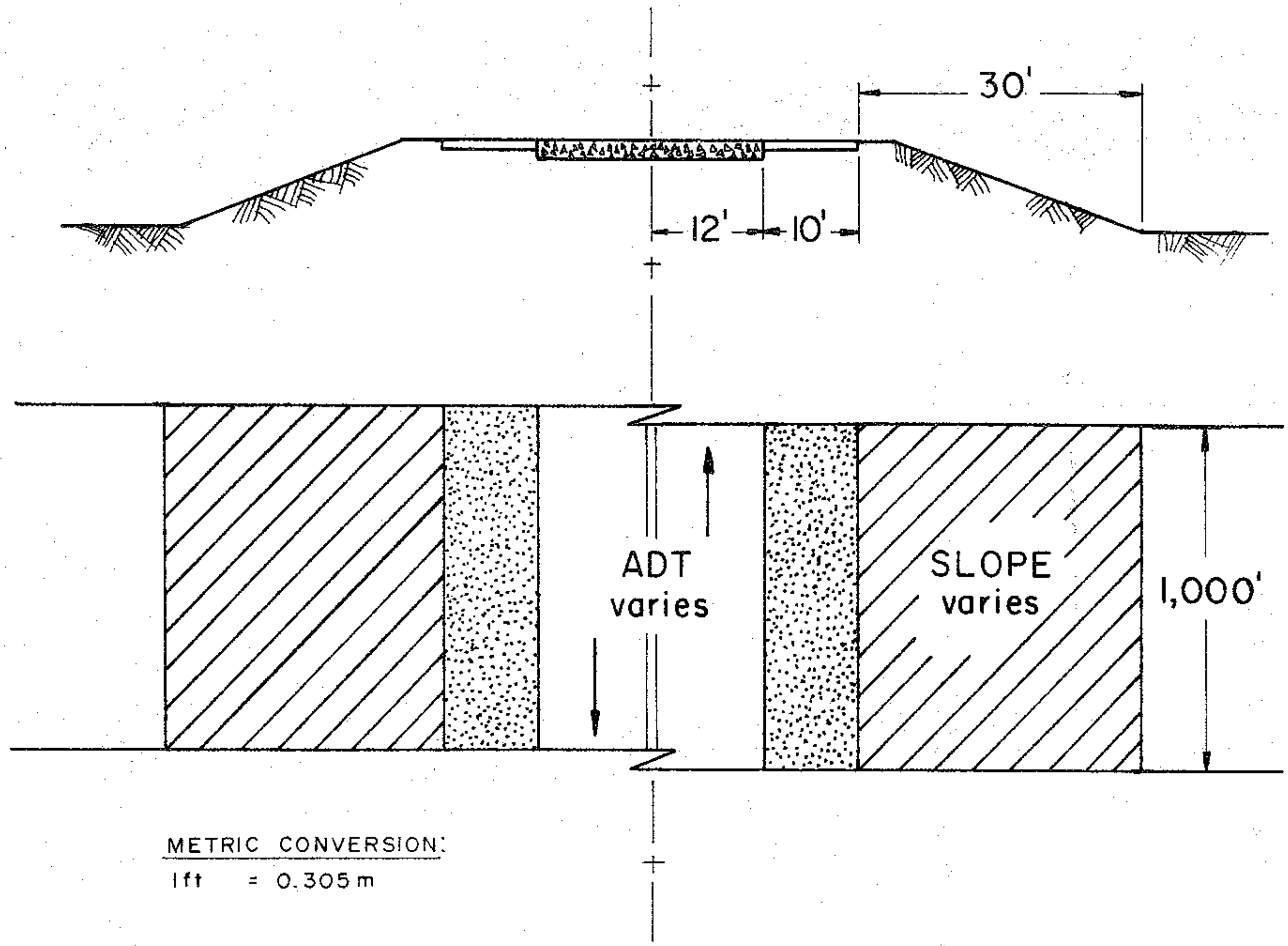


Figure VII-C-7. Roadside Slope Geometry

3. and the total rail length needed equals 256.53 ft (78.24 m). These lengths represent the total length of need of the flared section plus a breakaway cable terminal treatment.

