ARIZONA DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING GROUP
OFFICE MEMO

April 24, 1996

TO: Roadway Design Managers, 615E
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Statewide Project Management, 614E
Valley Transportation Group, 614E
Traffic Group, 061R
Bridge Group, 613E

FROM: Terry H. Otterness THO
Design Program Manager
Roadway Design Section

RE: **AASHTO Roadside Design Guide - January 1996**

The Department received ten copies of the new document for distribution from AASHTO. Please share them with your personnel. Additional copies are available for purchase from AASHTO.

Users of this document are reminded that it is to be utilized as a "guide" only and not as a standard or policy.

Also, ADOT has adopted design criteria for some applications which are different than those in the Guide. These treatments are outlined in Chapter 300 of the Roadway Design Guidelines scheduled for May 1996 distribution.

Examples of separate ADOT criteria include a) modification of Figure 5.1 to a 1:4 slope for barrier warrant in lieu of the 1:3 shown and b) non-adoption of barn roof sections as shown in Figure 3.7 of the Guide.

It is recommended that design consultants contemplating special treatments or adaptations based upon the guide discuss the application with representatives of Roadway Design Section prior to implementation.

Please advise the design consultants working in your areas of the availability of the Guide and this memorandum. Thanks for your consideration.

THO:tbw
023tho

c: John Louis (Memo only)
LeRoy Brady (Memo only)

American Association of
State Highway and
Transportation Officials

Wm. G. Burnett, P.E., President
Executive Director
Texas Department
of Transportation

Francis B. Francois
Executive Director

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MAR 22 1996
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BD-96-14-AA

March 12, 1996

To the Chief Administrative Officers
of the Member Departments of the
American Association of State
Highway and Transportation Officials

Subject: *Roadside Design Guide - 1996*

Dear Members:

We are pleased to provide with this letter our latest publication entitled, *Roadside Design Guide - 1996* (code RSDG-2).

This publication has been long-awaited by both the Highway Subcommittee on Design and our member departments, but was delayed due to a last-minute change in format and the reprinting of several photographs which are enclosed as errata pages. We regret any inconvenience which may have resulted from this delay.

We note that as a matter of convenience each of these books is accompanied by a "ROADSIDE" software disk compiled by the Federal Highway Administration, which represents one approach to utilizing the *Roadside Design Guide* as described in Appendix A. The software carries no guarantees or warranties from the American Association of State Highway and Transportation Officials. The FHWA advises that it is not copyrighted and may be duplicated.

Following our practice relating to distribution of new publications, we are enclosing ten (10) copies to Member Departments, one (1) copy to Associate Members, and one (1) copy to Affiliate Members. For those member departments receiving 10 copies you should expect to receive two cartons. One carton will contain 10 copies of the publication, and the other carton will contain (10) 2-inch three-ring binders.

Additional copies are available from this office at $55.00 per copy for member departments. Shipment will be made for additional copies upon receipt of remittance or an official departmental purchase order. We are sending a copy of this letter to the Designated Chief Highway Engineers, and the members of the Subcommittee on Design.

Very truly yours,

Francis Francois

Francis B. Francois
Executive Director

FBF:jle

Enclosures

cc: Designated Chief Highway Engineers
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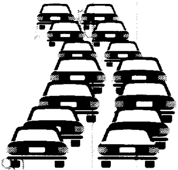
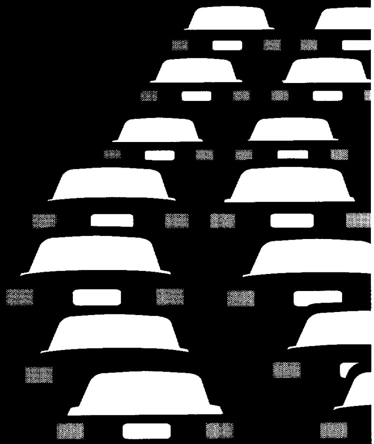
Roadside Design Guide





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444 North Capitol Street N.W. Suite 249
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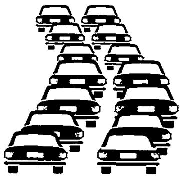
January 1996

Roadside Design Guide



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for Roadside Safety of the
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PREFACE

This Roadside Design Guide was developed by the AASHTO Subcommittee on Design, Task Force for Roadside Safety under the chairmanship of Mr. Wayne F. Cobine. This document presents a synthesis of current information and operating practices related to roadside safety and is developed in metric units. The roadside is defined as that area beyond the traveled way (driving lanes) and the shoulder (if any) of the roadway itself. Consequently, roadside delineation, shoulder surface treatments, and similar on-roadway safety features are not extensively discussed. While it is a readily accepted fact that safety can best be served by keeping motorists on the road, the focus of this guide is on safety treatments that minimize the likelihood of serious injuries when a driver does run off the road.

A second noteworthy point is that this document is a guide. It is not a standard or a design policy. It is intended for use as a resource document from which individual highway agencies can develop standards and policies. While much of the material in the guide can be considered universal in its application, there are several recommendations that are subjective in nature and may need modification to fit local conditions. However, it is important that significant deviations from the guide be based on operational experience and objective analysis.

To be consistent with the AASHTO *Policy on Geometric Design of Highways and Streets*, design speed has been selected as the basic speed parameter to be used in this guide. However, since the design speed is oftentimes determined by the most restrictive physical features found on a specific project, there may be a significant percentage of a project length where that speed will be exceeded by a reasonable and prudent driver. There will be other instances where roadway conditions will prevent most motorists from driving as fast as the design speed. Because roadside safety design is intended to minimize the consequences of a motorist leaving the roadway inadvertently, the highway engineer should consider the speed at which encroachments are most likely to occur when selecting an appropriate design standard or feature.

The reader is cautioned that roadside safety policy, criteria, and technology is a rapidly changing field of study. Changes in the roadside safety field were certain to occur after this document was written. Efforts should be made to incorporate the appropriate current design elements into project development. Comments from users of this guide on suggested changes or modifications resulting from further developmental work or hands-on experience will be appreciated. All such comments should be addressed to the American Association of State Highway and Transportation Officials, 444 North Capitol Street NW, Suite 249, Washington, DC 20001.

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GLOSSARY

Area of concern — An object or roadside condition that may warrant safety treatment.

Barricade — A device which provides a visual indicator of a hazardous location or the desired path a motorist should take. It is not intended to contain or redirect an errant vehicle.

Barrier — A device which provides a physical limitation through which a vehicle would not normally pass. It is intended to contain or redirect an errant vehicle.

Breakaway — A design feature which allows a device such as a sign, luminaire, or traffic signal support to yield or separate upon impact. The release mechanism may be a slip plan, plastic hinges, fracture elements, or a combination of these.

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

Clearance — Lateral distance from edge-of-traveled way to a roadside object or feature.

Clear Runout Area — The area at the toe of a non-recoverable slope available for safe use by an errant vehicle.

Clear Zone — The total roadside border area, starting at the edge of the traveled way, available for safe use by errant vehicles. This area may consist of a shoulder, a recoverable slope, a non-recoverable slope, and/or a clear run-out area. The desired width is dependent upon the traffic volumes and speeds and on the roadside geometry.

Cost-effective — An item or action taken which is economical in terms of tangible benefits produced by money spent.

Crash Cushion — Device that prevents an errant vehicle from impacting fixed object hazards by gradually decelerating the vehicle to a safe stop or by redirecting the vehicle away from the hazard.

Crash Tests — Vehicular impact tests by which the structural and safety performance of roadside barriers and other highway appurtenances may be determined. Three evaluation criteria are considered, namely (1) structural adequacy, (2) impact severity, and (3) vehicular post-impact trajectory.

Crashworthy — A feature that has been proven acceptable for use under specified conditions either through crash testing or in-service performance.

Design Speed — A speed determined for the design and correlation of the physical features of a highway that influence vehicle operation. It is the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features of the highway govern.

Drainage Features — Roadside items whose primary purpose is to provide adequate roadway drainage such as curbs, culverts, ditches, and drop inlets.

End Treatment — The designed modification of a roadside or median barrier at the end.

Experimental Barrier — One that has performed satisfactorily in full-scale crash tests and promises, but not yet demonstrated, satisfactory in-service performance.

Flare — The variable offset distance of a barrier to move it further from the traveled way.

Frangible — A structure readily or easily broken upon impact.

Fuse Plate — The plate which provides structural reinforcement to the sign post hinge to resist wind loads but which will release or fracture upon impact of a vehicle with the post.

Glare Screen — A device used to shield a driver's eye from the headlights of an oncoming vehicle.

Hinge — The weakened section of a sign post designed to allow the post to rotate upward when impacted by a vehicle.

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.

Impact Attenuator — See Crash Cushion.

Length of Need — Total length of a longitudinal barrier needed to shield an area of concern.

Level of Performance — The degree to which a longitudinal barrier, including bridge railing, is designed for containment and redirection of different types of vehicles.

Longitudinal Barrier — A barrier whose primary function is to prevent penetration and to safely redirect an errant vehicle away from a roadside or median hazard.

Median — The portion of a divided highway separating the traveled ways for traffic in opposite directions.

Median Barrier — A longitudinal barrier used to prevent an errant vehicle from crossing the highway median.

Non-Recoverable Slope — A slope which is considered traversable but on which the errant vehicle will continue on to the bottom. Embankment slopes between 1:3 and 1:4 may be considered traversable but non-recoverable if they are smooth and free of fixed-object hazards.

Offset — The distance between the traveled way and a roadside barrier or other obstacle.

Operating Speed — The highest speed at which reasonably prudent drivers can be expected to operate vehicles on a section of highway under low traffic densities and good weather. This speed may be higher or lower than posted or legislated speed limits or nominal design speeds where alignment, surface, roadside development, or other features affect vehicle operations.

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

Performance Level — See Level of Performance.

Recoverable Slope — A slope on which a motorist may, to a greater or lesser extent, retain or regain control of a vehicle. Slopes flatter than 1:4 are generally considered recoverable.

Recovery Area — Generally synonymous with clear zone.

Roadside — That area between the outside shoulder edge and the right-of-way limits. The area between roadways of a divided highway may also be considered roadside.

Roadside Barrier — A longitudinal barrier used to shied roadside obstacles or non-traversable terrain features. It may occasionally be used to protect pedestrians or "bystanders" from vehicle traffic.

Roadside Signs — Roadside signs can be divided into three main categories: overhead signs, large roadside signs, and small roadside signs. Large roadside signs may be defined as those 6 square meters or greater in area. Small roadside signs may be defined as those less than 6 square meters in area.

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

Rounding — The introduction of a vertical curve between two transverse slopes to minimize the abrupt slope change and to maximize vehicle stability and maneuverability.

Severity Index — A severity index (SI) is a number from zero to ten used to categorize accidents by the probability of their resulting in property damage, personal injury, or a fatality, or any combination of these possible outcomes. The resultant number can then be translated into an accident cost and the relative effectiveness of alternate safety treatments can be estimated.

Shielding — The introduction of a barrier or crash cushion between the vehicle and an obstacle or area of concern to reduce the severity of impacts of errant vehicles.

Shy Distance — The distance from the edge of the traveled way beyond which a roadside object will not be perceived as an immediate hazard by the typical driver to the extent that the driver will change the vehicle's placement or speed.

Slip Base — A structural element at or near the bottom of a post or pole which will allow release of the post from its base upon impact while resisting wind loads.

Slope — The relative steepness of the terrain expressed as a ratio or percentage. Slopes may be categorized as positive (backslopes) or negative (foreslopes) and as parallel or cross slopes in relation to the direction of traffic.

Temporary Barrier — Temporary barriers are used to prevent vehicular access into construction or maintenance work zones and to redirect an impacting vehicle so as to minimize damage to the vehicle and injury to the occupants while providing worker protection.

Traffic Barrier — A device used to prevent a vehicle from striking a more severe obstacle or feature located on the roadside or in the median or to prevent crossover median accidents. As defined herein, there are four classes of traffic barriers, namely, roadside barriers, median barriers, bridge railings, and crash cushions.

Transition — A section of barrier between two different barriers or, more commonly, where a roadside barrier is connected to a bridge railing or to a rigid object such as a bridge pier. The transition should produce a gradual stiffening of the approach rail so vehicular pocketing, snagging, or penetration at the connection can be avoided.

Traveled Way — The portion of the roadway for the movement of vehicles, exclusive of shoulders.

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

Traversable Slope — A slope from which a motorist will be unlikely to steer back to the roadway but may be able to slow and stop safely. Slopes between 1:3 and 1:4 generally fall into this category.

Vehicle — A motorized unit for use in transporting passengers or freight, ranging from an 820-kg automobile to a 36,000-kg van-type tractor-trailer.

Warrants — The criteria by which the need for a safety treatment or improvement can be determined.

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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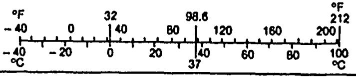
* SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

CHAPTER 1: AN INTRODUCTION TO ROADSIDE SAFETY

1.0 HISTORY OF ROADSIDE SAFETY

Roadside safety design, as one component of total highway design, is a relatively recent concept. Most of the highway design components were established in the late 1940s and the 1950s. These components included horizontal alignment, vertical alignment, hydraulic design and sight distance to name some of the most common highway design elements. These elements have been revised and refined over the years through experience and research. However, the highway design components themselves have remained about the same for several decades.

Roadside safety design did not become a much discussed aspect of highway design until the late 1960s and it would be the decade of the 1970s before this type of design was regularly incorporated into highway projects. Because most highways are designed for a twenty- to thirty-year projected traffic, many roadway projects placed in service before the 1970s are only now becoming candidates for major reconstruction. This reconstruction offers an opportunity to incorporate cost-effective roadside safety concepts and design features. The purpose of this Guide is to present the concepts of roadside safety to the designer in such a way that the most practical, appropriate, and beneficial roadside design can be accomplished for each individual project.

1.1 THE BENEFITS OF ROADSIDE SAFETY

Roadside design might be defined as the design of the area between the outside shoulder edge and the right-of-way limits. Some have referred to this aspect of highway design as off-pavement design. A question commonly asked revolves around whether spending resources off the pavement is really beneficial given the limited nature of infrastructure funds. Perhaps, some statistics bring the potential of accident reduction and roadside safety into focus.

The United States suffers approximately 40,000 traffic fatalities each year. As shown in Figure 1.1, the actual number has fluctuated around this level since the mid-1960s. At the same time, the exposure rate, represented by the vehicle kilometers traveled as indicated in Figure 1.2, has increased approximately two and one-half times since the mid-1960s. Therefore, the traffic fatality rate per one hundred million vehicle kilometers given in Figure 1.3 has fallen by more than half since the mid-1960s.

This significant reduction is due to several factors. Motor vehicles are much safer than vehicles have been in the past. Protected passenger compartments, padded interiors, and occupant restraints are some features that have added to passenger safety during impact situations. Roadways have been made safer through design improvements such as increased superelevation, intersection geometry, and the addition of grade separations. Drivers are more educated about safe vehicle operation as evidenced by the increased use of occupant restraints and a decrease in driving under the influence of alcohol or drugs. All these contributing factors have reduced the motor vehicle fatality rate.

How significant is the roadside environment involvement in highway accidents? Unfortunately, roadside accidents account for far too great a portion of the total fatal highway accidents. About thirty percent, or almost one in every three fatalities, is the result of a single vehicle run-off-the-road accident. These figures mean that the roadside environment comes into play in a very significant percentage of fatal and serious-injury accidents.

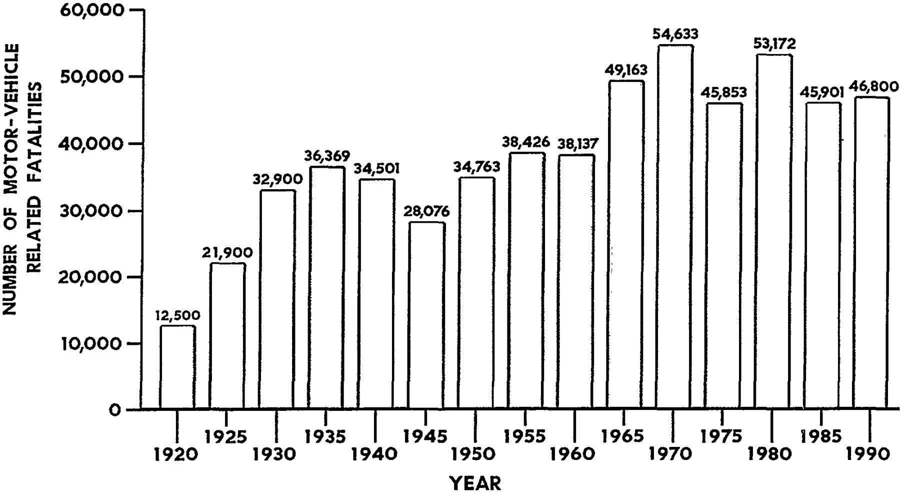


FIGURE 1.1 Number of Motor Vehicle Related Fatalities by Year

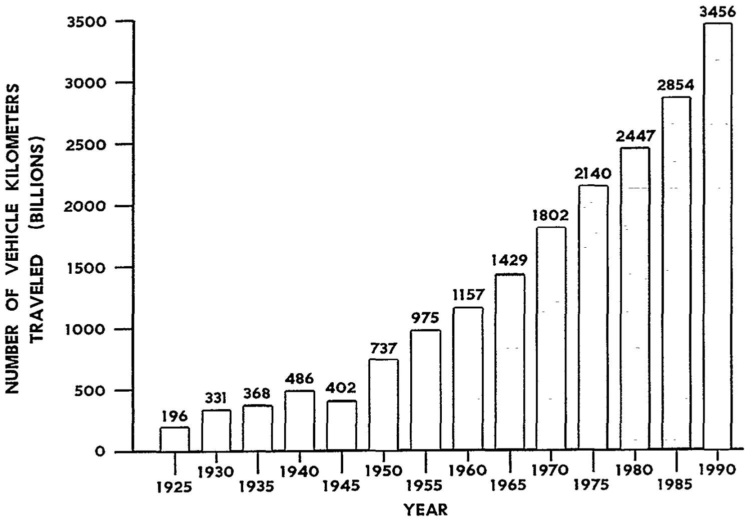


FIGURE 1.2 Number of Vehicle Kilometers Traveled by Year

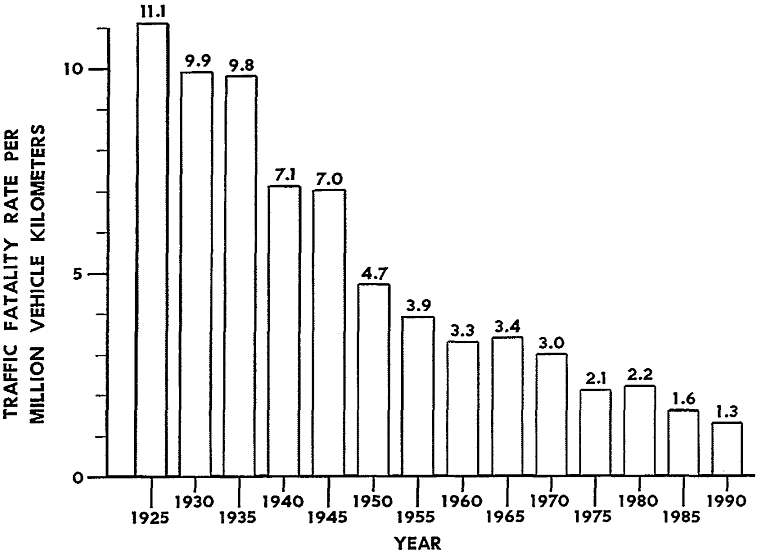


FIGURE 1.3 Traffic Fatality Rate Per Million Vehicle Kilometers by Year

1.2 THE FORGIVING ROADSIDE CONCEPT

There are many reasons why a vehicle will leave the pavement and encroach on the roadside including:

- Driver fatigue or inattention
- Excessive speed
- Driving under the influence of drugs or alcohol
- Collision avoidance
- Roadway conditions such as ice, snow, or rain
- Vehicle component failure
- Poor visibility

Regardless of the reason for a vehicle leaving the roadway, a roadside environment free of fixed objects with stable, flattened slopes enhances the opportunity for reducing accident severity. The forgiving roadside concept allows for errant vehicles leaving the roadway and supports a roadside design where the serious consequences of such an incident are reduced.

Through decades of experience and research, the application of the forgiving roadside concept has been refined to the point where roadside design is an integral part of transportation design criteria. For example, a summary of design options for reducing roadside obstacles might be represented by the following order:

- Remove the obstacle.
- Redesign the obstacle so it can be safely traversed.
- Relocate the obstacle to the point where it is less likely to be struck.
- Reduce impact severity by using an appropriate breakaway device.
- Shield the obstacle with a longitudinal traffic barrier designed for redirection and/or using a crash cushion.
- Delineate the obstacle if the above alternatives are not appropriate.

1.3 THE CONTENT AND FORMAT

This Guide replaces the AASHTO publication *Roadside Design Guide* (1989). This publication can be considered a companion document for such current publications as *A Policy on Geometric Design of Highway and Streets* and *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals.* There are also several research publications and additional reference literature given at the end of each chapter.

Chapter 2 discusses methods for selecting the appropriate alternative roadside safety enhancements. The discussion involves cost benefit analyses to determine a ranking of alternatives in the absence of better local information. Appendix A offers an example of one type of methodology for accomplishing a cost benefit analysis of various alternatives.

Chapter 3 contains a discussion of the clear roadside concept. It also gives some relative clear zone values from which design guidance might be derived. Examples of the application of the clear zone values are also given. The chapter further includes a discussion of the treatment of roadside drainage features.

Chapter 4 provides information on the use of sign and luminaire supports within the roadside environment. Both small and large signs are included, as well as breakaway and non-breakaway supports are presented. The chapter concludes with discussions of miscellaneous roadside features such as mailbox supports, utility poles, and trees.

Chapters 5, 6, 7, and 8 provide information concerning roadside barriers and crash cushions. Chapter 5 discusses roadside barriers. Appendix B gives selected details for these roadside barriers. Chapter 6 provides equivalent information for median barriers and Appendix C gives selected median barrier details. Chapter 7 includes information on appropriate bridge railings with Appendix D providing bridge railing design details. Chapter 8 offers the latest state-of-the-practice information on barrier end treatments and crash cushions.

Chapter 9 offers some discussion of the application of the roadside safety concept for the temporary conditions found in construction or maintenance work zones. For example, the chapter contains information on temporary barriers, truck-mounted attenuators, barricades, and other conditions commonly associated with work zones.

Chapter 10 discusses the application of roadside safety in the urban environment. While much of the information presented in this publication applies to rural, high-speed conditions, this chapter offers information on urban roadside practices.

1.4 THE APPLICATION OF THIS PUBLICATION

This publication is intended to represent information on the latest state-of-the-practice in roadside safety. The concepts, designs, and philosophies presented in the following chapters can not, and should not, be included in their totality on every single project. Each project is unique and offers an individual opportunity to enhance that particular roadside environment from a safety perspective.

The guidelines presented in this publication are most applicable to new construction or major reconstruction projects. These projects, which often include significant changes in horizontal or vertical alignment, offer the greatest opportunity for implementing many of the roadside safety enhancements presented in this document. For resurfacing, rehabilitation, or restoration (RRR) projects, the primary emphasis is generally placed on the roadway itself to maintain the structural integrity of the pavement. It will generally be necessary to selectively incorporate roadside guidelines on RRR projects only at locations where the greatest safety benefit can be realized. Because of the scope of RRR projects and the limited nature of most rehabilitation programs, the identification of areas which offer the greatest safety enhancement potential is critical. Accident reports, site investigations, and maintenance records offer starting points for identifying these locations.

The amount of monetary resources available for all roadside safety enhancement is limited. The objective of transportation engineers has to be to maximize roadside safety on a system-wide basis with the given funds. Accomplishing this objective means addressing those specific roadside features that can contribute the most to the safety enhancement of that individual highway project. If the inclusion of the highest level of roadside design criteria, regardless of cost or safety effectiveness, is routinely required in each highway design project, it is likely that system-wide safety may stay static or be degraded. This potential will certainly exist if other roadside needs are not improved because funds were not judiciously applied to the most viable safety enhancement need.

Applying the forgiving concept to roadside objects shows its relevance in Table 1.1. Given the fact that objects and slope changes must be introduced at varying points off the pavement edge, the enhancement of roadside safety involves selecting the "best" choice among several acceptable design alternatives. The experience gained in decades of selecting design alternatives, the research done on vehicle dynamics, and the technological advances in materials offers the potential for maintaining and enhancing one of the safest national transportation systems in existence.

This publication has several references to crash-testing criteria and crash-tested hardware. The intended implication of referring to a device as crash tested is that the roadside hardware was tested to the applicable criteria in existence at the time when the full scale crash testing was done. While full-scale crash-testing criteria subjects roadside devices to severe vehicle impact conditions, the testing can not duplicate every roadside condition or vehicle impact situation. The testing provides for an acceptable level of performance under normalized conditions. However, every roadside device or installation has limitations dictated by physical laws, the crashworthiness of vehicles and the limitation of resources. Some in-service impact situations may have more severe consequences if they occur beyond the design limits which the testing was intended to replicate. National Cooperative Highway Research Program Report 350, *Recommended Procedures*

TABLE 1.1 First Harmful Event—Fixed Object Fatalities by Object Type

FIXED OBJECT	1988	1989	1990	1991	1992
Tree/Shrub	3,329	3,296	3,252	3,236	3,053
Utility Pole	1,476	1,418	1,277	1,329	1,129
Culvert/Ditch	1,473	1,349	1,501	1,401	1,363
Guardrail	1,385	1,288	1,249	1,204	1,139
Embankment	1,360	1,332	1,334	1,187	1,138
Curb/Wall	891	860	843	774	752
Other Fixed Objects	682	696	731	634	619
Sign or Light Support	576	594	578	528	488
Bridge/Overpass	553	519	582	545	545
Other Pole/Support	501	449	450	411	388
Fence	482	448	505	500	455
Concrete Barrier	201	249	236	217	214
Building	106	98	97	111	89
Impact Attenuator	15	20	28	16	20
TOTALS	13,030	12,616	12,663	12,093	11,392

for the Safety Performance Evaluation of Highway Features, discusses the limitations of full-scale crash testing in greater detail.

This document is intended to represent the spectrum of commonly available roadside design alternatives. In most cases, these alternatives have shown significant benefits under appropriately selected field conditions. Many of these roadside enhancements have, over time, demonstrated their ability in the field to improve roadside safety conditions. In many areas, the publication strives to give the advantages and disadvantages of roadside technology. With this information, engineers can make more knowledgeable decisions about the best applications for individual projects. It should be noted that no attempt is made, or implied, to offer every single roadside enhancement design technique or technology.

Finally, this publication is not intended to be used as a standard or a policy statement. This document is made available to be a resource for current information in the area of roadside design. Agencies may choose to use this information as one reference upon which to build the roadside design criteria best suited to their particular location and projects. Knowledgeable design, practically applied at the local level, offers the greatest potential for a continually improved transportation system.

CHAPTER 2: ROADSIDE SAFETY AND ECONOMICS

2.0 OVERVIEW

The consistent application of geometric design standards for roads and streets provides motorists with a high degree of safety. Design features such as horizontal and vertical curvature, lane and shoulder width, and signing and pavement markings each play an important role in keeping motorists on the traveled way. Roadside safety features, such as breakaway supports, bridge railings, and crash cushions provide an extra margin of safety to motorists who inadvertently leave the roadway. Most of these appurtenances are routinely installed based on a subjective analysis of their benefits to the motorist. However, in some instances it may not be immediately obvious that the benefits to be gained from a specific safety design or treatment equal or exceed the additional costs. Thus, a design engineer must decide how and where limited funds should be spent to achieve the greatest overall benefit. One method that can be used to make this determination is a benefit/cost analysis.

2.1 BENEFIT/COST ANALYSIS

A benefit/cost analysis is a method by which the estimated benefits to be derived from a specific course of action are compared to the costs of implementing that action. If the estimated benefits of a specific design exceed the cost of constructing and maintaining that design over a period of time, the safer design may be implemented. However, simply having a benefit/cost ratio greater than one is not ample justification for the construction of a roadside safety treatment. Each project must compete with others for limited safety funds. The highway engineer must attempt to build those projects that best meet the public's need for safety and mobility.

The primary benefit obtained from selecting one design over another, relative to safety, is the expected reduction in future accident costs. These typically include property damage costs and personal injury costs. To estimate these costs, the expected number and severity of accidents that may occur for each roadside treatment must be estimated. In some cases, the total number of accidents may be reduced by a given treatment, such as providing a significantly wider roadside recovery area than previously existed. In other instances, the safety treatment may not reduce the total number of accidents but may reduce their severity. The installation of a median or roadside traffic barrier may have this effect.

The costs used in a benefit/cost analysis are generally the direct construction and maintenance costs incurred by the highway agency. They can usually be estimated with a high degree of accuracy.

A benefit/cost analysis must also consider the period of time (project life) over which each alternative treatment provides a benefit. Since different treatments can have different project lives, both benefits and costs must be annualized so direct comparisons between alternative design treatments can be made. To reduce total (life cycle) costs to annualized costs, discount rates must be considered. An annualized benefit/cost ratio thus compares the expected savings to society (through reduced accident costs) to the costs (construction and maintenance) incurred by the highway agency to provide a specific treatment.

The following subsections identify the type of data that are needed to make a benefit/cost analysis and the general availability of this information. The major factors include:

- encroachments
- roadside geometry
- accident costs

2.1.1 Encroachments

The benefits derived from a roadside safety treatment can be calculated by first estimating the number of vehicles that are likely to run off the road at a particular location. By definition, an encroachment occurs when a motorist strays from the traveled way. The primary factors which affect the number of encroachments are traffic volume, roadway alignment, and lane widths. The number of estimated encroachments is determined by multiplying an encroachment rate by the number of vehicles using the facility, resulting in a figure representing the number of encroachments per kilometer per year. Current encroachments rates are derived from a limited number of studies conducted over the past 30 years. These rates should be adjusted when actual data at a specific location is available. They may also be modified based on engineering judgement for non-typical conditions.

It should be further noted that all encroachments do not result in accidents. For example, for small angle encroachments, even a narrow recovery area may provide enough space for a driver to regain control and return safely to the roadway. To estimate the number of accidents that may result from encroachments, the angles of departure from the roadway and the speeds and types of vehicles involved must be considered.

2.1.2 Roadside Geometry

Once a vehicle has left the roadway, an accident may or may not occur. The end result of an encroachment depends upon the physical characteristics of the roadside environment. As noted earlier, the highway engineer has a significant degree of control over roadside geometry and appurtenances. Flat, traversable, stable slopes will minimize overturning accidents, which are usually severe. Elimination of roadside hardware, its relocation to less vulnerable areas, or the use of breakaway-type devices remain the options of choice in the development of safer roadsides. Hazardous objects that cannot be otherwise treated should be shielded by properly designed and installed traffic barriers or crash cushions if it is cost-effective to do so. Finally, if a fixed object or other roadside hazard cannot be eliminated, relocated, modified, or shielded, for whatever reason, consideration should be given to delineating the feature so it is readily visible to a motorist.

2.1.3 Accident Costs

Once an estimate has been made of the number of accidents that can be expected at a given location, this information must be translated into accident costs which are directly related to accident severity. One method of accomplishing this is by assigning a Severity Index (SI) to individual accidents. This SI will vary with the type of vehicle involved, its speed and impact angle, and the type of obstacle struck. An accident may range in severity from minor to fatal. If an SI system is used, an accident involving no personal injuries and negligible property damage might be assigned an SI of zero, while an accident with a 100 percent chance of a fatality might be assigned an SI of 10. Between these extremes, accidents typically involve varying degrees of property damage coupled with slight, moderate, or severe personal injuries.

Converting severity indices to accident costs is a relatively easy process, but it does require that dollar costs be assigned to each type of accident. This step involves considerable judgement because it requires that a value be assigned to each accident classification, including fatal accidents. Primary sources of accident cost data include the National Safety Council, the National Highway Traffic Safety Administration, and the Federal Highway Administration.

2.2 BENEFIT/COST ANALYSIS PROGRAMS

Several highway agencies have used versions of a procedure presented in the 1977 AASHTO *Guide for Selecting, Locating, and Designing Traffic Barriers* to both analyze site-specific alternative safety treatments and to develop design charts and tables using local data. Appendix A contains an updated and significantly revised version of those procedures and describes the application of a new version of the computer program ROADSIDE to the revised procedures.

CHAPTER 3: ROADSIDE TOPOGRAPHY AND DRAINAGE FEATURES

3.0 OVERVIEW

This chapter includes a discussion on the development and evaluation of the clear roadside concept and on its application to roadside design. It also discusses embankment slopes and ditches and how these features influence roadside features whose purpose is to provide adequate roadway drainage, such as curbs, culverts, and drop inlets. The design engineer is presented with several options that enhance safety without affecting the capabilities of these elements to drain the highway.

Most of the clear roadside design guidelines discussed in this chapter have been practiced to varying degrees for several years. This chapter attempts to reemphasize and collect the currently accepted design principles to provide guidance in the area of roadside clearances. However, to include every recommendation or design value in this chapter on every future highway project is neither feasible nor possible. Engineering judgement will have to play a part in the determination of the extent to which improvements can reasonably be made with the limited resources available.

As the designer studies the options available, some consideration should be given to the future maintenance of drainage facilities and roadside topography. Ongoing repair and upkeep will be necessary to ensure the continued function and safety of various roadside drainage features. Personnel, materials, equipment, and cost are some of the considerations in every maintenance program. The designer should take into account the exposure of crews to traffic conditions while completing repairs. Also, maintenance activities can cause various levels of disruption in the traffic flow. These disruptions may increase the potential for accidents.

3.1 THE CLEAR ROADSIDE CONCEPT

Beginning in the early 1960s, as more Interstate highways and other freeways became open to traffic, the nature and characteristics of the typical rural highway accident began to change. Instead of head-on collisions with other vehicles or accidents involving trees immediately adjacent to the roadway, many drivers were running off the new freeways and colliding with man-made objects such as bridge piers, sign supports, culverts, ditches, and other design features of the roadway. In 1967, the AASHO (currently AASHTO) Traffic Safety Committee issued a report entitled *Highway Design and Operational Practices Related to Highway Safety*. This document became known as the "Yellow Book" and its principles were widely applied to highway construction projects, particularly high-speed controlled access facilities. A second edition of the Yellow Book, published by AASHTO in 1974, stated that "... for adequate safety, it is desirable to provide an unencumbered roadside recovery area that is as wide as practical on a specific highway section. Studies have indicated that on high-speed highways, a width of 9 meters or more from the edge of the traveled way permits about 80 percent of the vehicles leaving a roadway out of control to recover. ..."

Subsequently, most highway agencies began to try to provide a traversable and unobstructed roadside area extending approximately 9 meters beyond the edge of the driving lane, particularly on high-volume, high-speed roadways. Many obstacles located within this clear zone distance were removed, relocated, redesigned, or shielded by traffic barriers or crash cushions. It soon became apparent however, that in some limited situations where the embankment sloped significantly downward, a vehicle could encroach further from the traveled way and a 9-meter recovery area might not be adequate. Conversely, on most low-volume or low-speed facilities, a 9-meter clear zone distance was excessive and could seldom be justified for engineering, environmental, or economic reasons.

The 1977 AASHTO *Guide for Selecting, Locating and Designing Traffic Barriers* modified the earlier clear zone concept by introducing variable clear zone distances based on traffic volumes and speeds, and on roadside geometry. Figure 3.1 or Table 3.1 can be used to determine the suggested clear zone distance for selected traffic volumes and speeds. However, the use of Figure 3.1 or Table 3.1, by themselves, results in numbers which are a general approximation. The curves are based on limited empirical data which was then extrapolated to provide information for a wide range of conditions. The designer must keep in mind site-specific conditions, design speeds, rural versus urban locations, and practicality. The numbers from Figure 3.1 or Table 3.1 should suggest only the approximate center of a range to be considered and not a precise distance to be held as absolute.

The designer may choose to modify the clear zone distance obtained from Figure 3.1 or Table 3.1 for horizontal curvature by using Table 3.2. These modifications are normally only considered where accident histories indicate a need, or a specific site investigation shows a definitive accident potential which could be significantly lessened by increasing the clear zone width, and such increases are cost-effective. Horizontal curves, particularly for high-speed facilities, are usually superelevated to increase safety and provide a more comfortable ride. Increased banking on curves where the superelevation is inadequate is an alternate method of increasing roadway safety within a horizontal curve, except where snow and ice conditions limit the use of increased superelevation.

For relatively flat and level roadsides, the clear zone concept is simple to apply. However, it becomes somewhat less clear when the roadway is in a fill or cut section where roadside slopes may be either positive, negative, or variable or where a roadside channel exists near the traveled way. Consequently, these features must be discussed before a full understanding of the clear zone concept is possible. The AASHTO publication *A Policy on Geometric Design of Highways and Streets* may be referenced for additional clear zone discussion.

3.2 ROADSIDE GEOMETRY

If a roadside is not flat, a motorist leaving the roadway will encounter an embankment slope (negative grade), a cut slope (positive grade), or a roadside channel (change in slope from negative to positive). Each of these features has an affect on a vehicle's lateral encroachment and trajectory as will be discussed in the next sections.

3.2.1 Embankments (Parallel Slopes)

Embankment or fill slopes parallel to the flow of traffic may be defined as recoverable, non-recoverable, or critical. Recoverable slopes are all embankment slopes 1: 4 or flatter. If such slopes are relatively smooth and traversable, the suggested clear zone distance may be taken directly from Figure 3.1 or Table 3.1. Motorists who encroach on recoverable slopes can generally stop their vehicles or slow them enough to return to the roadway safely. Fixed obstacles such as culvert headwalls will normally not extend above the embankment within the clear zone distance. Examples of suggested roadside design practices for recoverable slopes and the application of the clear zone concept are in Section 3.3.1.

A non-recoverable slope is defined as one which is traversable, but from which most motorists will be unable to stop or to return to the roadway easily. Vehicles on such slopes typically can be expected to reach the bottom. Embankments between 1: 3 and 1: 4 generally fall into this category. Since a high percentage of encroaching vehicles will reach the toe of these slopes, the clear zone distance cannot logically end on the slope. Fixed obstacles will normally not be constructed along such slopes and a clear runout area at the base is desirable. Section 3.3.4 provides an example of a clear zone computation for non-recoverable slopes.

A critical slope is one on which a vehicle is likely to overturn. Slopes steeper than 1:3 generally fall into this category. If a slope steeper than 1:3 begins closer to the traveled way than the suggested clear zone distance for that specific roadway, a barrier might be warranted if the slope cannot readily be flattened. Barrier warrants for critical embankments are included in Chapter 5.

Many State highway agencies typically construct "barn roof" sections, providing a relatively flat recovery area adjacent to the roadway for some distance, followed by a steeper foreslope. Such a cross section is more economical than providing a continuous flat slope from the edge of the traveled way to the original ground line and is generally perceived as safer than constructing a continuous steeper slope from the edge of the shoulder. Figure 3.7 depicts the clear zone distance reaching a non-recoverable parallel slope and the subsequent clear runout area which may be provided at the toe of the non-recoverable slope to provide a maximum desirable adjusted clear zone distance. Example: clear zone calculations for this type of cross section are also included in Section 3.3.4.

3.2.2 Embankments (Cross Slopes)

Common obstacles on roadsides are embankment slopes created by median crossovers, driveways, or intersecting side roads. These are generally more critical to errant

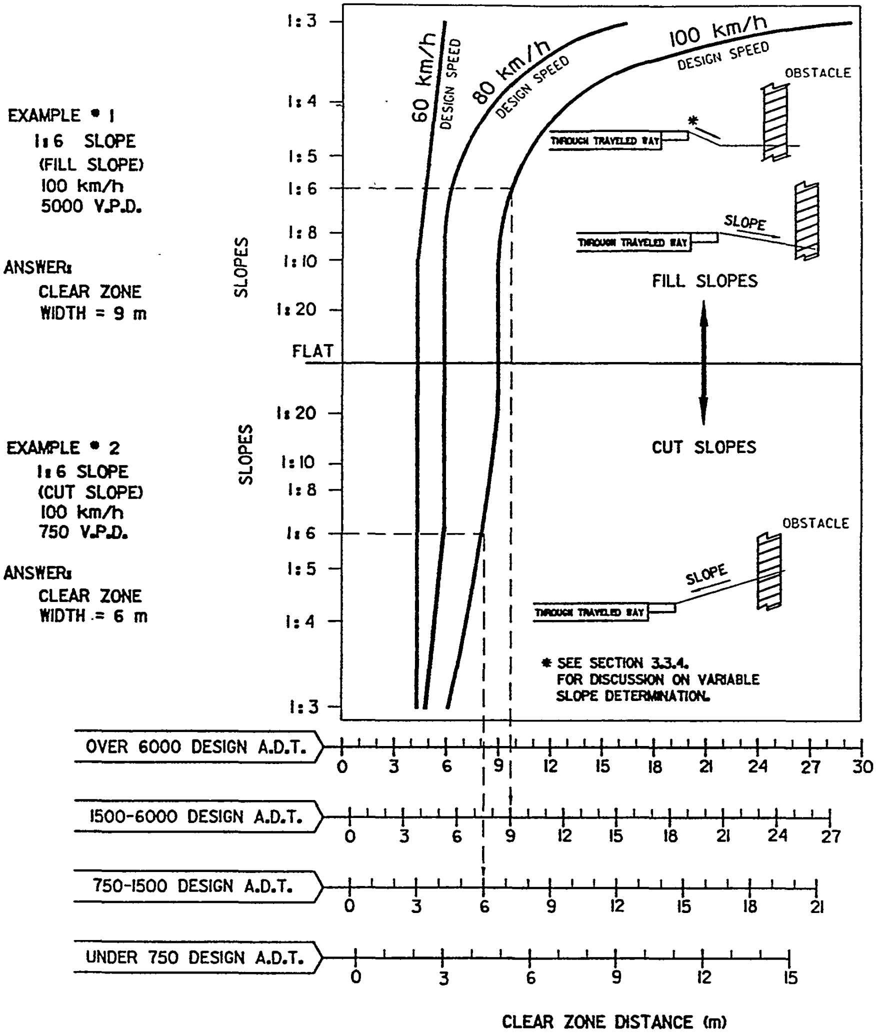


FIGURE 3.1 Clear Zone Distance Curves

TABLE 3.1 Clear Zone Distances (in meters from edge of driving lane)

DESIGN SPEED	DESIGN ADT	FILL SLOPES			CUT SLOPES		
		1:6 OR FLATTER	1:5 TO 1:4	1:3	1:3	1:5 TO 1:4	1:6 OR FLATTER
60 km/h or Less	UNDER 750	2.0-3.0	2.0-3.0	* *	2.0-3.0	2.0-3.0	2.0-3.0
	750-1500	3.0-3.5	3.5-4.5	* *	3.0-3.5	3.0-3.5	3.0-3.5
	1500-6000	3.5-4.5	4.5-5.0	* *	3.5-4.5	3.5-4.5	3.5-4.5
	OVER 6000	4.5-5.0	5.0-5.5	* *	4.5-5.0	4.5-5.0	4.5-5.0
70-80 km/h	UNDER 750	3.0-3.5	3.5-4.5	* *	2.5-3.0	2.5-3.0	3.0-3.5
	750-1500	4.5-5.0	5.0-6.0	* *	3.0-3.5	3.5-4.5	4.5-5.0
	1500-6000	5.0-5.5	6.0-8.0	* *	3.5-4.5	4.5-5.0	5.0-5.5
	OVER 6000	6.0-6.5	7.5-8.5	* *	4.5-5.0	5.5-6.0	6.0-6.5
90 km/h	UNDER 750	3.5-4.5	4.5-5.5	* *	2.5-3.0	3.0-3.5	3.0-3.5
	750-1500	5.0-5.5	6.0-7.5	* *	3.0-3.5	4.5-5.0	5.0-5.5
	1500-6000	6.0-6.5	7.5-9.0	* *	4.5-5.0	5.0-5.5	6.0-6.5
	OVER 6000	6.5-7.5	8.0-10.0*	* *	5.0-5.5	6.0-6.5	6.5-7.5
100 km/h	UNDER 750	5.0-5.5	6.0-7.5	* *	3.0-3.5	3.5-4.5	4.5-5.0
	750-1500	6.0-7.5	8.0-10.0*	* *	3.5-4.5	5.0-5.5	6.0-6.5
	1500-6000	8.0-9.0	10.0-12.0*	* *	4.5-5.5	5.5-6.5	7.5-8.0
	OVER 6000	9.0-10.0*	11.0-13.5*	* *	6.0-6.5	7.5-8.0	8.0-8.5
110 km/h	UNDER 750	5.5-6.0	6.0-8.0	* *	3.0-3.5	4.5-5.0	4.5-4.9
	750-1500	7.5-8.0	8.5-11.0*	* *	3.5-5.0	5.5-6.0	6.0-6.5
	1500-6000	8.5-10.0*	10.5-13.0*	* *	5.0-6.0	6.5-7.5	8.0-8.5
	OVER 6000	9.0-10.5*	11.5-14.0*	* *	6.5-7.5	8.0-9.0	8.5-9.0

* Where a site specific investigation indicates a high probability of continuing accidents, or such occurrences are indicated by accident history, the designer may provide clear zone distances greater than 9 meters as indicated. Clear zones may be limited to 9 meters for practicality and to provide a consistent roadway template if previous experience with similar projects or designs indicates satisfactory performance.

** Since recovery is less likely on the unshielded, traversable 1:3 slopes, fixed objects should not be present in the vicinity of the toe of these slopes. Recovery of high-speed vehicles that encroach beyond the edge of the shoulder may be expected to occur beyond the toe of slope. Determination of the width of the recovery area at the toe of slope should take into consideration right-of-way availability, environmental concerns, economic factors, safety needs, and accident histories. Also, the distance between the edge of the travel lane and the beginning of the 1:3 slope should influence the recovery area provided at the toe of slope. While the application may be limited by several factors, the fill slope parameters which may enter into determining a maximum desirable recovery area are illustrated in Figure 3.7.

motorists than foreslopes or backslopes because they are typically struck head on by run-off-the-road vehicles. Cross slopes of 1:6 or flatter are suggested for high-speed roadways, particularly for that section of the embankment that is located immediately adjacent to traffic. This slope can then be transitioned to a steeper slope as the distance from the traveled way increases.

Embankment cross slopes of 1:10 are desirable; however, their practicality may be limited by width restrictions and the maintenance problems associated with the long tapered ends of pipes or culverts. Embankment cross slopes steeper than 1:6 may be considered for urban areas or for low-speed facilities. Figures 3.2 and 3.3 show suggested designs for these slopes. Safety treatments for parallel drainage structures are discussed in Section 3.4.3.

Some alternative designs for drains at median openings are shown in Figure 3.4. The water flows into a grated drop inlet in the median to a cross-drainage structure or directly underneath the travel lanes to an outside channel. This eliminates the two pipe ends which would be exposed to traffic in the median. The side slopes of the median opening would then be desirably sloped at 1:10 or flatter.

TABLE 3.2 Horizontal Curve Adjustments K_{CZ} (Curve Correction Factor)

RADIUS (m)	DESIGN SPEED (km/h)					
	60	70	80	90	100	110
900	1.1	1.1	1.1	1.2	1.2	1.2
700	1.1	1.1	1.2	1.2	1.2	1.3
600	1.1	1.2	1.2	1.2	1.3	1.4
500	1.1	1.2	1.2	1.3	1.3	1.4
450	1.2	1.2	1.3	1.3	1.4	1.5
400	1.2	1.2	1.3	1.3	1.4	
350	1.2	1.2	1.3	1.4	1.5	
300	1.2	1.3	1.4	1.5	1.5	
250	1.3	1.3	1.4	1.5		
200	1.3	1.4	1.5			
150	1.4	1.5				
100	1.5					

$CZ_c = (L_c)(K_{cz})$.

Where: CZ_c = clear zone on outside of curvature, meter
L_c = clear zone distance, meter. Figure 3.1 or Table 3.1
K_{cz} = curve correction factor

Note: Clear zone correction factor is applied to outside of curves only. Curves flatter than 900 m do not require an adjusted clear zone.

FIGURE 3.2 Preferred Cross Slope Design. Slopes in the vicinity of the approach roadway have been flattened and the drainage pipe has been located as far from the main roadway as practicable to minimize its obstacles. Since a vehicle might be led into the culvert by the channel, safety would be further enhanced by eliminating the inlet headwall. Safety treatment of the inlet may be particularly advantageous where it is impractical to locate the pipe farther from the main roadway.

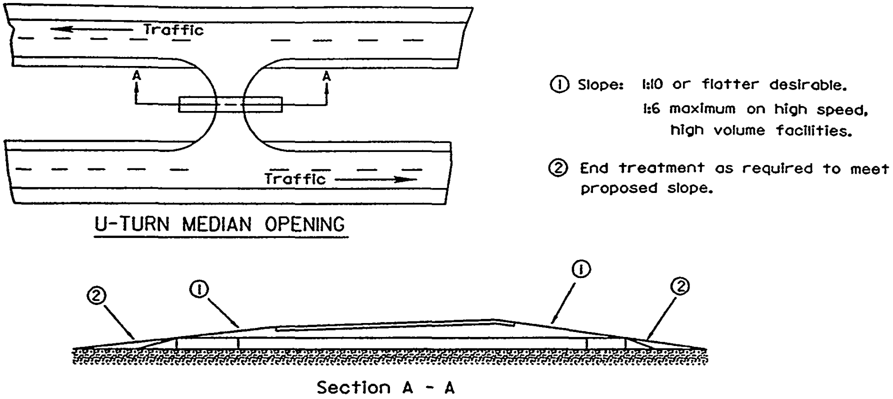


FIGURE 3.3 Median Cross Slope Design. Use of the flattest possible median cross slopes on high-speed highways, particularly within the appropriate clear zone area, can provide an improved roadside. Safety treatment of culverts as discussed in Section 3.4.3 may further enhance the improvement.

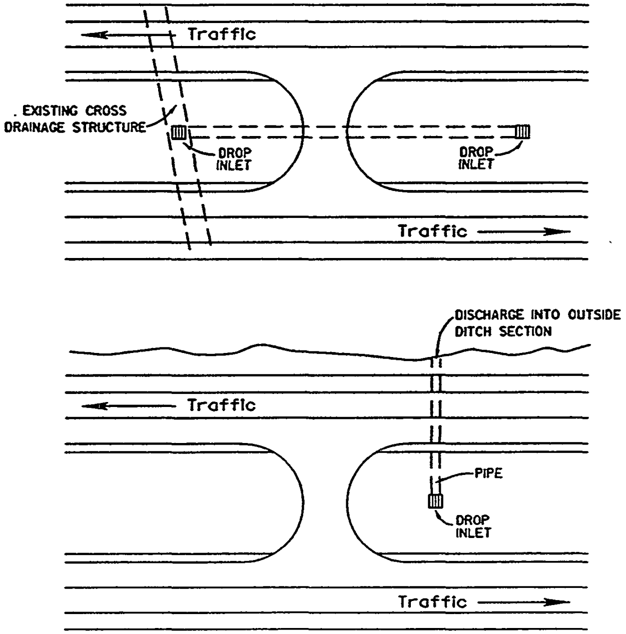


FIGURE 3.4 Examples of Alternate Median Drainage. These alternatives could be considered in lieu of a pipe underneath the median crossover.

3.2.3 Embankments (Backslopes)

When a highway is in a cut section, the backslope may be traversable depending upon its relative smoothness and the presence of fixed obstacles. If the slope between the roadway and the base of the backslope is traversable (1:3 or flatter) and the backslope is obstacle-free, it may not be a significant obstacle, regardless of its distance from the roadway. On the other hand, a steep, rough-sided rock cut should normally begin outside the clear zone or be shielded. A rock cut is normally considered to be rough-sided when the face will cause excessive vehicle snagging rather than provide relatively smooth redirection. Warrants for the use of a roadside barrier in conjunction with cut slopes are included in Chapter 5.

3.2.4 Roadside Channels

A roadside channel is defined as an open channel usually paralleling the highway embankment and within the limits of the highway right-of-way. The primary function of roadside channels is to collect surface runoff from the highway and areas which drain to the right-of-way and convey the accumulated runoff to acceptable outlet points. Channels must be designed to carry the design runoff and to accommodate excessive storm water flows with minimal highway flooding or damage. However, channels should also be designed, built, and maintained with consideration given to their effect on the roadside environment. Figures 3.5 and 3.6 present preferred foreslopes and backslopes for basic ditch configurations. Cross sections which fall in the shaded region of each of the figures are considered to have traversable cross sections. Channel sections which fall outside the shaded region are considered less desirable and their use should be limited where high-angle encroachments can be expected, such as the outside of relatively sharp curves. Channel sections outside the shaded region may be acceptable for projects having one or more of the following characteristics: restrictive right-of-way; rugged terrain; resurfacing, restoration, or rehabilitation (RRR) construction projects; or on low-volume or low-speed roads and streets, particularly if the channel bottom and backslopes are free of any fixed objects.

If practical, roadside channels with cross sections outside the shaded regions and located in vulnerable areas may be reshaped and converted to a closed system (culvert or pipe), or in some cases, shielded by a traffic barrier. Warrants for the use of roadside barrier to shield non-traversable channels within the clear zone are included in Chapter 5.

3.3 APPLICATION OF THE CLEAR ZONE CONCEPT

A basic understanding of the clear zone concept is critical to its proper application. The numbers obtained from Figure 3.1 or Table 3.1 imply a degree of accuracy that does not exist. Again, the curves are based on limited empirical data which was then extrapolated to provide data for a wide range of conditions. Thus, the numbers obtained from these curves represent a reasonable measure of the degree of safety suggested for a particular roadside; but they are neither absolute nor precise. In some cases, it is reasonable to leave a fixed object within the clear zone; in other instances, an object beyond the clear zone distance may require removal or shielding. Use of an appropriate clear zone distance amounts to a compromise between maximum safety and minimum construction costs. Appropriate application of the clear zone concept will often result in more than one possible solution. The following sections are intended to illustrate the process that may be used to determine if a fixed object or non-traversable terrain feature warrants relocation, modification, removal, shielding, or no treatment.

3.3.1 Recoverable Parallel Slopes

The clear zone distance for recoverable slopes of 1:4 or flatter may be obtained directly from Figure 3.1 or Table 3.1. However, these numbers are neither absolute nor precise. On new construction or major reconstruction, smooth slopes with no significant discontinuities and with no protruding fixed objects are desirable from a safety standpoint. It is desirable to have the top of the slope rounded so an encroaching vehicle remains in contact with the ground. It is also desirable for the toe of the slope to be rounded to make it essentially traversable by an errant vehicle. Designing smooth cross slopes is normally accomplished by using standard or typical cross sections. The flatter the selected slope, the easier it is to mow or otherwise maintain, and the safer it becomes to negotiate.

The guidelines in this chapter may be most applicable to new construction or major reconstruction. On resurfacing, rehabilitation, or restoration (RRR) projects, the primary emphasis is placed on the roadway itself. The actual performance of an existing facility may be measurable through an evaluation of accident records and on-site inspections as part of the design effort or in response to complaints by citizens or officials. Consequently, it may not be cost- effective or practical because of environmental impacts or limited right-of-way to bring a RRR project into full compliance with all of the clear zone recommendations provided in this guide. Because of the scope of such projects and the limited funding available, emphasis

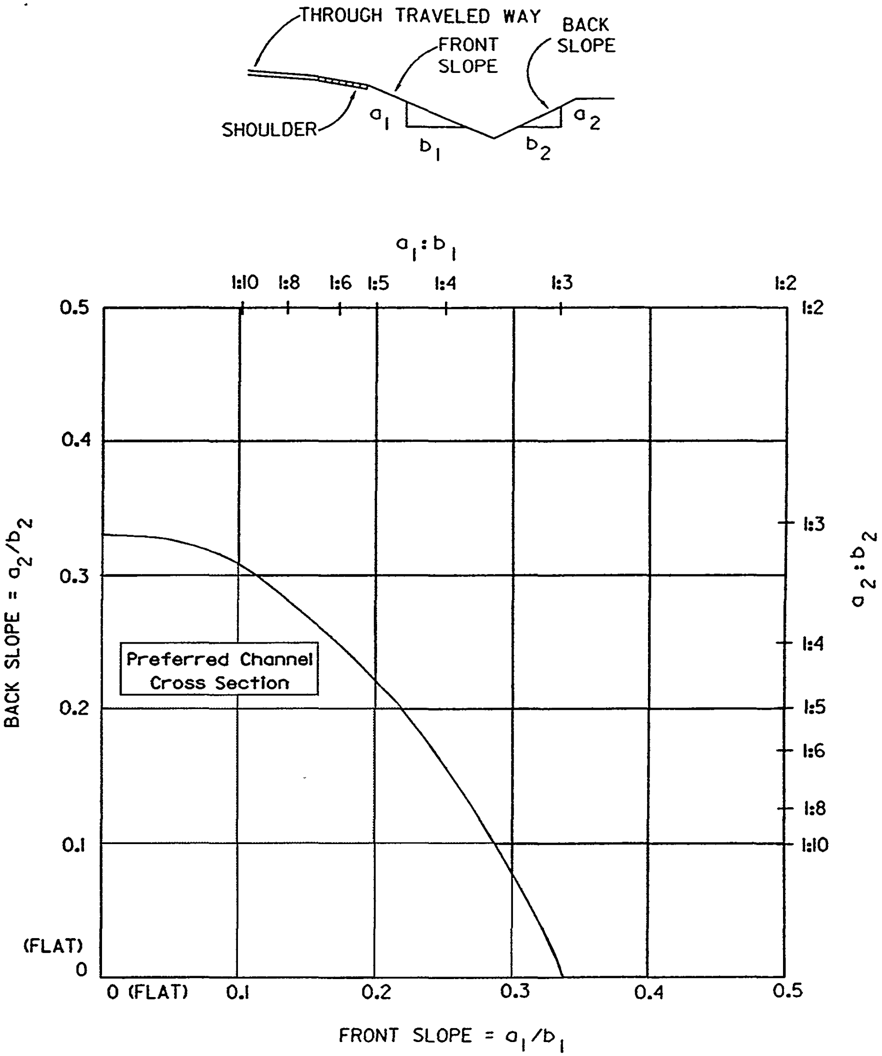


FIGURE 3.5 Preferred Cross Sections for Channels with Abrupt Slope Changes. This chart is applicable to all Vee ditches, rounded channels with a bottom width less than 2.4 meters and trapezoidal channels with bottom widths less than 1.2 meters.

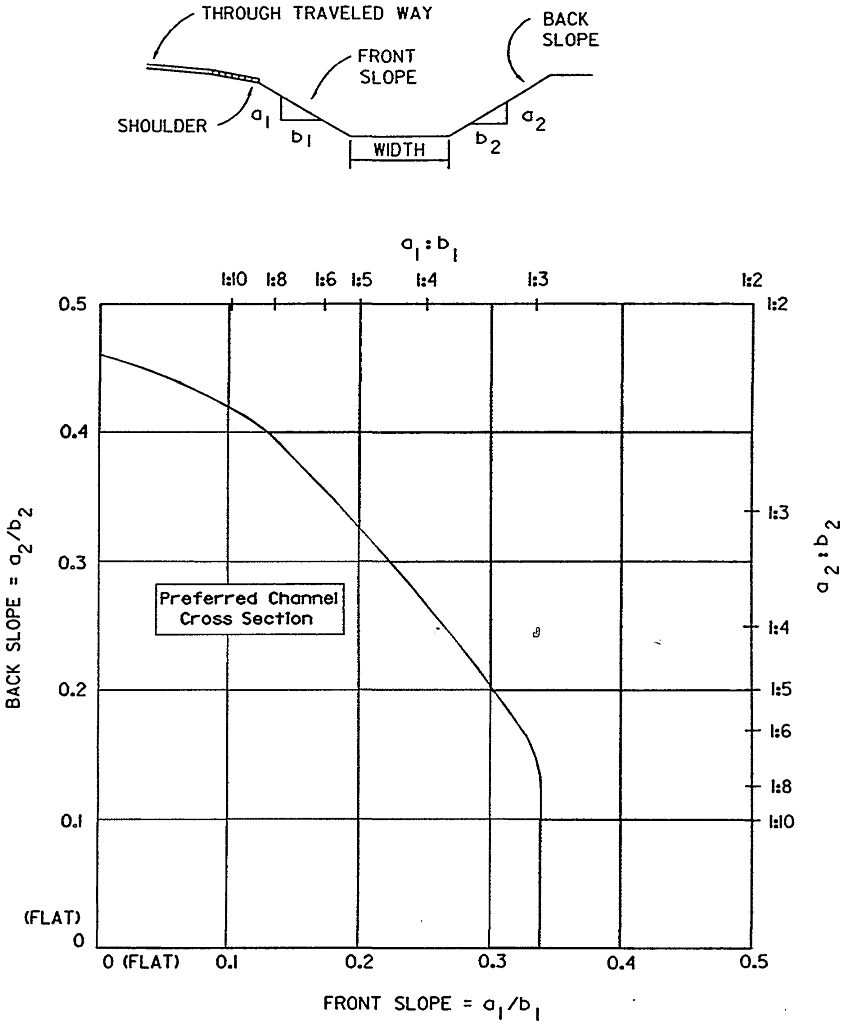


FIGURE 3.6 Preferred Cross Section for Channels with Gradual Slope Changes. This chart is applicable to rounded channels with bottom widths of 2.4 meters or more and to trapezoidal channels with bottom widths equal to or greater than 1.2 meters.

should be placed on correcting or protecting areas within the project that have identifiable safety problems related to clear zone widths. Bodies of water and escarpments are the types of areas which may be considered for special emphasis. The examples on the following pages illustrate the application of the clear zone concept to recoverable parallel slopes.

3.3.2 Non-Recoverable Parallel Slope

Embankment slopes from 1:3 up to 1:4 are considered traversable if they are smooth and free of fixed objects. However, since many vehicles on slopes this steep will continue on to the bottom, a clear runout area beyond the toe of the non-recoverable slope is desirable. The extent of this clear runout area could be determined by first finding the available distance between the edge of the traveled way and the breakpoint of the recoverable slope to the non-recoverable slope. This distance is then subtracted from the recommended clear zone distance based on the steepest recoverable slope before or after the non-recoverable slope. The result is the desirable clear runout area that should be provided beyond the non-recoverable slope if practical. The clear runout area may be reduced in width based on existing conditions or site investigation. Such a variable sloped typical section is often used as a compromise between roadside safety and economics. By providing a relatively flat recovery area immediately adjacent to the roadway, most errant motorists can recover before reaching the steeper slope beyond. The slope break may be liberally rounded so an encroaching vehicle does not become airborne. It is suggested that the steeper slope be made as smooth as practical and rounded at the bottom. Figure 3.7 illustrates a recoverable slope followed by a non-recoverable slope. Example C demonstrates the method for calculating the desirable runout area.

3.3.3 Critical Parallel Slopes

Critical embankment slopes are those steeper than 1:3. They will cause most vehicles to overturn and should be treated if they begin within the clear zone distance for a particular highway and meet the warrants for shielding contained in Chapter 5. Examples C, D, and E illustrate the application of the clear zone concept to critical slopes.

3.3.4 Examples of Clear Zone Application on Variable Slopes

A variable fill slope is often specified on new construction to provide a relatively flat recovery area immediately adjacent to the roadway followed by a steeper side slope. This design requires less right-of-way and embankment material than a continuous relatively flat slope and is commonly called a "barn roof" section. If an adequate recovery area (as determined from Figure 3.1 or Table 3.1) exists on the flatter slope, the steeper slope may be critical or non-traversable. Clear zone distances for embankments with variable side slopes ranging from essentially flat to 1:4 may be averaged to produce a composite clear zone distance. Slopes which change from negative to positive cannot be averaged and should be treated as roadside channel sections and analyzed for traversability using Figure 3.5 or 3.6.

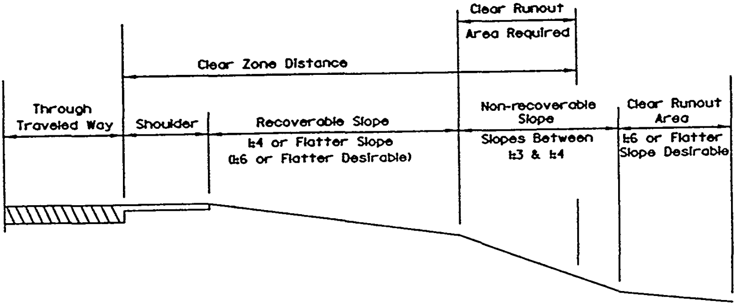
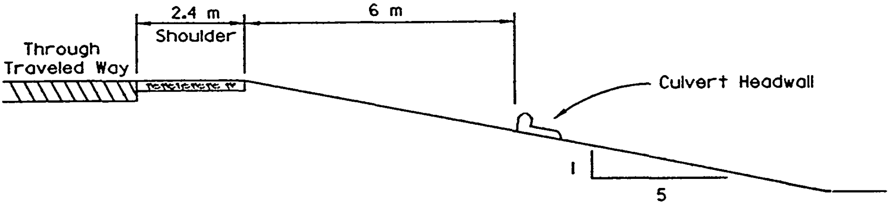


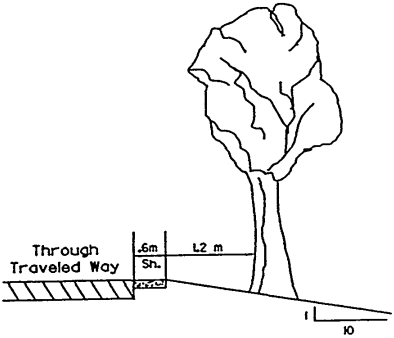
FIGURE 3.7 Example of a Parallel Embankment Slope Design

EXAMPLE A
Design ADT: 4000
Design Speed: 100 km/h
Recommended clear zone distance for 1:5 slope: 10-12 meters (from Table 3.1)



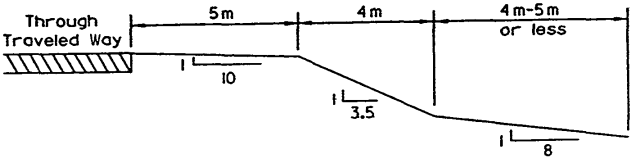
Discussion: The available recovery area of 8.4 meters is less than the recommended 10-12 meters. If the culvert headwall is the only obstruction on an otherwise traversable slope, it should be removed and the inlet modified to match the 1:5 slope. If the slope contains rough rock outcroppings or boulders and the headwall does not significantly increase the hazard to a motorist, the decision to do nothing may be appropriate. A review of the highway's accident history, if available, may be made to determine the nature and extent of vehicle encroachments and to identify any specific locations that may require special treatment.

EXAMPLE B
Design ADT: 300
Design Speed: 60 km/h
Recommended clear zone distance for 1:10 slope: 2-3 meters (from Table 3.1)



Discussion: The available clear zone distance is 1.8 meters, 0.2 to 1.2 meters less than the recommended recovery area. When an area has a significant number of run-off-the-road accidents, it may be appropriate to consider shielding or removing the entire row of trees within the accident area. If this section of road has no significant accident history and is heavily forested with most of the other trees only slightly farther from the road, this tree would probably not require treatment. If, however, none of the other trees are closer to the roadway than, for example, 4.5 meters, this individual tree represents a more significant hazard and should be considered for removal. If a tree were 4.5 meters from the edge of the traveled way, and all or most of the other trees were 7.5 meters or more, its removal might still be appropriate. This example emphasizes that the clear zone distance is an approximate number at best and that individual objects should be analyzed in relation to other nearby obstacles.

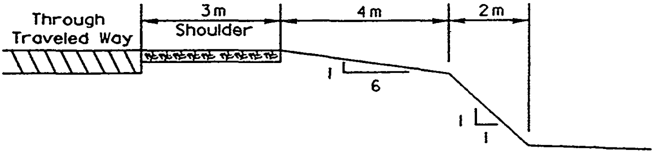
EXAMPLE C
Design ADT: 7000
Design Speed: 100 km/h
Recommended clear zone distance for 1:10 slope: 9-10 meters (from Table 3.1)
Recommended clear zone distance for 1:8 slope: 9-10 meters (from Table 3.1)
Available recovery distance before breakpoint of non-recoverable slope: 5 meters
Clear runout area at toe of slope: 9-10 meters minus 5 meters or 4-5 meters



Discussion: Since the non-recoverable slope is within the required clear zone distance of the 1:10 slope, a runout area beyond the toe of the non-recoverable slope is desirable. Using the steepest recoverable slope before or after the non-recoverable slope, a clear zone distance is selected from Figure 3.1 or Table 3.1. In this example, the 1:8 slope beyond the base of the fill dictates a 9-10 meter clear zone distance. Since 5 meters are available at the top, an additional 4-5 meters could be provided at the bottom. All slope breaks may be rounded and no fixed objects would normally be built within the upper or lower portions of the clear zone or on the intervening slope.

The designer may find it safe and practical to provide less than the entire 4-5 meters at the toe of the non-recoverable slope. A smaller recovery area could be applicable based on the rounded slope breaks, the flatter 1:10 slope at the top, or past accident histories. A specific site investigation may be appropriate in determining an approximate runout area beyond the toe of the non-recoverable slope.

EXAMPLE D
Design ADT: 12,000
Design Speed: 110 km/h
Recommended clear zone distance for 1:6 slope: 9-10.5 meters (from Table 3.1)



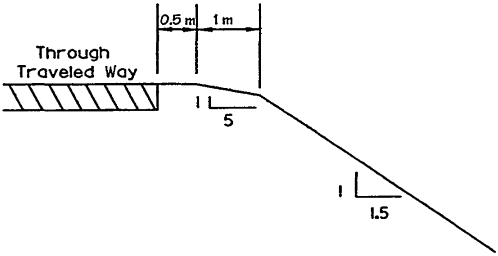
Discussion: Since the critical slope is only 7 meters from the traveled way, instead of the suggested 9-10.5 meters, it should be flattened if practical or considered for shielding. However, if this is an isolated obstacle and the roadway has no significant accident history, it may be appropriate to do little more than delineate the dropoff in lieu of slope flattening or shielding.

Although a "weighted" average of the slopes may be used, a simple average of the clear zone distances for each slope is accurate enough if the variable slopes are approximately the same width. If one slope is significantly wider, the clear zone computation based on that slope alone may be used.

3.3.5 Clear Zone Applications for Roadside Channels and Backslopes

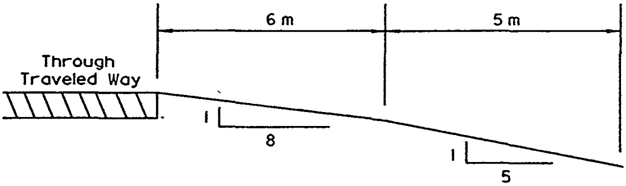
Roadside channel cross sections that are considered preferable in Figures 3.5 or 3.6 are not obstacles and need not

EXAMPLE E
Design ADT: 350
Design Speed: 60 km/h
Recommended clear zone distance for 1:5 slope: 2-3 meters (from Table 3.1)



Discussion: The available 1.5 meters is 0.5 to 1.5 meters less than the recommended recovery area. If much of this roadway has a similar cross section and no significant run-off-the-road accident history, neither slope flattening nor a traffic barrier would be recommended. On the other hand, even if the 1:5 slope was 3 meters wide and the clear zone requirement was met, a traffic barrier might be appropriate if this location had noticeably less recovery area than the rest of the roadway and the embankment was unusually high.

EXAMPLE F
Design ADT: 5000
Design Speed: 100 km/h
Recommended clear zone distance for 1:8 slope: 8-9 meters (from Table 3.1)
Recommended clear zone distance for 1:5 slope: 10-12 meters (from Table 3.1)



Discussion: The 1:8 slope and the 1:5 slope may be averaged taking into account the distance available on each slope. The distance (6 meters) along the 1:8 slope is multiplied by the reciprocal of the slope or 1/8. The distance (5 meters) along the 1:5 slope is multiplied by the reciprocal of the slope or 1/5. The resulting distances are added together and divided into the sum of the two distances (6 meters plus 5 meters) available. The result is an "average" slope which may be used in Figure 3.1 or Table 3.1. For sections flatter than or equal to 1:10, a slope of 1:10 is used. Decimal results of .5 or greater may be rounded up to the next even numbered slope while decimal results less than .5 may be rounded down to the next even numbered slope. The calculations are given below:

1. 6 meters x (1/8) + 5 meters x (1/5) = 1.75 meters
2. 6 meters + 5 meters = 11 meters
3. 11 meters/1.75 meters = 6.3 (rounded to 6)
4. Enter Table 3.1 for the 1:6 or flatter slopes
5. The clear zone distance from Table 3.1 is 9-10 meters for the given speed and traffic volume. Since the example has 11 meters available on the two slopes, it is acceptable without further treatment.

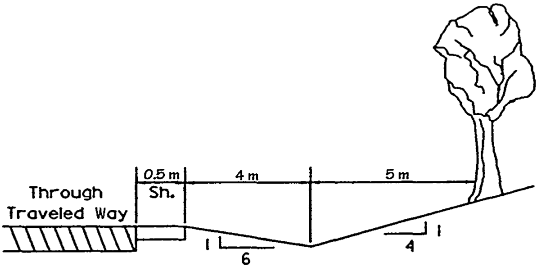
In this example, it would be desirable to have no fixed objects constructed on any part of the 1:5 slope. Natural obstacles such as trees or boulders at the toe of the slope would not be shielded or removed. However, if the final slope were steeper than 1:4, a clear runout area should be considered at the toe of the slope. The designer may choose to limit the clear zone distance to 9 meters if that distance is consistent with the rest of the roadway template; an accident analysis or site investigation does not indicate a potential run-off-the-road problem in this area; and the distance selected does not end at the toe of the non-recoverable slope.

be constructed at or beyond the clear zone distance for a specific roadway. It is important that roadside hardware not be located in or near ditch bottoms or on the backslope near the roadside channel. Any vehicle leaving the roadway may be funnelled along the roadside channel bottom or encroach to some extent on the backslope, thus making an impact more likely. Breakaway hardware may not function as designed if the vehicle is airborne or sliding sideways when contact is made. Non-yielding fixed objects should be located beyond the clear zone distance for these cross sections as determined from Figure 3.1 or Table 3.1.

3.4 DRAINAGE FEATURES

Effective drainage is one of the most critical elements in the design of a highway or street. However, drainage features should be designed and built with consideration given to their consequences on the roadside environment. In addition to roadside channels, which were addressed in Section 3.2.4, curbs, parallel and transverse pipes and culverts, and drop inlets are common drainage system elements that should be designed, constructed, and maintained with both hydraulic efficiency and roadside safety in mind.

EXAMPLE G
Design ADT: 1400
Design Speed: 100 km/h
Recommended clear zone distance for 1:6 slope (fill): 6-7.5 meters (from Table 3.1)
Recommended clear zone distance for 1:4 slope (cut): 5-5.5 meters (from Table 3.1)



Discussion: For channels within the preferred cross-section area of Figures 3.6 or 3.7, the clear zone may be determined from Figure 3.1 or Table 3.1. However, when the recommended clear zone exceeds the available clear zone for the front slope, an adjusted clear zone may be determined as follows:

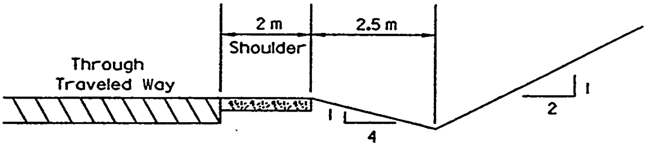
1. Calculate the percentage of the recommended clear zone range available from the edge of traveled way to the PVI of the slope (4.5/6 x 100 = 75% and 4.5/7.5 x 100 = 60%).
2. Subtract these percentages from 100% and multiply results by the recommended range of clear zones for the back slope (100-75% x 5 = 1.25 m and 100-60% x 5.5 = 2.2 m). The range of required clear zone on the back slope is 1.25 - 2.2 meters.
3. Add the available clear zone on the front slope to the range of values determined in Step 2 (4.5 + 1.25 = 5.75 m and 4.5 + 2.2 = 6.7 m). The adjusted clear zone range is 5.75 - 6.7 meters.

Since the tree is located beyond the adjusted clear zone, removal is not required. Removal should be considered if this one obstacle is the only fixed object this close to the traveled way along a significant length.

To determine the recommended clear zone for the front slope in a trapezoidal channel, an average front slope must be calculated. See Example F for the method of slope averaging.

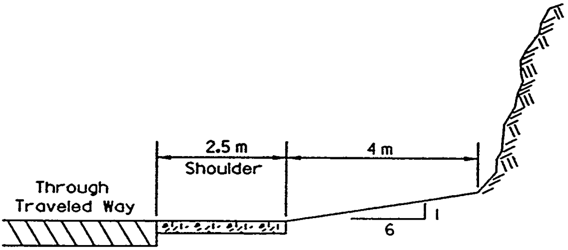
Non-preferred channels desirably should be located at or beyond the clear zone. However, backslopes steeper than 1:3 are typically located closer to the roadway. If these slopes are relatively smooth and unobstructed, they present little safety problem to an errant motorist. If the backslope consists of a rough rock cut or outcropping, shielding may be warranted as discussed in Chapter 5.

EXAMPLE H
Design ADT: 800
Design Speed: 80 km/h
Recommended clear zone distance for 1:4 slope: 5-6 meters (from Table 3.1)



Discussion: The channel is not within the preferred cross-section area of Figure 3.6 and is one-half to one and one-half meters less than the recommended clear zone distance. However, if the channel bottom and backslope are free of obstacles, no additional improvement is suggested. A similar cross section on the outside of a curve where encroachments are more likely and the angle of impact is sharper would probably be flattened if practical.

EXAMPLE I
Design ADT: 3000
Design Speed: 100 km/h
Recommended clear zone distance for 1:6 slope: 7.5-8 meters (from Table 3.1)



Discussion: The rock cut is within the given clear zone distance but would probably not warrant removal or shielding unless the potential for snagging, pocketing, or overturning a vehicle is high. Steep backslopes are clearly visible to motorists during the day, thus lessening the risk of encroachments. Roadside delineation of sharper than average curves through cut sections can be an effective countermeasure at locations having a significant accident history or potential.

In general, the following options, listed in order of preference, are applicable to all drainage features:

- Eliminate non-essential drainage structures.
- Design or modify drainage structures so they are traversable or present a minimal hazard to an errant vehicle.
- If a major drainage feature cannot effectively be redesigned or relocated, it should be shielded by a suitable traffic barrier if it is in a vulnerable location.

The remaining sections of this chapter identify the safety problems associated with curbs, pipes and culverts, and drop inlets and offer recommendations concerning the location and design of these features to improve their safety characteristics without adversely affecting their hydraulic capabilities. The information presented applies to all roadway types and projects. However, as with many engineering applications, the specific actions taken at a given location oftentimes rely heavily on the exercise of good engineering judgement and on a case-by-case assessment of the costs and benefits associated with alternative designs.

3.4.1 Curbs

Curbs are commonly used for drainage control, pavement edge support and delineation, right-of-way reduction, aesthetics, sidewalk separation, and reduction of maintenance operations. They are generally classified as barrier curbs or mountable curbs. Barrier curbs are relatively high and are intended to discourage motorists from deliberately leaving the roadway. The face of barrier curbs are 150 mm or higher and are nearly vertical. Mountable curbs are 150 mm or less in height and may have flatter, sloping faces that can be readily traversed. The designer may prefer a height for mountable curbs of 100 mm or less because higher curbs may drag the underside of some vehicles.

In general, neither barrier nor mountable curbs are desirable for use on high-speed roadways. If a vehicle is spinning or slipping sideways upon impact, either type of curb could cause it to trip and overturn. Under other impact conditions, a vehicle may become airborne which may result in loss of control by the motorist. The distance a vehicle travels and the height above and below normal bumper height which it attains become critical if secondary collisions occur with traffic barriers or other roadside appurtenances. In urban conditions, a minimum horizontal clearance of 0.5 m should be provided beyond the face of curbs to obstructions. The designer may reference NCHRP Report 150, *Effect of Curb Geometry and Location on Vehicle Behavior*, for additional data.

On high-speed roadways, curbs may not be desirable for use in front of traffic barriers because they can result in unpredictable post-impact trajectories. If a curb must be used, it should ideally be located flush with the face of the railing or behind it. Curb/barrier combinations, particularly for bridge railings, should be crash tested if extensive use of the combination exists or is planned and a similar combination has not been previously tested. Further guidelines concerning the use of curbs with traffic barriers is included in Chapter 5, Section 5.6.2, Terrain Effects. Chapter IV of the current AASHTO publication *A Policy on Geometric Design of Highway and Streets* contains additional information on the uses and types of curbs and on their placement.

3.4.2 Cross-Drainage Structures

Cross-drainage structures are designed to carry water underneath the roadway embankment and vary in size from 450-mm concrete or corrugated metal pipes to multibarreled concrete box culverts or structural plate pipes with clear spans of 3 meters or more. Typically, their inlets and outlets consist of concrete headwalls and wingwalls for the larger structures and bevelled-end sections for the smaller pipes. While these types of designs are hydraulically efficient and minimize erosion problems, they may represent an obstacle to motorists who run off the road. This type of design may result in either a fixed object protruding above an otherwise traversable embankment or an opening into which a vehicle can drop, causing an abrupt stop. The options available to a design engineer to minimize these obstacles are:

- Use a traversable design.
- Extend the structure so it is less likely to be hit.
- Shield the structure.
- Delineate the structure if the above alternatives are not appropriate.

Each of these options are discussed in the next three subsections.

3.4.2.1 Traversable Designs

A roadside designed with optimal safety features could be defined as one that is almost flat, completely traversable from the edge of the traveled way to the right-of-way line, and would include sufficient area for all desirable clear zone distance requirements. Such a facility would resemble a landing strip or runway at an airport. Thus, it is readily apparent from the start that roadside design must be a series of compromises between "absolute" safety and engineering, environmental, and economic constraints. The design engineer should strive for embankments as smooth or traversable as practical for a given facility. As indicated in Sections 3.1 and 3.2, traversable, non-recoverable slopes may be rounded at top and bottom and may provide a relatively flat runout area at the bottom.

If a slope is generally traversable, the preferred treatment for any cross-drainage structure is to extend (or shorten) it to intercept the roadway embankment and to match the inlet or outlet slope to the embankment slope. For small culverts, no other treatment is required. For cross-drainage structures, a small pipe culvert is defined as a single round pipe with a 1000-mm or less diameter or multiple round pipes each with a 750-mm or less diameter. Extending or shortening culverts to locate the inlets/outlets a fixed distance from the traveled way is not recommended if such treatment introduces discontinuities in an otherwise traversable slope. Matching the inlet to the slope results in an extremely small "target" to hit, reduces erosion problems, and simplifies mowing operations. Extending or shortening the pipe results in warping the sideslopes in or out to match the opening and produces a significantly longer area that affects the driver who has run off the road.

Single structures and end treatments wider than 1 meter can be made traversable for passenger size vehicles by using bar grates or pipes to reduce the clear opening width. Modifications to the culvert ends to make them traversable must not decrease the hydraulic capacity of the culvert. Safety treatments must be hydraulically efficient. In order to maintain hydraulic efficiency, it may be necessary to apply bar grates to flared wingwalls, flared end sections, or to culvert extensions that are larger in size than the main barrel. The designer should consider shielding the structure if significant hydraulic capacity or clogging problems could result.

Full-scale crash tests have shown that automobiles can cross grated-culvert end sections on slopes as steep as 1: 3 at speeds as low as 30 km per hour and as high as 100 km per hour, when steel pipes spaced on 750-mm centers are used for these cross-drainage structures. This spacing does not significantly change the flow capacity of a pipe unless debris accumulates and causes partial clogging of the inlet. This underscores the importance of accurately assessing the clogging potential of a structure during design and the importance of keeping the inlets free of debris. Figure 3.8 shows recommended sizes to support a full-sized automobile and is based on a 750-mm bar spacing. It is important to note the toe of the embankment slope and the ditch or stream bed area immediately adjacent to the culvert must be more or less traversable if the use of a grate is to have any significant safety benefits. Normally, grading within the right-of-way limits can produce a satisfactory runout path.

For median drainage where flood debris is not a concern and where mowing operations are frequently required, much smaller openings between bars may be tolerated and grates similar to those commonly used for drop inlets may be appropriate. It should also be noted that both the hydraulic efficiency and the roadside environment may be improved by making the culverts continuous and adding a median drainage inlet. This alternative eliminates two end treatments and is usually a practical design when neither median width nor height of fill are excessive. Figure 3.9 shows a median drainage inlet design that can be used where cover is insufficient to construct a drop inlet directly over the cross-drainage pipe.

3.4.2.2 Extension of Structure

For intermediate sized pipes and culverts whose inlets and outlets cannot readily be made traversable, an option often exercised by the highway designer is to extend the structure so the obstacle is located at or just beyond the appropriate clear zone. While this practice reduces the likelihood of the pipe end being hit, it does not completely eliminate the possibility. As noted in Section 3.1, the clear zone distance should not be viewed as a discrete, exact distance, but as the center of a zone which should then be analyzed on a site specific basis.

If the extended culvert headwall remains the only significant man-made fixed object immediately at the edge of the clear zone along the section of roadway under design, and the roadside is generally traversable to the right-of-way line elsewhere, simply extending the culvert to the edge of the clear zone may not be the best alternative, particularly on freeways and other high-speed, access-controlled facilities. On the other hand, if the roadway has numerous fixed objects, both natural and man-made, at the edge of the clear zone, extending individual structures to the same minimum distance from traffic may be appropriate. However, redesigning the inlet/outlet so it is no longer an obstacle is usually the preferred safety treatment.

SPAN LENGTH (m)	INSIDE DIAMATER (mm)
up to 3.65	75 mm
3.65 - 4.90	87 mm
4.90 - 6.10	100 mm
6.10 or less with center support	75 mm

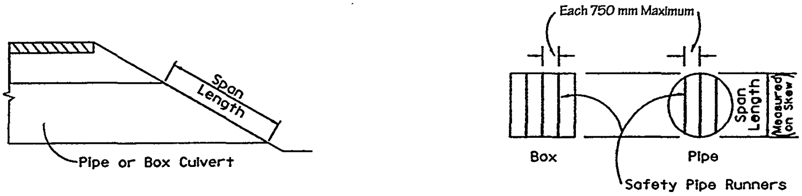


FIGURE 3.8 Design Criteria for Safety Treatment of Pipes and Culverts. The chart above shows recommended safety pipe runner sizes for various span lengths for cross-drainage structures. The safety pipe runners are Schedule 40 pipes spaced on centers of 750 mm or less.

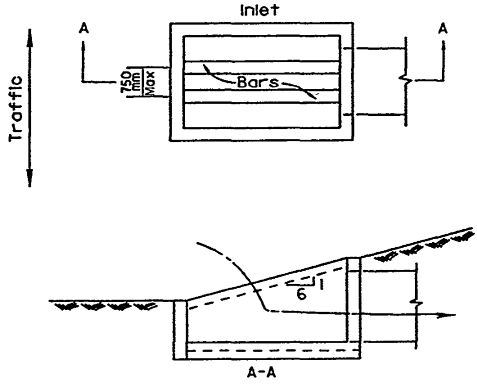


FIGURE 3.9 Drainage Design for Insufficient Cover

3.4.2.3 Shielding

For major drainage structures which are costly to extend and whose end sections cannot be made traversable, shielding with an appropriate traffic barrier is oftentimes the most effective safety treatment. Although the traffic barrier is longer and closer to the roadway than the structure opening and is likely to be hit more often than an unshielded culvert located further from the traveled way, a properly designed, installed, and maintained barrier system may provide an increased level of safety for the errant motorist.

3.4.3 Parallel Drainage Features

Parallel drainage culverts are those which are oriented parallel to the main flow of traffic. They are typically used under driveways, field entrances, access ramps, intersecting side roads, and median crossovers. Most such culverts are designed to carry relatively small flows until the water can be discharged into outfall channels or other drainage facilities and carried away from the roadbed. However, these drainage features can present a significant roadside obstacle because they can be struck head-on by impacting vehicles. As with cross-drainage structures, the designer's primary concern should be to design generally traversable slopes and to match the culvert openings with adjacent slopes. Section 3.2.2 recommended that embankment slopes that can be struck at 90 degrees by run-off-the-road vehicles be constructed as flat as practical, with 1:6 or flatter suggested for locations susceptible to high-speed impacts. On low-volume or low-speed roads, where accident history does not indicate a high number of run-off-the-road occurrences, steeper slopes may be considered as a cost-effective approach. Using these guidelines, safety treatment options are similar to those for cross-drainage structures:

- Eliminate the structure.
- Use a traversable design.
- Move the structure laterally to a less vulnerable location.
- Shield the structure.
- Delineate the structure if the above alternatives are not appropriate.

3.4.3.1 Eliminate the Structure

Unlike cross-drainage pipes and culverts which are essential for proper drainage and operation of a road or street, parallel pipes can sometimes be eliminated by constructing an overflow section on the field entrance, driveway, or intersecting side road. Care should be exercised in designing overflow structures to insure proper performance, particularly if several structures are closely spaced or water is subject to freezing on the overflow structures. This treatment will usually be appropriate only at low-volume locations where this design does not decrease the sight distance available to drivers entering the main road. Care must also be exercised to avoid erosion of the entrance and the area downstream of the crossing. This can usually be accomplished by paving the overflow section (assuming the rest of the facility is not paved) and by adding an upstream and downstream apron at locations where water velocities and soil conditions make erosion likely.

Closely spaced driveways with culverts in roadside channels are relatively common as development occurs along highways approaching urban areas. Since traffic speeds and roadway design elements are usually characteristic of rural highways, these culverts may constitute a significant roadside obstacle. In some locations such as along the outside of curves or where records indicate concentrations of run-off-the-road accidents, it may be desirable to convert the open channel into a storm drain and backfill the areas between adjacent driveways. This treatment will eliminate the ditch section as well as the transverse embankments with pipe inlets and outlets.

3.4.3.2 Traversable Designs

As emphasized earlier in this chapter, embankments should be designed with consideration given to their affect on the roadside environment. The designer should try to provide the flattest side slopes practical in each situation, particularly in areas where the embankment has shown a high probability of being struck head-on by a vehicle. Once this has been done, parallel drainage structures should match the selected sideslope and should be safety treated if possible when they are located in a vulnerable position relative to main road traffic. While many of these structures are small and present a minimal target, the addition of pipes and bars perpendicular to traffic can reduce wheel snagging in the culvert opening. Research has shown that, for parallel drainage structures, a grate consisting of pipes set on 600-mm centers will significantly reduce wheel snagging. It is recommended that the center of the bottom bar or pipe be set at 100 to 200 mm above the culvert invert.

Generally, single pipes with diameters of 600 mm or less will not require a grate. However, when a multiple pipe installation is involved, consideration of a grate for the smaller pipes may be appropriate. Reference may be made to Texas Transportation Institute Research Study 2-8-79-280, *Safe End Treatment for Roadside Culverts*, for additional information. Figure 3.10 illustrates a possible design for the inlet and outlet end of a parallel culvert. When channel grades permit, the inlet end may use a drop inlet type design to reduce the length of grate required.

The recommended grate design may significantly affect culvert capacity. However, since capacity is not normally the governing design criteria for parallel structures, hydraulic efficiency may not be an overriding concern. In those locations where headwater depth is critical, a larger pipe should be used or the parallel drainage structure may be positioned outside the clear zone as discussed in the following paragraph.

3.4.3.3 Relocate the Structure

Some parallel drainage structures can be moved laterally further from the traveled way. This treatment often affords

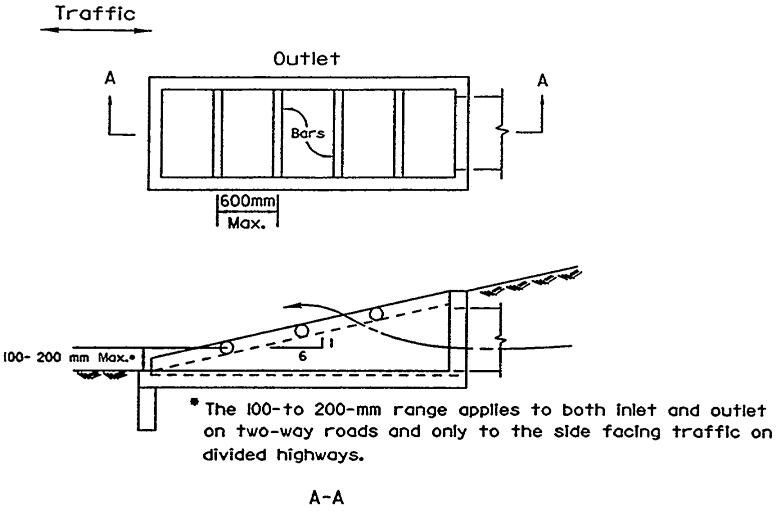


FIGURE 3.10 Inlet/Outlet Design Example for Parallel Drainage

the design engineer the opportunity to flatten the transverse embankment slope within the selected clear zone distance of the roadway under design. If the embankment at the new culvert locations is traversable and likely to be encroached upon by either main road or side road traffic, safety treatment should be considered. It is suggested that the inlet or outlet match the embankment slope regardless of whether or not additional safety treatment is deemed necessary. A suggested design treatment is shown in Figure 3.11.

3.4.3.4 Shielding

In cases where the embankment cannot be made traversable, the structure is too large to be safety treated effectively, and it cannot be relocated, it may be necessary to shield the obstacle with a traffic barrier. Specific information on the selection, location, and design of an appropriate barrier system is contained in Chapter 5.

3.4.4 Drop Inlets

Drop inlets can be classified as on-roadway or off-roadway structures. On-roadway inlets are usually located on or alongside the shoulder of a street or highway and are designed to intercept runoff from the road surface. These include curb opening inlets, grated inlets, slotted drain inlets, or combinations of these three basic designs. Since they are installed flush with the pavement surface, they do not constitute a significant safety problem to errant motorists. However, they must be selected and sized to accommodate design water runoff. In addition, they must be capable of supporting vehicle wheel loads and present no obstacle to pedestrians or bicyclists.

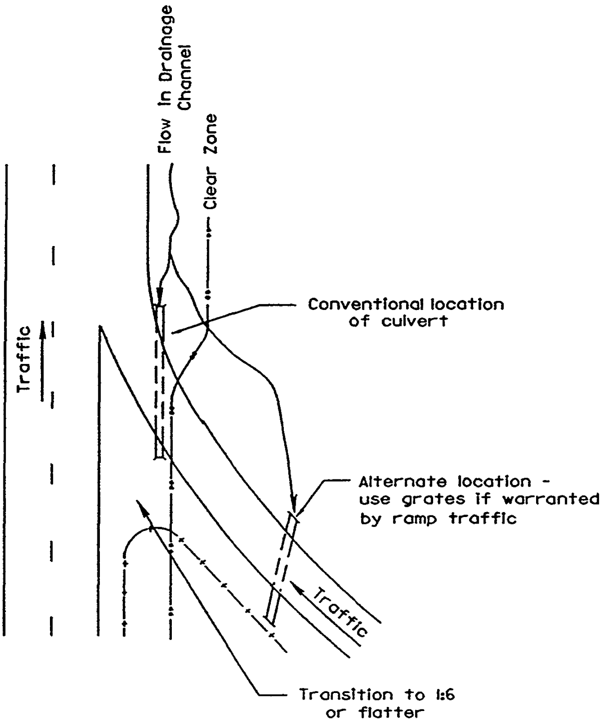


FIGURE 3.11 Alternate Location for a Parallel Drainage℃ulvert

Off-roadway drop inlets are used in medians of divided roadways and sometimes in roadside ditches. While their purpose is to collect runoff, they should be designed and located to present a minimal obstacle to errant motorists. This can be accomplished by building these features flush with the channel bottom or slope on which they are located. The design should not project high enough to cause significant vehicular snagging or instability within the clear zone. The opening should be treated to prevent a vehicle wheel from dropping into it; but unless pedestrians are a consideration, grates with openings as small as those used for pavement drainage are not necessary. Neither is it necessary to design for a smooth ride over the inlet. It is sufficient to prevent wheel snagging and the resultant sudden decelerations or loss of control associated with it.

CHAPTER 4: SIGN AND LUMINAIRE SUPPORTS AND SIMILAR ROADSIDE FEATURES

4.0 OVERVIEW

Although a traversable and unobstructed roadside is highly desirable from a safety standpoint, some appurtenances simply must be placed near the traveled way. Man-made fixed objects which frequently occupy highway rights-of-way include highway signs, roadway lighting, traffic signals, railroad warning devices, motorist-aid call boxes, mailboxes, and utility poles. Approximately 15 percent of all fixed object fatalities each year involve sign and lighting supports or utility poles. Although of a lesser order of magnitude, crashes into other roadside hardware frequently result in severe accidents as well. Finally, it must be recognized that approximately 3000 motorists a year are killed as a result of collisions with trees and other vegetation.

This chapter is not intended to provide technical design details. Virtually all highway agencies use standard drawings for their roadside sign installations and it is assumed that these drawings will comply with the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals.* Similarly, information on existing operational hardware is included only to the extent necessary to familiarize the designer with the types of breakaway devices available and with how each is intended to function.

The highway engineer is charged with providing the safest facility feasible, within given constraints. As noted in Chapter 1, there are generally five options from which to choose a safe design. In order of preference, these are:

(1) Remove the obstacle or redesign it so it can be traversed safely.
(2) Relocate the obstacle to a point where it is less likely to be struck.
(3) Reduce impact severity by using an appropriate breakaway device.
(4) Shield the obstacle with a longitudinal traffic barrier and/or crash cushion if it cannot be eliminated, relocated, or redesigned.
(5) Delineate the obstacle if the above alternatives are not appropriate.