In continuing, the roadside barrier cost-effectiveness analysis now involves two independent geometries - one being that characteristic of the flared rail sections, and the other being that characteristic of the roadside barrier proper. Consequently, the total barrier cost will be the sum of the costs determined in both calculations (see the following procedure). *During the cost determination, it should be kept in mind that the steps given below follow the format previously outlined.*

Flared End Treatment

1. A = 15.115 ft or approximately 15 ft (4.6 m)

   L = 255.73 ft or approximately 256 ft (78.0 m)

   W = 1 ft (.305 m) (rail width)
2. ADT = 10,000 (assumed)
3. $E_f = 5.5$
4. $C_f = 0.13$
5. Code 06-01-1-1; SI = 3.7
6. C_I = \$13.00 (assumed) per foot at 256.53 ft (78.24 m) or approximately 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 (78.39 m); C_M = \$386
9. C_{OVD} = \$7,192 at SI = 3.7
10. T = 15 years
11. $\left.\begin{array}{l} K_T = 8.559 \\ K_J = 0.3152 \end{array}\right\}$ at an assumed interest rate of 8%

12. C_S = \$3.00 per foot (assumed) at 257 ft (78.39 m) C_S = \$771

13. C_T = \$3,341 + \$225 (0.13)(8.559) + \$386 (8.559)

+ \$7,192 (0.13)(8.559) - \$771 (0.3152)

C_T = \$14,654.43

C_{TD} = \$3,341 + \$225 (0.13)(8.559) + \$386 (8.559)

- \$771 (0.3152)

C_{TD} = \$6,652.11

Barrier Proper

1. A = 10 ft (3.05 m) L = 1,000 ft (305 m) W = 1 ft (.31 m)
2. ADT = 10,000
3. E_f = 5.5
4. C_f = 0.50
5. Code 06-01-3-2; SI = 3.3 survey
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. $\left.\begin{array}{l} K_T = 8.559 \\ K_J = 0.3152 \end{array}\right\}$ at an assumed interest rate of 8%
12. C_S = \$3.00 per foot (assumed) at 1,000 ft (305 m); C_S = \$3,000
13. C_T = \$13,000 + \$225 (0.50)(8.559) + \$1,500 (8.559)

+ \$5,874 (0.50)(8.559) - \$3,000 (0.3152)

C_T = \$50,993.57

$$C_{TD} = \$13{,}000 + \$225\ (0.50)(8.559) + \$1{,}500\ (8.559)$$
$$- \$3{,}000\ (0.3152)$$
$$\underline{C_{TD} = \$25{,}855.79}$$

Total C_T = \$50,993.57 + \$14,654.43 = \$65,648.00

Total C_{TD} = \$25,855.79 + \$6,652.11 = \$32,507.90

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 C_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 severities are as follows:

1. (3.5:1) slope - severity index equals 3.5,
2. (3:1) slope - severity index equals 4.0,
3. (2.5:1) slope - severity index equals 4.5, and
4. (2:1) slope - severity index equals 5.0

Although the slope severities are not specifically identified in the hazard inventory information, a severity index is listed for a positive slope. Assuming that this positive 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. $E_f = 5.5$
4. $C_f = 0.51$
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. $\left.\begin{array}{l} K_T = 8.559 \\ K_J = 0.3152 \end{array}\right\}$ at an assumed interest rate of 8%

12. $C_S = \$0$

13. $C_T = \$0 + \$0\ (0.51)(8.559) + \$0\ (8.559) + \$6{,}533\ (0.51)$
$(8.559) - \$0\ (0.3152)$

$\underline{C_T = \$28{,}517.13}$

$C_{TD} = \$ + \$0\ (0.51)(8.559) + \$0\ (8.559) - \$0\ (0.3152)$

$\underline{C_{TD} = \$0}$

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 VII-C-8. 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, becomes less cost-effective than the barrier for an average daily traffic equal to or above 15,000 vehicles per day; and
3. the 2:1 slope, unprotected, becomes less cost-effective than the barrier for an average daily traffic equal to or above 7,500 vehicles per day.