While options one and two are the preferred choices, these solutions are not always possible, especially for highway signing and lighting which must remain near the roadway to serve its intended functions. This chapter deals primarily with option 3 — the use of breakaway hardware, which has become a cornerstone for the forgiving roadside concept since its inception in the mid-1960s. Emphasis is placed on the selection of the most appropriate device to use in a given location and on installing the support to ensure acceptable performance when it is hit. The final section of this chapter addresses the problems associated with trees and shrubs and provides the design engineer with some guidelines to follow on this oftentimes sensitive topic.

4.1 ACCEPTANCE CRITERIA FOR BREAKAWAY SUPPORTS

The term "breakaway support" refers to all types of sign, luminaire, and traffic signal supports that are designed to yield when hit by a vehicle. The release mechanism may be a slip plane, plastic hinges, fracture elements, or a combination of these. The criteria used to determine if a support is considered breakaway are found in the AASHTO *Standard Specifications for Structural Supports* *for Highway Signs, Luminaires, and Traffic Signals* and NCHRP Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. Basically, these criteria require that a breakaway support fail in a predictable manner when struck head-on by an 820-kg vehicle, or its equivalent, at speeds of 35 km/h and 100 km/h. It is desirable to limit the resultant occupant impact velocity to 3.0 m/s; but values as high as 5.0 m/s are considered acceptable. These specifications also establish a maximum stub height of 100 mm to lessen the possibility of snagging the undercarriage of a vehicle after a support has broken away from its base.

In addition to the change in velocity criterion, satisfactory breakaway support performance depends on the crash vehicle remaining upright during and after the impact with no significant deformation or intrusion of the passenger compartment. The appropriate procedures for acceptance testing of breakaway supports are described in NCHRP Report 350.

Full-scale crash tests, bogie tests, and pendulum tests are used in the acceptance testing of breakaway devices. In full-scale testing, an actual vehicle is accelerated to the test speed and impacted into the device being tested. The point of initial impact is the front of the vehicle, either centered or at the quarter point of the bumper. Full-scale tests produce the most accurate results; however, their main disadvantage is cost. Bogie vehicles are also used to test breakaway hardware. A bogie is a reusable, adjustable surrogate vehicle used to model actual vehicles. A nose, similar to a pendulum nose, is used to duplicate the crush characteristics of the vehicle being modeled. Bogie vehicles are designed to be used in the speed range of 35 to 100 km/h.

To reduce testing costs, pendulum tests are also used to evaluate breakaway hardware. Pendulum nose sections have been developed that model the fronts of vehicles. Pendulum tests have typically been used to test luminaire support hardware. However, due to the physical limitations of pendulums, pendulum testing is limited to 35-km/h impacts. In the past, 35-km/h test results were extrapolated to predict 100-km/h impact behavior.

4.2 DESIGN AND LOCATION CRITERIA FOR BREAKAWAY AND NON-BREAKAWAY SUPPORTS

Sign, luminaire, and similar posts must first be structurally adequate to support the device mounted on them and to resist ice and wind loads as outlined in Section 2 of the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*. Other concerns are that they be properly designed and carefully located to minimize the hazard they present to the traveling public. For example, sign supports should not be placed in drainage ditches where erosion and freezing might affect the proper operation of breakaway supports. It is also possible that a vehicle entering the ditch might be inadvertently guided into the support. Signs and supports that are not needed should be removed. If a sign is needed, then it should be located where it is least likely to be hit. Whenever possible, signs should be placed behind existing roadside barrier (beyond the design deflection distance), on existing structures, or in similar non-accessible areas. If this cannot be achieved, then breakaway supports should be used. Only when the use of breakaway supports is not practicable should a traffic barrier or crash cushion be used exclusively to shield sign supports.

As a general rule, breakaway supports should be considered in some urban and most rural areas or wherever vehicle speeds are moderate to high. An occupant striking the interior of a vehicle impacting a non-yielding object at only 40 km/h could sustain substantial injuries. However, in urban areas or other locations where pedestrians and bicyclists may be struck by falling breakaway hardware after a crash, yielding supports are typically not used. The designer must weigh the relative risks involved in these situations before selecting an appropriate design.

Supports placed on roadside slopes must not allow impacting vehicles to snag on either the foundation or any substantial remains of the support. Surrounding terrain must be graded to permit vehicles to pass over any non-breakaway portion of the sign installation which remains in the ground or rigidly attached to the foundation. Figure 4.1, adopted from the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals,* illustrates the method used to measure the required 100-mm maximum height.

Breakaway support mechanisms are designed to function properly when loaded primarily in shear. Most mechanisms are designed to be impacted at bumper height, typically about 500 mm above the ground. If impacted at a significantly higher point, the bending moment in the breakaway base may be sufficient to bind the mechanism, resulting in non-activation of the breakaway device. For this reason, it is critical that breakaway supports not be located near ditches or on steep slopes or at similar locations where a vehicle is likely to be partially airborne at the time of impact.

The type of soil may also affect the activation mechanisms of some breakaway supports. Fracture-type supports (i.e., high-carbon U-channel posts, telescoping tubes, wood supports, etc.) could push through loose or saturated soils, consuming energy and possibly adversely changing a post's fracture mechanism. Usually this is not a problem for a fracture-type support embedded less than 1 meter because the support will likely pull out of the soil, unless it has a special anchor plate designed to ensure the post

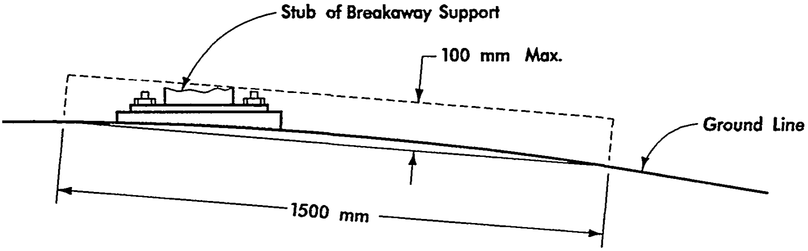


FIGURE 4.1 Breakaway Support Stub Height Measurement

does not pull out. However, for fracture-type supports with pull-out-resisting anchors or ones that are embedded more than one meter, or any other supports that might be sensitive to foundation movement, consideration should be given to qualifying them through crash testing in the "weak soil" described in the NCHRP Report 350 testing guidelines in addition to qualifying them through the "standard soil" crash tests called for in Report 350. As explained in the commentary to NCHRP Report 350:

> Weak soil should be used, in addition to the standard soil, for any feature whose impact performance is sensitive to soil-foundation or soil-structure interaction if identifiable areas of the state or local jurisdiction in which the feature will be installed contain soil with similar properties, and if there is a reasonable uncertainty regarding the performance of the feature in weak soil. Tests have shown that some base-bending or yielding small sign supports readily pull out of the weak soil upon impact. For features of this type, the strong soil is generally more critical and tests in the weak soil may not be necessary.

Special anchor plates or design details may also be used to accommodate expected wind loads. Since these design details could affect proper performance, it is recommended these designs also be tested in both soils. To effect a truly cost-effective program of breakaway sign supports, there are other items that need to be considered. Availability of a particular support will affect installation costs and replacement costs. Durability of the support will affect the expected life of a non-struck support. Also, there may be some supports that can be reused after being impacted by a vehicle and they may be more cost-effective even though the initial installed costs are high. Thus, the expected impact frequency and simplicity of maintenance may influence an agency's selection.

4.3 SIGN SUPPORTS

Roadway signs can be divided into three main categories: overhead signs, large roadside signs, and small roadside signs. The hardware and corresponding safety treatment of sign supports varies with the sign category.

4.3.1 Overhead Signs

Where possible, overhead signs should be installed on or relocated to nearby overpasses or other structures. Overhead signs, including cantilevered signs, generally require massive support systems which cannot be made breakaway. All overhead sign supports located within the clear zone must be shielded with a crashworthy barrier. If a barrier is used, or is required to shield the object, the sign bridge may be located just beyond the design deflection distance of the barrier to minimize the required span length.

4.3.2 Large Roadside Signs

Large roadside signs may be defined as those greater than 5 square meters in area. They typically have two or more support posts which are breakaway. The basic concept of the breakaway sign support is to provide a structure that will resist wind and ice loads, yet fail in a safe and predictable manner when struck by a vehicle. The loading conditions for which the support must be designed are shown in Figure 4.2. The desired impact performance is depicted in Figure 4.3. To achieve satisfactory breakaway performance, the following criteria should be met:

- The hinge should be at least 2100 mm above the ground so no portion of the sign or upper section of the support is likely to penetrate the windshield of an impacting vehicle.

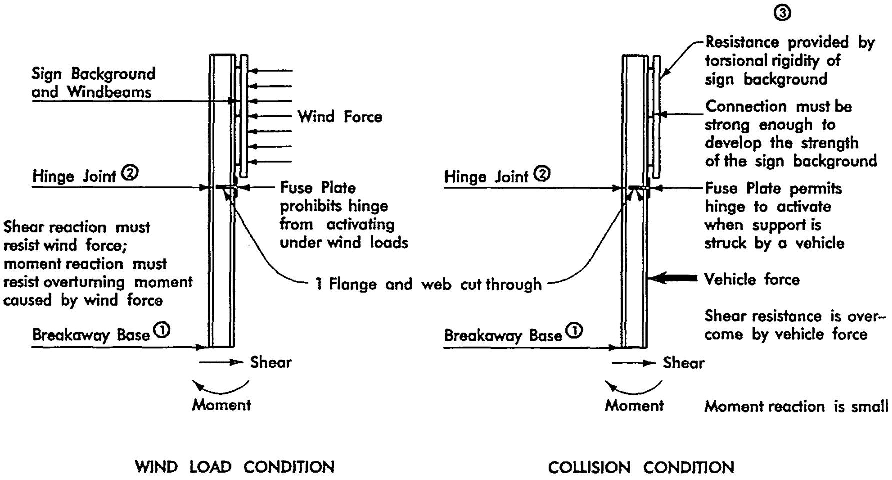


FIGURE 4.2 Wind and Impact Loads

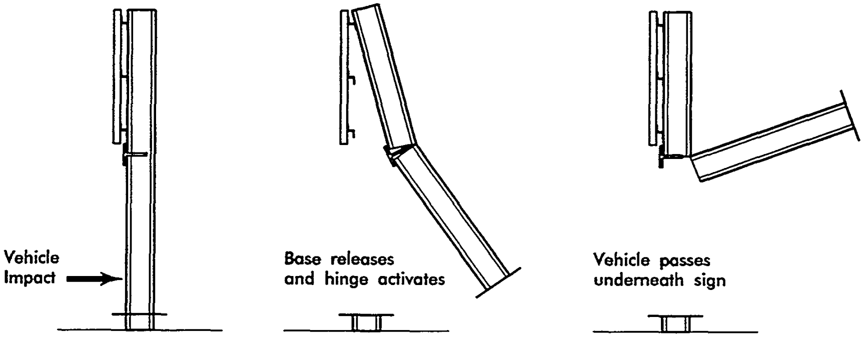


FIGURE 4.3 Impact Performance

- A single post, if 2.1 m or more from another post, should have a mass less than 65 kg/m and the total mass below the hinge, but above the shear plate of the breakaway base, should not exceed 270 kg. For two posts spaced less than 2.1 m apart, each post should have a mass less than 25 kg/m.
- No supplementary signs should be attached below the hinges if such placement is likely to interfere with the breakaway action of the support post or if the supplemental sign is likely to strike the windshield of an impacting vehicle.

The breakaway mechanisms of large roadside sign supports are either a fracture or a slip-base type. Fracture mechanisms consist of couplers or wood posts with reduced cross sections. Most couplers are considered to be multidirectional, i.e., they are expected to work satisfactorily when struck from any direction. Figure 4.4 shows one type of multidirectional coupler in common use.

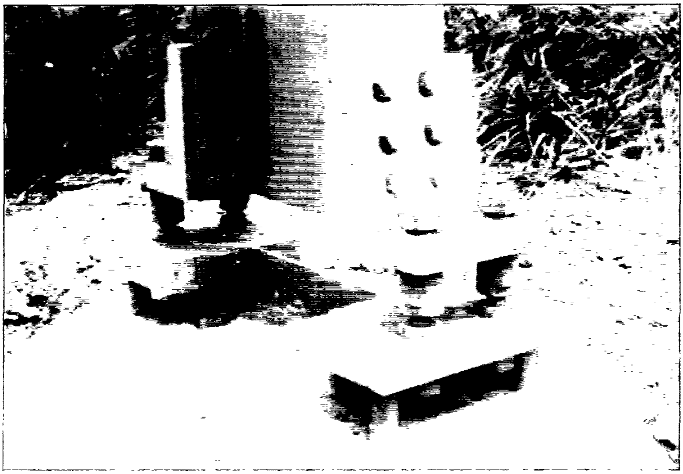


FIGURE 4.4 Multidirectional Coupler

Slip-base type mechanisms activate when two parallel plates slide apart as bolts are pushed out under impact. The designs may be either uni-directional or multidirectional. Horizontal slip bases using the four-bolt pattern shown in Figure 4.5 are uni-directional.

The upper hinge design for uni-directional impacts consists of a slotted fuse plate on the expected impact side and a saw cut through the web of the post to the rear flange. The rear flange then acts as a hinge when the post rotates upward. This commonly used design is shown in Figure

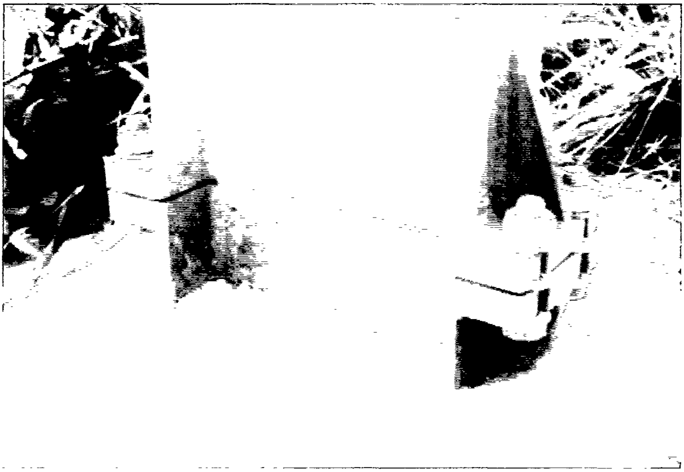


FIGURE 4.5 Typical Uni-Directional Slip Base

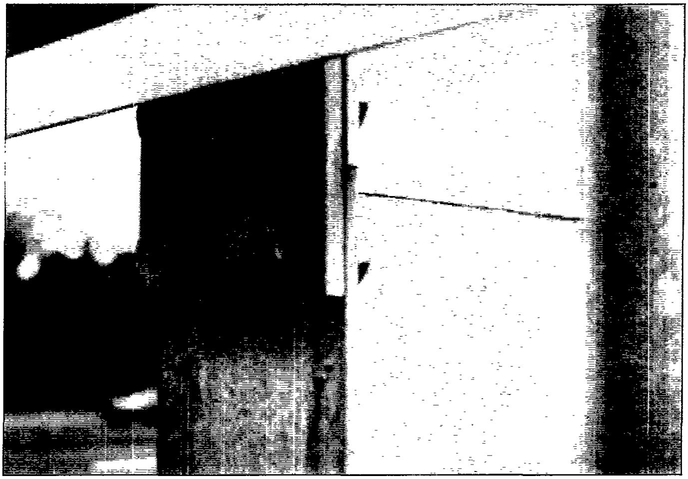


FIGURE 4.6 Slotted Fuse Plate Design

4.6. Slotted plates may be used on both sides of the post if impacts are expected from either direction.

Proper functioning of the slip base and fuse plate designs requires proper torque of the bolts. Bolt torque should be checked on a regular basis.

Designing for wind load is necessary for large signs and a check of the wind load designs on the fuse plates should also be made. A perforated steel fuse plate meeting the requirements of ASTM A36/A36M-94 has been shown to perform satisfactorily when used as the fuse plate on a steel post. Since this design does not require its connections to be torqued to a specific value, it is relatively fail-safe and recommended for use in lieu of slotted fuse plates. The perforated design is shown in Figure 4.7.

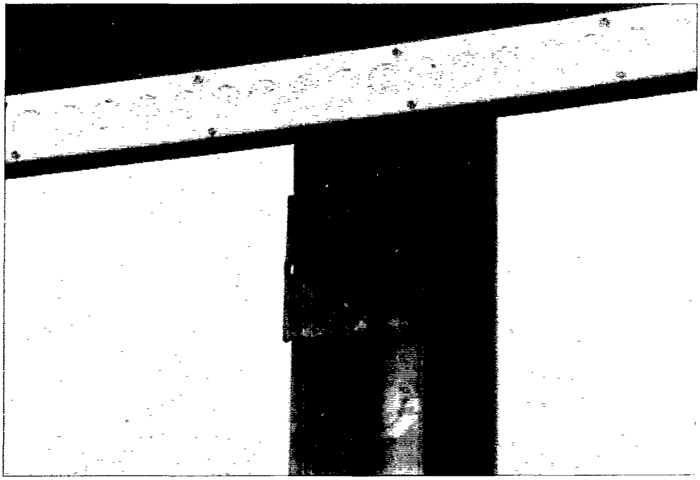


FIGURE 4.7 Perforated Fuse Plate Design

In some slow-speed tests, the fuse plates on large roadside sign supports have failed to activate and the support has pulled away from the sign panel. The change in vehicle speed has still been acceptable. However, fuse and hinge plates should not be deleted. While they are more likely to activate in a high-speed impact, they act as a backup safety feature in low-speed impacts.

Although the *Manual on Uniform Traffic Control Devices* (MUTCD) specifies the general location of large roadside signs, the highway design engineer has a significant degree of latitude in the exact placement of any given sign. Crash test results show that breakaway supports installed on level terrain will perform as intended when struck head-on by a vehicle. However, if these supports are installed on a slope or there is a possibility that a vehicle may be spinning or sliding on impact, the breakaway feature may not function as well as when it is installed on level terrain. Even if a sign is erected on breakaway supports, it can cause significant damage to an impacting vehicle and injuries to the vehicle occupants. Once hit, the sign becomes a maintenance problem. These are obvious reasons for locating all signs where they are least likely to be hit and, when feasible, outside of the clear zone, even if they are breakaway.

4.3.3 Small Roadside Signs

Small roadside signs may be defined as those supported on one or more posts and having a sign panel area of less than 5 square meters. Although not perceived as a significant obstruction, small signs can cause significant damage to impacting automobiles. Small sign supports are typically either driven directly into the soil, set in drilled holes, or mounted on a separately installed base. The breakaway mechanisms of small sign supports consist of either a base bending fracture or slip base design. The most commonly used small sign support hardware and the characteristics of each are described below.

Base bending or yielding sign supports typically consist of U-channel steel posts or standard steel pipe driven into the ground to a depth no greater than 1 meter. A steel plate measuring approximately 100 mm by 300 mm by 6 mm may be welded or bolted to the pipe support to prevent the sign from twisting from wind loads. Performance of these base bending supports is much more difficult to predict than other support types. Variations in the depth of embedment, the soil resistance, stiffness of the sign support, mounting height of the sign, and many other factors influence their dynamic behavior.

Splicing of steel U-channel posts is not recommended unless tested because impact performance of a spliced post cannot be accurately predicted. If used, however, it is imperative that they not be allowed where their separating under impact will cause the sign or sections of the post to penetrate a windshield. In no case should splices extend more than 600 mm above the ground nor should they extend into the ground. Similarly, diagonal bracing of a sign support should be avoided, because such bracing could significantly affect the crash performance of an otherwise acceptable design. This is particularly true for base bending or yielding supports. When it is absolutely necessary to increase the strength of a post support system, larger breakaway or multiple breakaway posts should be considered. If bracing is used as an interim measure, the bracing should be weaker than the main vertical supports, attached near the top of the vertical post to reduce likelihood of spearing, and attached at the ground in such a way that it will release when hit.

For single sign posts with bending or yielding characteristics, the sign panels should be adequately bolted to the post with oversized washers to prevent the panel from separating on impact and penetrating a windshield. It is further recommended that the bottom of the sign panel be a minimum of 2100 mm above the ground and that the top of the panel be a minimum of 2700 mm above the ground to minimize the possibility of the sign panel and post rotating on impact and striking the windshield of a vehicle.

Fracturing sign supports are either wood or steel posts or steel pipes connected at ground level to a separate anchor. Wood posts are typically set in drilled holes and backfilled while anchors for steel pipe or post systems are normally driven into the ground.

Slip base designs for small sign supports may be broadly classified as uni-directional or multidirectional. The most basic types of uni-directional breakaway sign supports are the horizontal and inclined slip bases. The design shown in Figure 4.8 is typical. The inclined designs shown utilize a 4-bolt slip base inclined in the direction of traffic at 10 to 20 degrees from horizontal. This angle ensures that the sign will move upward to allow the impacting vehicle to pass under the sign without its hitting the windshield or top of the car. When this type of slip base is used for small signs, hinges in the posts are not needed. The major limitation of this slip base design is its directional property. The inclined slip base can only be struck from one direction to yield satisfactorily, and neither design should be used in medians or traffic islands or other locations where hits from several directions are likely.

Multidirectional slip bases are typically triangular and are designed to release when struck from any direction. A typical design is shown in Figure 4.9. These types of breakaway supports are ideally suited for use on medians, channelizing islands, ramp terminals, and other locations where a sign may be hit from any one of several directions.

Slip base breakaway sign supports are subject to installation and maintenance problems which do not exist for rigid supports. Most significant is wind vibrations which may cause the bolts in the slip base to loosen. A keeper

FIGURE 4.8 Uni-Directional Slip Base for Small Signs

plate of thin (0.5 mm to 1.0 mm) sheet metal is used to prevent clamping bolts, having low torque requirements, from "walking" or migrating from the slots under wind loads.

A more common problem is the failure of a slip base to release properly due to over-torquing of the clamping bolts in the slip base and in the hinge of small sign supports. Since the slip base operates on the weakened shear plane concept, over-torquing creates high friction between the slip base elements and may prevent the post from releasing properly when hit. For this reason, breakaway designs that are not dependent upon a specific torque requirement are highly desirable. Problems with thread fabrication on clamping bolt nuts, improper assembly of slip base parts,

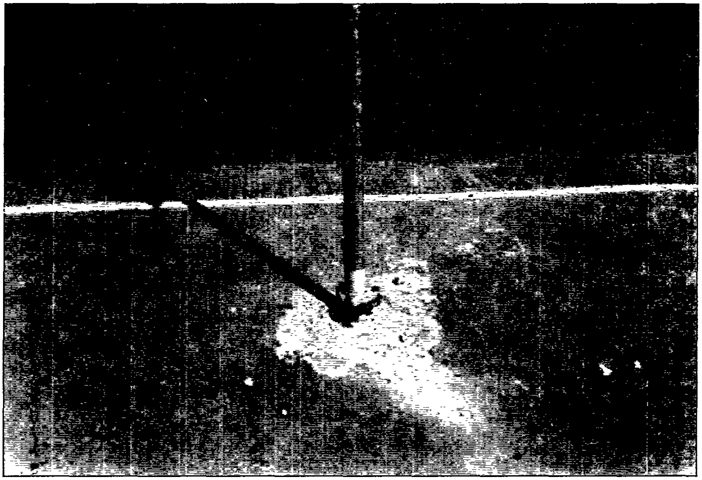


FIGURE 4.9 Multidirectional Slip Base For Small Signs

and anchor bolts projecting into the slip base are other common deficiencies which should be avoided.

In areas where critical wind velocities are prevalent, sign flutter can be a problem that should be considered. This phenomenon, where rapid rotation and twisting of the posts occur, can cause failure of the posts by fatigue if not considered in design.

4.4 MULTIPLE POST SUPPORTS FOR SIGN SUPPORTS

All breakaway supports within a 2100-mm width in multiple post sign structures are considered as acting together. This 2100-mm criterion is based on a need to minimize the potential for unacceptable performance of breakaway hardware. In some cases, a vehicle could leave the roadway at a sufficiently high angle so that two posts within a 2100-mm path would be struck. In some other cases, a vehicle could be yawing in the roadside to such an extent that two posts within a 2100-mm path would be struck. In many instances, the greatest change in vehicle velocity occurs when impacting breakaway hardware at slower speeds because less energy is available to activate the breakaway mechanism. Since vehicles leaving the roadway at very high angles or vehicles being in a yawing mode would likely be traveling at slower speeds, the 2100-mm criterion is a reasonable safety factor that should be used in roadside design of breakaway hardware.

4.5 BREAKAWAY LUMINAIRE SUPPORTS

Breakaway luminaire supports are typically frangible base (cast aluminum transformer base), slip base, or frangible coupling (couplers). Examples of each type in common use are shown in Figures 4.10 to 4.12. Breakaway luminaire supports can be similar to breakaway sign hardware. The breakaway mechanism properly activates if loaded in shear rather than bending and is designed to release in shear when impacted at typical bumper height of about 500 mm. Locating supports in the roadside where they are loaded in bending rather than shear may result in severe impacts and injuries to vehicle occupants. Superelevation, side slope, rounding and offset, and vehicle departure angle and speed will influence the striking height of a typical bumper. If the negative side slopes are limited to 1:6 or flatter between the roadway and the luminaire support, vehicles should strike the support at an acceptable height.

As a general rule, a luminaire support will fall near the line of the path of an impacting vehicle. The mast arm usually rotates so it is pointing away from the roadway when resting on the ground. This action generally prevents the pole from going into other traffic lanes. However, the designer must remain aware that these falling poles may endanger bystanders, such as pedestrians, bicyclists, and motorists.

At the present time, the height of poles with breakaway features should not exceed 17 meters. This maximum height is recommended because it is the approximate maximum height of currently accepted hardware and it is also

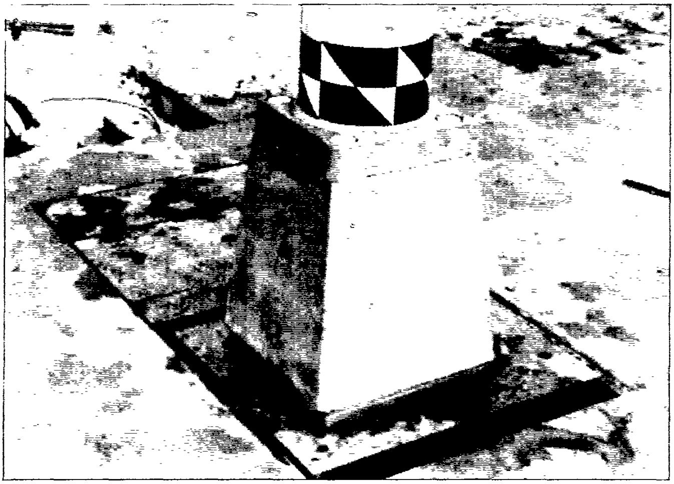


FIGURE 4.10 Example of a Cast Aluminum Transformer Base

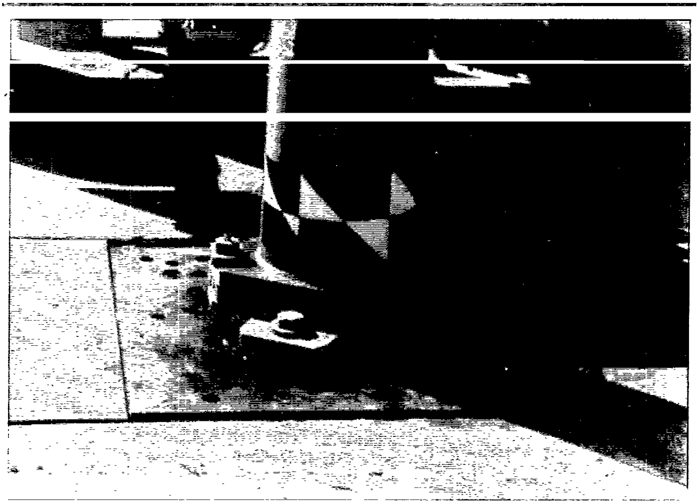


FIGURE 4.11 Example of a Luminaire Slip Base Design

the height that can accommodate modern lighting design practices when foundations are set at about roadway grade. In order to prevent a situation with potentially serious consequences should a pole fall on a vehicle, the mass of a breakaway luminaire support should not exceed 450 kg.

The type of soil surrounding a luminaire foundation may affect the performance of the breakaway mechanism. Experience shows that if foundations are allowed to push through the soil, the luminaire support will be placed in bending rather than shear resulting in non-activation of the breakaway mechanism. Foundations should be properly designed for surrounding soils.

Non-direct burial-type luminaire supports generally require a substantial foundation. The 100-mm maximum

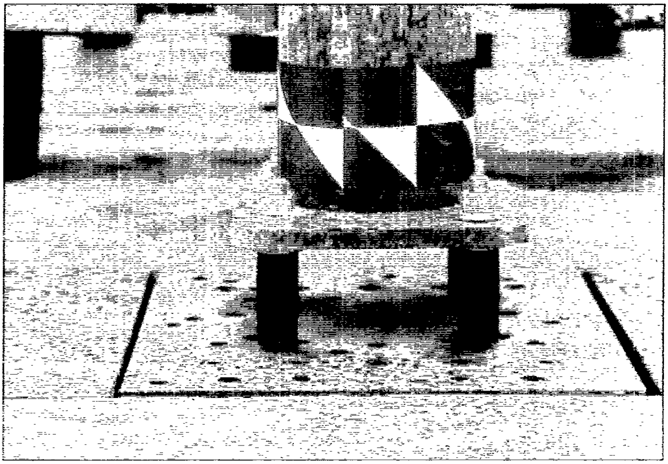


FIGURE 4.12 Example of a Frangible Coupling Design

stub height criterion in the AASHTO breakaway specifications is of particular importance. Also, quick disconnect circuitry should be used to facilitate the breakaway mechanisms and to reduce the risk of electrical shock from exposed wiring after impact.

When luminaire supports are located near a traffic barrier, breakaway bases may or may not be applicable, depending upon the type and characteristics of the barrier. In general, if the support is within the design deflection distance of the barrier, it should be a breakaway design or the railing should be strengthened locally to minimize the resultant deflection. Details on traffic barrier types and characteristics can be found in Chapters 5 and 6. Several state agencies mount luminaires on top of concrete median barriers, a practice that oftentimes requires modification to the luminaire support or median barrier or both. For high-angle impacts into the concrete barrier or accidents involving trucks or buses, a luminaire mounted on top of a concrete barrier is likely to be struck. This type of installation generally does not utilize breakaway supports because of the risk a downed pole might present to opposing traffic.

A final consideration on roadway lighting is a reduction in the total number of luminaires used along a section of highway. Higher mounting heights may significantly reduce the total number of supports needed. The ultimate design in this respect is the use of tower or high-mast lighting which requires far fewer supports located much further from the roadway. This is the preferred method for lighting major interchanges.

4.6 SUPPORTS FOR TRAFFIC SIGNALS AND MISCELLANEOUS TRAFFIC SERVICE DEVICES

Other relatively narrow objects that are usually located adjacent to the roadway include highway traffic signals, motorist-aid callboxes, railroad warning devices, fire hydrants, and mailboxes. These are discussed in the following sections.

4.6.1 Traffic Signals

Traffic signal posts present a special situation where a breakaway support may not be desirable. As with luminaire supports, a fallen signal post may become an obstruction. However, the potential risks associated with the temporary loss of full signalization at the intersection should be considered.

When traffic signals are installed on high-speed facilities (generally defined as those having speed limits of 80 km/h or greater), the signal supports should be placed as far away from the roadway as practicable. Shielding these supports can be considered if they are within the clear zone for that particular roadway.

4.6.2 Motorist-Aid Callboxes

Motorist-aid callboxes should be treated as roadside obstacles. Their close proximity to the traveled-way warrants the use of crashworthy breakaway supports. Because of their size and weight, they can usually be designed to meet vehicle change-in-velocity requirements. However, there are at least two concerns pertaining to the motorist-aid callbox support design: a callbox must be securely attached to its support to prevent its separating and penetrating the windshield, and the top of the support must be at least 2700 mm above the ground to prevent it from penetrating the windshield after impact.

To the extent possible, callboxes should be located behind traffic barriers warranted for other reasons. Not only would this make them unlikely to be hit at all, but it would also reduce the risk of a motorist using a callbox being struck by a vehicle.

4.6.3 Railroad Warning Devices

Warning devices at railroad-highway crossings are generally the responsibility of the railroads. Highway and railroad officials must cooperatively decide on the type of warning device needed at a particular crossing, i.e., crossbucks, flashing light signals, or gates. As a minimum, crossbucks are required and should be installed similar to an acceptable wood post sign support. Other warning device supports, i.e., signals or gates, can cause an increase in the severity of injuries to vehicle occupants if struck at high speeds. In these cases, consideration should be given to shielding the support with a crash cushion if the support is located in the clear zone. Longitudinal barrier is often not used because there is seldom sufficient space for a proper downstream end treatment; a longer obstacle is created by installing a guardrail; and a vehicle striking a longitudinal barrier when a train is occupying the crossing may be redirected into the train. The designer must also be aware of the immediate risk to other motorists just after the devices are knocked down by impacting vehicles.

4.6.4 Fire Hydrants

Fire hydrants are another type of roadside feature which may be an obstacle. While most fire hydrants are made of cast iron and could be expected to fracture upon impact, there has not been any crash testing meeting current testing procedures to verify that designs meet breakaway criteria. At least one fire hydrant stem and coupling design is available which provides for immediate water shutoff if struck by a vehicle.

Whenever possible, fire hydrants should be located sufficiently far away from the roadway so they do not become an obstruction for the motorist and yet are still readily accessible and usable to emergency personnel. Any portion of the hydrant not designed to breakaway should be within 100 mm of the ground.

4.6.5 Mailbox Supports

There are tens of millions of mailboxes on rural and suburban roads and streets. Limited accident data have shown that mailbox supports can contribute to the severity of an accident. The AASHTO *A Guide for Erecting Mailboxes on Highways* (Mailbox Guide) contains information on mailbox supports and their location on the roadside. Briefly, the following guidelines should be used for mailbox supports.

- Mailbox supports which should be considered are nominal 100-mm by 100-mm or 100-mm diameter wood posts, or a metal post with a strength no greater than a 50-mm diameter standard strength steel pipe, embedded no more than 600 mm into the ground. For example, a single 3.0 kg/m U-channel support would be acceptable under this structural limitation. Mailbox supports should not be set in concrete unless the support design has been shown to be safe by crash tests.
- Mailbox-to-post attachments should ideally prevent mailboxes from separating from their supports under vehicle impacts. The Mailbox Guide contains information on attachments that prevent their separation.
- Multiple mailbox installations should meet the same criteria as single mailbox installations. Multiple support installations should have their supports separated a minimum distance equal to three-fourths of their heights above ground. This will reduce interaction between adjacent mailboxes and supports.

Neighborhood delivery and collection box units are owned by the postal service and are a specialized type of multiple mailbox installation that should be located outside the clear zone, particularly on high-speed or heavily traveled highways. It is incumbent upon local highway officials and local postal officials to communicate with each other to ensure that this type of installation does not become a safety problem to the motorist. Additional information on recommended mailstop turnouts is contained in the Mailbox Guide.

4.7 UTILITY POLES

Motor vehicle collisions with utility poles result in approximately 10 percent of all fixed-object fatal crashes annually. This degree of involvement is related to the number of poles in use, their close proximity to the traveled way, and their unyielding nature.

As with sign and luminaire supports, the most desirable solution is to locate utility poles where they are least likely to be struck. One alternative unique to power and telephone lines is to bury them, thereby eliminating the obstacles. For poles that cannot be eliminated or relocated, a breakaway design has been developed and successfully crash tested. This alternative will be discussed in more detail under countermeasures. Since utility poles are generally privately owned and installed devices permitted on publicly owned right-of-way, they are not under the direct control of a highway agency. This dual responsibility may sometimes complicate the implementation of effective countermeasures.

For new construction or major reconstruction, every effort should be made to install or relocate utility poles as far from the traveled way as practical. The AASHTO publications, *A Policy on the Accommodation of Utilities Within Freeway Right-of-Way* and *A Guide for Accommodating Utilities Within Highway Right-of-Way*, provide more detailed information on locating utility facilities within highway right-of-way.

For existing utility pole installations identified for corrective action, the decision on what corrective measure to be taken should be based on a site-specific benefit/cost analysis. A manual procedure and a microcomputer program have been developed which enable a designer to determine which countermeasures could effectively reduce the frequency or severity of accidents at a given site. Details of this model are contained in Transportation Research Record (TRR) 970. The following specific countermeasures were included in the analysis:

- Placing utility lines underground
- Increasing lateral pole offset
- Increasing pole spacing
- Multiple pole use (joint usage)
- Breakaway design

Unlike the first three countermeasures, the use of a breakaway design is intended to reduce the severity of an accident rather than accident frequency. Although field experience is limited at present, the design shown in Figure 4.13 has been successfully crash tested and may be considered for poles in vulnerable locations that cannot economically be removed or relocated, such as gore areas, the outside of sharp curves, and opposite the intersecting road-

FIGURE 4.13 Prototype Breakaway Design for Utility Poles

way at T-intersections. An operational breakaway guy-wire connection has also been developed and successfully tested. It is shown schematically in Figure 4.14. Details of both designs are contained in Federal Highway Administration Report No. FHWA/RD-86/154, *Safer Timber Utility Poles.*

Another countermeasure that can be considered is adequate shielding of selected poles, particularly the massive supports used for major electrical transmission lines within the clear zone or in other vulnerable locations. Although not a common practice, there may be advantages to delineation of poles that are not otherwise treated, particularly

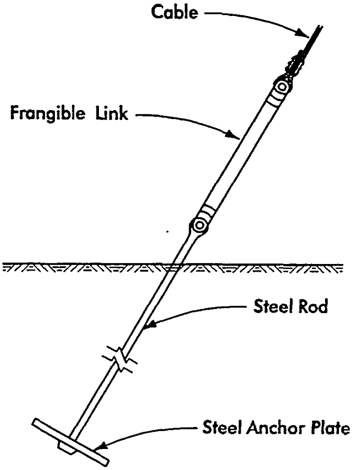


FIGURE 4.14 Breakaway Guy Wire Coupling for Utility Poles

along streets and highways where nighttime run-off-the-road accidents are prevalent.

4.8 TREES

Single vehicle collisions with trees account for nearly 25 percent of all fixed-object fatal accidents annually and result in the deaths of approximately 3000 persons each year. Unlike the roadside hardware previously addressed in this chapter, trees are not generally a design element over which highway engineers have direct control. With the exception of landscaping projects where the type and location of trees and other vegetation can be carefully chosen, the problem most often faced by designers is the treatment of existing trees that may present an obstruction to errant motorists. To promote consistency within a State, each highway agency should develop a formal policy to provide guidance to design, landscape, construction, and maintenance personnel. This section is intended to provide general guidelines from which a specific policy on trees may be developed.

Trees become potential obstructions by virtue of their size and their location in relation to vehicular traffic. Generally, a single tree with a trunk diameter greater than 150 mm is considered a fixed object. When trees or shrubs with multiple trunks or groups of small trees are close together, they may be considered as having the effect of a single tree with their combined cross-sectional area. Maintenance forces can minimize future problems by mowing clear zones to prevent seedlings from becoming established. The location factor is more difficult to address than tree size. Typically large trees should be removed from within the selected clear zone for new construction and for reconstruction. As noted in Chapter 3, the extent of the clear zone is dependent upon several variables, including highway speeds, traffic volumes, and roadside slopes. Segments of a highway can be analyzed to identify individual trees or groups of trees that are candidates for corrective measures. County and township roads, which generally have restrictive geometric designs and narrow off-road recovery areas, account for a large percentage of the annual tree-related fatal crashes, followed by State and U.S. numbered highways on curved alignment. Fatal accidents involving trees along Interstate highways are relatively rare.

Following several years of research by the Michigan Department of Transportation (MDOT), a *Guide to Management of Roadside Trees* was distributed nationally by the Federal Highway Administration as Report No. FHWA-IP-86-17. This document contains detailed information on identifying and evaluating higher risk roadside environments and provides guidance for implementing roadside tree removal. It also addresses environmental issues, alternative treatments, mitigation efforts, and maintenance practices. The remainder of this section is basically a summary of the information and recommendations included in that report.

Essentially, there are two methods of addressing the problem of roadside trees. The first is to keep the motorist on the road whenever possible and the second is to mitigate the danger inherent in leaving a roadway that has trees along it.

On-roadway treatments include:

- Pavement marking
- Delineators
- Signs
- Roadway improvements

Pavement markings are one of the most effective and least costly improvements that can be made to a roadway. Centerline and edge line stripes are particularly effective for roads with heavy nighttime traffic, frequent fog, and narrow lanes.

The installation of advance warning signs and roadway delineators can also be used to notify motorists of sections of roadway where extra caution is advised. Typically these will be used in advance of curves that are noticeably sharper than those immediately preceding it.

Roadway improvements such as curve reconstruction to provide increased superelevation, shoulder widening, and paving are relatively expensive countermeasures that may not be cost-effective in all cases.

Off-roadway treatments consist primarily of two options:

- Tree removal
- Shielding

The removal of individual trees should be considered when those trees are determined both to be obstructions and to be in a location where they are likely to be hit. Such trees can often be identified by past accident history at similar sites, by scars indicating previous accidents, or by field reviews. Removal of individual trees will not reduce the probability a vehicle will leave the roadway at that point but should reduce the severity of any resulting accident. Since tree removal can be expensive and often has adverse environmental impacts, it becomes important that this countermeasure be used only when it is an effective solution. For example, 1:3 and flatter slopes may be traversable, but a vehicle on a 1:3 slope will usually reach the bottom. If there are numerous trees at the toe of the slope, removal of isolated trees on the slope will not significantly reduce the vehicle/tree accident risk. Similarly, if the recommended clear zone for a particular roadway is 7 meters, including the shoulder, removal of trees 6 to 7 meters from the road will not materially change the risk to motorists if an unbroken tree line remains at 8 meters and beyond. However, isolated trees noticeably closer to the roadway may be candidates for removal. If a tree or group of trees is in a vulnerable location but cannot be removed, a properly designed and installed traffic barrier can be used to shield them. Roadside barriers should only be used when the severity of striking the tree is greater than striking the barrier. Specific information on the selection, location, and design of roadside barriers is contained in Chapter 5.

CHAPTER 5: ROADSIDE BARRIERS

5.0 OVERVIEW

A roadside barrier is a longitudinal barrier used to shield motorists from natural or man-made obstacles located along either side of a traveled way. It may occasionally be used to protect bystanders, pedestrians, and cyclists from vehicular traffic.

This chapter summarizes performance requirements and warrants for roadside barriers and contains guidelines for selecting and designing an appropriate barrier system. The structural and safety characteristics of selected roadside barriers and transition sections are presented here. For similar information on end treatments, see Chapter 8. Finally, placement guidelines are included and a methodology is presented for identifying and upgrading existing substandard installations.

5.1 PERFORMANCE REQUIREMENTS

The primary purpose of all roadside barriers is to prevent a vehicle from leaving the traveled way and striking a fixed object or terrain feature that is considered more objectionable than the barrier itself. This is accomplished by containing and redirecting the impacting vehicle. Since the dynamics of a crash are complex, the most effective means of assessing barrier performance is through full-scale crash tests. By standardizing such tests, highway engineers may compare the safety performance of alternate designs.

5.1.1 Current Crash Test Criteria

A series of standard crash tests are presented in National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. This report recommends a series of tests on standard sections of longitudinal barriers and transition sections for six test levels to evaluate occupant risk and structural integrity of the barrier and post-impact behavior of the vehicle for a variety of vehicle masses at varying speeds and angles of impact. The range of test levels provide for matching barrier performance to service needs.

5.1.2 Barrier Classifications

NCHRP Report 350 describes acceptance phases for roadside features — experimental and operational. In the experimental phase, a barrier that has acceptably passed crash testing is subjected to in-service evaluation. In the operational phase, a barrier that has been found acceptable through an in-service evaluation is classified as operational and it is recommended that performance continue to be monitored. In practice, the determination of whether a barrier must undergo an experimental in-service evaluation is at the discretion of the user agency. Additionally, a barrier may be considered operational if it has been used for an extended period and has demonstrated satisfactory field performance in terms of construction, maintenance, and accident experience. All the barriers cited in this chapter have been found acceptable through crash testing and may be considered operational, although this would not preclude a user agency from treating any of the barriers as experimental for purposes of determining if they meet its needs.

No matter what status, experimental or operational, an agency ascribes to a barrier, it is strongly recommended that the barrier's performance be monitored for any problems in construction, maintenance, or crashworthiness. See NCHRP Report 350 for guidance on conducting in-service evaluations.

Omission of a barrier system does not necessarily imply that it is not acceptable for use. There are numerous barriers in use today that have not been subjected to full-scale crash tests but have performed satisfactorily over time.

5.2 WARRANTS

Barrier warrants are based on the premise that a traffic barrier should be installed only if it reduces the severity of potential accidents. It is important to note that the probability or frequency of run-off-the-road accidents is not directly related to the severity of potential accidents.

Typically, guardrail warrants have been based on a subjective analysis of certain roadside elements or conditions. If the consequences of a vehicle striking a fixed object or running off the road are believed to be more serious than hitting a traffic barrier, then the barrier is considered warranted. While this approach can be used, often there are instances where it is not immediately obvious whether the barrier or the unshielded condition presents the greater risk. Furthermore, the subjective method does not directly consider the probability of an accident occurring nor the costs associated with the shielded and unshielded conditions.

Thus, warrants may also be established by using a benefit to cost analysis whereby factors such as design speed and traffic volume can be evaluated in relation to barrier need. Costs associated with the barrier (installation costs, maintenance costs, and accident costs) are compared to similar costs associated without barriers. This procedure is typically used to evaluate three options: (1) remove or reduce the area of concern so that it no longer requires shielding, (2) install an appropriate barrier, or (3) leave the area of concern unshielded. The third option would normally be cost-effective only on low-volume and/or low-speed facilities or where engineering studies show the probability of accidents is low. Appendix A presents an analysis procedure that can be used to compare several alternative safety treatments and provide guidance to the engineer who must select an appropriate design.

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

5.2.1 Embankments

Embankment height and side slope are the basic factors considered in determining barrier need as shown in Figure 5.1. These criteria are based on studies of the relative severity of encroachments on embankments versus impacts with roadside barriers. Embankments with slope and height combinations on or below the curve do not warrant shielding unless they contain obstacles within the clear zone. Figure 5.1, however, does not take into account either the probability of an encroachment occurring nor the relative costs of installing a traffic barrier versus leaving the slope unshielded. Figure 5.2 is a modified warrant chart developed by one state that addresses the decreased probability of encroachments on lower volume roads. Figure 5.3 is another example of a modified warrant chart, one which considers the cost-effectiveness of barrier installation for the site-specific conditions noted on the chart. Figures 5.2 and 5.3 are presented as examples only and are not intended for direct application. Highway agencies are encouraged to develop similar warranting criteria based upon their own cost-effectiveness evaluations.

Rounded slopes reduce the chances of an errant vehicle becoming airborne, thus reducing the hazard of an encroachment by affording the driver more control over the vehicle. Optimum rounding is arbitrarily defined as the minimum radius a standard-sized automobile can negotiate without losing tire contact. It is dependent on the encroachment angle and speed as well as the characteristics of individual vehicles.

5.2.2 Roadside Obstacles

Roadside obstacles may be non-traversable terrain or fixed objects and may be either man-made (such as culvert inlets) or natural (such as trees). Together, these highway conditions account for over thirty percent of all highway fatalities each year. Barrier warrants for roadside obstacles are a function of the obstacle itself and the likelihood that it will be hit. However, a barrier should be installed only if it is clear that the result of a vehicle striking the barrier will be less severe than the accident resulting from hitting the unshielded object.

Non-traversable terrain and roadside obstacles which normally warrant shielding are listed in Table 5.1. While roadside obstacles immediately adjacent to the traveled way are usually removed, relocated, modified or shielded, the optimal solution becomes less evident as the distance between the obstruction and the roadway increases. The clear zone table (3.1) contained in Chapter 3 is intended as a guide to aid the designer in determining if the obstruction constitutes a significant-enough threat to an errant motorist to warrant action. Most man-made objects incorporated into a highway construction project can be designed to minimize or eliminate the danger they present to a motorist and thus make shielding unnecessary. This is particularly true of drainage features such as small culverts and ditches.