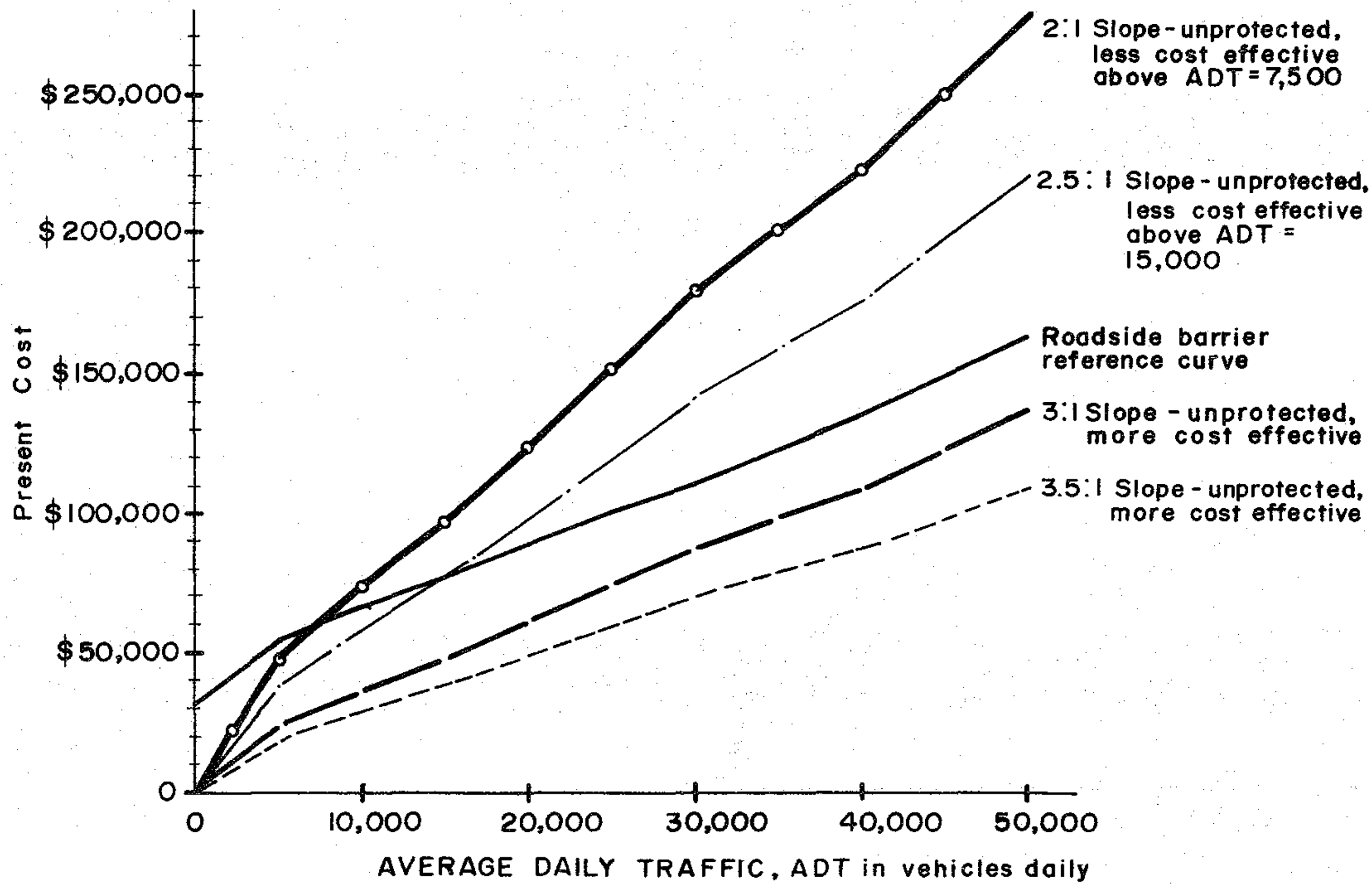


Figure VII-C-8. Cost Comparison Curves

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.