5.2.3 Bystanders, Pedestrians and Bicyclists

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. There are no criteria that would require that a barrier be installed. If, however, a barrier is installed it could be placed near the school boundary to minimize the potential for vehicle contact. Reference should be made to Section

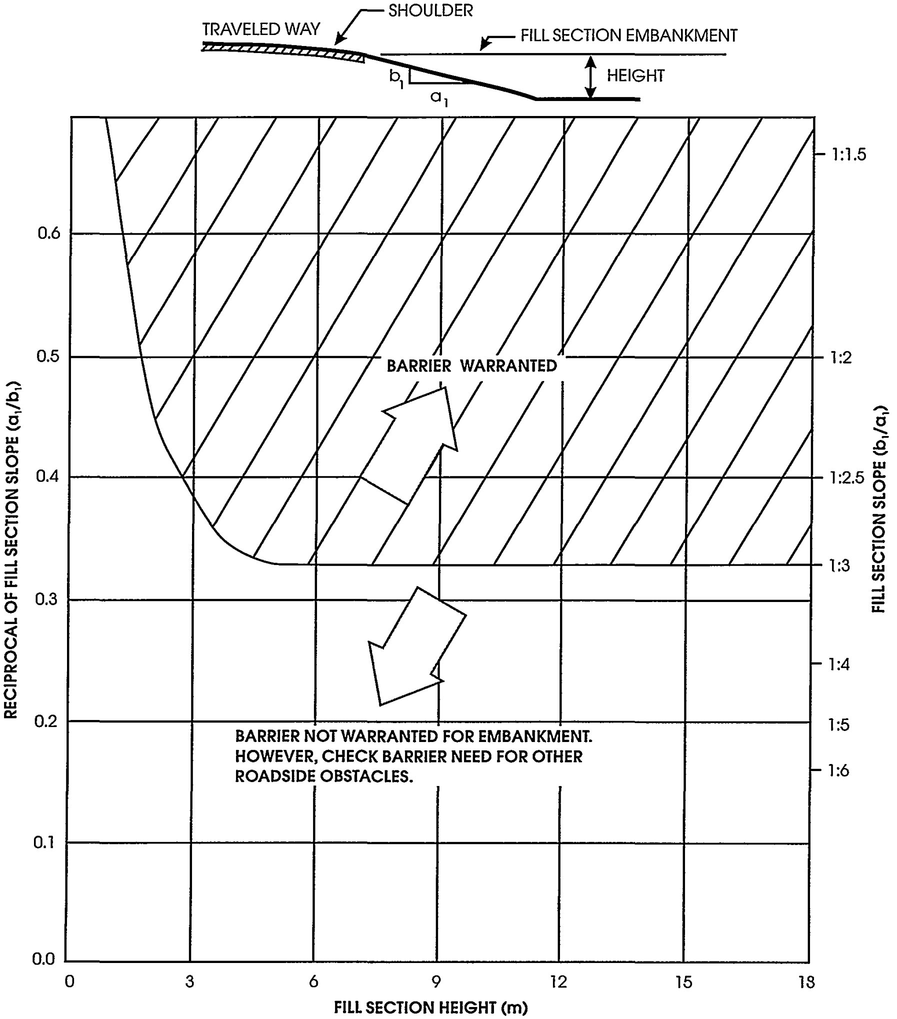


FIGURE 5.1 Comparative Risk Warrants for Embankments

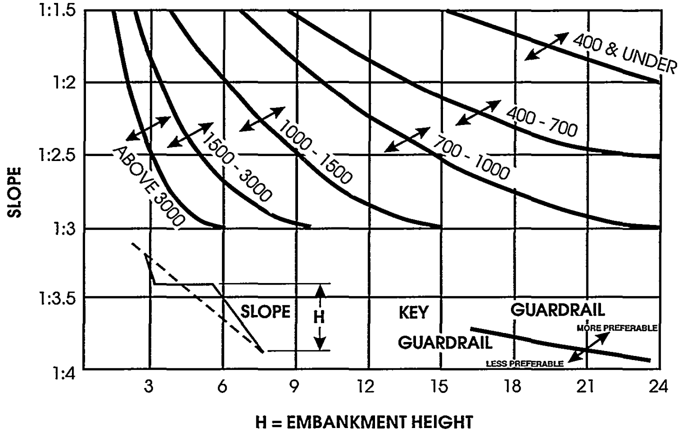


FIGURE 5.2 Example design chart for embankment warrants based on fill height and slope and on traffic volume (see text)

5.6.1 for lateral placement criteria. Consideration might also be given to installing a barrier to shield businesses and or residences which are near the right-of-way, particularly at locations having a history of run-off-the-road accidents.

Pedestrians and cyclists are another area of concern to highway engineers. The most desirable solution to this problem is to separate them from vehicular traffic. Since this solution is not always practical, alternate means of protecting them are sometimes necessary. As in the case of bystander warrants, there are no objective criteria to draw on for pedestrian and cyclist barrier warrants. On low-speed streets, a barrier curb will usually suffice to separate pedestrians and cyclists from vehicular traffic. However, at speeds significantly over 65 km/h, a vehicle may mount the curb for relatively flat approach angles. Hence, when sidewalks or bicycle paths are adjacent to the traveled way of high-speed facilities, some provision might be made for the safety of pedestrians and cyclists.

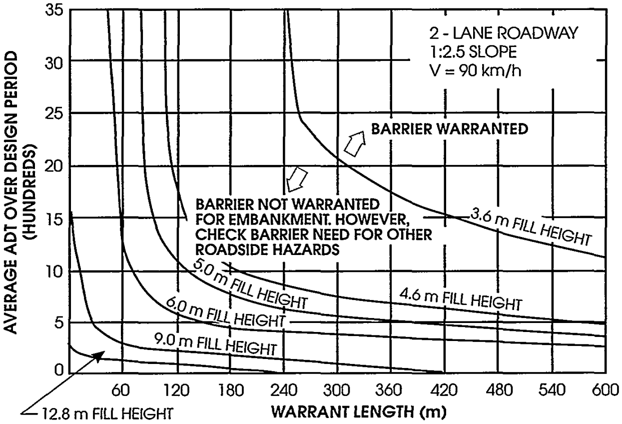


FIGURE 5.3 Example design chart for cost-effective embankment warrants based on traffic speeds and volumes, slope geometry, and length of slope (see text)

TABLE 5.1 Barrier Warrants for Non-Traversable Terrain and Roadside Obstacles^{1,2}

bridge piers, abutments and railing ends	shielding generally required
boulders	a judgement decision based on nature of fixed object and likelihood of impact
culverts, pipes, headwalls	a judgement decision based on size, shape and location of obstacle
cut slopes (smooth)	shielding not generally required
cut slopes (rough)	a judgement decision based on likelihood of impact
ditches (parallel)	refer to Figures 3.5 and 3.6
ditches (transverse)	shielding generally required if likelihood of head-on impact is high
embankment	a judgement decision based on fill height and slope (see Figure 5.1)
retaining walls	a judgement decision based on relative smoothness of wall and anticipated maximum angle of impact
sign/luminaire supports[3]	shielding generally required for non-breakaway supports
traffic signal supports[4]	isolated traffic signals within clear zone on high-speed rural facilities may warrant shielding
trees	a judgement decision based on site-specific circumstances
utility poles	shielding may be warranted on a case-by-case basis
permanent bodies of water	a judgement decision based on location and depth of water and likelihood of encroachment

[1] Shielding non-traversable terrain or a roadside obstacle is usually warranted only when it is within the clear zone and cannot practically or economically be removed, relocated, or made breakaway, and it is determined that the barrier provides a safety improvement over the unshielded condition.

[2] Marginal situations, with respect to placement or omission of a barrier, will usually be decided by accident experience, either at the site or at a comparable site.

[3] Where feasible, all sign and luminaire supports should be a breakaway design regardless of their distance from the roadway if there is reasonable likelihood of their being hit by an errant motorist.

[4] In practice, relatively few traffic signal supports, including flashing light signals and gates used at railroad crossings, are shielded. If shielding is deemed necessary, however, crash cushions are sometimes used in lieu of a a longitudinal barrier installation.

5.3 PERFORMANCE LEVEL SELECTION PROCEDURES

Traditionally, most roadside barriers were developed, tested and installed with the intention of containing and redirecting passenger vehicles with masses up to 2000 kg. Properly designed and installed barrier systems have proven to be very effective in reducing the amount of damage and lessening the severity of personal injuries when struck by automobiles and similar-sized vehicles at relatively shallow angles (less than 25°) and at reasonable impact speeds (less than 110 km/h). However, it has long been understood that barriers designed for cars should not be expected to perform equally well for larger vehicles, such as buses and trucks. Recognizing this fact, several highway agencies have developed and used barrier systems capable of redirecting vehicles as heavy as 36,000-kg tractor-trailer combination trucks. Although objective warrants for the use of higher performance traffic barriers do not presently exist, subjective factors most often considered for new construction or safety upgrading include:

- high percentage of heavy vehicles in traffic stream
- adverse geometrics such as sharp curvature oftentimes combined with poor sight distance
- severe consequences associated with penetration of a barrier by a large vehicle.

These same factors apply on reconstruction or rehabilitation projects but in these cases, the design engineer will usually have the added benefit of past accident history, the past performance of the system, and maintenance costs associated with the existing barrier. If the addition of a stronger barrier is likely to lessen the severity of future accidents or reduce maintenance costs significantly, many highway agencies will consider such an installation. Section 5.4 includes information on the size of vehicle for which each system has been successfully crash tested.

5.4 STRUCTURAL AND SAFETY CHARACTERISTICS OF ROADSIDE BARRIERS

This section includes information on the most commonly used operational roadside barriers as well as data on selected experimental systems. Separate subsections address standard sections of roadside barriers and transition sections. Figure 5.4 graphically depicts each of these elements for typical installations. Information on the structural and safety characteristics of each system is presented in a narrative format, and includes the following information:

- a photograph or sketch of the barrier;
- a barrier description showing the main elements of the barrier and post spacing. Prior to selection of a specific barrier system, the designer should obtain full details of the system from standard drawings or a similar source;
- a brief description of the impact performance of each system. This will describe the range of vehicles for which the system has been successfully crash tested. For standard sections, the dynamic deflection observed during the NCHRP 230 standard strength test (2000-kg car, 25° angle, 100 km/h) will be listed;
- field performance data for experimental barriers are included when available. This provides the designer with in-service evaluation information and is intended to encourage the use and evaluation of additional pilot installations at appropriate locations.

Additional information on individual barrier systems, including design details and barrier damage resulting from tests, is presented in Appendix B.

5.4.1 Standard Sections of Roadside Barriers

Roadside barriers are usually categorized as flexible, semi-rigid, or rigid, depending on their deflection characteristics on impact. Flexible systems are generally more forgiving than the other categories since much of the impact energy is dissipated by the deflection of the barrier and lower impact forces are imposed upon the vehicle.

This section is not intended to be all-inclusive, but to cover the most widely used roadside barriers. The barriers included in the following subsections are:

FLEXIBLE SYSTEMS:
- 3-Strand Cable
- W-Beam (Weak Post)
- Thrie-Beam (Weak Post)

SEMI-RIGID SYSTEMS:
- Box Beam (Weak Post)
- Blocked-out W-Beam (Strong Post)
- Blocked-out Thrie-Beam (Strong Post)
- Modified Thrie-Beam
- Self-Restoring Barrier (SERB) Guardrail
- Steel-Backed Wood Rail

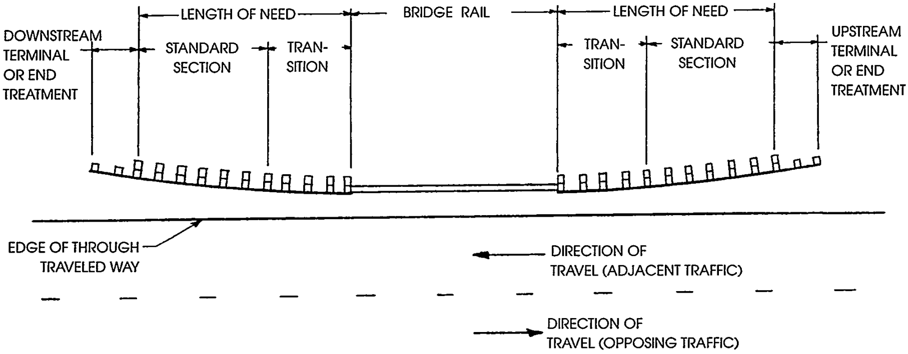


FIGURE 5.4 Definition of Roadside Barrier Elements

RIGID SYSTEMS:
- Concrete Safety Shape
- Stone Masonry Wall

5.4.1.1 3-Strand Cable

This system consists of steel cables mounted on weak posts. Several variations of this design have been successfully crash tested. (See Appendix B for individual designs.)

The top cable height of the tested systems ranges from 690 mm to 760 mm. However, recent analysis and testing by the State of New York indicates that this railing might perform better at the low end of this range, considering the risk of vehicle underride for vehicles with a low front profile.

Impact performance: This system will generally redirect vehicles in the 820-2000 kg range, but some discussion is needed to distinguish between design variations. The steel (S75 x 8.5) post design at 700-mm top rail height has been tested the most extensively of all the designs. In addition to the vehicle range described above, this design has successfully redirected a low front profile vehicle and a 1800-kg van.

Cable barrier redirects impacting vehicles after sufficient tension is developed in the cable, with the posts in the impact area offering only slight resistance. However, testing on the S75 x 8.5 post design has shown that closer post spacing can reduce lateral deflection to some extent. (Testing with a 1600-kg car at 100 km/h on this design produced deflections of 2.1 m to 3.3 m for associated post spacings of 1.2 m to 4.9 m). Several states with extensive experience using cable rail allow a backslope as steep as 1:2 behind the rail.

Cable barrier placed on the inside of curves all require additional deflection before tension develops in the cable. Among agencies using this barrier, guidelines vary regarding maximum curvature allowed. The State of New York installs the S75 x 8.5 post design on curves with radii up to 220 m with standard 4.9 m spacing and with radii up to 135 m with 3.7 m post spacing.

Primary advantages of cable guardrail include low initial cost, effective vehicle containment and redirection over a wide range of vehicle sizes and installation conditions, and low deceleration forces upon the vehicle occupants. It also is advantageous in snow or sand areas because its open design prevents drifting on or alongside the roadway. Major drawbacks to the use of cable guardrail include the comparatively long lengths of barrier which are nonfunctional and in need of repair following an impact, the clear area needed behind the barrier to accommodate the design deflection distance, its reduced effectiveness on the inside of curves, and its sensitivity to correct height installation and maintenance.

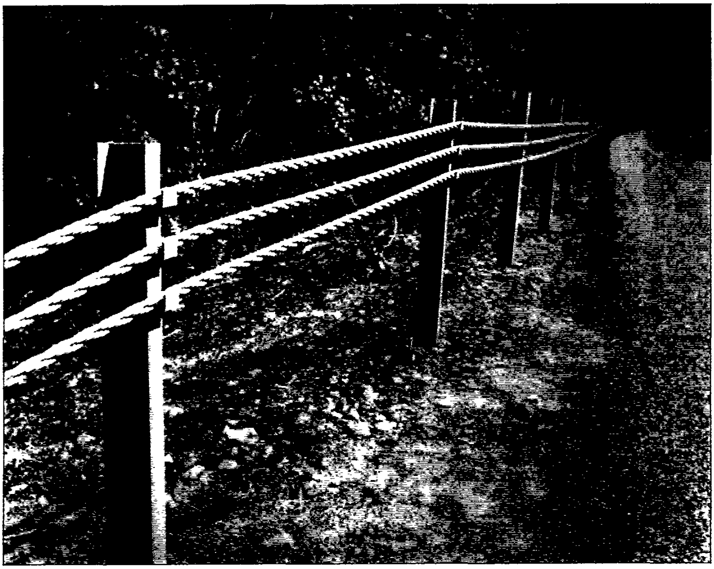


FIGURE 5.5 3-Strand Cable Barrier

5.4.1.2 W-Beam (Weak Post)

The barrier system shown in Figure 5.6 behaves very much like a cable guardrail, i.e., the posts serve primarily to hold the rail at the proper elevation and they separate readily when struck. The w-beam rail then redirects impacting vehicles as it is placed in tension. Post size is identical to the cable system (S75 x 8.5 design) but they are installed at 3.8 m centers to match the w-beam hole pattern. The recommended top of railing height is 760 mm.

Impact performance: In crash tests this system has successfully redirected vehicles in the 800-1800 kg range. Dynamic lateral deflection in the 1800-kg test (28°, 95 km/h) was 2.2 m. This barrier has not been crash tested with a 2000-kg vehicle, although field performance over a period of years has not indicated a problem relative to this vehicle size. In a test to establish upper performance limits, this barrier failed to keep a 2100-kg van upright following a 95 km/h, 24° impact.

This system may retain some degree of effectiveness after minor hits due to the rigidity of the w-beam rail element and thus has some advantage over a cable system. As with the cable system, lateral deflection can be reduced to some extent by closer post spacing. This system, as with all barriers having a relatively narrow restraining width, is somewhat vulnerable to vaulting or vehicle underride caused by incorrect mounting height or irregularities in the approach terrain.

5.4.1.3 Thrie-Beam (Weak Post)

This system, shown in Figure 5.7, differs from the weak post w-beam barrier only in its use of thrie-beam as its rail element. The added depth of rail can accommodate a greater range of vehicle sizes and can negate some of the problems associated with minor terrain irregularities. Although field experience with this system is very limited, it is considered operational because it is basically an improvement of an existing system. The recommended top of rail height is 840 mm.

Impact performance: In crash tests, this system has successfully redirected vehicles in the 800-2000 kg range. Dynamic lateral deflection in the 2000-kg strength test was 1.9 m. It should be noted that all testing was performed using 3.43-mm rail elements.

The thrie-beam element, unlike the w-beam, cannot be mounted symmetrically about one bolt. In tests where the thrie-beam was mounted on all posts with the upper bolt only, torsional twisting was observed in the beam element under vehicle impact. To prevent this twisting, it is recommended that the thrie-beam be mounted by alternating upper and lower bolts on successive posts.

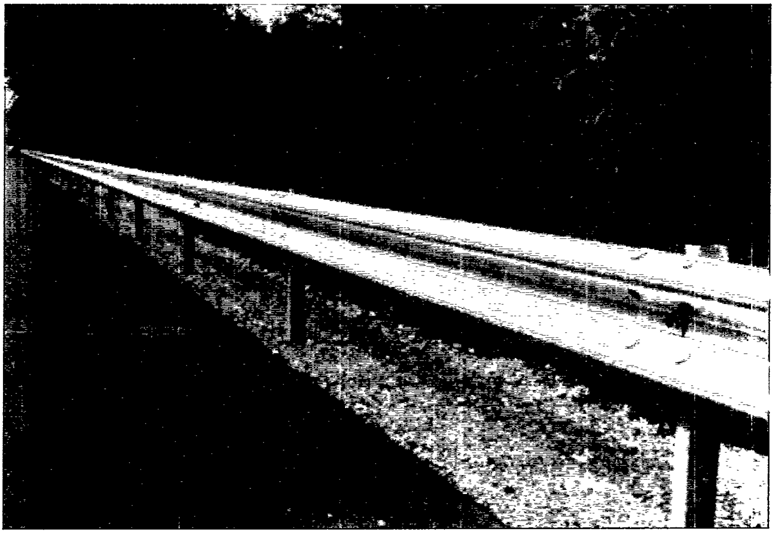


FIGURE 5.6 Weak Post W-Beam Barrier

FIGURE 5.7 Weak Post Thrie-Beam Barrier

5.4.1.4 Box Beam (Weak Post)

Figure 5.8 shows a typical installation of a box beam rail. Resistance in this system is achieved through the combined flexure and tensile stiffness of the rail. Posts near the point of impact are designed to break or tear away, thereby distributing the impact force to adjacent posts.

Impact performance: In crash tests, this system has successfully redirected passenger cars in the 800-1800 kg range. Dynamic lateral deflection in the 1800-kg test (26°, 94 km/h) was 1.5 m. This barrier has not been crash tested with a 2000-kg pickup truck, although field performance over a period of years has not indicated a problem with this vehicle size. In a test to establish an upper performance limit, this barrier failed to keep a 2100-kg van upright.

This system shares the same sensitivity to mounting height and irregularities in terrain as the weak post w-beam systems. Recommended top of railing height is 690 mm.

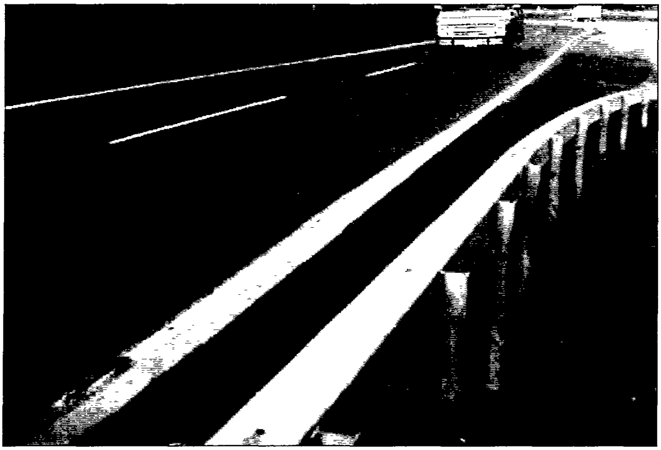


FIGURE 5.8 Weak Post Box Beam Barrier

5.4.1.5 Blocked-Out W-Beam (Strong Post)

Strong-post w-beam is the most common barrier system in use today. It is characterized by wood or steel posts and a w-beam rail element that is blocked out from the posts. The blockout minimizes vehicle snagging, and reduces the likelihood of a vehicle vaulting over the barrier by maintaining rail height during the initial stages of post deflection. Resistance in this and all strong post systems results from a combination of tensile and flexural stiffness of the rail and the bending or shearing resistance of the posts.

Several acceptable post designs are in use as shown in Figure 5-9. Blockouts are typically of the same material and cross-section as the posts. Individual designs for these and other strong-post w-beam variations are shown in Appendix B.

A design improvement suggested for new installations of this and other strong post guardrail systems is deletion of the rectangular post bolt washers. These washers are not necessary for system strength over the normal range of expected impacts. Furthermore, during severe impacts producing large post deflections, it is desirable that the rail break away from the posts as they rotate down. This keeps the railing height relatively constant and reduces the likelihood that an impacting vehicle will vault the barrier.

Impact performance: Based primarily on testing of the two common designs noted above, this system will redirect vehicles in the 800-2000 kg range. It has also redirected a 2100-kg van at 95 km/h and 21° angle of impact. The dynamic lateral deflection observed during the van test and the standard strength testing ranges from 0.6 m to 0.9 m.

In testing to establish an upper performance limit, this barrier was marginally successful in redirecting two pickup trucks (1500-1900 kg), but failed in a similar van test (25°) and in a school bus test due to rolling of the respective vehicles.

Strong post barrier systems usually remain functional after moderate collisions, thereby eliminating the need for immediate repair.

5.4.1.6 Blocked-Out Thrie-Beam (Strong Post)

This system, shown in Figure 5.10 and in Appendix B, is a stronger version of the blocked-out w-beam rail. The additional corrugation in the rail element stiffens the system, making it less prone to damage during vehicle impacts. It also allows higher mounting of the rail, which increases its ability to contain vehicles somewhat larger than standard passenger vehicles. Although this barrier has been successfully crash tested with a top railing height of 810 mm, recent research has suggested that the barrier would be effective through a range of heights with 900 mm being perhaps the optimum.

Impact performance: In crash tests, this system has successfully redirected vehicles ranging from an 820-kg subcompact car to a 1990-kg van (97 km/h, 25°). The standard strength test with a 2000-kg vehicle has not been performed; however, the barrier is assumed to meet that criteria by virtue of tests with larger vehicles and by comparison with the strong-post w-beam.

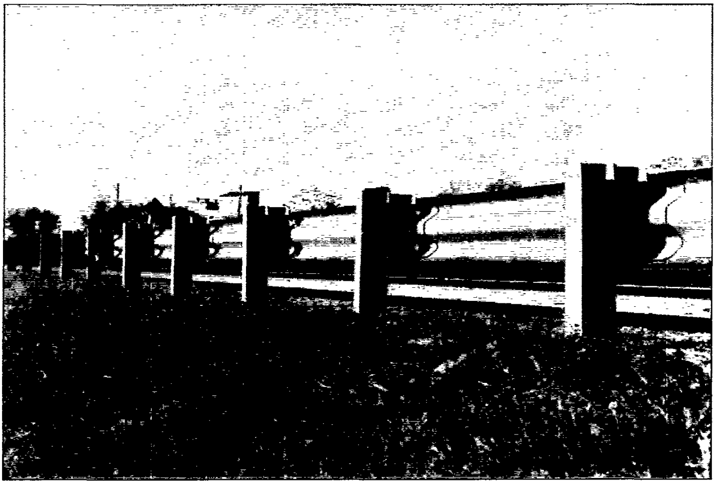


FIGURE 5.9 Blocked-Out W-Beam (Strong Post)

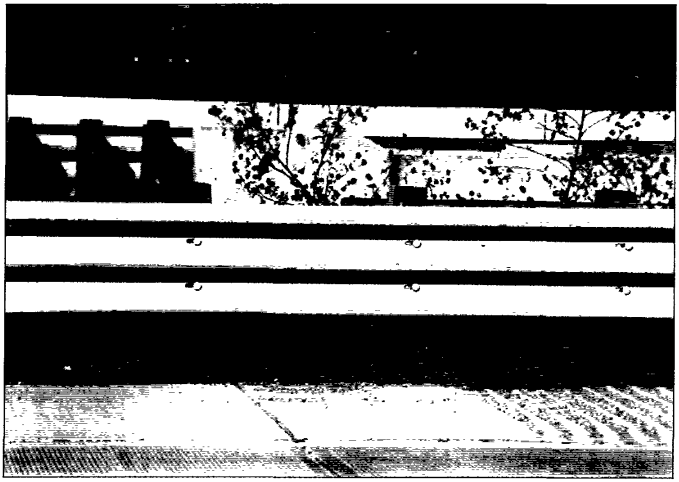


FIGURE 5.10 Strong Post Thrie-Beam Barrier

The dynamic lateral deflection observed during strength testing with a 1800-kg car and with the van was 0.5 m and 1.0 m respectively. In a test to establish an upper performance limit, this barrier at 810-mm top rail height contained and redirected a 9100-kg school bus but failed to keep the school bus upright during the test.

5.4.1.7 Modified Thrie-Beam

To improve the performance of thrie-beam guardrail for heavy vehicles, a modified spacer block was developed. This block has a triangular notch cut from its web (see Figure 5.11). The spacer design allows the lower portion of the thrie-beam and the flange of the spacer block to bend

FIGURE 5.11 Modified Thrie-Beam Guardrail

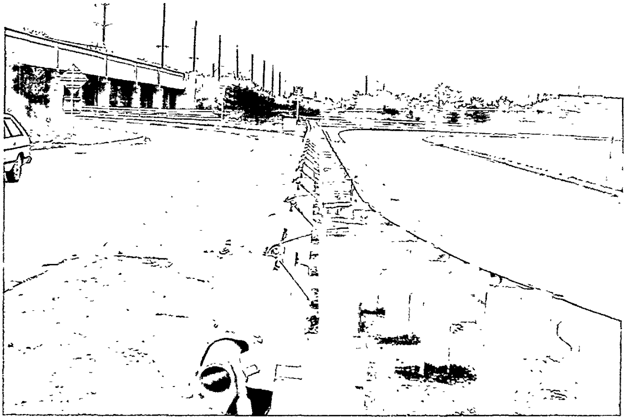


FIGURE 5.12 Self-Restoring Barrier (SERB) Guardrail

in during a collision, keeping the rail face near vertical in the impact zone as the posts are pushed backwards. This raises the height of the rail and further minimizes the likelihood of a vehicle rolling over the barrier. Other modifications to the standard thrie-beam design which have been incorporated into this barrier are: deletion of the rectangular post bolt washers and increase in top of rail height to 860 mm.

Impact performance: This system has been crash tested only at the extremes of the current vehicle fleet. Successful crash tests have been conducted with an 820-kg vehicle, a 9100-kg school bus (90 km/h, 15°), and a 14,500-kg intercity bus (97 km/h, 14°). Dynamic lateral deflection in the school bus test was 0.9 m.

Repair costs for either of the thrie-beam systems may be considerably less than other metal beam guardrail systems because the thrie-beam is not significantly damaged in shallow-angle impacts. Even for moderate to severe crashes, the barrier remains functional and does not usually require immediate repair. Also, thrie-beam is generally easier to install and maintain than a w-beam/rubrail system, where a higher effective barrier height is the design goal.

5.4.1.8 Self-Restoring Barrier (SERB) Guardrail

The self-restoring barrier (SERB) guardrail is a high-performance roadside barrier designed to be maintenance free for most impacts and capable of containing and redirecting larger vehicles. As shown in Figures 5.12, this system is comprised of a tubular thrie-beam rail element supported from wood posts by steel pivot bars and cables. Top of rail is set at 840 mm. When impacted, the rail deflects backwards and up, returning to its original position after the vehicle has been redirected.

Impact Performance: This system has been successfully crash tested for a wide range of vehicles, from an 820-kg car to an 18,000-kg intercity bus (92 km/h, 16°). Dynamic lateral deflection of the rail element in the standard strength test (2000-kg car) was 0.8 m and in the bus test was 1.2 m.

Actual field performance of the system to date has confirmed that the SERB is essentially maintenance free (except when installed on sharp-radius curves) and significantly minimizes the likelihood of occupant injuries. The SERB has the highest initial cost of any of the barriers presented in this section, costing about twice as much as the concrete safety shape. The combination of high cost and high performance makes this barrier more suited for use at high accident frequency locations than to system-wide use.

5.4.1.9 Steel-Backed Wood Rail

The semi-rigid barrier shown in Figure 5.13 was developed as an aesthetic alternative to conventional guardrail systems. The system consists of a wood rail backed with a steel plate and supported on timber posts. The steel plate provides needed tensile strength to the system. The wood members provide a more rustic appearance than the steel and concrete normally used in barriers. Thus, this railing is often specified for use along roads under the jurisdiction of the National Park Service and similar agencies.

Impact performance: To date, this railing has been successfully crash tested with an 820-kg vehicle at 81 km/h

FIGURE 5.13 Steel-Backed Wood Rail

and an impact angle of 20° and with a 2000-kg vehicle at 81 km/h and an impact angle of 25°. It is appropriate for use at locations where impacts within these ranges can be expected.

5.4.1.10 Concrete Safety Shape

The concrete safety shape roadside barrier is a rigid system having a sloped front face and a vertical back face. Except for the back face, the design details and performance of this barrier are identical to the concrete median barrier (CMB) and the reader is referred to Section 6.4.1.7 for a more complete discussion of this design. The reduced cross-section of this barrier (as compared to the CMB) makes it more vulnerable to overturn; therefore, the roadside version usually contains more reinforcing steel and/or a more elaborate footing design, unless earth support is available.

Top of barrier height for the basic design is 810 mm, *but higher designs have been tested and built to obtain* redirection of vehicles heavier than passenger cars.

Impact performance: While several of the semi-rigid barriers are capable of containing and redirecting buses, only rigid barriers have generally been tested with vehicles as large as tractor-trailer combinations. The New Jersey shape has been the most commonly tested concrete barrier design in recent years, and it has generally been tested in the median barrier configuration. At a height of 810 mm, this barrier shape has successfully redirected vehicles in the 820-2000 kg range and has occasionally redirected buses up to 18,000 kg during moderate impacts. A 1070-mm New Jersey shape barrier has successfully redirected a 36,300-kg tractor-trailer at 15° and 84 km/h.

To counteract the overturning moment of trucks with higher centers of gravity or unrestrained loads, walls even higher than 1070 mm are effective. At least two significantly higher barriers have been constructed. One highway agency constructed a 2290-mm high heavily reinforced safety shape on the outside of a loop ramp that had been the scene of numerous truck accidents. This installation has contained all impacting tractor-semitrailers but has not totally eliminated the rollover problem.

A second truck barrier consisted of a 1630-mm high concrete safety shape buttressed by an earth berm and topped with a metal w-beam guardrail, raising its total height to 2310 mm. The base of the wall was 1070 mm and its top width was 710 mm. The back of the wall was vertical. This installation is shown in Figure 5.15. Since its completion, the truck barrier was hit once by a large vehicle which left the scene. The guardrail along the top of the wall was pushed back slightly and the concrete was scraped, but no repairs were necessary. The use of the earth berm eliminated the need for an extensive footing and for excessive reinforcing in the wall itself. The semi-rigid metal beam guardrail on top appears to limit vehicle roll and minimize rebound in heavy vehicle impacts.

5.4.1.11 Stone Masonry Wall

A barrier consisting of a reinforced concrete core (pre-cast or cast in place) that is faced and capped with stone and mortar

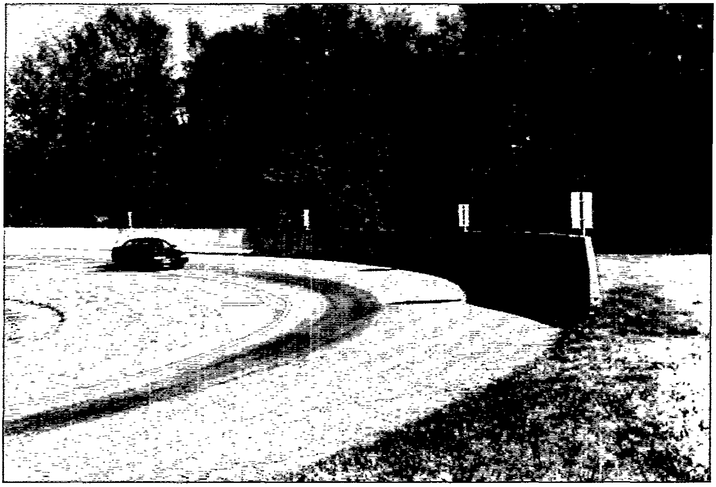


FIGURE 5.14 Extended Concrete Safety Shape Barrier

to give it the appearance of a vertical-faced stone masonry wall has been developed as an aesthetic barrier for use by the National Park Service for roads under its jurisdiction.

Impact performance: A smooth-faced design was successfully crash tested with an 820-kg car impacting at 97 km/h and approximately 15° and a 1950-kg car at 97 km/h and a 25° angle.

A 690-mm high barrier consisting of rough stone masonry covering a 510-mm high reinforced concrete core has also been successfully tested at 97 km/h with 820-kg

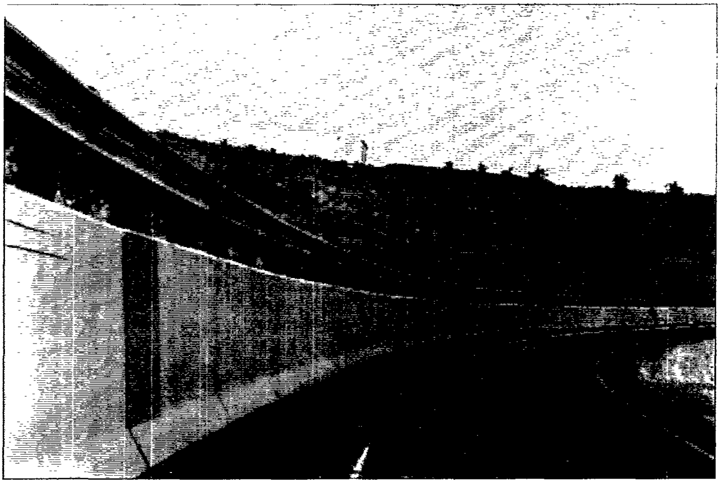


FIGURE 5.15 Extended Concrete Safety Shape/Metal Rail Barrier

and 2000-kg cars. The 50-mm deep raked mortar joints add to the rustic appearance of this barrier.

5.4.2 Transition

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. Since the most common use of a transition section occurs between approach roadside barriers and bridge rail ends, the reader should refer to Section 7.8 in Chapter 7 for a full discussion on transition sections that are considered operational.

5.5 SELECTION GUIDELINES

Once it has been decided that a roadside barrier is warranted, a specific barrier type must be selected. Although this selection process is complicated by a number of variables and the lack of objective criteria, there are some general guidelines that can be followed. The most desirable system is usually one that offers the required degree of shielding at the lowest cost. Table 5.2 summarizes the factors that should be considered before making a final selection. Each of these factors is described in more detail in the following subsections.

5.5.1 Barrier Performance Capability

The first decision to be made when selecting an appropriate traffic barrier concerns the level of performance required. Traditionally, most barriers have been developed and tested for passenger cars and offer marginal protection when struck by heavier vehicles such as trucks and buses at high speeds and large angles of impact. If passenger vehicles are the main concern, a standard railing which satisfies other concerns (as listed in subsequent sections) will normally be selected. Locations with poor geometrics, high traffic volumes and/or speeds, and a significant volume of heavy truck traffic may warrant a higher performance level or stronger railing system. This is especially true if barrier penetration by a vehicle is likely to have serious consequences to other than the motorist. Similarly, for low-volume, low-speed roadways, a standard barrier may not be cost-effective. At locations like these, a less expensive system may adequately contain the likely range of expected vehicle impacts. Any design used should indicate satisfactory performance, either through crash testing or favorable accident experience within the range of expected conditions.

The roadside barriers identified in Section 5.4 are listed in general order of increasing capabilities to contain and redirect large vehicles. Information on the specific type and weight of vehicle that was successfully contained and redirected by each barrier is included so the designer can select a barrier system that is capable of restraining a design vehicle larger than a standard-sized automobile.

TABLE 5.2 Selection Criteria for Roadside Barriers

Criteria	Comments
1. Performance Capability	Barrier must be structurally able to contain and redirect design vehicle.
2. Deflection	Expected deflection of barrier should not exceed available room to deflect.
3. Site conditions	Slope approaching the barrier and distance from traveled way may preclude use of some barrier types.
4. Compatibility	Barrier must be compatible with planned end anchor and capable of transitioning to other barrier systems (such as bridge railing).
5. Cost	Standard barrier systems are relatively consistent in cost, but high-performance railings can cost significantly more.
6. Maintenance	
A. Routine	Few systems require a significant amount of routine maintenance.
B. Collision	Generally, flexible or semi-rigid systems require significantly more maintenance after a collision than rigid or high performance railings.
C. Materials storage	The fewer different systems used, the fewer inventory items/storage space required.
D. Simplicity	Simpler designs, besides costing less, are more likely to be reconstructed properly by field personnel.
7. Aesthetics	Occasionally, barrier aesthetics is an important consideration in its selection.
8. Field Experience	The performance and maintenance requirements of existing systems should be monitored to identify problems that could be lessened or eliminated by using a different barrier type.

5.5.2 Barrier Deflection Characteristics

Once the desired performance level or barrier capability has been determined, site characteristics may dictate the type of barrier to install. If the distance between the barrier and the shielded object or terrain feature is relatively large, a barrier which deflects upon impact, thereby imposing lower impact forces on the vehicle and its occupants, may be the best choice. If the obstacle is immediately adjacent to the barrier, a semi-rigid or rigid railing system may be the only choice available. Most semi-rigid systems can be strengthened locally by adding additional posts or by reinforcing the rail element to shield isolated fixed objects located near the rail. Table 5.3 summarized the results of a computer simulation using the Numerical Analysis of Roadside Design (NARD) to determine maximum deflections for Standard SGR04a and SGR09 systems by varying post spacing and using single or double rails. The results should be reasonably accurate; however, as they were generated by computer simulation, they may not be as precise as indicated in the table. This table should be used to indicate a safe range and not an exact placement guide for fixed objects beyond the barrier. It should be noted that the table assumes adequate anchorage and a strong soil.

5.5.3 Site Conditions

The choice of barrier type will often be influenced by conditions at the site. The distance from the edge of the traveled way, if too great, may preclude the use of a rigid barrier. If the barrier is to be placed on a slope steeper than about 1:10, a flexible type should be used. Narrow grade widths, with corresponding narrow shoulders, may result in reduced post restraint and the need for deeper embedment, a closer post spacing, or soil plates.

5.5.4 Compatibility

As a general practice, most highway agencies use only a few different roadside barrier systems on new construction and on reconstruction. The advantages of this are relatively obvious: the systems in use have been proven effective over the years; construction and maintenance personnel are familiar with the systems; parts and inventory requirements are simplified when only a few different types of barrier are routinely used; and end treatments/transition sections for normal installations can also be standardized. The only time a non-standard or special barrier design need be considered is when site characteristics or performance requirements cannot be satisfied with a standard railing.

TABLE 5.3 Summary of Maximum Deflections
(Simulation of 2000-kg Sedan at 97 km/h)

Run Number	Post Spacing (mm)	Beam Description	Impact Angle	Maximum Deflection (mm)
1	1905	Sgl W-Beam	15	589
2	1905	Sgl W-Beam	25	907
3	952	Sgl W-Beam	15	389
4	952	Sgl W-Beam	25	541
5	952	Dbl W-Beam	15	358
6	952	Dbl W-Beam	25	437
7	476	Dbl W-Beam	15	NA
8	476	Dbl W-Beam	25	320
9	1905	Sgl Thrie-Beam	15	488
10	1905	Sgl Thrie-Beam	25	716
11	952	Sgl Thrie-Beam	15	386
12	952	Sgl Thrie-Beam	25	480
13	952	Dbl Thrie-Beam	15	333
14	952	Dbl Thrie-Beam	25	414
15	952	Sgl Thrie-Beam	15	NA
16	476	Sgl Thrie-Beam	25	353
17	476	Dbl Thrie-Beam	15	NA
18	476	Dbl Thrie-Beam	25	307

5.5.5 Life Cycle Costs

Initial costs and future maintenance costs of alternate barrier systems may weigh heavily in the final selection process. Normally, the initial cost of a system increases as its strength increases, but maintenance costs decrease. Conversely, a system having a relatively low installation cost usually requires significantly more maintenance effort following impacts.

5.5.6 Maintenance

Maintenance factors can be grouped into one of three categories: routine maintenance, collision maintenance, and material and storage requirements.

5.5.6.1 Routine Maintenance

Routine maintenance costs are usually not appreciably different for any of the operational roadside barrier systems. Although some cleaning and painting is occasionally done, use of preservative-treated wood posts and galvanized steel posts and rail components have nearly eliminated the need for this activity. Some systems may interfere more with right-of-way mowing and vegetation control, but no one system appears to create significantly more problems in this area than any of the others.

5.5.6.2 Collision Maintenance

Collision maintenance includes any and all repairs or adjustments to barriers that are necessitated by vehicle impacts. These costs 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 along a particular installation depends upon a number of factors including traffic speed and volume, roadway alignment, and the distance between the edge of the traveled way and the barrier itself. The extent of barrier damage for any specific impact depends upon the strength of the railing system. Collision maintenance costs may become an overriding consideration in areas where traffic volumes are extremely high, and collisions with the barrier are frequent. This is almost always the case along urban freeways, where rail repair is difficult for a repair crew to accomplish without interfering with the motorists using the roadway. For this reason, a rigid traffic barrier such as the concrete safety shape is often the barrier of choice at such locations.

A consideration in collision maintenance for post and rail systems is the ability of the rail element and possibly the posts to be re-used after a hit. Savings may be realized if the rail can be straightened. In some cases, of course, the rail will be damaged beyond repair in which case salvage value may be a consideration.

5.5.6.3 Material and Storage Requirements

Before selecting a barrier system, an effort should be made to determine the future availability of the materials needed for repairs and their storage requirements. The need for stocking spare parts increases as the number of required parts increases. Thus, there are obvious advantages to using only a few barrier systems whose component parts are standardized, easy to stockpile, and readily available.

5.5.6.4 Simplicity of Barrier Design

The simpler the railing system is, the easier it is to repair properly. Thus, the degree of expertise or the level of working knowledge of the system by the repair crew should be considered when selecting a barrier. An operational system that is improperly installed or maintained is only partially effective at best.

5.5.7 Aesthetic and Environmental Considerations

While aesthetics are a concern, they are not normally controlling factors in the selection of a roadside barrier except in the environmentally sensitive locations such as recreational areas or parks. In these instances, a natural-looking barrier that blends with its surroundings is often selected. In such cases, it is important that the systems used be crashworthy as well as visually acceptable to the highway agency.

Environmental factors may be important to consider in the selection process. For example, barriers with considerable frontage area may contribute to drifting of sand or snow in some areas. Snow plow operators should be cautioned against running the blade next to the face of roadside barriers. Experience has shown that this practice will tear a metal rail and loosen mounting hardware and posts. Certain types of railing may deteriorate rapidly in highly corrosive urban/industrial environments. In some cases, solid barriers may restrict sight distances of motorists entering the highway from a side road or intersection or may block a motorist's view of a particularly scenic panorama.

5.5.8 Field Experience

There is no substitute for documented proof of a barrier's field performance. If a particular barrier system is working satisfactorily and does not require an extraordinary amount of maintenance, there is little reason to install a barrier for which these characteristics are not conclusively known. If site conditions warrant a non-standard installation, the highway agency which developed and/or used the new system should be contacted for specific information on the system and on its performance.

It is particularly important that impact performance and repair cost data be maintained by appropriate highway agency personnel and that the information be made available to design and construction engineers charged with selecting and installing traffic barriers.

5.6 PLACEMENT RECOMMENDATIONS

Having decided that a roadside barrier is warranted at a given location and having selected the type of barrier to be used, the design engineer must specify the exact layout required. The major factors that must be considered include the following:

- lateral offset from the edge-of-traveled way
- terrain effects
- flare rate
- length of need

Most of these factors are interrelated to the extent that the final design may be a compromise selected by the designer. More detailed guidelines on each of these factors are included in the next subsections.

TABLE 5.4 Suggested Shy Line Offset (L_S) Values

Design Speed (km/h)	Shy Line Offset L_S (m)
130	3.7
120	3.2
110	2.8
100	2.4
90	2.2
80	2.0
70	1.7
60	1.4
50	1.1

5.6.1 Lateral Offset

As a general rule, a roadside barrier should be placed as far from the traveled way as conditions permit. Such placement gives an errant motorist the best chance of regaining control of the vehicle without having an accident. It also provides better sight distance, particularly at nearby intersections.

It is generally desirable that there be uniform clearance between traffic and roadside features such as bridge railings, parapets, retaining walls, and roadside barriers, particularly in urban areas where there is a preponderance of these elements. Uniform alignment enhances highway safety by reducing driver concern for and reaction to those objects. The distance from the edge of the traveled way, beyond which a roadside object will not be perceived as an obstacle and result in a motorist's reducing speed or changing vehicle position on the roadway, is called the shy line offset. This distance varies for different design speeds as indicated in Table 5.4. If possible, a roadside barrier should be placed beyond the shy line offset, particularly for relatively short, isolated installations. For long, continuous runs of railing, this offset distance is not so critical, especially if the barrier is first introduced beyond the shy line and gradually transitioned nearer to the roadway. Uniform alignment also reduces the probability of vehicle snagging. However, care must be exercised to insure proper transition designs where a roadside barrier connects to one of these other features. Care must also be exercised to insure a proper barrier-to-obstruction distance, as discussed below.

Where a roadside barrier is needed to shield an isolated condition, adherence to the uniform clearance criteria is not critical. It is more important in such cases that the barrier be located as far from the traveled way as conditions permit. However, short gaps (less than approximately 60 m) between barrier installations should be avoided, particularly when the cost of the additional barrier is about the same as the cost to install two separate end anchors, and access behind the rail for maintenance or other purposes is not required.

The distance a barrier will deflect upon impact is a critical factor in its selection as well as in its placement, especially if the obstruction being shielded is a rigid object. Figure 5.16 illustrates the two basic situations where deflection distance must be considered. If the obstruction being shielded is a rigid object, the barrier-to-object distance should be sufficient to avoid snagging by the vehicle on the rigid object. If the rail is hit by a vehicle with a relatively high center of gravity, the vehicle may roll or tip far enough to allow the vehicle to strike the shielded object even if the design deflection distance exists. This factor should be considered if the vehicle of concern is significantly larger than a passenger vehicle, pickup truck, or van.

The barrier-to-obstruction distance for rigid objects should not be less than the dynamic deflection of the barrier for impact by a full-sized automobile at impact conditions of approximately 25° and 100 km/h. (Some reduction in deflection distance may be justified if the operating speed is less than 100 km/h.) In some cases, the available space between the barrier and the object may not be adequate. In such cases, the barrier should be stiffened in advance of and alongside the fixed object. Commonly used methods to reduce deflection in a semi-rigid or flexible barrier system include reduced post spacing, increased post size or use of soil plates, intermediate anchorages, and stiffened rail elements. The effects on deflection of reduced post spacing are shown in Table 5.3 with the individual barrier descriptions.

If an embankment requires shielding, the barrier-to-embankment distance should be sufficient to provide adequate support for the posts to ensure proper operational characteristics of the barrier. However, limited test results indicate that the offset distance for embankments is not as critical as it is for rigid objects. A 0.6 m distance, as shown in Figure 5.16, is desirable for adequate post support but may vary depending on the slope of the embankment, soil type, expected impact conditions, and post cross-section and embedment. Deflection characteristics of selected roadside barriers are given in Section 5.4.