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, it is necessary to consider an equal time span for each alternative in order to make the comparison legitimate.
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 formula may be used for determining a ranking factor, R:

$$R = \frac{C_{T_H} - C_{T_I}}{C_{TD_I}}$$

where

C_{T_H} = total cost associated with the unshielded hazard over the period T;

C_{T_I} = total cost associated with the improvement over the period T; and

C_{TD_I} = total 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 for an ADT of 10,000 would be computed as follows:

C_{T_H} = \$72,000 (Slope) (From Figure VII-C-8)

C_{T_I} = \$65,648 (Barrier) (From Figure VII-C-8)

C_{TD_I} = \$32,507 (From previous calculations)

thus

$$R = \frac{72{,}000 - 65{,}648}{32{,}507}$$

or

$$R = 0.2$$

VII-C-2. Example 2 - Bridge Piers

Figure VII-C-9 shows a typical bridge pier hazard. Three alternatives will be considered in the cost analysis as follows:

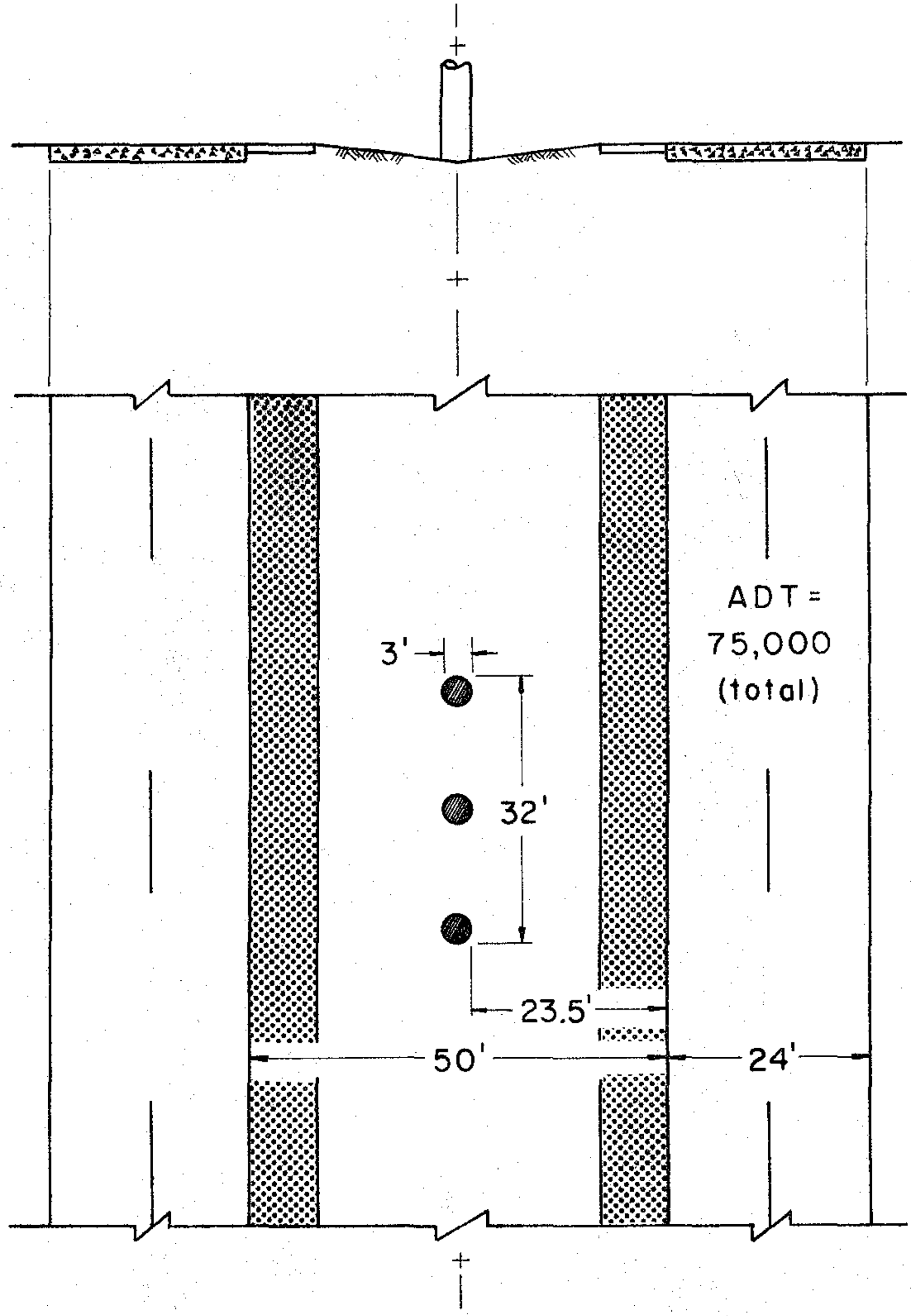


Figure VII-C-9. Bridge Pier Hazard

1. no protection of the bridge piers;
2. protection of the bridge piers with a roadside barrier rail; and
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 Section VII-C.