5.6.2 Terrain Effects

Regardless of the type of roadside barrier being used or the size and type of vehicle which strikes it, the best results will usually occur if, at the moment of impact, all of the vehicle's wheels are on the ground and its suspension system is neither compressed nor extended. Thus, terrain conditions between the traveled way and the barrier can have significant effects on the barrier's impact performance.

Curbs and roadside slopes are two particular features which deserve special attention. A vehicle which traverses one of these features prior to impact may override the barrier if the vehicle is partially airborne at the moment of impact or may submarine under the rail elements and snag on the support posts if it strikes the barrier too low. Limited research studies and computer simulations have provided some information on the dynamic behavior and trajectories of vehicles traversing curbs or slopes. The impact position of a car relative to a roadside barrier at a given lateral distance from a curb or slope is known for a variety of impact conditions (vehicle mass, speed, and angle). These data are presented in the following two subsections.

5.6.2.1 Curbs

Section 3.4.1 addresses the use of curbs primarily as drainage control features and presents only very general guidelines concerning their use in conjunction with traffic barriers. When a vehicle strikes a curb, the trajectory of that vehicle depends upon several variables: the size and suspension characteristics of the vehicle, its impact speed and angle, and the height and shape of the curb itself.

Crash tests have shown that use of any guardrail/curb combination where high-speed, high-angle impacts are likely should be discouraged. Where there are no feasible alternatives, the use of a curb no higher than 100 mm or stiffening of the guardrail to reduce its deflection by bolting a w-beam to the back of the posts or the addition of a rubrail usually proves satisfactory. On lower speed facilities, a vaulting potential still exists, but since the risk of such an occurrence is lessened, a design change may not be cost effective. A case-by-case analysis of each situation considering anticipated speeds and consequences of vehicular penetration should be used.

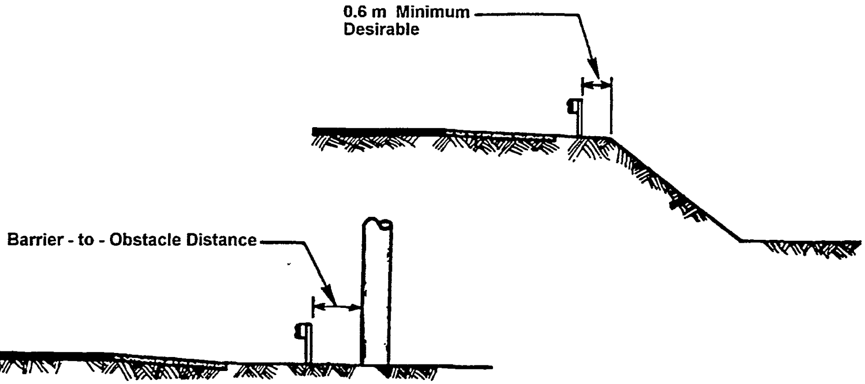


FIGURE 5.16 Recommended Barrier Placement for Optimum Performance

Curb/barrier combinations should be crash tested if possible to quantify expected railing performance under typical impact conditions if extensive use of the combination is planned.

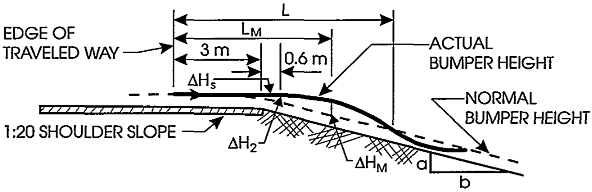
5.6.2.2 Slopes

Most roadside barriers are designed for and tested on level terrain. When a barrier is placed on slopes steeper than 1:10, studies have shown that for certain encroachment angles and speeds an errant vehicle may go over many standard roadside barriers or impact them too low.

As a car leaves the traveled way and crosses the shoulder and the embankment, the bumper path deviates from the normal bumper height as shown. The primary area of concern is the zone of higher than normal bumper height. A barrier placed in this zone can be expected to be hit at a higher than normal bumper position, and unless it has been designed for such impacts, its performance may be inadequate.

Five parameters have been selected to describe the embankment data. With reference to Figure 5.17 these are ΔH_S, ΔH_M, ΔH_2, L_M and L. Values of ΔH_S, and ΔH_2 are important because most roadside barriers are placed between the edge of the shoulder and 0.6 m off the shoulder. Table 5.5 contains trajectory data for rounded embankments for 100-km/h encroachments at angles of 25° and 15°. These numbers were obtained primarily from computer simulations and are included mainly to illustrate the problem rather than to provide design guidelines.

The type of barrier also comes into play. Strong post w-beam and thrie-beam installations were tested on 1:6 slopes and found to be only marginally satisfactory, due to the tendency of the rail element to bend backward and "ramp" the vehicle. These installations were successful in redirecting vehicles impacting at the more common angle of 15° but ramped vehicles in the more severe 25° tests. Based on these results, it is recommended that existing installations of these barrier systems may be retained (within the placement guidelines of Figure 5.18), but new installations on 1:6 slopes are not generally recommended. In this same series of tests, cable guardrail on 1:6 slopes performed very well for both angles of impact.



ΔH_S = HEIGHT BUMPER ABOVE NORMAL HEIGHT
AT OUTER EDGE OF SHOULDER
ΔH_M = MAXIMUM HEIGHT BUMPER ABOVE
NORMAL HEIGHT
ΔH_2 = HEIGHT BUMPER ABOVE NORMAL HEIGHT
AT 0.6 m FROM OUTER EDGE OF SHOULDER

FIGURE 5.17 Design Parameters for Vehicle Encroachments on Embankments

TABLE 5.5 Example Bumper Trajectory Data (see text)

ENCROACHMENT ANGLE (DEG)	ROUNDING 2R (m)	EMBANKMENT SLOPE a:b	L (m)	ΔH_S (mm)	ΔH_2 (mm)	ΔH_M (mm)	ΔL_M (m)
25	2.9	1:6	9.1	102	122	175	6.1
25	4.9	1:4	10.7	102	122	200	7.0
25	6.8	1:3	12.2	102	122	200	7.0
25	10.5	1:2	12.2	102	122	200	7.0
15	1.4	1:6	7.0	48	71	114	4.9
15	2.4	1:4	7.9	48	71	175	5.5
15	3.4	1:3	9.5	48	71	210	6.1
15	5.2	1:2	10.1	48	71	486	7.6

In summary, roadside barriers perform most effectively when they are installed on slopes of 1:10 or flatter. Caution should be taken when considering installations on slopes as steep as 1:6 and only if they are located so that an errant vehicle is in its normal attitude at the moment of impact. Depending on actual encroachment conditions, the distance from the traveled way at which a barrier can be installed and expected to perform adequately will vary, but in general the placement recommendations shown in Figure 5.18 should be followed.

5.6.3 Flare Rate

A roadside barrier is considered flared when it is not parallel to the edge of the traveled way. Flare is normally used to locate the barrier terminal farther from the roadway; to minimize a driver's reaction to an obstacle near the road by gradually introducing a parallel barrier installation; to transition a roadside barrier to an obstacle nearer the roadway such as a bridge parapet or railing; or to reduce the total length of rail needed.

One disadvantage to flaring a section of roadside barrier is that the greater the flare rate, the higher the angle at which the barrier can be hit. As the angle of impact increases, the severity of the accident increases, particularly for rigid and semi-rigid barrier systems. A second disadvantage to flaring a barrier installation is the increased likelihood that a vehicle will be redirected back into or across the roadway following an impact. This situation is especially undesirable on two-way roadways where the impacting vehicle could be redirected into oncoming traffic.

As shown in Table 5.6, the maximum recommended flare rates are a function of highway design speed and barrier type. Flatter flare rates may be used and often are, particularly where extensive grading would be required to ensure a flat approach to the barrier from the traveled way. This is often the case on existing facilities having relatively steep embankment slopes. It should also be noted that a flatter flare rate is suggested when a barrier must be located within the shy line offset distance.

5.6.4 Length of Need

Figure 5.19 illustrates the variables that must be considered in designing a roadside barrier to shield an obstruction effectively. The primary variables are the Runout Length, L_R, and the Lateral Extent of the Area of Concern, L_A. Both of these factors must be clearly understood by the designer to be used properly in the design process.

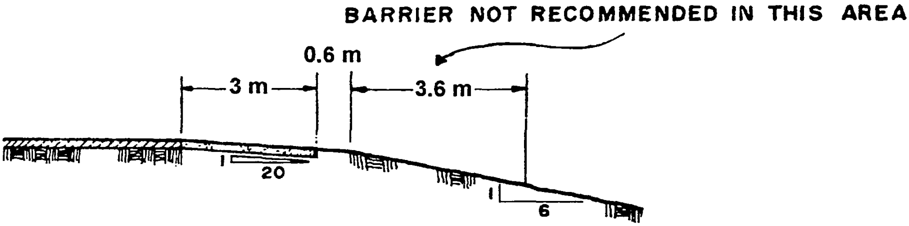


FIGURE 5.18 Recommended Barrier Location on 1:6 Slope

TABLE 5.6 Suggested Flare Rates for Barrier Design

Design Speed (km/h)	Flare Rate for Barrier inside Shy Line	Flare Rate for Barrier beyond Shy Line	
		*	**
110	30:1	20:1	15:1
100	26:1	18:1	14:1
90	24:1	16:1	12:1
80	21:1	14:1	11:1
70	18:1	12:1	10:1
60	16:1	10:1	8:1
50	13:1	8:1	7:1

* suggested maximum flare rate for rigid barrier systems

** suggested maximum flare rate for semi-rigid systems

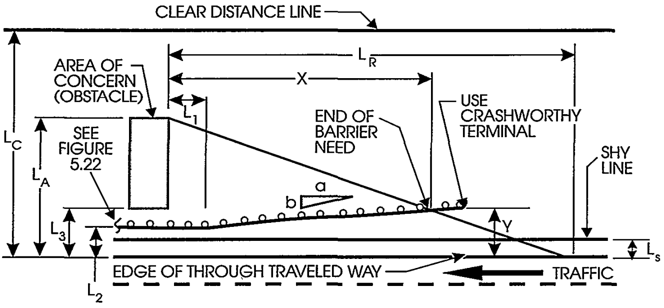


FIGURE 5.19 Approach Barrier Layout Variables

The Runout Length, L_R, is the theoretical distance needed for a vehicle that has left the roadway to come to a stop. It is measured from the upstream extent of the obstruction along the roadway to the point at which a vehicle is assumed to leave the roadway. These distances are variable, based on operating speeds and the available friction between the vehicle tires and the ground. The figures shown in Table 5.7 are based in part on an adjustment of the findings of Hutchinson and Kennedy from their study of freeway median encroachments and in part on driver reaction times and vehicle stopping characteristics for low-speed encroachments. They have been further modified to lessen the lengths of barriers recommended on low-volume roads and streets. Some highway agencies consider these values to be excessive and have developed different methods to determine the length of need based on locally available data. One alternate method is to assume a specific encroachment angle and install a length of barrier that will intercept a vehicle's runout path.

The Lateral Extent of the Area of Concern, L_A, is the distance from the edge of the traveled way to the far side of the fixed object or to the outside edge of the clear zone, L_C, of an embankment or a fixed object that extends beyond the clear zone. Selection of an appropriate L_A distance is a critical part of the design process and is illustrated in the examples at the end of this Section.

Once L_R and L_A have been selected, the length of barrier required at a specific location depends upon the tangent length of barrier upstream from the Area of Concern, (L_1), its lateral distance from the edge of the traveled way (L_2), and the flare rate (a:b) specified for the installation. There are several factors that must be considered in the selection of these three variables.

As previously noted, a traffic barrier should be set as far as possible from the traveled way. This practice minimizes the likelihood that the barrier will be hit by providing a motorist with the maximum amount of traversable, unobstructed recovery area. It is critical that a vehicle contact most types of barriers with its center of gravity at or near its normal position. This reduces the tendency for a vehicle to wedge under or go over the barrier. Thus, the slopes between a barrier installation and the roadway should be 1:10 or flatter or the barrier should be far enough from the road that a vehicle is on the ground with its suspension system neither compressed nor extended at the time of

TABLE 5.7 Suggested Runout Lengths for Barrier Design

	Traffic Volume (ADT)			
	Over 6000	2000-6000	800-2000	Under 800
Design Speed (km/h)	Runout Length L_R (m)	Runout Length L_R (m)	Runout Length L_R (m)	Runout Length L_R (m)
110	145	135	120	110
100	130	120	105	100
90	110	105	95	85
80	100	90	80	75
70	80	75	65	60
60	70	60	55	50
50	50	50	45	40

contact. Figure 5.18 approximates the acceptable location of a traffic barrier for approach slopes as steep as 1:6.

A second reason for installing a barrier as far as practical from the roadway is to keep the barrier from causing drivers to slow down, change lanes, or shift positions within their own traffic lanes. As noted in Section 5.6.1, the distance beyond which a driver will not react to an object near the roadway is called the shy line offset. This distance varies by design speed as shown in Table 5.4 and by type and location of objects. An object outside a paved or graveled shoulder generally has no measurable effect on a motorist's behavior. Problems arise when the roadway appears narrower, or is narrowed, such as at a bridge that is narrower than the approach roadway. On facilities with no shoulders, barriers or other fixed objects 1.8 meters or more from the edge of the traveled way may not create driver reactions. It is also worth noting that median barriers can be set closer to the edge of the driving lane without affecting vehicle placement. When the barrier is to the left, the driver can clearly see how close the barrier is, whereas for a right shoulder installation, depth perception becomes more of a problem for many drivers and they tend to position their vehicles further from the barrier than is necessary.

The tangent length of barrier immediately upstream from the area of concern, L_1, is a variable length selected by the designer. If a semi-rigid railing is connected to a rigid barrier, the tangent length should be at least as long as the transition section to reduce the possibility of pocketing at the transition and to increase the likelihood of smooth redirection if the guardrail is struck immediately adjacent to the rigid barrier.

The final variable to be selected by the designer to calculate the required length of guardrail at a specific location is the flare rate, a factor that was introduced in Section 5.6.3. The steeper this rate, the further from the roadway the barrier begins and the shorter the required length. However, a relatively steep flare results in increased impact angles and increases the need for slope flattening in the area between the roadway and the barrier. Recommended maximum flare rates for semi-rigid and rigid barriers are shown in Table 5.6. Note that the recommended flare rate for barriers within the shy line is approximately twice that for barriers located outside the shy distance.

Once the appropriate variables have been selected, the required length of need, X, in advance of the area of concern, for straight or nearly straight sections of roadway, can be calculated with the following equation:

$$X = \frac{L_A + (b \mid a)(L_1) - L_2}{b \mid A + (L_A) \mid (L_R)}$$

Note that for a parallel installation, i.e., no flare rate, the first equation reduces to:

$$X = \frac{L_A - L_2}{(L_A) \mid (L_R)}$$

The lateral offset, Y, from the edge of the traveled way to the beginning of the length of need can be calculated using the following equation:

$$Y = L_A - \frac{(L_A)}{(L_R)}(X)$$

Since metal beam guardrail is manufactured in nominal 3.8 or 7.6 meter lengths, the amount of rail installed should be a multiple of these lengths. The above formulas will serve to locate the beginning of the length of need for an approach barrier. To this length, a crashworthy end treatment must be added if this end treatment is located within the clear zone or in a location where it is likely to be struck. If the design of the end treatment permits vehicle penetration, the end treatment must extend upstream from the barrier itself to preclude a vehicle from going through the end treatment and then striking the shielded feature. If the approach barrier is on or near a cut section, it may be advantageous to terminate the barrier by anchoring it in the back slope.

Some highway agencies use a parabolic layout for a flared section, which is acceptable provided the maximum slope of the curve does not exceed the suggested flare rates in Table 5.6. However, these rates should be exceeded in the end treatments if greater flare rates are essential for proper impact performance. As an alternative to computing a length of need, design charts have been developed by some states to enable a length of barrier to be selected directly, based on standard conditions. Examples of such charts are shown in Figures 5.20 and 5.21 for flared and parallel installations respectively.

Figure 5.22 illustrates the layout variables of an approach barrier for opposing traffic. The length of need and the end of the barrier are determined in the same manner as previously described, but all lateral dimensions are measured from the edge of the traveled way of the opposing traffic, e.g., from the centerline for a two lane roadway. If there is a two-way divided roadway, the edge of the traveled way for the opposing traffic would be the edge of the driving lane on the median side.

There are three ranges of clear zone width, L_C, that deserve special attention for an approach barrier for opposing traffic. (Refer to Figure 5.22.)

1. If the barrier is beyond the appropriate clear zone, no additional barrier and no crashworthy end treatment is required.
2. If the barrier is within the appropriate clear zone but the area of concern is beyond it, no additional barrier

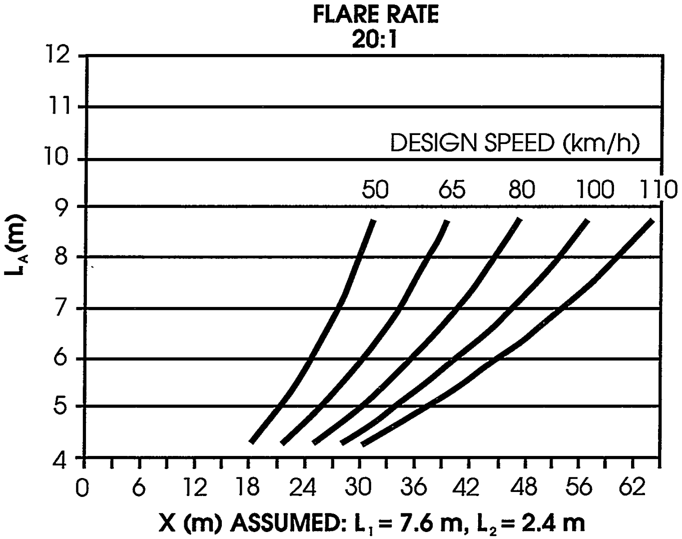


FIGURE 5.20 Example Design Chart for a Flared Roadside Barrier Installation

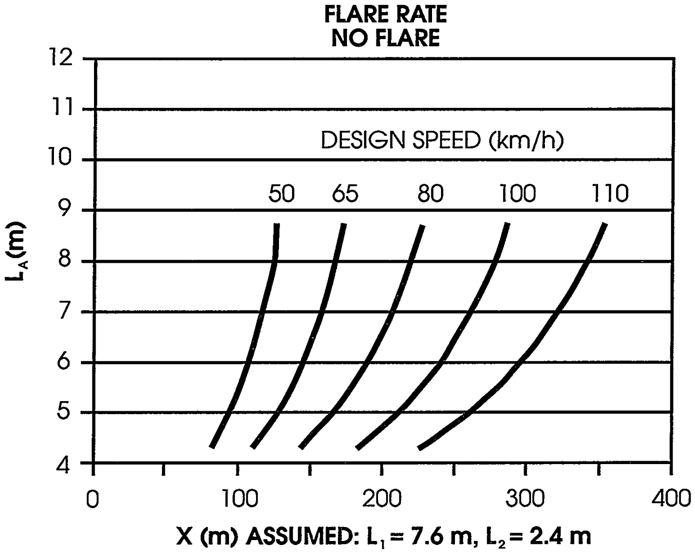


FIGURE 5.21 Example Design Chart for a Parallel Roadside Barrier

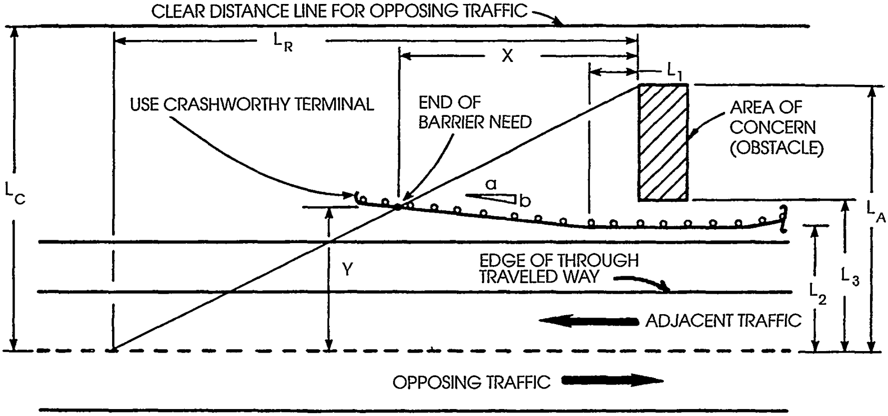


FIGURE 5.22 Approach Barrier Layout for Opposing Traffic

is required but a crashworthy end treatment should be used.

3. If the area of concern extends well beyond the appropriate clear zone (e.g., a river), the designer may choose to shield only that portion which lies within the clear zone by setting L_A equal to L_C.

The lateral placement of the approach rail should satisfy the criteria for embankment slopes. If the existing slope is steeper than 1:10, it is suggested that the slope be flattened as illustrated in Figure 5.23. In lieu of flattening the slope, the designer may decrease the flare rate of the barrier so the embankment criteria is not violated.

In many cases, particularly on projects which do not include a significant amount of earthwork, no flare is used and the barrier is installed parallel to the roadway. This requires a longer installation, the cost of which must be weighed against the cost of additional slope flattening. Perhaps the most straightforward method to determine length of need is to scale the barrier layout directly on the highway plan sheets. By selecting an appropriate runout length and the lateral distance to be shielded, the designer can specify a guardrail installation (i.e., lateral offset and flare) that satisfies all placement criteria. This method is most appropriate for determining the length of barrier needed to shield embankments or fixed objects on non-tangent sections of roadway. Figures 5.24 through 5.27 provide examples of this technique for typical situations.

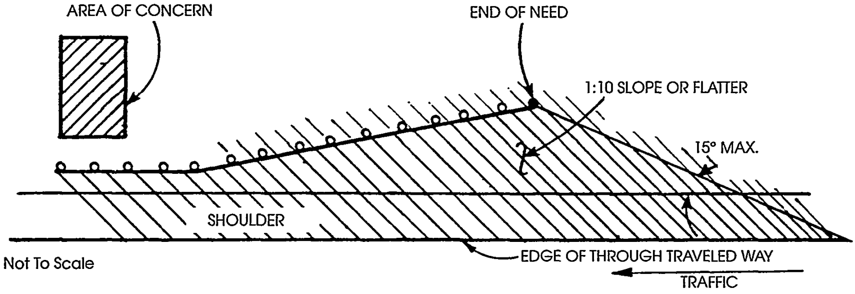


FIGURE 5.23 Suggested Roadside Slopes for Approach Barriers

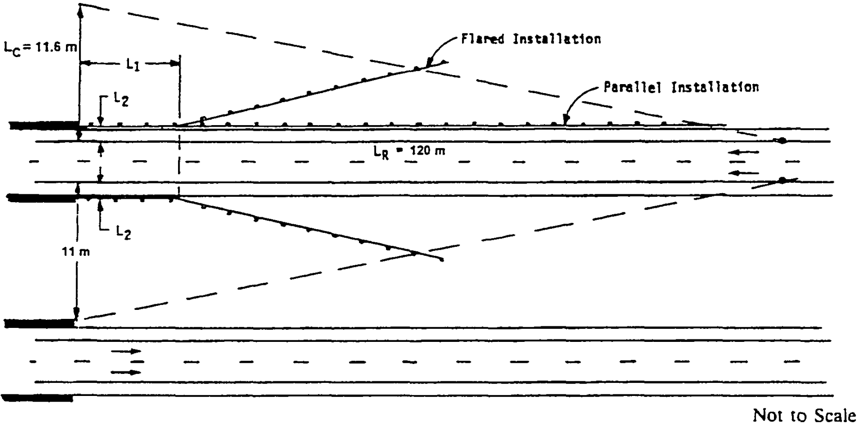


FIGURE 5.24 Example of Barrier Design for Bridge Approach

Given:
ADT = 6200
Speed = 110 km/h
Embankment slopes: 1:5 (right); 1:10 (median)

Select:
Clear Zone, L_C, = 11.5-14 m (for 1:5 slope from Table 3.1)
Clear Zone, L_C, = 9-10.5 m (for 1:10 median slope from Table 3.1)
Runout length, L_R, = 145 m (Table 5.5)
Transition, L_1, = 3.8 m
Barrier offset, L_2 = 3.6 m (right); 2.4 m (median)
Flare rate = 15:1 (Table 5.6)

Discussion: For the right shoulder installation, the designer can scale 145 m back from the bridge rail end and 11.5 m laterally from the same point. The hypotenuse of this triangle approximates a vehicle's runout path. To shield the bridge end and the river to the edge of the clear zone, the barrier installation must intersect this line. Based on the variables selected, a barrier length of 57.1 m is required. If this were an existing bridge and the approach embankment slopes were 1:2, the barrier would most commonly be installed parallel to the shoulder to minimize earthwork and approximately 84 m would be needed to shield the same area. Calculations for the flared installation are as follows:

$$\text{Length of need} = \frac{11.5 + (1/15)(7.6) - 3.6}{(1/15) + (11.5/145)} = 57.6 \text{ m (use 57.1)}$$

Note that on the median side, the designer may shield the entire opening even though this distance slightly exceeds the recommended clear zone for the 1:10 slope. This emphasizes that the clear zone distance is not a precise number and that engineering judgement must be used in its application.

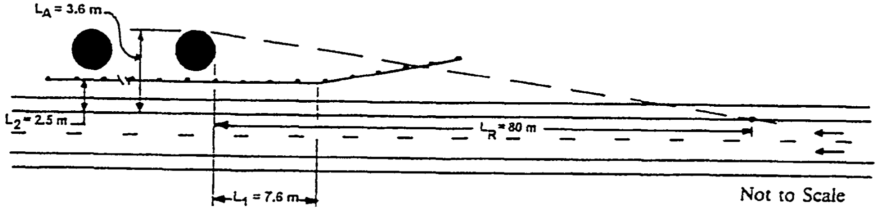


FIGURE 5.25 Example of Barrier Design for Bridge Piers

Given:
ADT = 850
Speed = 80 km/h
Embankment slope 1:10

Select:
Clear Zone, L_C, = 4.5-5 m (Table 3.1) (4.5 m chosen by designer)
Runout length, L_R, = 80 m (Table 5.7)
Barrier offset, L_2, = 2.4 m
Transition, L_1, = 7.6 m
Flare rate = 11:1 (Table 5.6)

Discussion: If the bridge piers are the only fixed object within the clear zone, the barrier needed is a function of L_A, L_1, L_R, and the selected flare rate. However, if the bridge abutment also lies within the clear zone, the designer may elect to shield it as well, in which case an L_A greater than 4.5 m would be used to determine the length of barrier needed in advance of the piers. The calculations for shielding only the piers are as follows:

$$\text{Length of need} = \frac{4.5 + (1/11)(7.6) - 2.4}{(1/11) + (4.5/95)} = 20.2 \text{ m (use 22.9)}$$

A semi-rigid rail system must be far enough in front of the piers to permit deflection of the rail without vehicle snagging on the piers; otherwise, a stiffened transition section must be used as in this example. Even if a fixed object is beyond the design deflection distance of a semi-rigid barrier, a vehicle with a high center of gravity may roll far enough to snag on the shielded object. If this is a major concern, a stiffer and/or higher barrier should be considered.

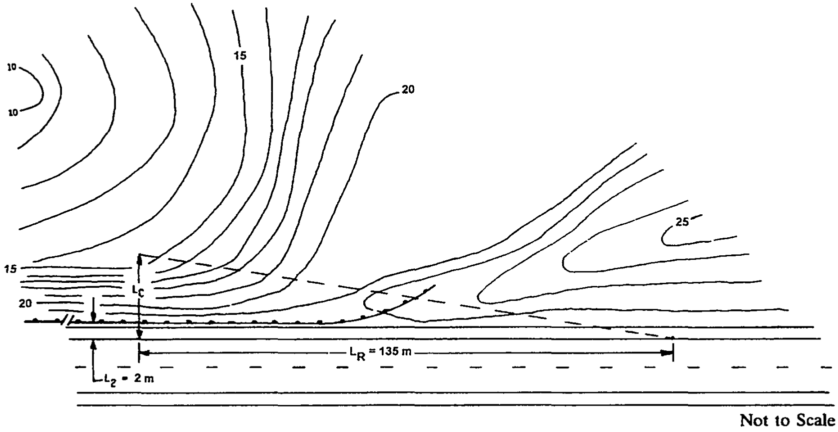


FIGURE 5.26 Example of Barrier Design for Non-traversable Embankment

Given: ADT = 3000
Speed = 110 km/h
Embankment slope at beginning of L_R,
= 1:6 slope at L_C is critical, e.g., 1:2

Select: Clear Zone, L_C, = 8.5-10 m (Table 3.1)
Runout length, L_R, = 135 m (Table 5.6)
Barrier offset, L_2, = 1.8 m

Discussion: The area of concern begins at the top of the critical slope. Since the purpose of a barrier installation is to prevent a vehicle from reaching a non-traversable terrain feature or fixed object, the designer may elect to shield more of the slope by selecting a larger clear zone distance. It is often advantageous to review planned barrier lengths on-site just before installation to ensure that the barrier shields the area of concern to the extent desired.

The barrier may be introduced by anchoring it in a backslope, thus placing an end treatment so that it is not vulnerable to impact. This treatment effectively blocks off the entire embankment area. However, if no backslope exists or if it would require a significantly longer barrier installation to reach it without exceeding the recommended flare rate, a free-standing end treatment remains appropriate.

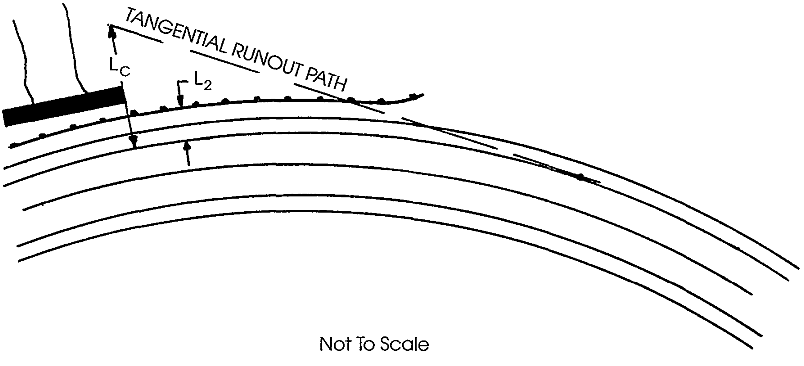


FIGURE 5.27 Example of Barrier Design for Fixed Object on Horizontal Curve

Given: ADT = 650
Speed = 100 km/h
Embankment slope = 1:6
Horizontal curvature = 450 m radius

Select: Clear Zone, L_C, = 5.0-5.5 m (Table 3.1) 5.5 m chosen by designer
Adjustment factor for curvature = 1.4 (Table 3.2)
Adjusted clear zone = 5.5 (1.4) = 7.7 m
Runout length, L_R, = not applicable (see discussions below)
Barrier offset, L_2, = 1.2 m
Flare rate: not applicable

Discussion: The length of need formula for a traffic barrier is directly applicable to straight highway alignment only. A vehicle leaving the road on the outside of a curve will generally follow a tangential runout path. Thus, rather than using the theoretical L_R distance to determine a barrier length of need, the tangent line from the curve to the outside edge of the obstacle (or to the clear zone if a continuous non-traversable terrain feature, such as the stream bed shown above, is being shielded) should be used to determine the appropriate length of barrier needed. The barrier length then becomes a function of the distance it is located from the edge of the driving lane and can most readily be obtained graphically by scaling. A flare rate is not generally used along a horizontal curve.

5.7 UPGRADING SYSTEMS

It has been noted that the number of fixed-object fatal accidents involving traffic barriers is exceeded only by fatal impacts with utility poles and trees. One possible explanation for the number of barrier-related fatalities is the fact that many older installations do not always meet currently recommended performance levels. Older installations usually fall into one of two categories—those that do not meet current structural guidelines and those that do not meet current design and location guidelines. Although barrier installations can be deficient in both categories, each will be discussed separately below. A suggested barrier inspection checklist is shown in Table 5.8.

5.7.1 Structural Inadequacies

Structural inadequacies can be defined as characteristics which would result in reduced performance if the rail were struck by passenger cars at design speeds and impact angles. The most obvious include: substandard or obsolete roadside barrier; inadequate post spacing; no block out or rub rail for a strong post system; inadequate, non-conforming, or non-existent end treatment; or inadequate transition section.

5.7.2 Design/Placement Inadequacies

Design and/or placement inadequacies are those which increase the likelihood of reduced performance from an otherwise acceptable barrier system. Four of the most common deficiencies in this category are barriers which are too short to shield completely an obstacle or non-traversable terrain feature; barriers with deflection distances which exceed the distance between the rail and the shielded fixed object; barriers which are constructed too high or too low; and barriers which are improperly placed on slopes or behind curbs. A design consideration is use of a low maintenance and/or higher performance level barrier in areas of frequent vehicle impacts.

5.7.3 Prioritizing Upgrading Needs

Deficient roadside barriers are generally upgraded through spot or system-wide safety improvement projects, or in conjunction with other roadway work, most commonly resurfacing, rehabilitation, or restoration projects. In each case, the designer must determine the scope and extent of the barrier upgrading to be accomplished. The major factors which should be considered are:

- nature and extent of barrier deficiency
- past accident history
- cost-effectiveness of recommended improvement

These factors are interrelated and the designer must oftentimes rely heavily on past experience and judgement to reach an optimal solution. The first step should be an analysis of the continued need for an existing barrier. If it is cost-effective to eliminate the shielded object by removal, relocation, or re-design, this is the option of choice. If the feature requiring shielding cannot be eliminated, the designer must assess the adequacy of the barrier installation. If the barrier is essentially non-functional (i.e., it cannot reasonably be expected to function satisfactorily under most expected impacts), it should be upgraded to current standards. Common deficiencies in this case include non-standard barrier types, transition sections and/or end treatments, barriers improperly installed on slopes or behind curbs, and installations that are too short, too low, or too high to be effective. In some cases these deficiencies will be so obvious that the best course of action is readily apparent; but many times the deficiencies may be marginal and a decision will be based on engineering judgement. Then the past accident history at a specific site (or area-wide accident experience with a specific feature) and the cost of upgrading the barrier must be considered. If traffic speeds and volumes are relatively low and the non-standard barrier is not in a location where impacts are likely, delineation of the untreated condition may be adequate until such time as full upgrading is deemed necessary.

TABLE 5.8 Roadside Barrier Inspection Checklist

- I. Structural Adequacy[1]
    - A. Longitudinal Section
        - 1. Standard barrier design[2]
        - 2. Adequate post spacing
        - 3. Rail element blocked out on strong-post system
        - 4. Adequate splices in rail element
    - B. Terminal
        - 1. Standard terminal design[2]
        - 2. Adequate anchorage strength
    - C. Transition Section
        - 1. Standard transition design[2]
        - 2. Adequate anchorage strength
        - 3. Adequate stiffening in advance of rigid system
        - 4. Adequate blockout and/or rubrail

- II. Functional Adequacy[3]
    - A. Longitudinal Section
        - 1. Adequate length to shield area of concern
        - 2. Proper height of rail[4]
        - 3. Proper flare rate
        - 4. Barrier to object distance exceeds barrier deflection distance
        - 5. Placement behind curb consistent with vehicle trajectory data (Figure 5.15 and Table 5.5)
        - 6. Placement on flat slopes (1:10) or on slopes up to 1:6 consistent with vehicle trajectory data
        - 7. Beam back-up plates present on steel strong-post system
    - B. Terminal
        - 1. Adequate clear recovery area behind yielding terminal
        - 2. Adequate offset of terminal end

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[1] Structural adequacy is inherent in the barrier itself, rather than resulting from design, placement, or maintenance.

[2] Standard systems or elements are those which are currently an approved agency standard or have been successfully crash tested. Certain barriers that fall outside these categories may be left in place depending on the characteristics of the barrier and the results of an engineering analysis of the site.

[3] Functional adequacy results from barrier design or placement and is essential for barrier effectiveness.

[4] Generally, a 75-mm variation from the nominal height is acceptable.

CHAPTER 6: MEDIAN BARRIERS

6.0 OVERVIEW

A median barrier is a longitudinal barrier most commonly used to separate opposing traffic on a divided highway. It is also used along heavily traveled roadways to separate through traffic from local traffic or to separate carpool/vanpool traffic from other highway users. By definition, any longitudinal barrier placed on the left side of a divided roadway may be considered a median barrier, but this chapter will address only those that are designed to redirect vehicles striking either side of the barrier.

This chapter references the performance requirements for median barriers, provides warrants for their use, and contains guidelines for selecting and installing an appropriate barrier system. The structural and safety characteristics of selected median barriers, including end treatments and transition sections, are presented. Finally, selection and placement guidelines are included for new construction and methods are presented for identifying and upgrading existing substandard systems.

6.1 PERFORMANCE REQUIREMENTS

The performance requirements for median barriers are identical to those for roadside barriers as stated in Section 5.1. National Cooperative Highway Research Program (NCHRP) Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features,* contains detailed information on the required series of standard crash tests needed to evaluate the performance of longitudinal barriers.

6.2 WARRANTS

As with all types of traffic barriers, a median barrier should be installed only if striking the barrier is less severe than the consequences that would result if no barrier existed. Figure 6.1 suggests a warrant for median barriers on high-speed, controlled-access roadways which have relatively flat, traversable medians. These criteria are based on a limited analysis of median crossover accidents[1] and research studies,[2] and are suggested for use in the absence of more current (or site-specific) data. Barriers are typically considered for combinations of average daily traffic (ADT) and median widths that fall within the indicated area. At low ADTs, the frequency of median encroachments is relatively low. Thus, for ADTs less than 20,000 and median widths within the optional areas of Figure 6.1, a barrier is warranted only if there has been a history of cross-median accidents. Likewise, for relatively wide medians the probability of a vehicle crossing the median is also low. Thus, for median widths greater than 10 m and within the optional area of the figure, a barrier may or may not be warranted, again depending on the cross-median accident history. Flat medians that are wider than 15 m do not warrant a barrier unless there is an adverse accident history. It should be noted that after a warranted median barrier is installed, accident severity may decrease, but accident frequency may increase since the space available for return-to-the-road maneuvers is reduced. Further, it should be noted that as a result of metrication the former warrant limit of 9.1 m (30 feet) became 10 m (32.8 feet). Existing medians with a width of 9.1 m or more should also be considered as meeting the suggested warrants.

Median barriers are sometimes used on high-volume, non-access controlled facilities. However, safely terminating such barriers can be difficult and sight distance may be a significant problem at intersections.

Special consideration should be given to barrier needs for medians separating roadways at different elevations. The ability of an errant driver leaving the higher roadway to return to the road or to stop diminishes as the difference in elevation increases. Thus, the potential for cross-over accidents increases. For such sections, the clear zone criterion given in Chapter 3 should be used as a guideline for establishing barrier need. Section 6.6.1.2 addresses the placement of barrier on sloped medians.

6.3 PERFORMANCE LEVEL SELECTION PROCEDURES

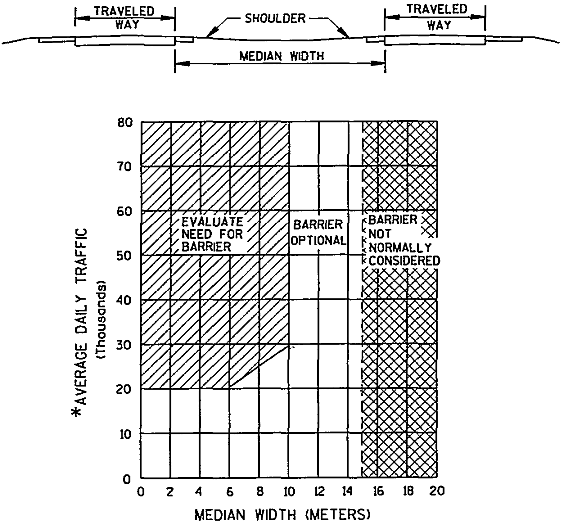
As with roadside barriers, most median barriers have been developed, tested, and installed with the intention of containing and redirecting passenger vehicles. Some highway agencies have identified locations, however, where heavy vehicle containment was considered necessary and have designed and installed high performance median barriers having significantly greater capabilities than commonly used designs. Factors most often considered in reaching a decision on such barrier use include:

- high percentage or large average daily number of heavy vehicles
- adverse geometrics (horizontal curvature)
- severe consequences of vehicular (or cargo) penetration into opposing traffic lanes

Section 6.4 includes information on the maximum size of vehicle which has been successfully crash tested for each median barrier system described in that Section.

6.4 STRUCTURAL AND SAFETY CHARACTERISTICS OF MEDIAN BARRIERS

This section identifies selected median barrier systems and summarizes the structural and safety characteristics of each. It is subdivided into standard sections, transitions, and end treatments. Characteristics unique to each system are emphasized.



* Based on a 5-year projection

FIGURE 6.1 Median Barrier Warrants for Freeways and Expressways

6.4.1 Standard Sections

As with roadside barriers, median barriers can be categorized as flexible, semi-rigid, or rigid. This section includes descriptions and performance capabilities of the most commonly used and recently developed median barrier systems, beginning with flexible median barriers and ending with rigid systems. Some barriers designed to restrain and redirect large vehicles are also identified and included in this section. The barriers to be addressed are:

- 3-Strand Cable
- 6-Strand Cable
- W-Beam (Weak Post)
- Box Beam
- Blocked-Out W-Beam (Strong Post)
- Blocked-Out Thrie-Beam (Strong Post)
- Self-Restoring Median Barrier
- Concrete Safety Shape
- Single Slope Concrete Barrier
- Quick Change Movable Barrier
- Earth Berm

Each of these systems is described in the following subsections. The mounting heights included in these descriptions are measured from the ground to the top of the rail, cable, or barrier. A 75-mm variation from the nominal heights shown is generally considered acceptable for the rigid systems, 50 mm for the flexible and semi-rigid systems. Additional information on individual median barrier systems, including design details, is included in Appendix C.

6.4.1.1 3-Strand Cable

This flexible barrier is essentially the same one described in Section 5.4.1.1 as a roadside barrier except, when used in a median, one of the 3 cables should be installed on the opposite side of each post from the other two.

A cable barrier should be used only if adequate deflection distance exists to accommodate approximately 3.5 m of movement, i.e., the median width should be at least 7 m if the barrier is centered. The cable barrier remains effective when mounted on a moderate slope (up to 1:6). Cable systems in order to function properly have to be installed and maintained as close to the design height as feasible. The approach should be flat, without a curb or a ditch. Proper anchorage at the ends is critical. To accommodate both larger and smaller vehicles, at least one State has installed the lower cable at 540 mm and the top cable at 840 mm. The center cable was set 690 mm above the ground. To date, this spacing has performed satisfactorily. Ontario has developed a one plane 6-strand cable on metal posts.

Although the cable guardrail is relatively inexpensive to install and performs well when hit, it must be repaired after each hit to maintain its effectiveness. Consequently, its use in areas where it is likely to be hit frequently is not recommended. Further, it is not recommended on sharp curves and on facilities with high truck volumes. A typical installation is shown in Figure 6.2.

6.4.1.2 Weak Post W-Beam

This system, shown in Figure 6.3, is similar to the roadside flexible barrier described in Section 5.4.1.2 except for the recommended mounting height of 840 mm and a 2.1 m design deflection distance. The weak post w-beam is even more sensitive to height variations than the cable barrier and should not be used as a median barrier where terrain irregularities exist. Because the w-beam barrier does not interlock with a vehicle sheet metal, the likelihood of going over or under the rail is increased if the impact is in a higher or lower than normal range. Consequently, this system is recommended for use only in relatively flat, traversable medians without curbs or ditches that could affect vehicle trajectories. It should not be used where frost heave or erosion is likely to alter the beam mounting height relative to the shoulder beyond 50 mm. A proper anchorage at each end is critical.

6.4.1.3 Box Beam

The box beam median barrier shown in Figure 6.4 is considered a semi-rigid barrier and is similar to the roadside box beam described in Section 5.4.1.4. Its design deflection distance is approximately 0.9 m.

As with the weak post w-beam, this system is most suitable for use in traversable medians having no significant terrain irregularities. The weak posts have to be repaired after most hits in order to maintain the correct beam height. Temporary supports may be used. Consequently, the box beam should not be used in areas where it is likely to be frequently hit. This system also performs well when located behind a mountable curb.

6.4.1.4 Blocked-Out W-Beam (Strong Post)

Blocked-out w-beam using wood or steel posts and blocks have been extensively used to prevent crossover accidents in relatively narrow medians. Since these are both semi-rigid systems having design deflection distances in the 0.6 to 1.2-m range, they have typically been used in medians approximately 3 m wide. Recognizing the inherent danger in crossover accidents, designers have often specified 760-mm mounting heights, higher than their roadside barrier coun-

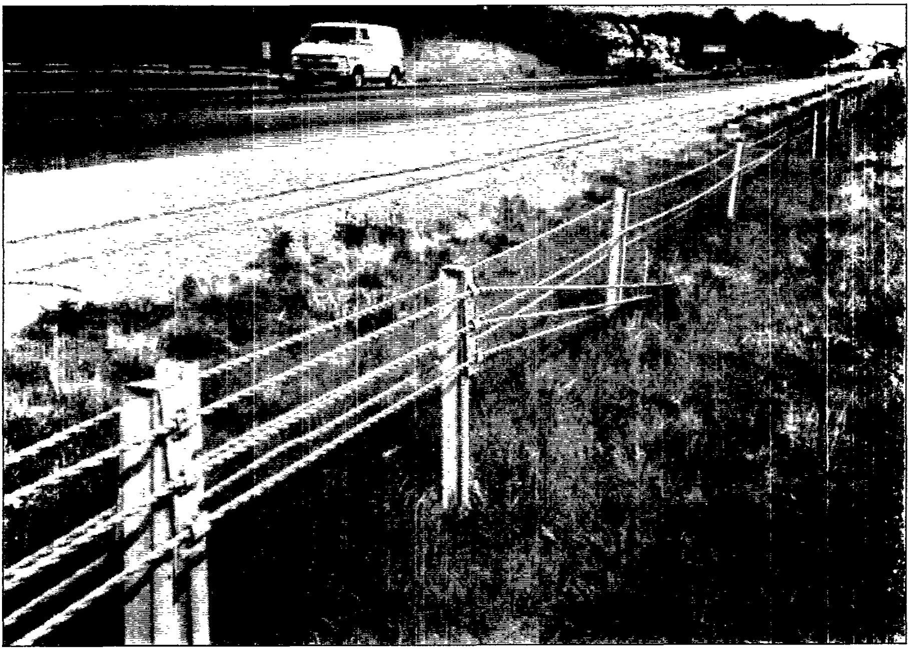


FIGURE 6.2 Median Cable Barrier

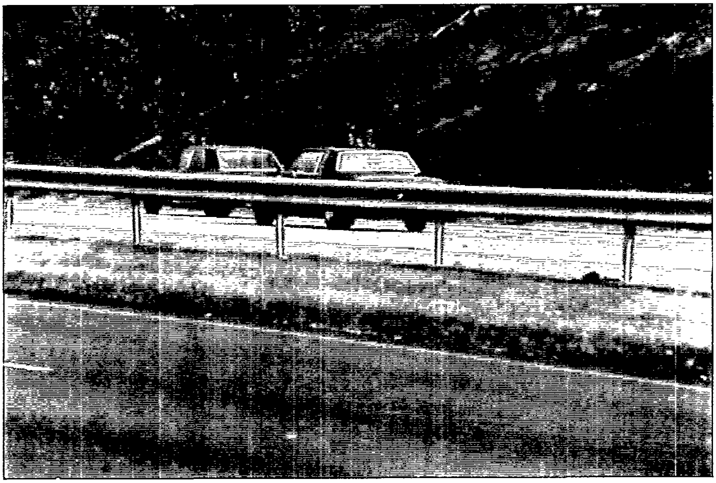


FIGURE 6.3 Weak Post W-Beam

FIGURE 6.4 Box Beam Median Barrier

terparts. To minimize post snagging problems with the higher mounting heights, a separate rubrail has sometimes been added to the design. It has also been added when the w-beam is placed behind a curb, typically on structure approaches. Most State agencies have used a C-channel, but occasionally a separate w-beam centered 250 mm above grade is specified. Strong post w-beam median barriers generally cause higher forces on impacting vehicles and their occupants than do flexible systems, but they do not usually require immediate repair to remain functional.

6.4.1.5 Blocked-Out Thrie-Beam (Strong Post)

This system is similar in most respects to the blocked out w-beam median barrier but is capable of accommodating a larger range of vehicle sizes due to its increased beam depth. The use of thrie-beam also eliminates the need for a separate rub rail. Design deflection for this barrier is in the range of 0.3 to 0.9 m, and its typical mounting height is 810 mm. Performance of the thrie-beam median barrier can be significantly enhanced by using the spacer blocks developed in conjunction with the modified thrie-beam roadside barrier described in Section 5.4.1.7. With the modified block-outs, this barrier contained and redirected an 18,000-kg bus impacting at 80 km/h and an impact angle of approximately 15 degrees, but the rail ruptured and the bus rolled onto its side. Although significant modifications to the barrier would be required to improve its performance under severe impacts, some improvement may be achieved by using a 3.5-mm thickness for the rail element in place of the commonly used 2.8-mm thickness. This barrier may be appropriate for use in a flood plain where a concrete barrier would form a dam.