No Protection

1. A = 23.5 ft (7.17 m) or approximately 23 ft (7.02 m); L = 32 ft (9.76 m) and W = 3 ft (.92 m)
2. ADT = 75,000 (assumed)
3. $E_f = 31.0$
4. $C_f = 0.091$
5. Code 11-01; SI = 9.3
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. $\left.\begin{array}{l} K_T = 9.818 \\ K_J = 0.2145 \end{array}\right\}$ at an assumed interest rate of 8%
12. C_S = \$0
13. C_T = \$0 + \$0 (0.091)(9.818) + \$0 (9.818) + \$169,340 (0.091) (9.818) - \$0 (0.2145)

C_T = \$151, 295

C_{TD} = \$0 + \$0 (0.091)(9.818) + \$0 (9.818) - \$0 (0.2145)

C_{TD} = \$0

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

C_T = \$302,590 and C_{TD} = \$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 in Section III-C, the placement values to be used in the cost procedure were determined to be the following:

1. the average offset for the flared sections equal 16.52 ft (5.04 m),
2. the horizontal length of the barrier flare equals 150.94 ft (46.04 m), and
3. the total length of need for the barrier flare equals 152.20 ft (46.42 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 = 16.52 ft (5.04 m) or approximately 16 ft (4.88 m), L = 150.94 ft (46.04 m) or approximately 151 ft (46.01 m), and W = 1 ft (.31 m)
2. ADT = 75,000
3. $E_f = 31.0$
4. $C_f = 0.41$
5. Code 06-01-1-3   SI = 3.6
6. C_I = \$13.00 per foot (assumed) at 152.20 ft (52.37 m) or approximately 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} = \$6,862 at SI = 3.6
10. T = 20 years
11. $\left.\begin{array}{l} K_T = 9.818 \\ K_J = 0.2145 \end{array}\right\}$ at an assumed interest rate of 8%
12. C_S = \$1.50 per foot (assumed) at 153 ft (46.67 m) C_S = \$230
13. C_T = \$1,989 + \$225 (0.41)(9.818) + \$230 (9.818)

    + \$6,862 (0.41)(9.818) - \$230 (0.2145)

C_T = \$32,726

C_{TD} = \$1,989 + \$225 (0.41)(9.818) + \$230 (9.818)

- \$230 (0.2145)

C_{TD} = \$5,104

<u>Barrier Proper</u>

1. A = 13.5 ft (4.12 m); L = 32 ft (9.76 m); and W = 1 ft (.31 m)
2. ADT = 75,000
3. E_f = 31.0
4. C_f = 0.15
5. Code 06-01-3-2   SI = 3.3
6. C_I = \$13.00 per foot (assumed) at 32 ft (4.12m); 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. $\left.\begin{array}{l} K_T = 9.818 \\ K_J = 0.2145 \end{array}\right\}$ at an assumed interest rate of 8%
12. C_S = \$1.50 per foot (assumed) at 32 ft (4.12 m); thus C_S = \$48
13. C_T = \$416 + \$225 (0.15)(9.818) + \$48 (9.818)

    + \$5,874 (0.15)(9.818) - \$48 (0.2145)

    C_T = \$9,859

    C_{TD} = \$416 + \$225 (0.15)(9.818) + \$48 (9.818)

    - \$48 (0.2145)

    C_{TD} = \$1,208

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_T = \$32,726 + \$9,859 = <u>\$42,585</u>

Total C_{TD} = \$5,104 + \$1,208 = <u>\$6,312</u>

and for protection to both ends:

Total C_T = <u>\$85,170</u>

Total C_{TD} = <u>\$12,624</u>

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 geometries, and a total present worth may be fixed.

<u>Crash Cushion - End Treatment</u>

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
5. Code 15-00-0-0 SI = 1.0
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. $\left.\begin{array}{l} K_T = 9.818 \\ K_J = 0.2145 \end{array}\right\}$ an assumed interest rate of 8%

12. $C_S = 0.0$

13. C_T = \$5,000 + \$1,000 (0.12)(9.818) + \$150 (9.818)

    + \$2,095 (0.12)(9.818)

    C_T = \$10,119

    C_{TD} = \$5,000 + \$1,000 (0.12)(9.818) + \$150 (9.818)

    C_{TD} = \$7,651

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. $C_f = 0.10$
5. Code 06-01-3-3   SI = 3.3
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. $\left.\begin{array}{l} K_T = 9.818 \\ K_J = 0.2145 \end{array}\right\}$ 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_T = \$416 + \$225 (0.10)(9.818) + \$48 (9.818)

+ \$5,874 (0.10)(9.818) - \$48 (0.2145)

C_T = \$6,865

C_{TD} = \$416 + \$225 (0.10)(9.818) + \$48 (9.818)

- \$48 (0.2145)

C_{TD} = \$1,098

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

For protection to one end:

Total C_T = \$10,119 + \$6,865 = \$16,984

Total C_{TD} = \$7,651 + \$1,098 = \$8,749

and for shielding for both sides:

Total C_T = 2(\$16,984) = \$<u>33,968</u>   Total C_{TD} = 2(\$8,749) = \$<u>17,498</u>

Comparison

Table VII-C-4 summarizes the results of this example. By collectively reviewing the three proposed alternatives, several observations and conclusions may be outlined based on relative costs.

1. While the no shielding alternative requires no direct expenditures, it does represent a very substantial total cost in terms of accident losses.
2. The roadside barrier option is more cost-effective than the unshielded hazard.
3. The roadside barrier/crash cushion system is approximately 3.0 times more cost-effective than the roadside barrier alternative.

Table VII-C-4. Example and Comparison

OPTION	Direct Cost, C_{TD} (\$)	Total Cost, C_T (\$)	Ranking Factor, R[1]
1. No Shielding	0	151,295	--
2. Shielding by Roadside Barrier	12,624	85,170	5.2
3. Shielding by Crash Cushion/ Roadside Barrier	17,498	33,968	6.7

[1]See item 4 in summary of Section VII-C-1 for definition.

However, it does require a somewhat higher direct expenditure.

4. The ranking factor indicates that of the two improvements, the crash cushion/roadside barrier combination would provide the greatest return per dollar spent.

These findings, based on relative costs, provide the means for justifying a decision regarding whether or not shielding is necessary and which alternative is most desirable. Obviously, the roadside barrier/crash cushion system offers the best choice for the given conditions; however, it should not be construed that this analysis in itself justifies a certain improvement because of the fact that other locations may be even more critical. Whatever the case, the most cost-effective design with regards to this problem is the roadside barrier/crash cushion system.

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.

VII-C-3. 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 VII-C-10. 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 the 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.

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:

$$C_f = \frac{33.5}{10,560} \Big[1\ (0.730) + 31.4\ (0.617) + 5.14\ (0.455 + 0.405 + 0.360 + 0.325) \Big]$$

C_f = .0809 and by applying an adjustment factor of 3.0 for higher than normal encroachments (assumed),