6.4.1.6 Self-Restoring Median Barrier

The Self-Restoring Median Barrier (SERB Median Barrier) shown in Figure 6.5 consists of two thrie-beam elements bolted to two truss web members and hung on specially designed posts. This design allows the rail section to deflect upwards and back during contact and to return to its pre-impact position after a vehicle is redirected. Crash testing has indicated that little or no maintenance will be required for most passenger car hits; the SERB median barrier also redirected an 18,000-kg intercity bus at 100 km/h and a 15-degree impact angle. The dynamic deflection of the system for this severe hit was approximately 0.6 m.

The SERB median barrier should be considered as an alternate to a standard concrete median barrier at locations where the likelihood of medium size vehicle hits at high impact angles might result in unsatisfactory performance from the rigid barrier, such as on alignments with multiple sharp curves. Because the SERB median barrier weighs only 77 kg/m, its use might also be appropriate where a median barrier is to be carried across an existing bridge and the added weight of a concrete barrier is not desirable.

FIGURE 6.5 Self-Restoring Median Barrier

6.4.1.7 Concrete Safety Shape

The concrete safety shape, often referred to as concrete median barrier (CMB), is by far the most common rigid traffic barrier in use today. Its popularity is based on its relatively low cost, generally effective performance, and its maintenance-free characteristics. Field performance has shown successful redirection of truck combinations at shallow approach—typically less than 10 degrees.

Research[3] has shown that variations in the face of the concrete barrier can have a significant effect on barrier performance. Figure C.8, Appendix C compares dimensions of the New Jersey and F-shape which are recommended for new installations. The critical variable is the height above the road surface of the break between the upper and lower slope. If this break is higher than 330 mm, the chances of a vehicle's overturning are increased, particularly for compact and subcompact automobiles. Therefore, the earlier General Motors (GM) shape, having the break point at 380 mm, is no longer recommended. The research found the F shape, which has the slope break at 250 mm, performed better for small vehicles with respect to vehicle roll than did the New Jersey shape. As a result, several highway agencies have converted to the F-Shape. The basic New Jersey and F-shapes have an overall height of 810 mm; this includes provision for a 75-mm future pavement overlay, reducing the height to 735-mm minimum. When total overlay depths are expected to exceed 75 mm or when an 810-mm height is considered inadequate, the total height of the concrete must be adjusted. This adjustment must be made above the slope breakpoint. The height extension may follow the slope of the upper face if the barrier is thick enough or adequately reinforced at the top or the extension may be vertical. Many variations exist between highway agencies regarding reinforcing and footing details for concrete median barriers; however, there have been few reported problems with any particular design and a need (or desirability) for a standard detail is not apparent. Research[4] by the California Department of Transportation has shown that a concrete footing is not necessary; the concrete can be cast directly on asphalt concrete, Portland cement concrete, or a well-compacted aggregate base. This research also revealed no adverse effects to barrier performance when contraction joints were left to form uncontrolled in lightly reinforced concrete. Longitudinal reinforcement in the upper portion of the barrier stem serves to control the size and scatter of concrete fragments that may occur as a result of severe barrier impacts. Several states use non-reinforced concrete barrier. Shrinkage cracks of up to 20 mm have not affected the operational strength of concrete barriers and no breakouts have been experienced where the top width is at least 300 mm. In general, if the in-service performance of a State's concrete barrier design reflects desired results, that design may be considered acceptable. Additional research is warranted in this area, particularly for temporary, precast sections of concrete. These types of installations are discussed in more detail in Chapter 9.

Concrete median barrier may be slip-formed, precast, or cast-in-place. Slip-formed barriers are cost-effective where long lengths of barrier can be placed without interruption. Equipment is available to slip-form barriers to a variable height where necessary to fit a stepped median cross section where the elevations of adjacent roadways do not vary by more than 0.9 m. Precast construction is sometimes used as an alternate to slip-formed barrier and is frequently used where split median barriers are needed to shield objects such as bridge piers or overhead sign supports. Cast-in-place construction is the most versatile method because forming can be varied to fit non-typical situations.

Although the concrete median barrier does not deflect when struck, two factors are important to note. For high-angle, high-speed impacts, passenger size vehicles may become partially airborne and in some cases may reach the top of the barrier. Fixed objects, e.g., luminaire supports, on top of the wall may cause snagging. New York State had designed and tested a box beam retrofit (Figure 6.6) that is installed near the top of the upper face of the barrier to limit vehicle climb and to improve performance under these conditions. The second factor to consider is that, even for shallow angle impacts, the roll angle toward the barrier imparted to high center of gravity vehicles may be enough to permit contact by the top portion of the cargo box with fixed objects on top of or immediately behind the wall. Bridge piers are one of the common obstacles typically shielded by a concrete safety shape. Unless the barrier is significantly higher than 810 mm or modified as noted above, a bus or tractor trailer is likely to lean enough to strike the pier even though it does not penetrate the barrier. Even the 1070 mm high concrete safety shape shown in Figure C.9, Appendix C produced significant roll when struck by a 36,000-kg combination truck at 15 degrees and 80 km/h. This so called "Tall Wall" barrier is classified as a high performance barrier. It has been successfully used for many years by the New Jersey Turnpike Authority in its reinforced version and in Ontario without reinforcement.[6]

A single slope concrete barrier has been developed and tested. The performance is anticipated to be similar to the F-Shape barrier. The primary advantage of this barrier is that the pavement adjacent to it can be overlaid several times without affecting the performance of the barrier. The original height of 1070 mm may thus be reduced to 760 mm.

Vertical concrete barrier wall can be an effective alternative to the wider safety shape barriers and preserve available median shoulder width at narrow locations such as in front of bridge piers. Vehicle damage in crashes with a vertical wall is greater than with safety shaped barriers, but injuries are comparable and the preservation of shoulder width is a safety benefit.

6.4.1.8 Quick Change Movable Barrier System

This proprietary portable barrier system is composed of a chain of modified F-shape shaped concrete barrier segments 940 mm in length which can be readily shifted laterally. Steel rods run the length of each segment, and specially designed hinges are attached to either end which are then joined by pins. The top of each segment is "T" shaped to allow pick up by a special vehicle and movement laterally from 1.2 to 5.5 m. The "T" slot is engaged by the

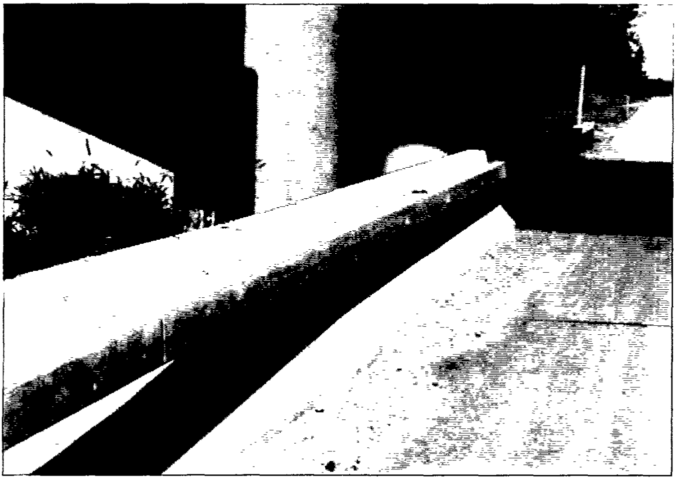


FIGURE 6.6 Concrete Barrier Modification to Limit Roll Angle

vehicle conveyor system and the segment is lifted from the road. Continuous lengths of the barrier are transported on conveyor wheels through an elongated "S" curve, moved across the roadway and set down to form a new parallel lane. Transfer speeds of 8 to 16 km/h are obtained depending on the lateral distance of movement.

The system has been successfully crash tested with a 2300-kg vehicle at 90 km/h and 25 degrees. This test resulted in a deflection of approximately 1.5 m.

The system may be used in construction zones on high-volume freeways, where due to construction operations and a desire to maintain traffic capacity, traffic lanes are opened and closed frequently. The system requires cost, energy, and time to set up the barriers initially; however, it allows a work zone to be quickly created and protected during periods of low traffic flow, and be changed back to full lane utilization during the busy daytime period.

The system may also be used to advantage on roadways with unbalanced directional traffic, such as commuter or tourist routes. Once set up the barrier can be moved rapidly to provide additional capacity in the direction of heavy traffic flow.

6.4.1.9 Earth Berm

An earth berm or redirectional land form can be used to mitigate obstructions located in medians. Figures 6.7 and 6.8 show a schematic drawing of this feature and an actual installation, respectively. The heights and slope rates are not fixed and slopes should be flatter wherever practical. Heights over 3 m are not recommended and slope rates should not exceed 1:2, although steeper slopes can be used if they are smooth and liberally rounded at the base. Earth berms are typically used in lieu of a roadside or median barrier to shield bridge piers. It is critical that the berm be gradually introduced so it does not become an obstacle to an errant vehicle. The designer must also recognize that the redirectional capabilities of the berm are minimal throughout much of its length and it should not be used where high angle impacts are likely (such as on the outside of horizontal curves) or where vehicle encroachments beyond the berm may have severe consequences.

Grate inlets or median drains required to drain the roadway shoulder and median ditch areas should be designed to blend with the smooth contours of the earth berm.

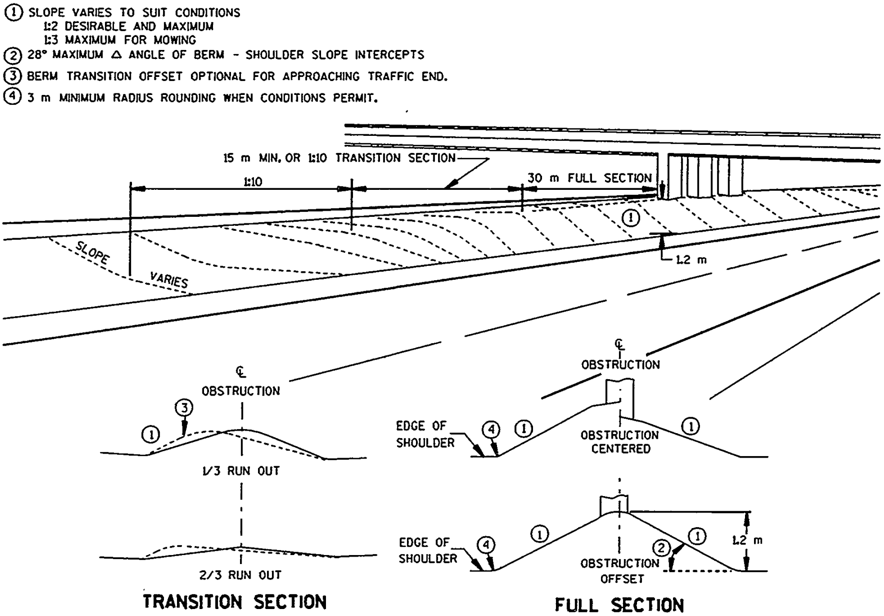


FIGURE 6.7 Schematic Drawing of a Median Berm

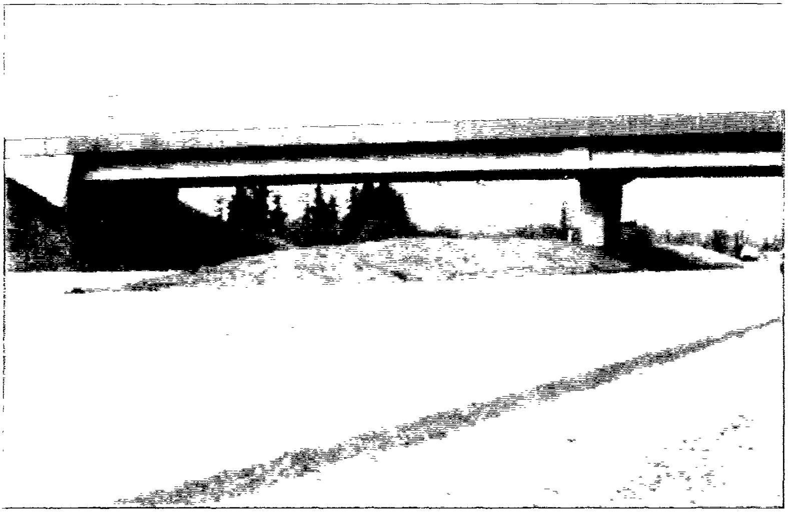


FIGURE 6.8 Median Earth Berm in Place

6.4.2 End Treatments

The end of a median barrier is a concern. Impact with the untreated end of a metal beam type system may result in the beam penetrating the passenger compartment or stopping the vehicle abruptly. Impact with the untreated end of a concrete median barrier will result in intolerable impact forces. A crashworthy end treatment for a median barrier is essential if the barrier is terminated where it is vulnerable to high-speed, head-on impacts.

To be crashworthy, the end treatment should not spear, vault, snag, or roll the vehicle. Vehicle decelerations should not exceed the recommended limits. For impacts at or near the end of the terminal yet within the required length of need, the end treatment should have the same redirectional characteristics as the standard median barrier. Thus, the end must be properly anchored and capable of developing the full tensile strength of the standard rail element, whether a crashworthy end treatment is warranted or not. This is particularly true for flexible and semi-rigid systems.

Median barriers used on non-freeways normally result in an increased number of exposed barrier ends at median crossovers. Because of the problems with these ends, openings in median barriers are to be avoided if possible. A gate may be placed across the openings on highways with fully controlled access if problems arise with unauthorized crossings. Other designs have been used for emergency openings. These have included w-beam barriers with quick release fasteners, load binder cable release mechanisms for the cable barrier and sliding steel gates for concrete systems. Each application should be evaluated considering site specific conditions and accident history.

Specific median barrier end treatments described in this section are:

- Flared
- Tapered
- Flared and Tapered
- Earth Beam
- Anchored in Backslope
- Shielded with Appropriate Crash Cushion

6.4.2.1 Flared End Treatment

In variable width medians, a barrier can sometimes be introduced far enough from approaching traffic that it can be considered non-hazardous and no additional safety treatment is required. The flare rate should meet the minimum criteria shown in Table 5.6, and a semi-flexible system must have a positive end anchorage to preclude penetration of the barrier within the design length of need. In some instances, flaring the barrier away from the road at an acceptable rate will require significantly more barrier.

6.4.2.2 Tapered End Treatments

This type of end treatment is primarily intended to eliminate the spearing or high decelerations characteristic of blunt-ended terminals. However, since a tapered end treatment can cause an impacting vehicle to become airborne and/or overturn, its use should be confined to low-speed situations and/or locations where end-on hits are unlikely. There have been cases where a vehicle has ridden up a tapered end anchor onto the top of the barrier and been directed into the hazard which the barrier was intended to shield.

6.4.2.3 Flared and Tapered End Treatment

By combining both of the above treatments, a median barrier terminal can be located where it is unlikely to be hit and designed so any hits that do occur do not result in a severe accident.

6.4.2.4 Earth Berm

Use of an earth berm to introduce or terminate a median barrier is essentially the same as tapering the end section. Once again, the designer must be aware that a gradually-introduced earth berm has virtually no redirectional capabilities and one should not be used where an errant motorist would be likely to cross into opposing traffic.

6.4.2.5 Anchored in Backslope

This treatment is similar in concept to the construction of an earth berm. In this case, the berm or backslope already is in place and the median barrier is carried into it.

6.4.2.6 Shielded

Because median barriers are typically warranted and installed in narrow medians, space limitations often limit the types of crash cushions that can be effectively used to shield the barrier ends. Refer to Chapter 8 for acceptable crash cushions.

6.4.3 Transitions

Transition sections are needed between adjoining median barriers having significantly different deflection characteristics, between a semi-rigid median barrier and a rigid barrier such as a bridge rail, or when a median barrier must be stiffened to shield fixed objects in the median such as overhead sign supports or median lighting fixtures.

Impact performance requirements for 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 section. Structural details of special importance include the following:

- All rail splices should be capable of developing the full tensile and flexure strength of the weaker rail.
- A flared or sloped connection should be used when the connection could snag an opposite direction vehicle. In this regard, a standardized terminal connector is suggested for attaching approach w-beam or thrie-beam rail to a rigid bridge railing or parapet. Another effective rail-to-parapet connection can be achieved by providing a recessed area in the parapet wall to receive the rail.
- Strong post median barrier systems are typically used on transitions to the concrete safety shape and to bridge rails, 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. 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. The designer is encouraged to investigate the potential use of the thrie-beam system for transition rail sections. Tests have shown that the thrie-beam performs well as a transition and eliminates the need for a separate rub rail.
- The transition section should be long enough so significant changes in deflection do not occur within a short distance. Generally, the transition length should be 10 to 12 times the difference in the lateral deflection of the two systems in question. In most cases, a transition length of 7.5 m will be the minimum distance required.
- 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, decreasing the post spacing and increasing the post size, and/or using nested sections of w-beam or thrie-beam.

Although differing in details, the transition designs for an approach barrier/bridge railing end described in Chapter 7 address the same type of concerns common to median barrier transitions.

6.5 SELECTION GUIDELINES

Once it has been determined that a median barrier is warranted, a specific barrier type must be selected. In general, the most desirable system is one that satisfies performance requirements at the least total cost. Table 5.2 summarizes the major factors which should be considered before making a final selection. Each of these is described in the following sections.

6.5.1 Barrier Capability

The first decision to be made when selecting an appropriate median barrier concerns the level of performance required. In most cases, a standard barrier capable of redirecting passenger cars and light vans and trucks will be adequate. However, locations with poor geometrics, high traffic volumes and speeds, and a significant volume of heavy truck traffic may warrant higher performance level median barriers, particularly if the result of a heavy vehicle penetrating the barrier is likely to be catastrophic. The median barriers identified in Section 6.4.1 are listed in order of increasing capabilities to contain and redirect large vehicles. Information on vehicle weight, type, impact speed, and impact angle is also included for each barrier.

6.5.2 Barrier Deflection Characteristics

Once the desired performance level has been determined, site characteristics often dictate the type of median barrier to install. Relatively wide, flat medians are suited for flexible or semi-rigid barriers, provided the design deflection distance is less than one-half the median width. On the other hand, narrow medians within heavily traveled roadways usually require a rigid barrier having little or no deflection when hit. Deflection distances for each type of operational median barrier are discussed in Section 6.4.1.

6.5.3 Compatibility

The specific type of median barrier selected will also depend to some extent upon its compatibility with other median features, such as luminaire and overhead sign supports and bridge piers. If a non-rigid barrier is used in such cases, crashworthy transition sections must be available to stiffen the barrier locally if the fixed object is within the design deflection distance of the barrier. In addition to acceptable transition designs, a crashworthy end treatment is also necessary if the barrier begins or terminates in a location where it is likely to be struck by an errant motorist. Detailed information on end treatments and transition sections are included in Section 6.4.2 and 6.4.3.

6.5.4 Costs

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 rigidity and strength increases, but 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. These costs include personal injuries to the driver and occupants as well as property damage to the impacting vehicle. If a barrier can be located in the center of a median where it is less likely to be hit, and repairs do not necessitate closing a lane of traffic, flexible or semi-rigid median barrier may be the best choice. However, if a barrier must be located immediately adjacent to a high-speed, high-volume traffic lane, a rigid barrier requiring no significant maintenance is recommended.

6.5.5 Maintenance

Although the same general maintenance considerations in the selection of a roadside barrier also apply to median barriers, collision maintenance is usually a more important factor. Because median barriers are typically installed closer to the traveled way, one or more high-speed lanes usually have to be closed to repair or replace damaged barriers. This creates a potentially hazardous situation for both the repair crew and for motorists using the road. Consequently, a rigid barrier system (usually concrete) is the barrier of choice in many locations, particularly high-volume urban freeways and expressways.

6.5.6 Aesthetic and Environmental Considerations

As with the roadside barriers, aesthetic concerns are seldom an overriding consideration in the selection of an appropriate median barrier. In those instances where a "natural" barrier is required, care must be exercised to ensure that structural requirements remain adequate.

Environmental factors that warrant consideration are similar to those summarized in Section 5.5.7 for roadside barriers.

6.5.7 Field Experience

To make effective decisions regarding the type of barrier to install on new construction, each highway agency should have a process to monitor and evaluate the performance and maintenance characteristics of its existing installations. If a specific type of barrier is performing satisfactorily when hit and does not require excessive maintenance, there is no need to use a different type on new construction. In any event, it is essential that maintenance personnel communicate any concerns to design engineers so that a cost-effective system can be selected.

6.6 PLACEMENT RECOMMENDATIONS

All of the barriers included in Section 6.4.1 are capable of containing and redirecting their respective design vehicles if they are properly installed in the field. Without exception, all traffic barriers perform best when an impacting vehicle has all its wheels on the ground at the time of impact, and its suspension system is neither compressed nor extended. Thus, a major factor 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 vehicle's trajectory. Two other significant factors affecting barrier performance are the flare rate of the barrier, especially at transition sections, and the treatment of rigid objects in the median. A discussion of each of these three factors follows.

6.6.1 Terrain Effects

Terrain conditions between the traveled way and the barrier can have significant affects on the barrier's impact performance. Curbs and sloped medians (including superelevated sections) are two prominent features which deserve attention. A vehicle which traverses one of these features prior to impact may go over or under the barrier or snag on its support posts.

6.6.1.1 Curbs

Curbs offer no safety benefits on high-speed roadways from the standpoint of vehicle behavior prior to or 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, a vehicle, traveling at approximately 100 km/h will not likely vault the barrier if the barrier face is within approximately 225 mm of the curb's face. However, if the top of the rail is approximately 685 mm 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. It is a common practice in such cases to add a rub rail to the barrier system to minimize any snagging potential. If a specific curb/median barrier combination is to be used extensively or is already in service, crash testing is recommended to ensure effective performance within the anticipated range of impact angles and speeds.

6.6.1.2 Sloped Medians

The most desirable median is one that is relatively flat (slopes of 1:10 or less) 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 6.9 shows three basic median sections for which placement guidelines are presented. In each section, it is assumed that a median barrier is warranted. Section I applies to depressed medians or medians with a ditch section. Section II applies to stepped medians or medians that separate travel ways with significant differences in elevation, and Section III applies to raised medians, or median berms.

Section I—The slopes and the ditch section should first be checked by the criteria in Chapter 3 to determine if a roadside barrier is warranted. If both slopes require shielding (Illustration 1), a roadside barrier should be placed near the shoulder on each side of the median ("b" and "d"). If only one slope requires shielding, 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 to prevent vehicles that have crossed the ditch from snagging on a post and beam railing system.

If neither slope requires shielding but both are steeper than 1:10 (Illustration 2), a median barrier should be placed on the side with the steeper slope when warranted. For example, if

$$S_2 = 1{:}6 \text{ and } S_3 = 1{:}10,$$

the barrier would be placed at "b." A rigid or semi-rigid system is suggested in this situation. If both slopes are relatively flat (Illustration 3), a median barrier may be placed at or near the center of the median (at "c") if vehicle override is not likely. Any type of median barrier can be used, provided its dynamic deflection is not greater than one-half the median width.

Section II—If the embankment slope is steeper than approximately 1:10 (Illustration 4), a median barrier

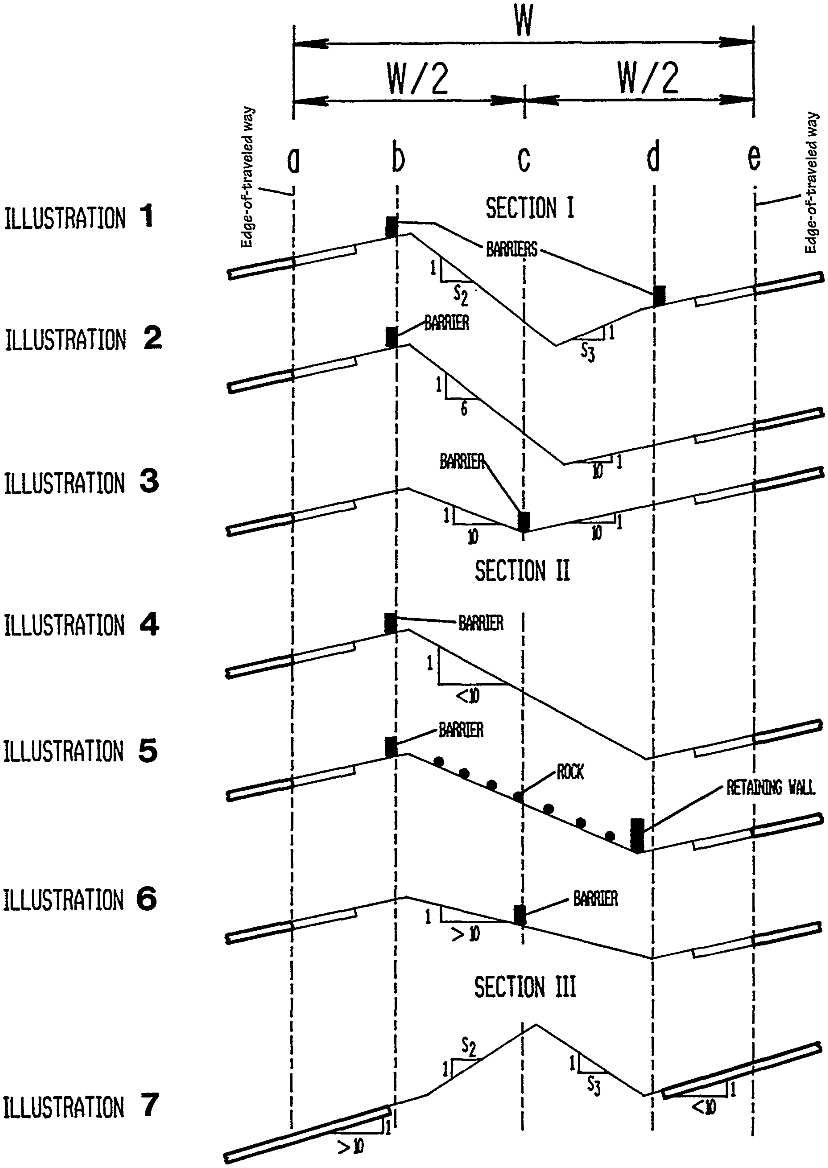


FIGURE 6.9 Recommended Barrier Placement in Non-Level Medians

should be placed at "b." If the slope is not traversable (rough rock cut, etc.), a roadside barrier should be placed at both "b" and "d" (Illustration 5). 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 a concrete median barrier. If the cross slope is flatter than approximately 1:10, a barrier could be placed at or near the center of the median (Illustration 6).

Section III—Placement criteria for median barriers on this cross section (Illustration 7) are not clearly defined. Research has shown that such a cross section, if high enough and wide enough, can itself redirect vehicles impacting at relatively shallow angles.

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.

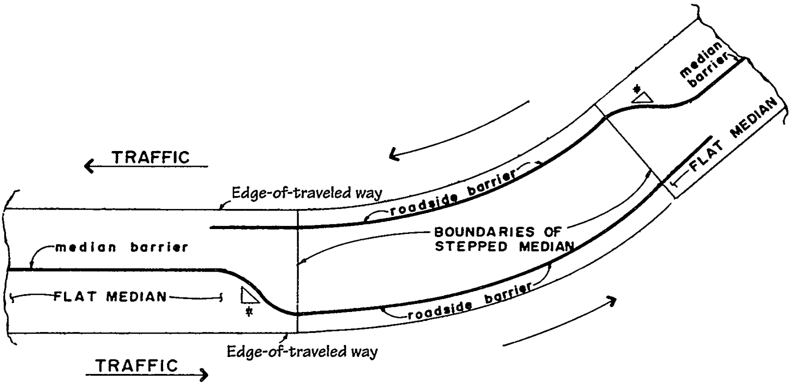
If slopes are not traversable (rough rock cut, etc.), a roadside barrier should be placed at "b" and "d." If retaining walls are used at "b" and "d," it is recommended that the base of the wall be contoured to the exterior shape of a standard concrete barrier.

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 6.9 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" as illustrated in Figure 6.10. Most of the operational median barriers can be split this way, especially box beams, w-beam types and the shaped concrete barrier.

6.6.2 Flare Rate

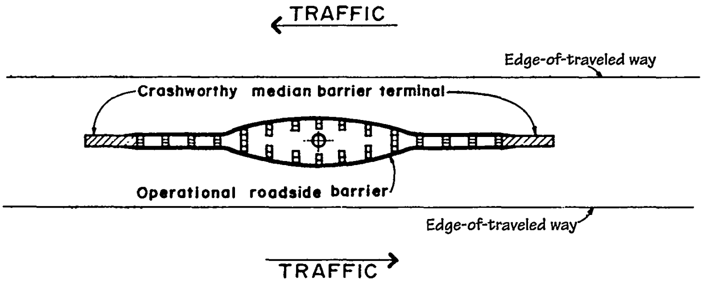
It may be necessary to flare a median barrier, such as at a rigid object in a median. The flare rates shown in Table 5.6 for roadside barriers apply to median barriers also.

Another special layout problem concerns medians whose widths are such that a median barrier is not warranted but which have a rigid object which warrants shielding. Typical examples are bridge piers and overhead sign support structures. 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 5 should be used. If shielding for both directions of travel is necessary and if the median is flat (side slopes less than approximately 1:10), two means of protection are suggested. In the first case, the designer should investigate the possible use of a crash cushion (or an earth berm) to shield the object. A second suggestion is to employ either semi-rigid or rigid barriers with crash cushions or earth berms to shield the barrier ends as illustrated in Figure 6.11. If semi-rigid systems are used, the distance from the barrier to the obstruction should be greater than the dynamic deflection of the barrier. If a concrete safety shape is used, the barrier can be placed adjacent to the obstruction unless there is a concern for a high center of gravity vehicle striking the obstruction when contact with the barrier causes the top of the vehicle to lean over the railing.



*Flare rate should not exceed suggested limits (Refer to Table 5.6)

FIGURE 6.10 Example of a Split Median Barrier Layout



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

FIGURE 6.11 Suggested Layout for Shielding a Rigid Object in a Median

6.7 UPGRADING SYSTEMS

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

Table 5.8 provides a checklist for evaluating the structural adequacy of roadside barriers. The same factors can be applied to median barriers, and persons inspecting existing installations should stay abreast of current traffic barrier standards and guidelines, as well as promising new research findings. Of course, there is no substitute for field data or accident records to evaluate the performance of a system.

If a barrier system does not meet current guidelines, it is suggested that the barrier be modified to conform to an operational system or be replaced by an operational system. It is recognized that this action is not always cost-effective and some decisions must be based on a case-by-case analysis. If an upgraded system still does not conform to an operational system, crash tests are suggested to verify the design, especially if substantial use of the system is planned.

Table 5.8 may also be used to evaluate the functional adequacy 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 criteria recommended in Table 5.6.

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CHAPTER 7: BRIDGE RAILINGS AND TRANSITIONS

7.0 OVERVIEW

A bridge railing is a longitudinal barrier intended to prevent a vehicle from running off the edge of a bridge or culvert. Normally they are constructed of a metal or concrete post and railing system, a concrete safety shape, or a combination of metal and concrete. Most bridge railings differ from roadside barriers in that they are an integral part of the structure (physically connected) and are usually designed to have virtually no deflection when struck by an errant motorist.

This chapter summarizes the performance and structural requirements for various types of bridge railings and presents guidelines for their use. It also addresses bridge railings and longitudinal barriers as a complete system and provides detailed information on appropriate transition sections between the two barrier types. Finally, selection and placement guidelines are provided for new construction as well as retrofit designs for older bridges having substandard railings.

The information presented here is intended to supplement that found in the AASHTO *Standard Specifications for Highway Bridges* rather than repeat it. Those seeking detailed information on analytic design procedures, design loadings, and materials specifications should refer to that document.

As with other traffic barriers, current design criteria for bridge railings has traditionally related primarily to standard sized automobiles. However, several State highway agencies and the Federal Highway Administration have recognized the fact that it may be desirable in certain situations to design and install railings which can contain and redirect heavy vehicles such as buses and trucks. Although penetration of any railing by a vehicle is potentially hazardous to its occupants, locations where vehicular penetration of a railing system could be particularly disastrous to others as well should be given careful evaluation before deciding on the type of railing to install. At the other extreme, some bridges carry only low traffic volumes at greatly reduced speeds. Bridge railings for these and similar structures may not need to be designed to the same standard as railings to be used on high-speed, high-volume facilities.

In late 1988, AASHTO approved *Guide Specifications for Bridge Railings*, a document which may be used in lieu of the *Standard Specifications for Highway Bridges*. These "Guide Specifications" require full-scale crash testing of all railings used on new construction. Further, they formally introduce the concept of multiple performance levels (see Section 7.3) and provide a rational means for selecting an appropriate bridge railing by considering design speeds, traffic volumes, and the percentage of heavy vehicles in the traffic stream.

7.1 PERFORMANCE REQUIREMENTS

The AASHTO *Standard Specifications for Highway Bridges* requires that bridge railings meet specific geometric criteria and be capable of resisting applied static loads without exceeding allowable stresses in any of their component members. These specifications do not presently mandate that a bridge railing designed to AASHTO standards be crash tested prior to its use. However, a railing that has been successfully tested may be used even if it does not comply with the specifications in all areas.

7.2 WARRANTS

Virtually all structures require some type of railing; however, on many small structures on low-speed, low-volume roadways, a railing designed to full AASHTO standards may be neither necessary nor desirable. A rigid railing requires approach guardrail and a transition section as well. This full treatment may not be cost-effective on bridge-length culverts and alternate treatments should be considered. Such treatments could include widening the structure and leaving the edges unshielded or utilizing a less expensive, semi-rigid type railing.

When a bridge also serves pedestrians and/or cyclists, a barrier to shield them from vehicular traffic may be warranted. The need for a pedestrian and/or cyclist railing should be based on the volume and speed of roadway traffic, the number of pedestrians and/or cyclists using the bridge, and conditions on either end of the structure.

7.3 PERFORMANCE LEVEL SELECTION PROCEDURES

Application of the AASHTO *Standard Specifications for Highway Bridges* results in railings designed to contain and redirect passenger size vehicles, light trucks, and vans. In some cases, it is appropriate to design railing systems to withstand impacts by larger vehicles. Section 5.3 listed some subjective factors most often considered in making this determination. A recently published analysis of full-scale crash tests has shown that longitudinal barriers, including bridge railings, can be designed and constructed to restrain heavy vehicles such as buses and trucks. To redirect large vehicles, a railing must have adequate strength to resist impact forces which may be as high as 900 kN for a 36,000-kg tractor-trailer striking the railing at 80 km/h and at a 15-degree angle.

A second concern that must be considered in designing a high-performance railing is its effective height. A railing may have adequate strength to prevent physical penetration but unless it also has adequate height, an impacting vehicle or its cargo may roll over the railing or may roll onto its side away from the railing after redirection.

In addition, the shape of the face of the railing will have a significant effect on its performance. For example, a safety shape concrete railing can cause a large vehicle to roll up to 24 degrees before it contacts the upper edge of the railing. Thus, a vertical face may be more desirable whenever heavy vehicle rollover is a primary concern. It should also be noted that the deflection characteristics of a railing also have a significant effect on its overall performance. In general, a railing that allows some deflection results in smoother redirection of impacting vehicles and imparts a lesser roll angle than a rigid railing.

7.4 SELECTION GUIDELINES

There are five factors that should be considered in selecting a bridge railing. Although not necessarily listed in order, the capability of a railing to contain and redirect the design vehicle should never be compromised.

7.4.1 Railing Performance

Generally, all bridge railings designed in accordance with AASHTO specifications since 1964 have adequate strength to prevent penetration by passenger cars. Most of these railings also provide smooth redirection, although full-scale crash testing has revealed poor performance in some railing designs. Post-crash evaluation of some of the failed systems revealed a lack of design capacity in a detail (such as base plate thickness or a post-to-base plate connection) which adversely affected the capacity of the railing.

7.4.2 Compatibility

When the approach roadside barrier significantly differs in strength, height and/or deflection characteristics from a bridge railing, a crash worthy transition section, as defined in Section 7.8, is usually required. In cases with low roadway speeds and with sidewalks between the traveled way and the bridge rail, high-performance level transitions may not be warranted. Nevertheless, it is important that the railings selected be considered part of a system that must function effectively.

7.4.3 Costs

Costs generally fall into one of three categories: initial construction costs, long-term maintenance costs, and motorists' costs resulting from impacts with the railing. As a general rule, the initial cost of a system increases as its rigidity and strength increases but it seldom becomes a significant portion of total construction costs except on extremely long bridges or when a high-performance level railing is used. In this case, the railing to bridge deck anchorage requirements may significantly increase the total cost of the structure. This would be particularly true for a high-performance level concrete railing that adds considerable dead load to the bridge.

Maintenance costs generally decrease significantly as the strength of a railing increases. Some high-performance railings can be essentially maintenance-free unless they are struck by the heavy vehicles for which they are designed. Railing designs that are susceptible to impact damage should be standardized to the extent possible so the availability of replacement parts does not become a major problem. Railings that eliminate or minimize bridge deck damage are extremely desirable from a maintenance viewpoint.

Accident costs include both damages to vehicles and injury costs to motorists. Generally, the less yielding a railing is, the more damage is inflicted upon the impacting vehicle and its occupants when the railing is hit.

7.4.4 Field Experience

It is important that the in-service performance of any bridge railing that is widely used be evaluated to see if it is working as intended. By reviewing accidents involving bridge railings where available and by documenting damage and repair costs, highway agency personnel can readily determine if a specific design is performing well or if changes could be made to improve its performance or significantly decrease repair costs.

7.4.5 Aesthetics

While there is no question that an aesthetic bridge railing may be particularly important in scenic areas or along park roads, the safety performance of a railing must not be sacrificed. Some rustic appearing railings have been developed and crash tested to provide railings that are both effective and acceptable in appearance. Any non-standard bridge railing designed primarily for appearance should be crash tested before being used.

7.5 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. However, there are many existing bridges which are narrower than the approach roadway and shoulder. When the bridge railing is located within the recommended shy distance (see Table 5.4), the approach railing should have the appropriate flare rate shown in Table 5.6.

Curbs in front of bridge railings are to be avoided if possible. However, in low-speed situations, a curb may provide marginal protection for pedestrians. In urban areas, a bridge railing between traffic and the sidewalk affords maximum pedestrian protection. A pedestrian railing would then be needed at the outer edge of the sidewalk. Terminating this bridge railing requires special treatment considerations. Flaring the end section away from the roadway is seldom practical because it would then encroach onto the sidewalk. In some instances, a crash cushion or a metal beam barrier terminal can be used to advantage, but the usual presence of a curb may adversely affect the performance of this type of end treatment. Thus, in many cases, a tapered end section parallel to the roadway may be the best compromise. The taper should be of sufficient length off the end of the bridge so that an impacting vehicle is ramped on and over the sloped end treatment before reaching the outside edge of the structure, yet not extend so far as to intrude on the sight distance of intersecting streets just off the end of the bridge. This method of terminating a railing in low-speed situations is shown in Figure 7.1.

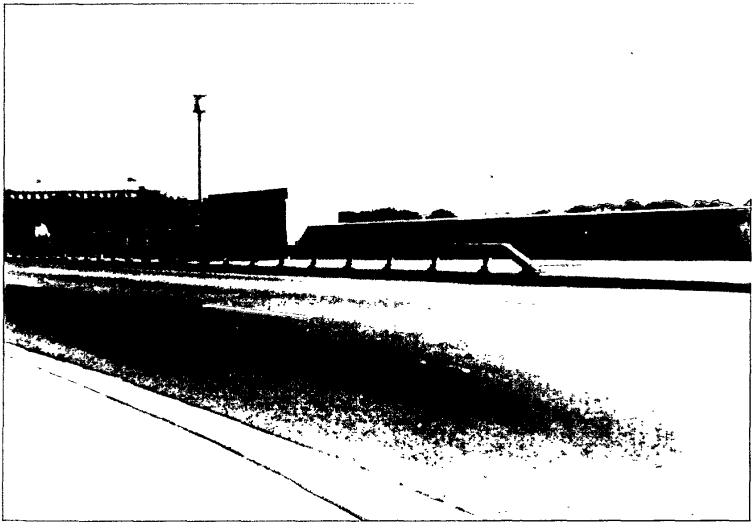


FIGURE 7.1 Example of End Treatment for Traffic Railing Over a Bridge

7.6 UPGRADING OF BRIDGE RAILINGS

This section provides general guidelines for highway agency personnel responsible for identifying and correcting potentially deficient bridge railings.

7.6.1 Identification of Potentially Deficient Systems

Since the primary purpose of a bridge railing is to prevent penetration, it must be strong enough to redirect an impacting vehicle. Bridge railings designed to AASHTO Specifications prior to 1964 may not meet current Specifications. Most railings properly designed after 1964, if tested, will contain and redirect a 2000-kg passenger car impacting at 100 km/h and 25 degrees. If the capacity of a railing appears questionable, further evaluation should be made to verify critical design details (such as base plate connections, anchor bolts, material brittleness, welding details, and reinforcement development) to ensure the design meets the intent of the current specifications.

Occupant protection is also of considerable importance in a crash. Open-faced railings in particular may cause snagging which produces high deceleration forces, leading to occupant injuries. This type of deficiency can usually be detected best through full-scale crash testing or, in the case of an existing railing, through an analysis of available accident reports.

A third deficiency in many older railing systems is the presence of a curb or walkway between the driving lane and the bridge railing. These may cause an impacting vehicle to go over the railing or at least strike it from an unstable position and subsequently roll over.

Finally, an adequate approach rail to bridge rail transition is essential as discussed in detail in section 7.8.

Figures 7.2 through 7.5 illustrate some of the more common deficiencies found in pre-1964 bridge railings. The next section identifies corrective measures that can be taken to improve the performance of these and similarly deficient systems.

7.6.2 Upgrading Systems

This section discusses retrofit designs only, i.e., changes, modifications and/or additions to existing substandard railings that bring these railings up to acceptable performance levels. These retrofit designs may increase the strength of the railing, provide longitudinal continuity to the system, reduce or eliminate undesirable effects of curbs or narrow walkways in front of the bridge rail and/or eliminate snagging potential. A retrofit design should also provide an acceptable transition from the approach rail to the bridge rail itself.

While some retrofit designs may not bring a substandard bridge railing to full AASHTO standards, significant improvements can nevertheless be made. One of the most common improvements consists of rebuilding the approach roadside barrier to current standards, including a transition section, and continuing the metal beam rail element across the structure to provide railing continuity.

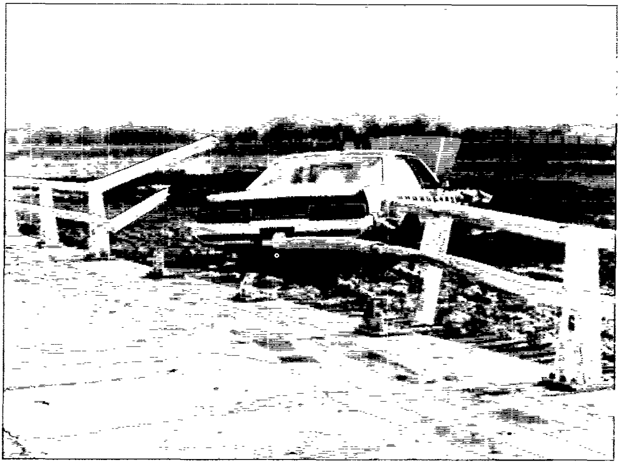


FIGURE 7.2 Inadequate Railing Strength

FIGURE 7.3 Lack of Continuity in Railing

If the existing bridge has a safety curb, the retrofit railing can be blocked out to minimize the possibility of a vehicle ramping over the bridge railing. However, for most high-speed, high-volume roads, retrofit designs should be crash tested before they are used. The next sections of this chapter provide information on tested designs that can be used once a determination is made that retrofitting a substandard bridge railing is a cost-effective alternative to leaving an existing railing as is or constructing a new crash-tested railing.

Existing railings that are deficient by current standards may sometimes be left in place until such time as the section of highway that includes the bridge is brought to full standards. Until such time that a complete upgrading is done, each deficient railing should be evaluated to determine the most cost-effective treatment. In general,

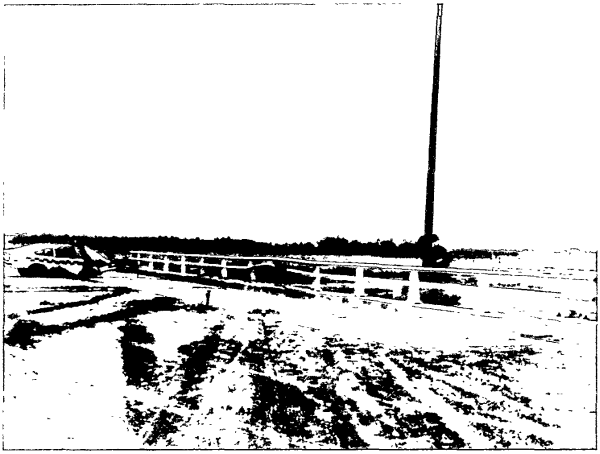


FIGURE 7.4 Snagging Potential

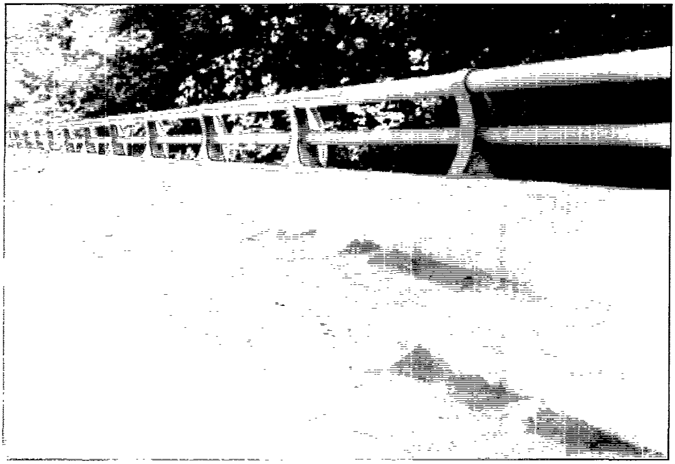


FIGURE 7.5 Presence of Brush Curb

existing concrete post and open railing systems which predate 1964 must be replaced or retrofitted. However, many existing safety curb and parapet railings are still performing well. Even though they do not meet current full railing strength, they are not severely deficient since they can contain and redirect out-of-control vehicles in all but the most severe impacts.

Some specific retrofit concepts that can be adapted to numerous types of deficient designs are:

- Concrete retrofit (safety shape or vertical)
- W-beam/thrie-beam retrofits
- Metal post and beam retrofits
- Tubular thrie-beam retrofits
- Self-restoring bridge rail (SERB) retrofit

Each of these are discussed below and illustrated in Figures 7.6 through 7.11.

7.6.2.1 Concrete Retrofit (Safety Shape or Vertical)

The concrete safety shape which is commonly used for new construction can often be added to an existing substandard bridge railing as an economical retrofit design if the structure can carry the added dead load and if the existing curb and/or railing configuration can meet the anchorage and impact forces needed for the retrofit barrier. This design is most cost-effective when the existing railing can remain in place and does not require extensive modifications. Although a vertically faced retrofit can cause relatively high deceleration forces for sharp angle impacts, its addition to the top of an existing safety curb as shown in Figure 7.6 creates an effective barrier. Care must be taken to avoid a protruding curb which can cause considerable wheel and suspension system damage and may contribute to vehicular vaulting in shallow angle impacts.

7.6.2.2 W-Beam/Thrie-Beam Retrofits

An inexpensive, short term solution to the inadequacies of pre-1964 bridge railings is to carry an approach roadside barrier (w-beam or thrie-beam) across the structure. While this treatment may not bring an existing bridge railing into full compliance with AASHTO design criteria, it can significantly improve the impact performance of a substandard railing. This treatment can be particularly cost-effective on low-volume roadways with structures having timber railings. Testing done in conjunction with the development of the SL-1 bridge railing has conclusively shown that a bridge railing can be effective even if it deflects several feet upon impact. Continuous metal beam rail across a structure also eliminates one of the major problems of a bridge rail-approach rail transition, i.e., adequate anchorage to prevent the approach rail from pulling out on impact. By carrying the approach rail across the bridge, the only transition design elements that remain critical are gradual stiffening and elimination of a snagging potential. These concerns, too, become less critical if the bridge railing is not totally rigid, as is the case on most timber bridges.

FIGURE 7.6 Concrete Retrofit

Both Washington and New York State have successfully crash tested thrie-beam retrofits of existing substandard railings. Their designs are shown in Figures 7.7 and 7.8, respectively.