C_f (adjusted) = 3 (0.089) = 0.267

5. Code 12-06-0-0 SI = 9.3
6. C_I = \$0

MAIN LANES

TOTAL TWO-WAY

ADT = 80,000

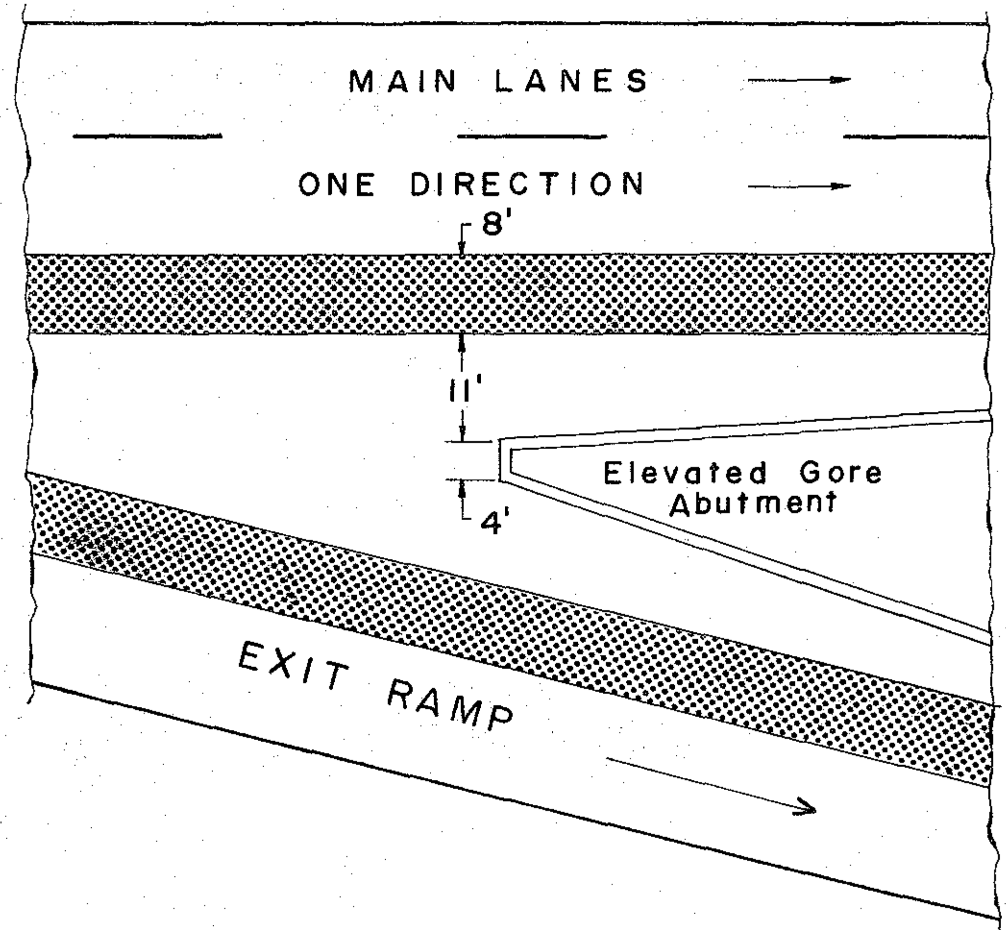


Figure VII-C-10. Elevated Gore Abutment

7. C_D = \$0 (assumed)

8. C_M = \$0 (assumed)

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

10. T = 15 years

11. $\left.\begin{array}{l} K_T = 8.061 \\ K_J = 0.2745 \end{array}\right\}$ at an assumed interest rate of 8%

12. C_S = \$0

13. C_T = \$0 + \$0 (0.267)(8.061) + \$0 (8.061) + \$169,412 (0.267)(8.061) - \$0 (0.2745)

    C_T = \$364,623

    C_{TD} = \$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:

$$C_f = \frac{33.5}{10,560}\Big[25\ (0.790) + 31.4\ (0.695) + 5.14\ (0.550 + 0.505 + 0.455 + 0.405 + 0.360 + 0.320 + 0.290 + 0.260)\Big]$$

   C_f = 0.183 and by applying an adjustment factor of 3.0 for higher than normal encroachments (assumed)

   C_f (adjusted) = 3 (0.183) = 0.549

5. Code 15-00-0-0 SI = 1.0

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. $\left.\begin{array}{l} K_T = 8.061 \\ K_J = 0.2745 \end{array}\right\}$ at an assumed interest rate of 8%

12. $C_S = \$0$ (assumed)

13. $C_T = \$5{,}000 + \$1{,}000\ (0.549)(8.061) + \$200\ (8.061)$
$+ \$2{,}095\ (0.549)(8.061)$

$C_T = \underline{\$20{,}309}$

$C_{TD} = \$5{,}000 + \$1{,}000\ (0.549)(8.061) + \$200\ (8.061)$

$C_{TD} = \underline{\$11{,}038}$

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 31.2 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.

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