7.6.2.3 Metal Post and Beam Retrofits

A metal post and beam retrofit railing such as that shown in Figure 7.9 may be appropriate for use on an existing structure that has a relatively wide raised walkway. This

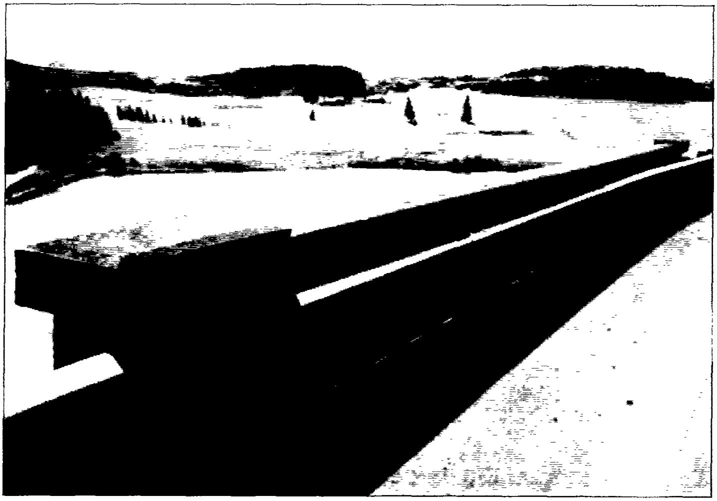


FIGURE 7.7 Thrie-Beam Retrofit (Washington)

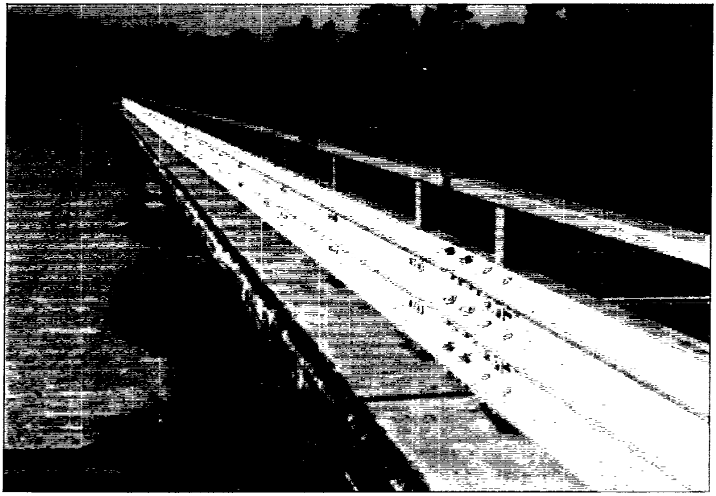


FIGURE 7.8 Thrie-Beam Retrofit (New York)

design functions well as a traffic barrier separating motor vehicles from pedestrians using a sidewalk across a bridge. In may cases, the existing bridge railing can be used as, or converted to, a pedestrian railing.

The post attachment to the curb or bridge deck can be designed to withstand the design loads contained in the current AASHTO *Standard Specifications for Highway Bridges* or can be a yielding design that eliminates bridge deck damage in high-angle, high-speed impacts. The metal rail elements should be in line with the face of the curb and spaced to minimize the likelihood of vehicle intrusion and subsequent snagging on the posts.

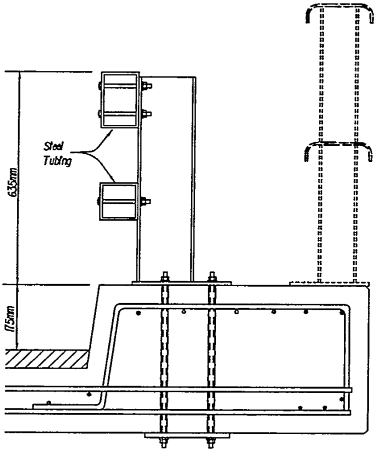


FIGURE 7.9 Metal Post and Beam Retrofit

7.6.2.4 Tubular Thrie-Beam Retrofits

Using a tubular thrie-beam rail element to retrofit a substandard concrete bridge railing results in a barrier that can significantly strengthen the existing railing. The tubular thrie-beam is blocked out from the existing rail by brackets consisting of a relatively stiff box section and a tube section. The railing is set in line with the face of the curb. The collapsing tubes provide the dynamic deflection, thereby attenuating the lateral deceleration forces on a vehicle. Although a larger deflection distance would further reduce deceleration forces, additional collapse of the rail would permit vehicle interaction with the exposed curb and could therefore result in undesirable post impact vehicular trajectory.

A major advantage to this retrofit system is its adaptability to various existing geometrics. By changing the size of the box section and/or crushable pipes, this retrofit can be used on several different railings. By raising the total height of the thrie-beam, the capabilities of the design are greatly increased. When set at a height of 960 mm, the tubular thrie-beam retrofit successfully redirected an 18,000-kg intercity bus impacting at 80 km/h and an angle of 15 degrees. Typical tubular thrie-beam retrofits are shown in Figure 7.10.

7.6.2.5 Self-Restoring Bridge Rail (SERB) Retrofit

This design is similar to a tubular thrie-beam retrofit, but has the added advantage of requiring minimal maintenance for most impacts. This retrofit bridge railing consists of an articulated tubular thrie-beam rail mounted on an existing narrow safety wall/parapet by box posts and blockouts. The beam element is connected to the blockouts by T-shaped pivot bars as shown in Figure 7.11. In its original position, the tubular thrie-beam is 840 mm above the pavement surface. It reaches a maximum height of 940 mm when hit and returns to its original position after moderate impacts.

This design passed a full range of vehicle impacts, from a subcompact at 100 km/h, and a 20-degree impact angle to an 18,000-kg intercity bus impacting at 85 km/h and 15.5 degrees. It is suggested for use on rehabilitation projects where an existing bridge rail is inadequate but not scheduled for removal or replacement. Structures in urban areas where the containment of large vehicles is a serious consideration are likely candidates for a railing of this type.

7.7 CRASH-TESTED RAILINGS

This section identifies a series of bridge railings that have been successfully crash tested and provides a simplified drawing and narrative description of each railing. This listing is not intended to be all-inclusive, but rather describes a variety of tested railings in order of generally increasing strength. Test procedures were in accordance with NCHRP Report 230. The systems included are:

- Side-Mounted Thrie-Beam Bridge Railing
- Tubular W-Beam Bridge Railing
- Side-Mounted Rectangular Tube Bridge Railing
- Oklahoma Modified TR-1 Bridge Rail (Open concrete Beam and Post)
- 2-Tube Curb-Mounted Bridge Railing
- BR1 Type C Aluminum Bridge Railing
- Safety Shape Concrete Bridge Railing
- Nevada Safety Shape Parapet
- Texas Type HT
- Texas Type TT (Extended New Jersey Safety Shape)

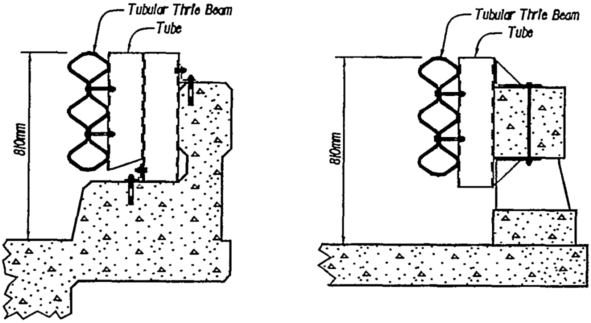


FIGURE 7.10 Tubular Thrie-Beam Retrofits

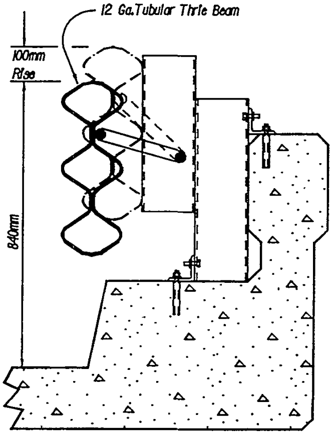


FIGURE 7.11 Self-Restoring Bridge Rail (SERB) Retrofit

Each of these systems is described in the following subsections. Additional information on individual bridge railings, is contained in Appendix D. A list of additional crash-tested bridge railings may be obtained from the Federal Highway Administration, Office of Engineering.

7.7.1 Side-Mounted Thrie-Beam Bridge Railing

The side-mounted thrie-beam bridge railing shown in Figure 7.12 is unique because it is presently the only non-rigid bridge railing that has been successfully crash tested to

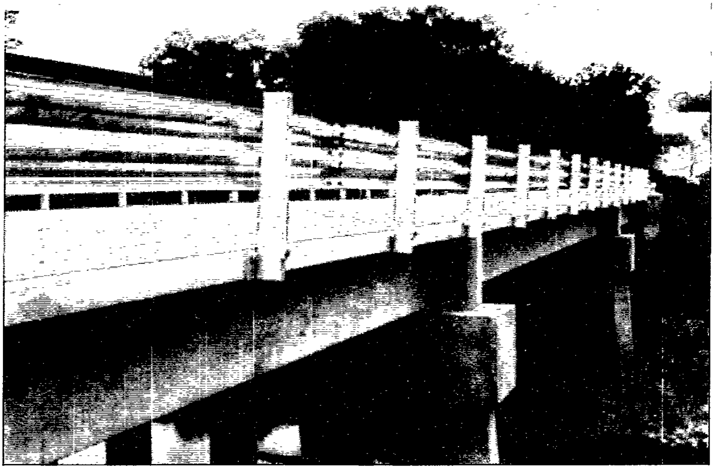


FIGURE 7.12 Side-Mounted Thrie-Beam Bridge Railing

meet the lower service level performance criteria included in NCHRP Report 230. Intended primarily for use on lower volume secondary roads, the thrie-beam system consists of a thrie-beam rail element the center of which is mounted 550 mm above the deck on wood or steel posts. Since the thrie-beam railing is designed to deflect on impact, an approach rail transition is not needed since there is not a hard point in the system. Tests with compact and full-sized automobiles at impact speeds of 100 km/h and impact angles of 15 degrees resulted in smooth redirection and no evidence of snagging. A 70 km/h and 7-degree impact with a 9000-kg school bus resulted in similar performance.

Advantages to using this system include its relative simplicity and low cost. The post attachment detail is designed to yield on impact rather than cause damage to the bridge deck. Thus, the thrie-beam railing is significantly more forgiving than a rigid design and is likely to be easier to repair after a hit.

7.7.2 Tubular W-Beam Bridge Railing

The tubular w-beam bridge railing shown in Appendix D Figure D.2 is a strong beam and moderately weak post concept which is designed to separate at the base plate before deck damage can occur. The tubular member is almost 7 times stiffer than a single w-beam member and thus deflection is limited to an amount that retains the vehicle on the bridge deck. The 700-mm mounting height is the same as most standard approach guard fence which results in no transition discontinuities. It successfully contained and smoothly redirected a 2000-kg car impacting at approximately 100 km/h and 27.5 degrees.

7.7.3 Side-Mounted Rectangular Tube Bridge Railing

This railing, shown in Figure 7.13, consists of standard barrier hardware, including wide flange support blockouts, a w-beam rail element, and steel tubing. This side-mounted system is considered a rigid railing; some bridge deck damage can be expected in severe impacts. It is not designed for vehicles significantly larger than full-sized passenger cars.

7.7.4 Oklahoma Modified TR-1 Bridge Railing

The Oklahoma TR-1 Bridge Railing shown in Figure 7.14 is a reinforced concrete post and beam system. The beam is offset 115 mm towards the roadway from the post to minimize any snagging potential. This design provides a rigid, maintenance-free railing that is aesthetic and reduces accumulations of snow on the bridge deck by providing openings between the posts. This railing satisfactorily redirected a 2000-kg vehicle impacting at 100 km/h and at an approximate 25-degree angle.

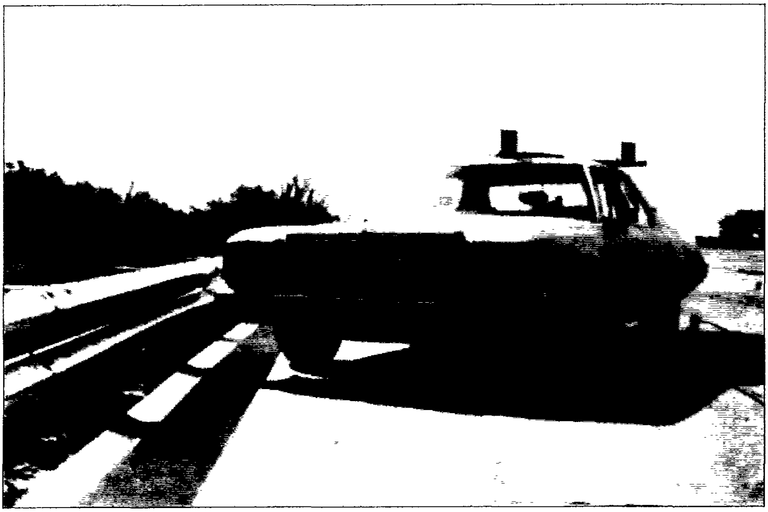


FIGURE 7.13 Side-Mounted Rectangular Tube Bridge Railing

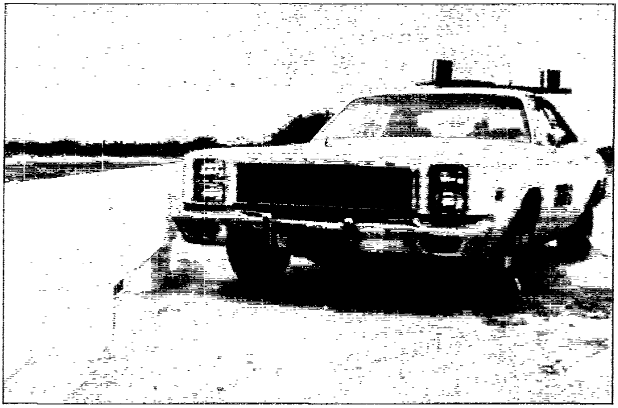


FIGURE 7.14 Oklahoma TR-1 Bridge Railing

7.7.5 2-Tube Curb-Mounted Bridge Railing

The 810-mm high railing shown in Figure 7.15 is a rigid steel railing system that was successfully tested with both compact and full-sized passenger cars. Its strength and height may also be capable of redirecting larger vehicles but to date no additional testing has been done to determine its ultimate capabilities.

7.7.6 BR1 Type C Aluminum Bridge Railing

The system shown in Figure 7.16 consists of a metal railing, either aluminum or galvanized steel, on top of a 460-mm vertically faced concrete parapet. This railing has significant strength and can readily redirect passenger cars and vans; when tested with a 9000-kg school bus, this bridge rail redirected the vehicle in a 100-km/h, 15-degree impact, but the bus rolled onto its side. Thus, this 810-mm high barrier is not adequate to prevent rollover with high center of gravity vehicles.

FIGURE 7.15 2-Tube Curb-Mounted Bridge Railing

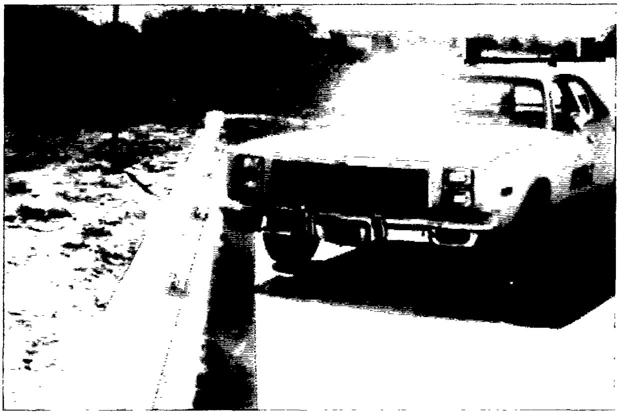


FIGURE 7.16 BR-1 Type C Aluminum Bridge Railing

7.7.7 Safety-Shaped Concrete Bridge Railing

The concrete safety shape shown in Appendix D Figure D.7 is one of the most common bridge railings used on new construction. Identical to concrete median barrier in the shape of its front face, the architectural treatment of the outside face may vary considerably, depending upon its location. Reinforcing of the shape when it is used as a bridge railing is significant. The concrete requires virtually no maintenance for most hits and successfully redirects compact and full-sized vehicles. It also successfully redirects heavy trucks and buses in relatively low-angle (less than 15 degrees) hits. The shape may need to be higher to contain or prevent rollover of high center of gravity vehicles at high speeds and angles of 15 degrees or more.

7.7.8 Nevada Concrete Safety Shape (With Steel Rail)

Figure 7.17 depicts a modified concrete safety shape used by Nevada. The addition of the steel rail on top of the 685-mm concrete parapet raises the overall rail height to 990 mm. This design successfully contained and redirected an 18,000-kg intercity bus impacting at 100 km/h and an impact angle of approximately 15 degrees.

7.7.9 Texas Type HT (Heavy Truck)

The bridge railing shown in Appendix D Figure D.9 was designed and successfully tested to contain and redirect heavy vehicles up to a 36,000-kg tractor-trailer. Total railing height is 1270 mm (810-mm strengthened safety shape and 460-mm steel rail with posts). The railing test configuration had the face of the steel member flush with the top face of the concrete, thus allowing a significant roll angle of the truck. The truck was contained in the shoulder area, but rolled on its side after leaving the test section. Extending the steel member over the upper face of the concrete will reduce the roll angle.

7.7.10 Texas Type TT (Tank Truck)

Appendix D Figure D.10 shows an extremely strong barrier railing which successfully contained and redirected a 36,000-kg tractor-tank trailer at 80 km/h and 15 degrees. This railing should be warranted for use in only the most rare situations. Future improvements in the crashworthy behavior of hazardous vehicles may eliminate even this rare need. The railing as tested consists of a very heavily reinforced and widened concrete safety shape with a massively reinforced continuous concrete member and post. Total railing height is 2290 mm.

7.8 TRANSITIONS

A transition section is usually needed where semi-rigid approach roadside guard fence must join a rigid bridge railing. Transitions may not be necessary when bridge railings with some flexibility (such as the tubular w-beam described in Section 7.7.2) are used. The transition design should produce a gradual stiffening of the overall approach

FIGURE 7.17 Nevada Concrete Safety Shape

protection system so vehicular pocketing, snagging, or penetration can be reduced or avoided at any position along the transition. Details of special importance for transitions are as follows:

- The approach rail-bridge rail splice or connection must be as strong as the approach rail itself so it will not fail on impact by pulling out. The use of a cast in place anchor or through-bolt connection is recommended. It must also be designed to minimize the likelihood of snagging an errant vehicle, especially one from the opposing lane on a two-way facility.
- Strong post systems (usually blocked out) or combination normal post and strong beam systems can be used on transitions to rigid bridge railings or other hazards. These systems should usually be blocked out from their posts unless the railing member is of sufficient width to prevent or reduce snagging to an acceptable level. However, blockouts or railing offsets alone may not be sufficient to prevent potential snagging at the immediate upstream end of the rigid bridge railing. A rub rail may be desirable in some designs using flexible w-beam or box beam transition members. Tapering of the rigid bridge railing end behind the transition members at their connection point may also be desirable. Rub rails or tapering are especially needed when the approach transition is recessed into the concrete end of the bridge railing or other rigid hazard.
- The transition section should be long enough so significant changes in deflection do not occur within a short distance. Generally, the transition length should be 10 to 12 times the difference in the lateral deflection of the two systems in question.
- The stiffness of the transition should increase smoothly and continuously from the less rigid to the more rigid system. This is usually accomplished by decreasing the post spacing and/or increasing the post size, and by strengthening the rail element.
- Drainage features such as curbs, raised inlets, curb inlets, ditches or drainage swales, when constructed in front of barriers, especially in the transition area may initiate vehicle instability which can, in some instances, adversely affect the crashworthiness of the transition. The slope between the edge of the driving lane and the barrier should be no steeper than 1:10.
- When a minor road or driveway intersects a main road close to a bridge, it is oftentimes difficult to shield the bridge railing end adequately. The preferred solution is to close or relocate the intersecting road and install an approach railing with a standard transition section. If this solution cannot be done, an attempt should be made to ensure the errant vehicles do not go behind,

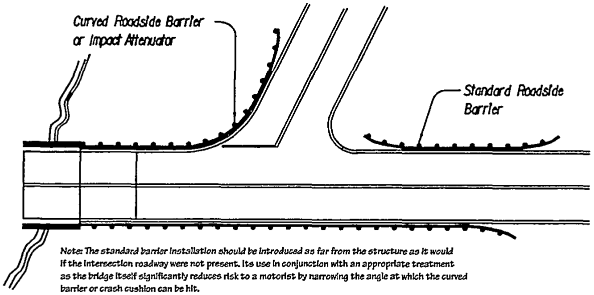
through, or over the barrier. Some sacrifice in the crashworthiness of the barrier may be unavoidable in such circumstances, but the installation should be made as forgiving as possible. The use of appropriate crash cushions or other commercially available appurtenances may provide cost-effective solutions in some cases. Figure 7.18 depicts another possible solution using standard w-beam barrier which minimizes the risk to a motorist by shielding most of the hazard through the use of a separate guardrail run.

NCHRP Report 230 recommended that transition designs be crash tested at approximately 100 km/h and at an impact angle of 25 degrees with an approximately 2000-kg automobile. Although the use of w-beam approach rail with neither an adequate blockout connection to the bridge rail nor with a rub rail is relatively common, recent crash testing has shown that such a design can produce catastrophic results by allowing an impacting vehicle to snag on the end of the rigid bridge railing or concrete safety shape or parapet. These tests have also demonstrated that a more rigid guardrail transition to the bridge railing is necessary. This can be accomplished through reduced post spacing, larger posts, stronger rail elements, and other special features.

Several new and retrofit systems have been tested and proven satisfactory in accordance with NCHRP Report 230. Some of these systems are shown in Figures 7.19 through 7.24. The first two show transition details for a w-beam approach rail to a straight, vertical concrete rail or end post and to a flared vertical concrete section, respectively.

Key design features include:

- additional posts



Note: The standard barrier installation should be introduced as far from the structure as it would if the intersection roadway were not present. Its use in conjunction with an appropriate treatment as the bridge itself significantly reduces risk to a motorist by narrowing the angle at which the curved barrier or crash cushion can be hit.

FIGURE 7.18 Possible Solution to Intersecting Side Road Near Bridge

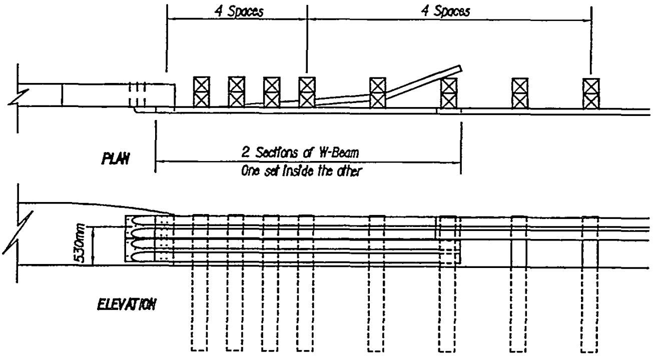


FIGURE 7.19 Vertical Concrete Bridge Railing with W-Beam Approach Rail/Rubrail

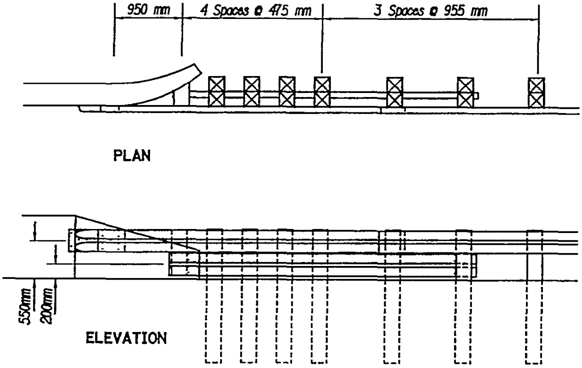


FIGURE 7.20 Flared Concrete Bridge Railing with W-Beam Approach Rail/Rubrail

- double w-beam section (one w-beam nested inside the other) on the top rail near the barrier-bridge rail connection
- rubrail

A similar design for a flared concrete bridge railing is shown in Figure 7.21 and uses a crushable steel pipe section to absorb energy and facilitate vehicular redirection. Wood or steel blocks were found to be too rigid to accomplish that purpose.

Figures 7.22 and 7.23 illustrate two transition designs which use thrie-beam as the transitional railing element. The first design is unique because it provides a large open space between the bridge railing end and the first post off the bridge. This space can be advantageously used to accommodate a drainage structure or element. In addition to nested thrie-beam, this design uses larger posts rather than a reduced spacing with standard posts.

A thrie-beam transition may offer several advantages over a w-beam system. Usually the deeper thrie-beam railing matches the geometry of the bridge railing better and is significantly stronger than w-beam. Its use also eliminates the need for a separate rubrail. Since the design is both stronger and requires fewer different parts than a w-beam/rubrail transition, repairs following a hit should be required less frequently and should be easier to make.

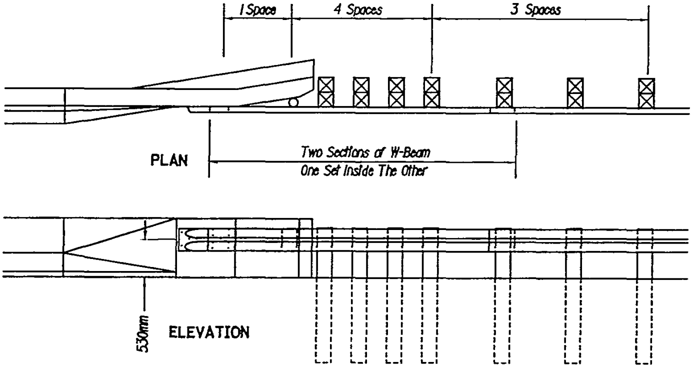


FIGURE 7.21 Flared Concrete Bridge Railing with W-Beam Approach Rail

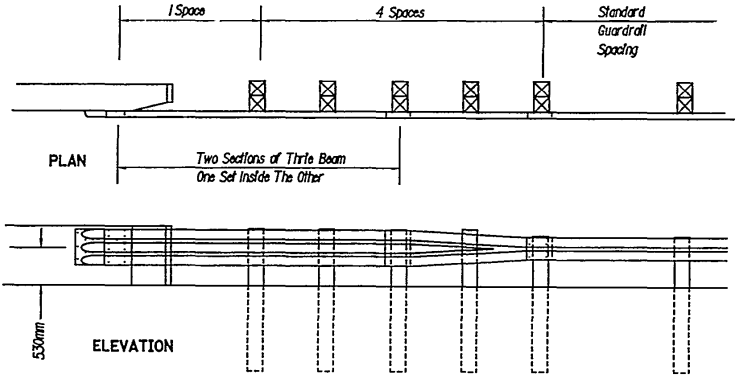


FIGURE 7.22 Tapered Concrete Bridge Railing with Thrie-Beam Approach Rail and Oversized Posts

Figure 7.24 shows a tubular w-beam transition that has been successfully tested. The tubular section is identical to the railing used for the Type T6 bridge railing described in Section 7.7.2 and is mounted on standard wood posts. The toe of the bridge railing end is tapered to minimize the likelihood of vehicular snagging. The tubular member is connected to the bridge railing end to allow development of the full bending strength of the tube as well as to provide adequate tensile anchorage for the approach barrier.

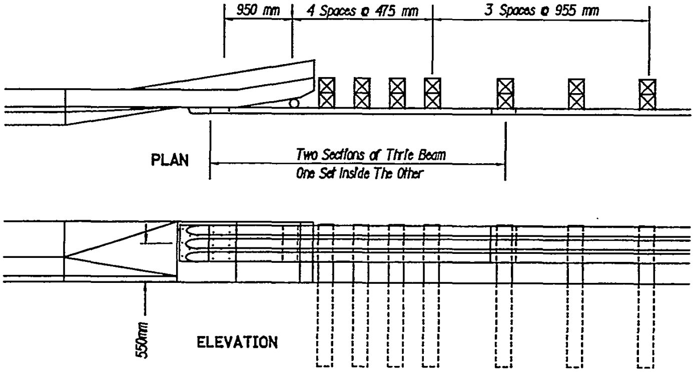


FIGURE 7.23 Flared Concrete Bridge Railing with Thrie-Beam Approach Rails and Reduced Post Spacing

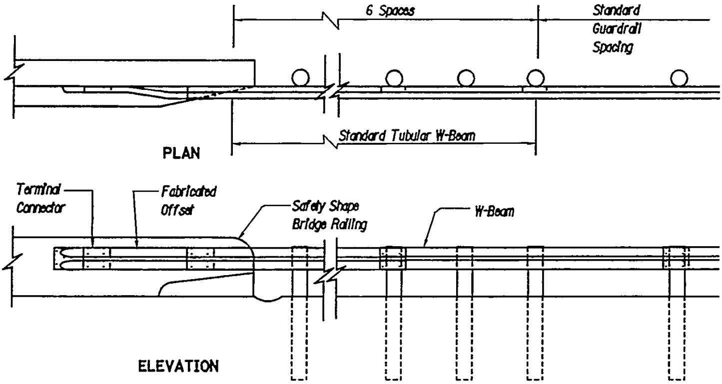


FIGURE 7.24 Tubular W-Beam Transition

CHAPTER 8: BARRIER END TREATMENTS AND CRASH CUSHIONS

8.0 OVERVIEW

An accident involving a vehicle impacting an untreated end of a roadside barrier or a fixed object has a high severity potential, since vehicles are usually stopped abruptly. In addition, an impact with a longitudinal barrier can result in barrier elements penetrating the passenger compartment thereby increasing the risk to the occupants. Barrier terminals and crash cushions are frequently used to prevent impacts of this type by gradually decelerating an impacting vehicle to a stop or by redirecting it around the object of concern.

This chapter will explain the warrants for installation and the structural and performance requirements of barrier end treatments and crash cushions. Descriptions, selection guidelines and placement recommendations for systems which have been successfully crash tested under previous or current performance criteria are provided, except as noted.

8.1 PERFORMANCE REQUIREMENTS

National Cooperative Highway Research Program (NCHRP) Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features,* contains the current recommendations for testing and evaluating the performance of crash cushions and barrier end terminals. The evaluation criteria by which the success of each test is judged require that the impacting vehicle be gradually stopped or redirected by the crash cushion or end terminal when impacted end-on. In addition to end-on impacts, barrier end terminals and redirective crash cushions must be capable of safely redirecting a vehicle impacting the side of the device. No debris may penetrate the passenger compartment or encroach on other traffic. Generally, the vehicle must remain upright during and after the collision and not be redirected into adjacent traffic lanes. Finally, the velocity with which an unrestrained passenger strikes the interior of the vehicle should not exceed 12 m/s and the subsequent vehicle deceleration should not exceed 20 g's (highest 10 millisecond average). Preferred values are 9 m/s and 15 g's. The occupant risk criteria differ from earlier guidelines. These criteria specify ride-down accelerations and are not directly comparable with the average acceleration for the entire crash event which is often associated with crash cushion design. However, the acceptance levels of safety performance are approximately the same, and the various design charts prepared by the manufacturers of proprietary crash cushions and terminals may be used to select an appropriate unit. If these charts are used, the maximum average deceleration level should not exceed approximately 7.0 g's.

8.2 END TREATMENTS

A crashworthy end treatment is considered essential if a barrier terminates within the clear zone and/or is in an area where it is likely to be hit head-on by an errant motorist. To be crashworthy the end treatment should not spear, vault, or roll a vehicle for head-on or angled impacts. For impacts within the length of need, 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 for longitudinal barriers which rely on tensile strength for redirective capacity must be capable of developing the full tensile strength of the standard rail element whether a crashworthy end treatment is warranted or not.

Specific end treatments to be covered in the following subsections are:

- Breakaway Cable Terminal (BCT)
- Eccentric Loader BCT
- Modified Eccentric Loader Terminal (MELT)
- Extruder Terminal (ET-2000)
- Turned-Down Guardrail Terminal
- Sloped Concrete End Treatment
- Crash Cushion Attenuating Terminal (CAT)
- Safety End Treatment Terminal (SENTRE)
- Transitioned End Treatment (TREND)
- Brakemaster
- Advanced Dynamic Impact Extension Module (ADIEM)
- 3-Strand Cable Terminal
- Anchored in Backslope
- Earth Mound
- Wyoming Box Beam End Terminal (WYBET)

8.2.1 Breakaway Cable Terminal (BCT)

The breakaway cable terminal (BCT), shown in Figure 8.1, was designed to minimize the spearing and rollover potential of earlier guardrail terminal designs while developing the full tensile strength of the rail for downstream impacts. For end-on impacts the first two posts are intended to fracture or slip free, allowing the rail element to bend away from the vehicle which then passes behind the terminal. Bending of the rail is encouraged by the deletion of the post bolt washers on all except the first post and by the curvature in the rail itself. For impacts within the length of need (for which vehicle redirection is desired) tensile strength is developed by the cable, which transfers tensile forces from the w-beam to the base of the end post. To ensure optimum performance, the area behind the terminal must be essentially traversable and free of fixed objects.

The parabolic flare is critical for proper impact performance. Omitting the flare or modifying the design in the field results in terminals with greatly reduced safety effectiveness. If the flare is not provided, the rail will be too stiff to bend as designed upon end-on impacts. Figures 8.2 and 8.3 show the proper layouts for the wood post and steel post BCT designs, respectively. The offsets shown are taken from an extended tangent section of guardrail and may not necessarily be parallel to the tangent section of roadway.

Impact performance: The BCT ending, at 700-mm top of rail height, has been successfully crash tested with 1020-kg and 2000-kg passenger cars. In tests with 820-kg passenger cars, however, this ending has proven too stiff to buckle readily under the reduced weight. As a result of the recent tests, the BCT should no longer be used for new installations on the approach end of guardrail installations on high-speed, high-volume roads. Where the BCTs currently exist in these conditions, they should be upgraded as required by the state's policies and practices during rehabilitation projects or as needed during maintenance operations.

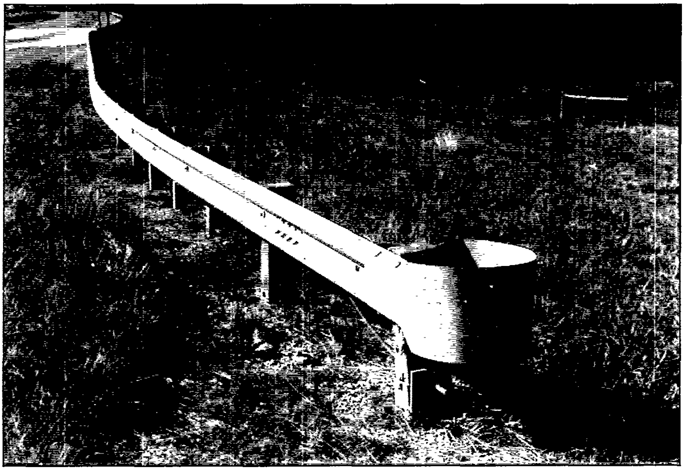


FIGURE 8.1 Breakaway Cable Terminal

The BCT is 12 m in length and is intended to be attached to a strong post or weak post w-beam rail system. It can be adapted to thrie-beam designs by means of a w-beam/thrie-beam transition section, but this transition should be made prior to the beginning of the parabolic flare. Redirection with this end treatment begins at the third post or 3.81 m from the approach end.

Provision of a 1:10 slope on the approach in front of the BCT is critical to its performance. This flat area should extend in back of the BCT so that impacting vehicles will be relatively horizontal and the possibility of rollover on the slope is minimized.

8.2.2 Eccentric Loader BCT

Efforts to modify the BCT resulted in the development of the eccentric loader BCT, shown in Figure 8.4. The metal end of the standard BCT has been replaced with a fabricated steel lever nose inside a section of corrugated steel pipe. The bolts have been removed from all the posts in the BCT except the post where the curved flare and the tangent rail join and the adjacent post in the flared section. A strut between the steel tube foundations for the two end posts enables these posts to act together to resist cable loads resulting from downstream impacts. The next four standard BCT posts are replaced by wood posts with two holes drilled in each, one at ground line and one below ground, to make them breakaway and a blockout is added to the second post to increase the curvature near the end of the rail. This further reduces the column strength of the rail and makes it less likely to penetrate an impacting vehicle.

Two alternative design layouts were developed for this end treatment: a 1220-mm offset (similar to the standard BCT) and a 460-mm offset from the tangent line of the standard guardrail section. The 460-mm offset was developed for use on narrow roadways where providing for the larger offset is judged to be impractical by the designer. This layout results in a 200-mm bulge toward the roadway at the second post from the end.

Impact Performance: Both layouts have been successfully crash tested with 820-kg and 2000-kg passenger cars. However, the 460-mm offset proved only marginally satisfactory even with the flat runout area used in these tests. Therefore, the larger offset design, which performed significantly better, is the preferred layout whenever site conditions permit its use.

This end treatment, like the standard BCT, is 700 mm in height throughout its 12-m length. It is intended to be attached to w-beam or thrie-beam systems. Redirection begins at the third post.

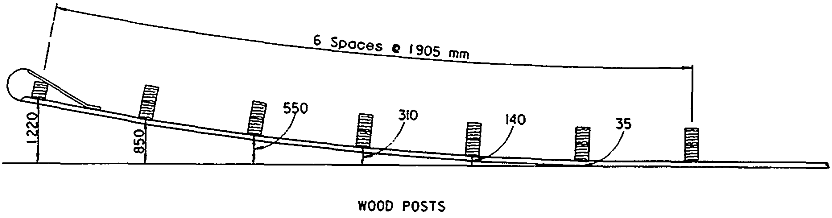


FIGURE 8.2 Parabolic Offsets for Wood Post BCT

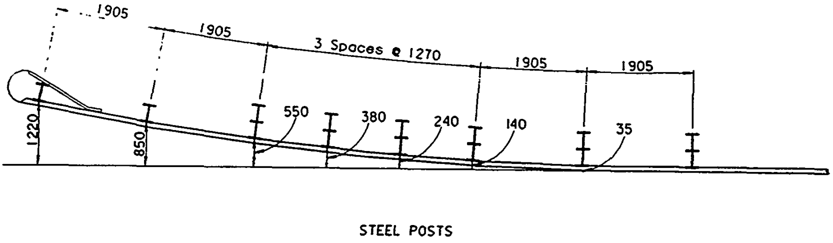


FIGURE 8.3 Parabolic Offsets for Steel Post BCT

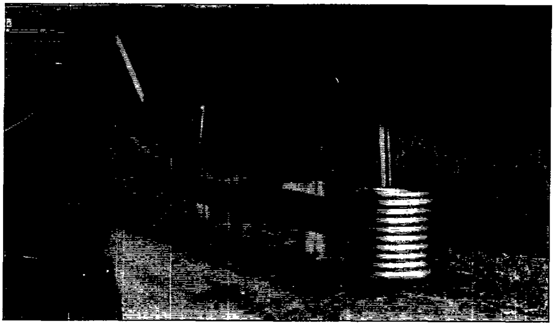


FIGURE 8.4 Eccentric Loader BCT

8.2.3 Modified Eccentric Loader Terminal (MELT)

In general, state agencies have been reluctant to adopt the eccentric loader terminal despite demonstrating significantly better performance than the standard BCT in end-on impacts. The complexity of the design, need to stockpile the parts for repairs, and the sensitivity to construction variation are some reasons for its lack of acceptance. As a result, a simplified design known as the Modified Eccentric Loader Terminal (MELT) was developed. This terminal utilizes a standard BCT end section with the addition of two 2.7-mm thick steel diaphragms in the nose section. All other details of the MELT are similar to the Eccentric Loader BCT. The MELT is shown in Figure 8.5.

Impact Performance: The MELT with a 1220-mm parabolic flare was tested with an 820-kg passenger car impacting end-on and a 2000-kg passenger car impacting the face of the rail. The results of these tests indicated that the performance of the terminal is acceptable. To date, no testing has been done on a similar terminal using a 460-mm flare; therefore, the design is only considered acceptable if installed with the 1220-mm flare as tested.

8.2.4 Extruder Terminal (ET-2000)

The Extruder Terminal (ET-2000) is a proprietary system which consists of an extruder shoe and a modified cable anchor (similar to the BCT) installed at the end of a standard w-beam guardrail element. (See Figure 8.6.) No flare is required for this end treatment. An advantage of this terminal design is that nearly all parts, with the exception of the w-beam rail and posts, are reusable and can be reinstalled when the terminal is repaired following a hit.

The extruder shoe is made up of two sections, a squeezing section and a bending section. When impacted end-on, the impact energy is dissipated as the extruder shoe travels

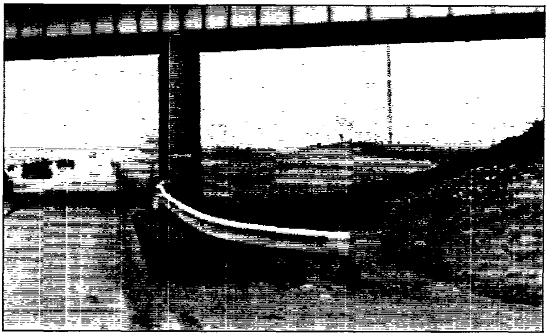


FIGURE 8.5 Modified Eccentric Loader Terminal (MELT)

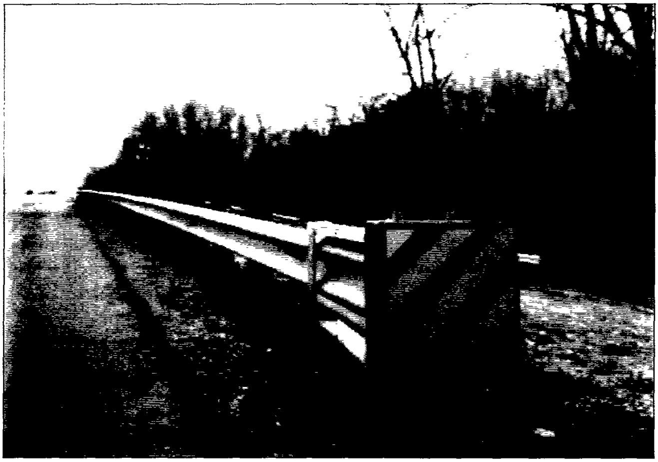


FIGURE 8.6 Extruder Terminal (ET-2000)

along the rail. The w-beam is fed through the squeezing section which reshapes the rail into a flat plate; then the bending section bends it around a small radius and directs it out to the side away from the vehicle. A quick release cable attachment is utilized which allows the w-beam to feed into the extruder during end-on impacts. The cable provides anchorage for side impacts. In many instances most of the parts other than the w-beam rail and posts can be reinstalled when the terminal is repaired following a hit. However, the sophistication of this system requires a number of special components which places demands on the maintenance system for storage and on maintenance personnel for continuing expertise.

Impact Performance: Four full-scale crash tests were performed to verify compliance with NCHRP criteria. These included two end-on and two side impact tests, each with the 820-kg passenger car and the 2000-kg passenger car. All tests were performed at 100 km/h and either met or exceeded the requirements of NCHRP Report 230 which contained applicable crash test criteria at the time of testing. No significant damage was sustained by the extruders or the release mechanisms during any of the full-scale crash testing.

8.2.5 Turned-Down Guardrail Terminals

One of the first efforts to eliminate the problem of vehicle impalement on roadside barrier ends was the use of turned-down terminals. In this type of end treatment the w-beam rail is reduced from full height to ground level, typically over a distance of 8 m. The turned-down rail is intended to collapse on impact, allowing an impacting vehicle to pass over the rail without becoming unstable or airborne. This treatment effectively eliminated the impalement problems and, when properly detailed, provided adequate end anchorage. However, subsequent testing and field experience with the original turned-down designs revealed a tendency for these designs to vault and sometimes roll impacting vehicles.

Research efforts have resulted in several variations of the turned-down terminal, all of which are intended to "weaken" the terminal by reducing the vertical load capacity of the rail-to-post attachments for several posts near the terminal. In the original design the rail was connected to the posts with 16-mm post bolts. Later designs have substituted weaker post bolts or fastening straps (clips) to hold the rail in position. In general, most such modifications have not proven totally satisfactory because the connections, which have been weakened for impact performance, are susceptible to other loads. Snow accumulations, mowing operations, and normal vibration in the rail due to passing traffic have caused some rails to fall to the ground, resulting in maintenance problems.

Another aspect of this terminal's performance that should be considered by the designer is the possibility that the turned-down rail will capture an impacting vehicle and channel it along the line of guardrail into the area of concern. For end-on impacts, after the rail becomes detached, the vehicle will continue to strike posts until it comes to a stop. If the impact speed is high enough or if the rail-to-post attachment is too strong for the impacting vehicle, the vehicle may still get on top of the rail and eventually roll over or hit the object the rail is intended to shield. Flaring a turned-down terminal away from the roadway, as shown in Figure 8.7, reduces the likelihood of its capturing a vehicle. For angle impacts, if the rail does drop before the front wheels of the vehicle leave the ground, the car is likely to travel a good distance beyond the terminal. Therefore, a clear, traversable runout path behind the terminal is required for maximum effectiveness.

Impact Performance: Several of the turned-down designs have been successfully crash tested with 1020-kg and 2000-kg passenger cars. Notably, these designs have included use of clips for the rail-release feature and some amount of flare in the end treatment itself. The original turned-down design, using the 16-mm post bolts, was successfully tested with a 2000-kg passenger car but performed unsatisfactorily in testing with a 1020-kg passenger car. None of the conventional turned-down designs can satisfactorily accommodate an 820-kg car impacting in the vicinity of the buried end.

As a result of the recent tests, the turned-down end terminal should no longer be used for new installations on the approach end of guardrail installations on high-speed, high-volume roadways. Where turned-down guardrails currently exist in these conditions, they should be upgraded as required by the state's policies and practices during rehabilitation projects or as needed during maintenance operations.

The several turned-down end treatment designs vary in length, with 15 m to 23 m being typical. These designs can be attached to strong post or weak post w-beam systems, or by use of the transition section, to any of the thrie-beam systems. Redirection with this end treatment begins at the post where the w-beam attains full height.

8.2.6 Sloped Concrete End Treatment

It is often appropriate to terminate a concrete safety shape barrier by tapering the end. This treatment should only be used in locations where the traffic speeds are low (60 km/h or less) and space is limited by right-of-way constraints or the presence of other roadside features. Other applications include locations where the barrier is flared out beyond the clear zone or where end-on impacts are not likely to occur. Recommended length of the taper is 6 m with 10 to 13 m desirable. The height of the end of the taper should be no greater than 100 mm. Figure 8.8 shows a tapered end treatment on a concrete barrier.

8.2.7 Crash Cushion Attenuating Terminal (CAT)

The Crash Cushion Attenuating Terminal (CAT), shown in Figure 8.9, is a proprietary device designed to provide adequate anchorage for w-beam guardrail systems and to function as a crashworthy energy absorbing device when impacted end-on by errant vehicles. It can also redirect side hits from either side. The CAT is a three-stage system utilizing energy absorbing beam elements, breakaway wood posts, and a cable anchorage system. The beam element is a slotted w-beam, at 700-mm top of rail height, that telescopes backward during impact. Staging of the system is such that an 820-kg passenger car impacting at 100 km/h crushes only the first three spans of the CAT;

FIGURE 8.7 Turned-Down Guardrail Terminal

FIGURE 8.8 Sloped Concrete End Treatment

more severe impacts, including a 2000-kg passenger car at 100 km/h, collapse the entire terminal. The stages are sequentially activated, so damage is directly related to the severity of the impact. The CAT was developed and tested for parallel installation to the roadway and, therefore, is especially suitable for use as a terminal for a semi-rigid median barrier or in narrow gore areas where traffic may pass on either side of the installation.

The CAT may also be used as an attenuation device, but if used as such, an additional transition section is required between the CAT and an unyielding structure (such as a pier or concrete median barrier). This transition section is necessary to develop the gradual barrier stiffening. (Reduced deflection is always required to avoid pocketing the vehicle in side impacts just ahead of the structure.)

Impact Performance: The CAT has been successfully crash tested with 820-kg and 2000-kg passenger cars for impacts to both sides. The CAT has also passed head-on impact attenuator testing with these vehicles.

This end treatment is approximately 14 m in length. The CAT is intended to be attached to a strong post or weak post w-beam rail system with transition to thrie-beam, if desired, beyond the ending itself. Redirection for a side hit begins at the fourth post from the approach end.

8.2.8 Safety End Treatment Terminal (SENTRE)

The SENTRE, shown in Figure 8.10, is a proprietary guardrail end treatment having design principles and performance similar to the CAT; i.e., a combination of guardrail redirection and impact attenuation. The SENTRE unit consists of telescoping thrie-beam fender panels, slip base support posts, and sand-filled plastic containers which dissipate a portion of the collision energy. For head-on impacts a redirecting cable guides a vehicle behind the barrier, directing it around the hard part of the system where the terminal and guardrail proper meet. The entire installation is recommended to be mounted on a concrete pad, concrete footings, or driveable steel piles.

Impact Performance: The SENTRE guardrail terminal has been successfully crash tested with 820-kg and 2000-kg passenger cars for two layouts: parallel to the line of rail and with a 1220-mm offset. Performance of the terminal was good for both layouts.

As indicated by the testing, the SENTRE can be installed parallel to the roadway or flared up to a 1220-mm offset. The sophistication of this system requires a large number of components parts, which places demands on the maintenance system for storage and on maintenance personnel for continuing expertise. On the other hand, this system has been designed so that many major component parts will be reusable after a typical impact.

The SENTRE end treatment is 7 m in length, including thrie-beam to w-beam transition panel. Top of rail height is set at 800 mm. The SENTRE can be attached directly to a strong or weak post thrie-beam guardrail or to a w-beam system using the transition section. Redirection with this end treatment begins at the sixth post from the approach end.

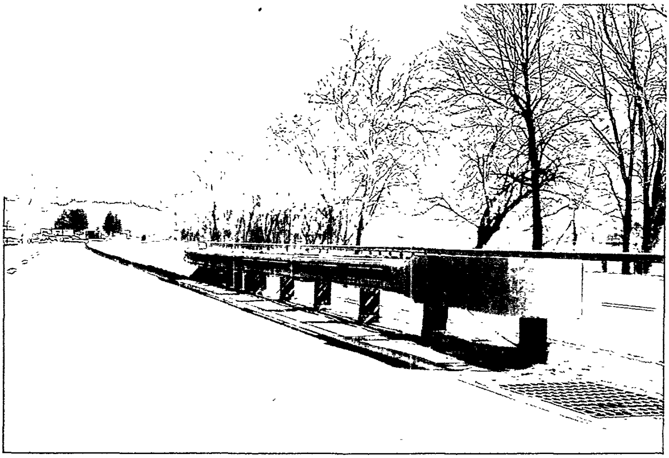


FIGURE 8.9 Crash-Cushion Attenuating Terminal (CAT)

8.2.9 Transition End Treatment (TREND)

The TREND system, shown in Figure 8.11, is a proprietary end treatment specifically intended to shield rigid barrier ends and other fixed objects where a standard length of guardrail is not practical. This terminal is similar to the SENTRE end terminal except for the addition of a steel tension strap which connects the upper rear of all posts to the rigid barrier. This strap provides adequate redirective capacity for angle impacts into the side of the terminal. By combining the redirective properties of a transition section with a crashworthy end treatment, the TREND can effectively shield a rigid barrier end in a distance of 6 m.

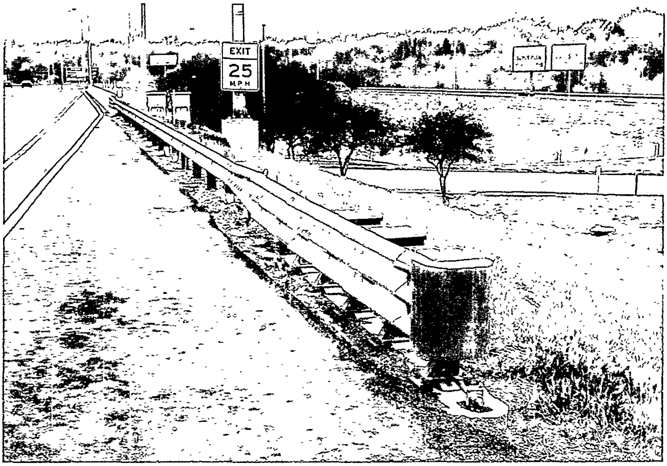


FIGURE 8.10 SENTRE Guardrail Terminal

The TREND terminal is intended for use at locations where a standard guardrail length of need and transition section cannot be installed due to space restrictions, such as at bridge rail ends, railroad warning signals, or similar fixed objects located near intersecting roadways or driveways. In using this very short terminal, the designer should remain aware that it provides vehicle protection from the fixed object to which it is attached and does not shield the area behind the terminal, which remains vulnerable to vehicle penetration.

Impact performance: This ending has been successfully crash tested, for the usage recommended in this text, with 820-kg and 2000-kg passenger cars.

8.2.10 3-Strand Cable Terminal

Several agencies that use the 3-strand cable barrier have developed a terminal specific to their barrier design. The end treatment used with the S75 x 8.5 steel post design, shown in Figure 8.12, has performed the best in crash testing. In the latest modification to this design the cable barrier is flared backward at full height to an end post offset 1070 mm from the tangent barrier line. From the end post, all three cable strands are then turned down at a 45-degree vertical angle and anchored to a concrete block in the ground. Even though the cable system is placed on supposedly "weak" posts, the end post is further weakened by use of a slip base. Impacts on or near the end post will disengage the end post, releasing the tension in the cable and allowing the vehicle to pass through. Therefore, it is essential that a clear area be provided in back of the terminal.

Impact Performance: The modified design discussed here has been successfully crash tested with 820-kg and 2000-kg passenger cars. Testing for redirection was done 7.3 m from the end post with the small car and 11.6 m with the large car. An alternate terminal designed for the wood post cable rail has no flare and no weakened post. This terminal has performed satisfactorily in testing with a 2000-kg passenger car but not with an 820-kg passenger car. It has not been crash tested with mid-sized vehicles.

8.2.11 Brakemaster

The Brakemaster, shown in Figure 8.13, is a proprietary system which is intended to be used as a terminal for a w-beam guardrail or as a crash cushion for protecting narrow obstacles. The manufacturer recommends its use in low-frequency impact areas. Bridge pillars or double-sided guardrail ends in wide medians are two possible conditions where the Brakemaster could be an appropriate treatment.

The design of this terminal consists of an anchor assembly, a cable/brake assembly, and w-beam panels. When impacted end-on, the w-beam panels telescope back with the cable/brake assembly absorbing most of the energy through frictional resistance. The anchor assembly provides sufficient anchorage to redirect side-impacting vehicles.

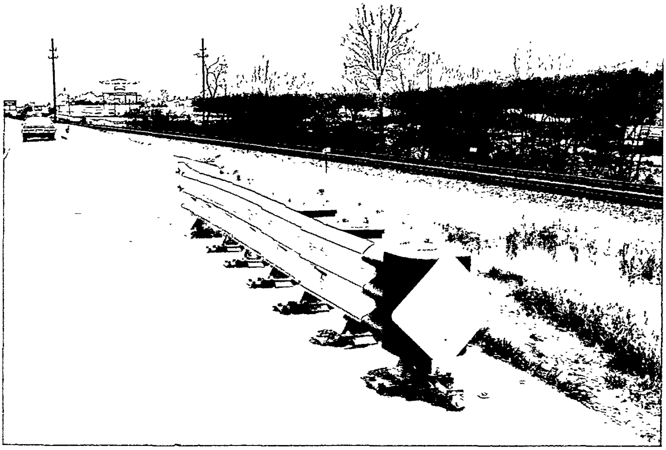


FIGURE 8.11 TREND Barrier Terminal

FIGURE 8.12 3-Strand Cable Terminal

Since the Brakemaster is a proprietary item, detailed information on design, installation, and maintenance of the system should be obtained from the manufacturer.

Impact Performance: The Brakemaster system has been fully tested in accordance with NCHRP Report 230. The system was found to meet or exceed all performance requirements specified.

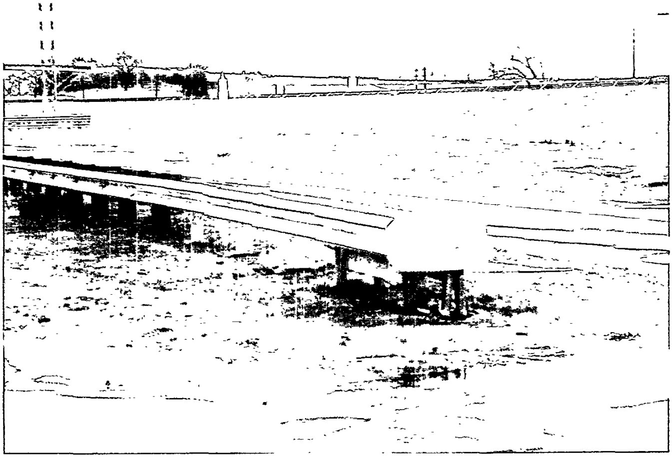


FIGURE 8.13 Brakemaster Terminal

8.2.12 Advanced Dynamic Impact Extension Module (ADIEM)

The Advanced Dynamic Impact Extension Module (ADIEM) is a proprietary terminal which is intended to be a low-cost, high-performance terminal for use at the ends of concrete median barriers or portable concrete barriers. The ADIEM is shown in Figure 8.14.

The terminal consists of a 9.1-m long carrier beam or base structure constructed of standard concrete onto which are mounted ten Perlite concrete crushable modules. Energy is dissipated by the vehicle crushing the modules as it impacts the terminal.

Perlite is an expanded inert mineral soil filler normally used for soil aeration. When Perlite is substituted for the coarse aggregate in a concrete mix, the resulting material is extremely lightweight and crushable. Strength levels in the Perlite concrete are closely controlled to insure that it falls within acceptable levels to stop the vehicle within tolerable deceleration limits.

Impact Performance: A number of full-scale crash tests in accordance with end terminal requirements of NCHRP Report 230 were performed on the ADIEM with both the 820-kg and 2000-kg passenger cars. The terminal successfully passed these crash-test requirements.

8.2.13 Anchored in Backslope

In areas of roadway cut section, or where the road is transitioning from cut to fill, it is sometimes possible to terminate a traffic barrier in the backslope, as shown in Figure 8.15. This treatment eliminates the dangers of an untreated end and greatly reduces the opportunity for vehicles to penetrate behind the ending, since nearly all of the exposed barrier is intended to redirect impacting vehicles. The section of barrier between the buried end and the point where the barrier reaches full height is an area of uncertain performance, which should be minimized by design.

This treatment is most appropriate for rigid and semi-rigid barriers. Design considerations common to both barrier types are barrier height, flare rate, and approach terrain. To the extent possible, these design parameters should be treated the same as for a standard section of barrier. Barrier height should be maintained throughout the flare to provide redirection. The flare rate should comply with the values in Table 5.6, for the portion of the barrier which is within the clear zone. Beyond that point the likelihood of vehicular impacts is lessened and the flare rate becomes less critical. Lastly, the approach terrain should be graded essentially flat (not to exceed 1:10 fill slope), with ditches either minimized or avoided altogether. If a barrier cannot be terminated in a backslope without violating one or more of these principles, a different type of end treatment may be more appropriate.

A fourth design consideration, which applies only to semi-rigid barriers, is the development of adequate tensile strength in the rail element through a positive anchorage system. The anchor design should be capable of developing at least 220 kN (equivalent to a BCT anchorage) to prevent the rail from pulling out of the backslope and permitting vehicle penetration.

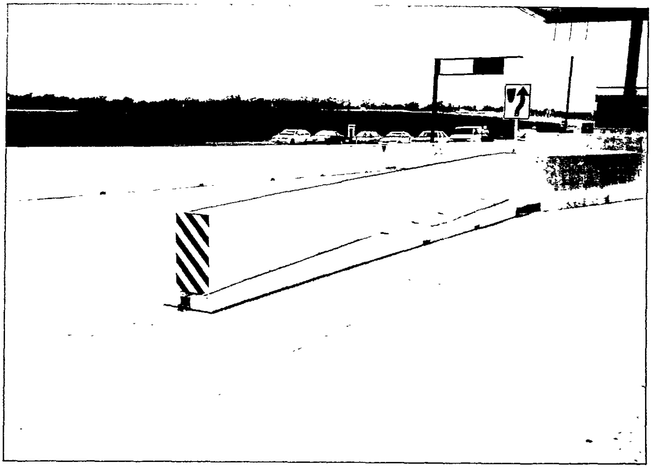


FIGURE 8.14 ADIEM Terminal

Impact Performance: Because this end treatment is not exposed, typical crash-testing criteria for terminals do not apply. Limited crash testing has been done on several design variations, however, to determine whether the flared rail in the area of the terminal would pass the standard redirection tests for longitudinal barriers. Grading at the test site included a shallow (150 mm deep by 900 mm wide) ditch in front of the backslope, to simulate common field conditions. In this testing, a 2000-kg passenger car at 100 km/h and angled 25 degrees to the roadway vaulted a w-beam rail at 700-mm height, when the rail was struck in the area of the ditch. The w-beam was flared at 1:13. The rail height was then raised to a constant elevation throughout the flare, even though the ground sloped away and a rub-rail was added. This higher rail system satisfactorily redirected the 2000-kg passenger car at conditions noted above, as well as an 820-kg passenger car at 100 km/h and 20 degrees. In additional testing with the 2000-kg passenger car, the w-beam/rub-rail system with a sharper turnback into the backslope was unsatisfactory. No tests have been conducted on this terminal close to the anchor where the rail is lower than full height.

8.2.14 Earth Berm

An earth berm can also be used to protect the untreated end of a traffic barrier. A typical layout is shown in Figure 8.16. In this type of treatment, earth coverage of the barrier end is developed by construction of a berm, as opposed to using an existing backslope. The designer should be aware of two important differences between the earth berm and the anchored-in-backslope technique. First, because the berm is being introduced onto the site by the designer, it should be designed with appropriate slopes so as not to be a safety concern in itself. Secondly, and as a consequence of good design, the berm will be traversable through much of its length and, therefore, must be constructed beyond the length of need for a particular barrier installation.

The earth berm treatment has been used to end rigid and semi-rigid barriers, more typically in the median than on the right-hand side of the road. When used with semi-rigid barriers, the need for positive end anchorage is the same as with the anchored-in-backslope treatment. An earth berm should be constructed on native soil and seeded to prevent erosion.

Impact Performance: This type of barrier end treatment has not been crash tested and there is no general agreement on what crash-test criteria should apply. For instance, if this treatment were subjected to an end-on impact, it is probable that an impacting vehicle of any size would straddle the barrier with unpredictable results. However, proper design and construction may decrease the likelihood of an end-on impact to the point where that test may not be an appropriate criteria for the ending.

8.2.15 Wyoming Box Beam End Terminal (WYBET)

A crashworthy end treatment for the box beam barrier (discussed in Chapter 5) has been developed. This treatment is known as the Wyoming Box Beam End Terminal (WYBET). The terminal consists of a nose piece welded to a short section of 150-mm x 150-mm box beam inserted into a 175-mm x 175-mm tube and held in place by a wood post. Inside the larger tube is a two-stage fiberglass composite tube. This terminal is shown in Figure 8.17.

When impacted end-on, the wood post shears releasing the cable anchorage. The nose piece telescopes into the

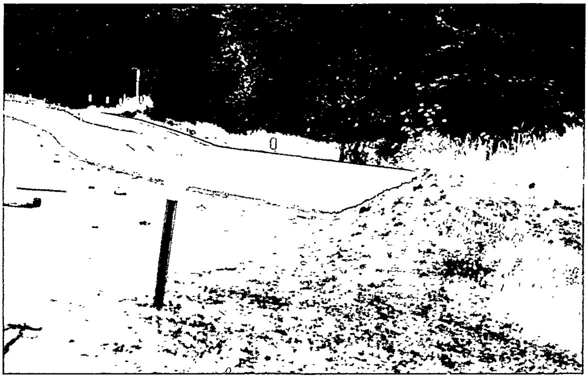


FIGURE 8.15 Barrier Anchored in Backslope

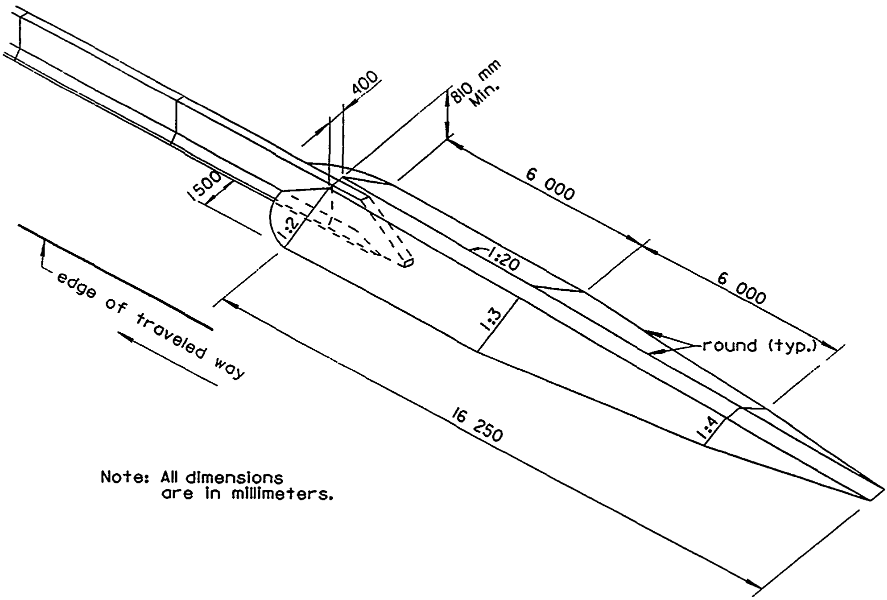


FIGURE 8.16 Typical Earth Berm Barrier End Treatment

175-mm x 175-mm tube. The tube then crushes the composite tubes. Normally the first stage of the composite tube is sufficient to stop a small (820-kg) vehicle. The second stage is needed for larger vehicles. Vehicles impacting the face of the terminal are redirected in a manner similar to a standard section of the Wyoming Box Beam Guardrail.

The terminal may be installed parallel or flared out at a maximum rate of 1:10. Redirection of face impacts is considered to begin at the third post from the end of the terminal, allowing 10 m of the terminal to be included in the "length of need."

Impact Performance: The Wyoming Box Beam Terminal has been fully crash tested with both the 820-kg and 2000-kg passenger cars at 100 km/h. The testing included both end-on impacts and angled impacts with the face of the terminal. The terminal performed within acceptable limits for both types of tests.

8.3 CRASH CUSHIONS

Crash cushions or impact attenuators are protective devices that prevent errant vehicles from impacting fixed objects. This is accomplished by gradually decelerating a vehicle to a safe stop for head-on impacts or, in most instances, by redirecting a vehicle away from the object for side impacts. Crash cushions are ideally suited for use at locations where fixed objects cannot be removed, relocated, or made breakaway and cannot be adequately shielded by a longitudinal barrier.

Before the development of crash cushions, many types of objects could not be shielded at all or could only be partially shielded by conventional barriers. Since their inception, crash cushions have proven to be an effective and safe means of shielding particular types of roadside obstacles. Their prudent use has saved numerous lives by reducing accident severities. Their relatively low cost and potentially high safety payoff make them ideally suited for use at selected locations. Like other safety hardware, crash cushions primarily serve to lessen the severity of accidents rather than to prevent them from happening.

Most operational crash cushions are patented and have been carefully designed and tested by their manufacturers. Acceptable units can be selected directly from design charts, thus eliminating in most instances the need for case-by-case design.

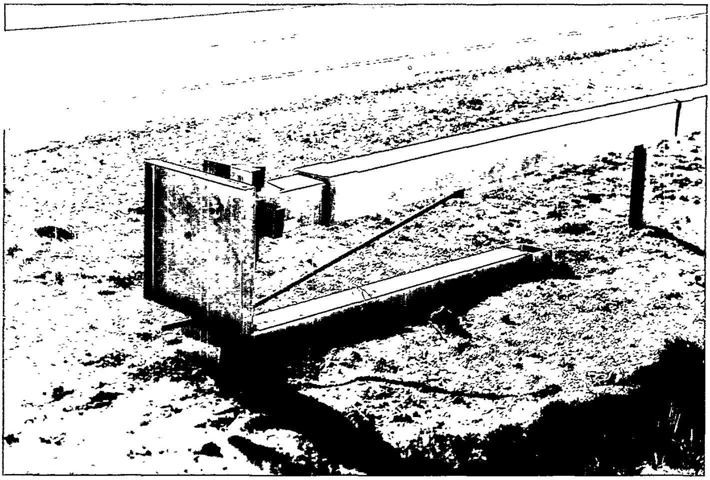


FIGURE 8.17 Wyoming Box Beam End Terminal (WYBET)

This section briefly explains how crash cushions work, what performance requirements they must satisfy, and where their use may be warranted. Descriptions, design procedures, selection guidelines, and placement recommendations for systems which have been successfully crash tested are also provided.

8.3.1 Concepts

A crash cushion's major contribution to highway safety is its ability to absorb energy at a controlled rate, stopping an impacting vehicle in such a way that the potential for serious injury to its occupants is reduced. Commonly used crash cushions generally employ one of two concepts to accomplish this task—absorption of kinetic energy or transfer of momentum.

8.3.1.1 Kinetic Energy Principle

The first concept of crash cushion design involves absorption of the kinetic energy of a moving vehicle by "crushable" or "plastically deformable" materials or by the use of hydraulic energy absorbers placed in front of an obstacle. Some of the energy is also dissipated by the crushing of the front end of the impacting vehicle. This type of system is generally referred to as a compression crash cushion. Crash cushions of this type need a rigid backup or support to resist the vehicle impact force that deforms the energy-absorbing material. Figure 8.18 illustrates this principle applied to a compression-type crash cushion.

8.3.1.2 Conservation of Momentum Principle

The second concept of crash cushion design involves the transfer of the momentum of a moving vehicle to an expendable mass of material located in the vehicle's path. The expendable mass usually consists of containers filled with sand. Devices of this type need no rigid backup or support to resist the vehicle impact force since the kinetic energy of the vehicle is not absorbed, but rather transferred to the other masses. This type of crash cushion is generally referred to as an "inertial barrier."

Figure 8.19 illustrates this principle applied to a vehicle impacting a series of five masses or containers filled with sand. Basically, the combined momentum of the vehicle and the sand after impact must be equal to the momentum of the vehicle just prior to impact. Momentum is equal to the mass of a body multiplied by its velocity so:

$$M_v V_o = M_v V_1 + M_1 V_1$$

Where: M_v = Mass of Vehicle (kilograms)
V_o = Original Impact Velocity (meters/second)
M_1 = Mass of sand (kilograms) in first barrel(s)
V_1 = Velocity (meters per second) after first impact

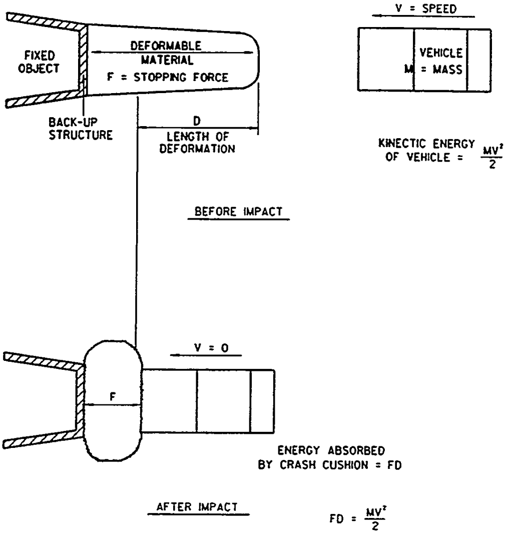


FIGURE 8.18 Kinetic Energy Principle

Applying the conservation of momentum concept, the vehicle speed after its first impact is:

$$V_1 = V_o M_v/(M_v + M_1)$$

This speed is then used as the initial speed as the vehicle strikes the second row of sand barrels. The final speed after the nth impact will be :

$$V_n = V_{n-1} M_v/(M_v + M_n)$$

Where: M_n = The mass of sand in the nth container(s)

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 velocity to about 15 km/h after the last module has been impacted. The remaining energy is imparted to the sand as the vehicle "bulldozes" through the modules. Although not required, some manufacturers recommend the placement of one additional row of heavy modules beyond the point where the vehicle velocity is reduced below 15 km/h.

Although the design procedure for inertial barriers is relatively straightforward, the manufacturers of currently operational systems have developed design charts that can be used to select a layout or to check a design for adequacy.

8.3.2 Applications

Fixed objects that generally require shielding when located within the designated clear zone for a specific highway were listed in Table 5.1 in Chapter 5. Some of these objects can best be shielded with a crash cushion. The most common application of a crash cushion is in an exit ramp gore on an elevated or depressed structure where a bridge rail end or a pier requires shielding. Crash cushions are also frequently used to shield the ends of roadside and median barriers. Typical applications are shown in Figure 8.20.

Long, steep downgrades present a unique type of problem with regard to traffic barriers. Loss of brakes on a vehicle on such a grade increases the potential for the vehicle to leave the roadway or impact other vehicles. Where such problems exist special consideration should be given to the installation of a roadside deceleration device. One device that has shown considerable promise is the gravel-bed attenuator discussed in Section 8.3.3.13. Some states have installed similar systems with good results, primarily to decelerate large vehicles safely.

Another special condition for which crash cushions are applicable is the protection of construction and maintenance personnel as well as motorists in work zones. Portable and/or temporary crash cushions have been developed for use in such situations. Also, several "truck mounted

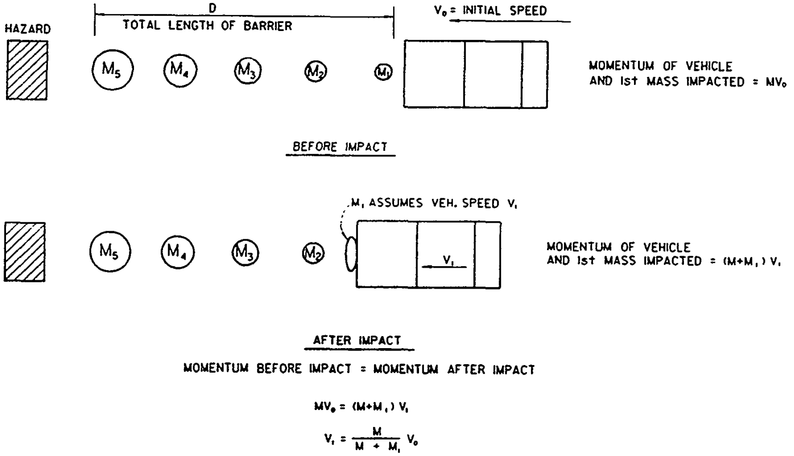


FIGURE 8.19 Conservation of Momentum Principle

attenuators" (TMAs) are available for use in construction and maintenance zones. These types of crash cushions are discussed in detail in Chapter 9, "Traffic Barriers, Traffic Control Devices, and Other Features for Work Zones."

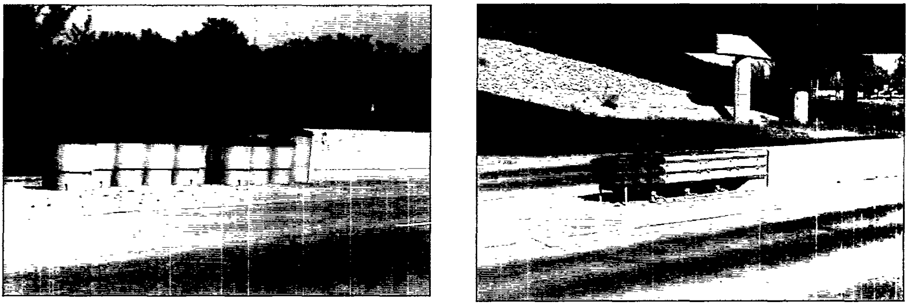


FIGURE 8.20 Crash Cushion Applications

8.3.3 Characteristics of Operational Attenuation Systems

This section identifies the numerous crash cushions or impact attenuation systems in common use today. A brief description of each of the following systems is included in the next sections:

- Hi-Dro Sandwich System
- Hi-Dro Cell Cluster
- Hex-Foam Sandwich System
- Guardrail Energy Absorbing Terminal (G-R-E-A-T)
- Sand-filled Plastic Barrels
- Connecticut Impact Attenuation System (CIAS)
- Bullnose Attenuator
- Dragnet
- CAT
- Brakemaster
- Low Maintenance Attenuator (LMA)
- Advanced Dynamic Impact Extension Module (ADIEM)
- Gravel-Bed Attenuator

8.3.3.1 Hi-Dro Sandwich System

This attenuator is a proprietary system which dissipates the kinetic energy of an impacting vehicle by the discharge of water from plastic tubes and by the transfer of energy from the vehicle to the expelled water. A typical unit is shown in Figure 8.21.

The energy absorption elements of this device are 150-mm diameter, polyvinyl plastic tubes filled with water. These cells are arranged in bays separated by diaphragms. A rigid backup structure is necessary at the rear of the cushion. Steel cables restrain the unit vertically and laterally, but it is free to collapse to the rear upon impact. There is very little debris following a crash except water which could create secondary problems by temporarily reducing the skid resistance of the pavement, especially if it freezes. Some agencies fill the tubes with a liquid calcium chloride solution to reduce the freezing problem.

The Hi-Dro Sandwich System absorbs the energy of an impacting vehicle by forcing the water in the tubes up through orifices in the top of each cartridge and by moving the mass of the cushion rearward as the vehicle is slowed and stopped. In head-on impacts the nose cluster is directly contacted and the nose cluster cartridges are compressed. Since there are no diaphragms in the nose cluster, all of the resisting force is directed toward the vehicle bumper, making the initial impact relatively soft. As the vehicle continues to penetrate the cushion, it exerts a force on the first bay of cartridges which contains a diaphragm. The diaphragms distribute the impact forces uniformly to all the cartridges in each bay until the vehicle eventually stops. The depth of penetration is dependent upon both the original impact speed and the mass of the impacting vehicle. Energy dissipation with this crash cushion is a complex

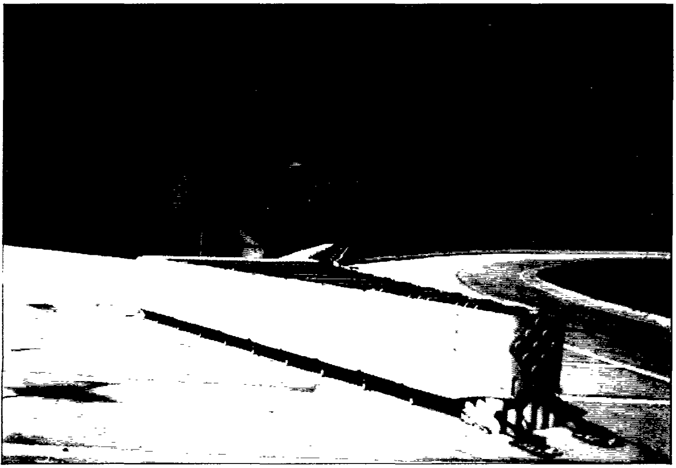


FIGURE 8.21 Hi-Dro Sandwich System

interaction of events, since several things occur simultaneously. During impact:

- Water is expelled from each tube.
- The mass of the cushion is moved backward.
- The mass of the cushion is changing as water is lost.
- The crash cushion is dragged along the pavement surface.
- The front of the impacting vehicle is crushed.

Because of this interrelated chain of events, a simplified design procedure for the Hi-Dro Sandwich System has not been developed. However, the system has been extensively tested and the manufacturer has developed a series of standard units which will suit most typical crash cushion requirements. Design tables are available from the manufacturer for determining space requirements for standard configurations. The units can be ordered in one of three standard widths: 900 mm, 1600 mm, or 2000 mm. Special units can be designed to shield objects up to 4600 mm wide. The manufacturer should be consulted regarding non-typical installations.

The Hi-Dro Sandwich System is also designed to redirect a vehicle if hit from the side. This redirection is achieved through fender panels attached to the side of the barrier as illustrated in Figure 8.22. An impact near the rear corner of the unit can result in subsequent contact with the back-up structure or fixed object if these redirection panels are not provided.

Following most impacts, Hi-Dro Sandwich units can be restored by repositioning the unit and refilling the tubes with water, making them relatively economical if subjected to repeated hits. Most side impacts result in no damage at all and have little effect on the unit's efficiency. It is important, of course, for maintenance personnel to check each unit periodically to ensure that the tubes are filled and have not lost water through evaporation or as a result of vandalism. Where freezing temperatures are encountered, anti-freeze or calcium chloride must be added to the water to prevent the unit from freezing.

Full-scale crash testing of this system was performed between 1967 and 1973 prior to development of a nationally accepted set of standard crash-testing criteria. No testing has been performed to specifically show compliance with NCHRP Report 230 or NCHRP Report 350.

8.3.3.2 Hi-Dro Cell Cluster

When vehicle speeds are below 70 km/h, redirective capability is not provided and there are space limitations which prevent the use of a larger crash cushion, a Hi-Dro Cell Cluster as shown in Figure 8.23 may be used. The energy-absorbing elements are the same 150-mm diameter tubes used in the Hi-Dro Sandwich System described in Section 8.3.3.1. These tubes are fastened together in a cluster and wrapped with a flexible "safety belt." A backup structure is required for this system.

Design of this device involves determining the minimum stopping distance needed to provide an allowable deceleration force to be exerted on an impacting vehicle. A site specific design can be made using deceleration charts available from the manufacturer of the system.

Hi-Dro Cell Clusters can be arranged in various patterns to fit the object being shielded. Typical low-speed applications are the shielding of gore areas, bridge piers or abutments, traffic control devices, and toll booths. Specific design details on this "water wall" can be obtained from the manufacturer.

Similar to the Hi-Dro Sandwich System, the Hi-Dro Cell Cluster has not been shown to meet the criteria of NCHRP Report 230.

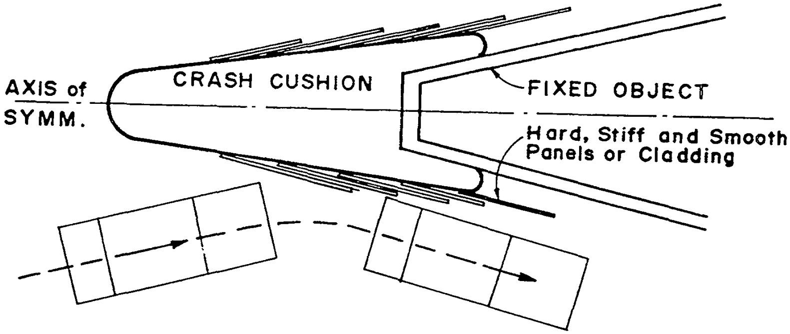


FIGURE 8.22 Illustration of Side Impacts in Transition Zone

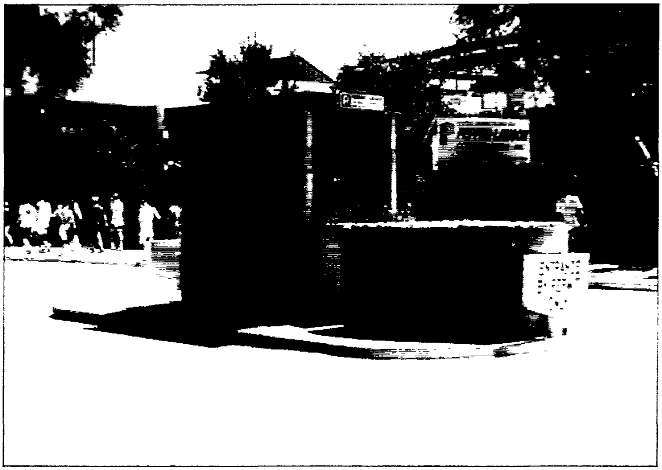


FIGURE 8.23 Hi-Dro Cell Cluster

8.3.3.3 Hex-Foam Sandwich System

The Hex-Foam Sandwich System is shown in Figure 8.24. This proprietary system is similar to the Hi-Dro Sandwich in outward appearance and operation. The Hex-Foam Sandwich System dissipates the kinetic energy of an impacting vehicle primarily through the crushing of expendable cartridges containing a patented material called Hex-Foam. This is a matrix of hexagonal-shaped cardboard filled with polyurethane foam; the cardboard is stacked in 25-mm layers in a criss-crossed arrangement. When a crash cushion containing Hex-Foam is hit, the cartridges crush, the unit collapses progressively from front to rear, and the front of the impacting vehicle is crushed as impact forces are built up. Because of this complex interaction, an analytical design procedure for the Hex-Foam Sandwich has not been developed. This device has been tested extensively and a design chart, which is available from the manufacturer, has been developed from which a standard unit can be selected based on a specific impact speed. Three standard width units are available with back-up widths of 900 mm, 1600 mm, and 2000 mm. Special units can be designed to shield hazards up to 4600 mm wide. Fender panels on the Hex-Foam Sandwich System serve to redirect vehicles in side impacts. Hi-Dro Sandwich units can be converted to the less maintenance-intensive Hex-Foam Sandwich System relatively easily by installing new steel diaphragms in the first two bays and by making modifications to the remaining hardware to accommodate the Hex-Foam cartridges.

8.3.3.4 Guardrail Energy Absorbing Terminal (G-R-E-A-T)

The Guardrail Energy Absorbing Terminal, shown in Figure 8.25, more commonly known by its acronym, G-R-E-A-T, was specifically designed to shield the ends of median barriers and other narrow fixed objects likely to be struck head-on. The G-R-E-A-T attenuator is a proprietary device which functions in a manner similar to the Hex-Foam Sandwich System to absorb and dissipate the kinetic energy of impacting vehicles. The G-R-E-A-T uses Hex-Foam cartridges similar to those described in Section 8.3.3.3. These cartridges are held in place within a framework of triple-corrugated steel rail panels which "telescope" backwards during end-on impacts. Only the cartridges and plastic nose section are expended. When hit from the side, these panels are restrained laterally by leg pins and guidance cables and redirect the errant vehicle with little or no damage to the unit. Standard G-R-E-A-T impact attenuators are available in widths of 610 mm, 760 mm, and 910 mm.

A table is available from the manufacturer which may be used to select an appropriate unit for specific site conditions. To specify an attenuator for highway use, the designer must first select an appropriate impact speed and then determine the number of bays required by referring to the design chart. This chart was developed for the impact condition of a head-on collision by a 2000-kg passenger car. A temporary version of the G-R-E-A-T, suitable for work zone applications, is described in Chapter 9.

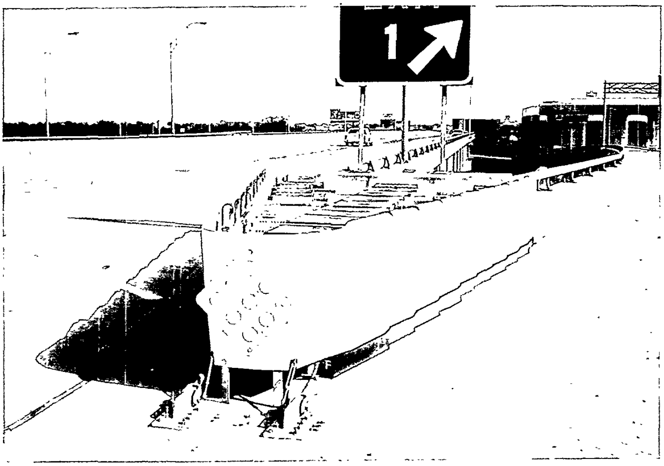


FIGURE 8.24 Hex-Foam Sandwich System

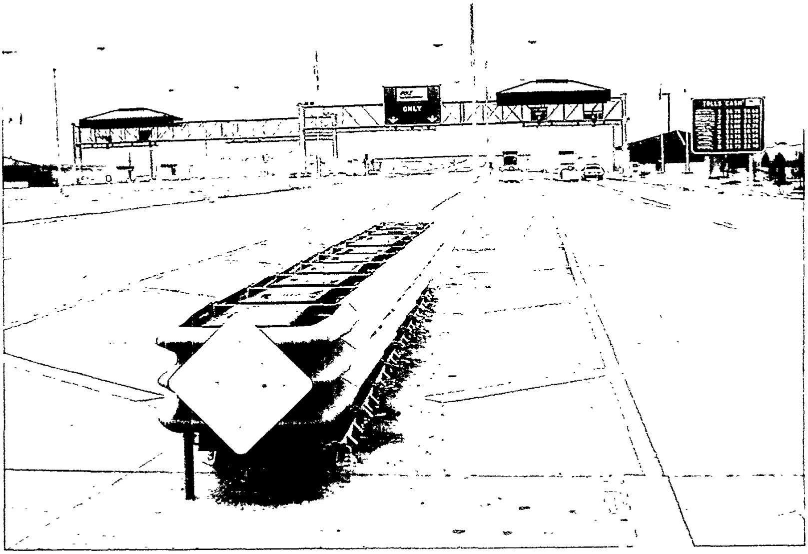


FIGURE 8.25 G-R-E-A-T System

8.3.3.5 Sand-Filled Plastic Barrels

Unlike the previously described crash cushions, sand-filled plastic barrels dissipate the kinetic energy of an impacting vehicle by transferring the vehicle's momentum to the variable weights of sand in the barrels that are hit. There are presently two manufacturers of these inertial crash cushion systems. Two examples of this type crash cushion are shown in Figures 8.26 and 8.27. These systems are patented. Although there are differences in the parts that comprise the individual modules of each system, the overall size and mass of the modules of both systems are so similar that the modules can be intermixed in the same array without affecting the performance of the crash cushion. Module size is approximately 910 mm diameter and height. Standard module masses are 90 kg, 180 kg, 320 kg, 640 kg, and 960 kg. No backup structure or wall is required for these barriers since the force that a vehicle exerts on the individual modules is not transmitted through the cushion. Neither system is designed to redirect vehicles for side impacts; consequently, modules near the rear of the array must be carefully placed to minimize the likelihood of a motorist striking the corner of the obstacle being shielded. Figure 8.28 shows a suggested layout for the last three exterior modules in an inertial barrier. While this arrangement will not accommodate all side impacts at recommended deceleration levels, it may be an acceptable compromise at sites where rear corner impacts are likely to be rare.

Inertial systems are designed on the principle of conservation of momentum, as outlined in Section 8.3.1.2. Both inertial systems have been extensively tested and have generally performed successfully for many years. The standard module masses provide adequate flexibility in the shape, depth, and width of a crash cushion array so that virtually any type or shape fixed object can be shielded. Trial layouts are checked to ensure acceptable or tolerable deceleration limits for both 820-kg and 2000-kg passenger cars. Example design procedures and calculations are shown in Table 8.1.

Both manufacturers have also developed standard arrays that can be used for specific types of fixed objects as well as design charts that may be used to analyze a particular layout. More detailed information can be obtained directly from the manufacturers. Sand barrel modules should be set as far from the traveled way as possible to minimize the number of brush or nuisance hits. However, the width of the last row of modules should always be greater than the width of the shielded object as suggested in Figure 8.28. This will soften the impact of those vehicles striking the rear portion of the crash cushion at an angle and provide some deceleration prior to its reaching the fixed object.

There is some danger inherent in using the 960-kg module at the rear of the array if this module will be the first (or only) one struck in a corner impact, particularly by a low-mass vehicle. If space permits, extra rows of lighter modules may be placed alongside the array to make it softer for rear-corner, angle impacts. Also, space should be left behind the last row of modules so sand and debris will not be confined to produce a ramping effect on a vehicle. Approximately one-half meter is the recommended minimum space requirement.

The sand barrels have been sized to hold a standard mass based on a sand density of 1600 kg/m^3. Moisture content of the loose sand should be three percent or less and clean sand should be used to minimize caking. A significant variation in the density of the sand could have some effect on the performance of the crash cushion. This

FIGURE 8.26 The Fitch System

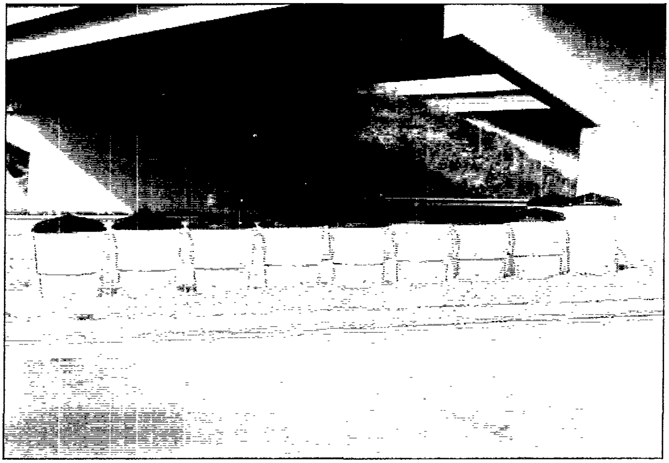


FIGURE 8.27 The Energite System

effect can be readily checked by the designer using the design procedures already described.

If the sand contains a high enough moisture content and temperatures remain below freezing for several days, the sand may freeze. Testing has shown that frozen sand reduces the safety performance of inertial barriers to some degree and produces large blocks of frozen sand that can be thrown up to 20 m during an impact. Mixing a percentage (by volume) of rock salt with the sand will prevent wet sand from freezing under most conditions. This percentage may range from 5 to 25 percent depending on the climate. Each highway agency should determine through experience the portions that produce satisfactory results. The use of pea gravel may also be considered since this material will drain well and is less likely to freeze than wet sand.

In the past some agencies have filled the sand barrels with sacked sand to facilitate cleanup after an impact. Recent crash tests demonstrated acceptable performance with a 2000-kg passenger car, but higher-than-desirable occupant deceleration levels with an 820-kg passenger car, plus some passenger compartment intrusion. Thus, the use of sacked sand is no longer considered acceptable.

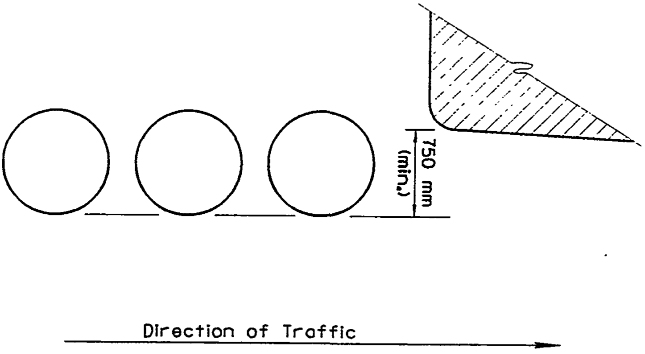
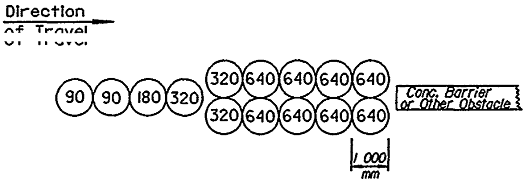


FIGURE 8.28 Suggested Layout for the Last Three Exterior Modules in an Inertial Barrier

TABLE 8.1 Sample Design Calculation for a Sand Barrel System



Design Velocity = 100 km/h (27.8 m/s)

	820 kg Vehicle				2000 kg Vehicle			
M_1 (kg)	V_0 (m/s)	V_1 (m/s)	G	t(s)	V_0 (m/s)	V_1 (m/s)	G	t(s)
90	27.8	25.1	7.41	0.038	27.8	26.6	3.32	0.037
90	25.1	22.6	6.04	0.042	26.6	25.5	3.04	0.038
180	22.6	18.5	8.53	0.049	25.5	23.4	5.25	0.041
320	18.5	13.3	8.41	0.063	23.4	20.2	7.17	0.046
640	13.3	7.5	6.17	0.096	20.2	15.3	8.86	0.056
1280	7.5	2.9	2.42	0.192	15.3	9.3	7.50	0.082
1280					9.3	5.7	2.77	0.134
1280					5.7	3.5•	1.04	0.216

$V_1 = \frac{MV_0}{M + M_1}$

M = MASS OF VEHICLE

V_0 = ORIGINAL VELOCITY

M_1 = MASS OF CONTAINER

V_1 = VELOCITY OF VEHICLE AFTER IMPACTING ONE ROW OF CONTATINERS

$a = \frac{V_0^2 - V_1^2}{2D}$

D = DECELERATION DISTANCE

a = DECELERATION DISTANCE

$G = \frac{a}{g}$

g = ACCELERATION OF GRAVITY

G = DECELERATION FORCE

$t = \frac{V_0 - V_1}{a}$

t = TIME OF EVENT

t = TIME OF EVENT

• AT THIS POINT THE VEHICLE IS TRAVELING AT LESS THAN 15 km/h AND IS STOPPED BY THE "BULLDOZING" ACTION OF THE VEHICLE ROLLING THROUGH SAND AND ONE ADDITIONAL ROW OF HEAVY CONTAINERS.

8.3.3.6 Connecticut Impact Attenuation System (CIAS)

Virtually all of the impact attenuation systems heretofore discussed entrap or capture vehicles which hit them head-on and redirect vehicles in side impacts. The only exceptions are the inertial barriers which have no redirection capability. The CIAS is a nonproprietary impact attenuator designed to provide both capabilities. Errant vehicles which impact the unit from the front or front sides are "captured," but cars which impact the unit close to a rear corner where there is insufficient space to decelerate the vehicle safely are redirected.

This system is comprised of thin-walled steel cylinders which, when hit, collapse within acceptable deceleration levels. Redirection is brought about by steel tension straps and compression pipes inside the cylinders in the last three rows. Specific design details are shown in Figure 8.29. Apparent advantages of this attenuator are its relatively low cost, minimal maintenance following nuisance hits, reusability of partially crushed cylinders, and simplicity of design. The CIAS is shown in Figure 8.30.

One disadvantage of the standard CIAS has been the need for a 2700-mm wide backup structure. For narrower obstacles a Narrow Connecticut Impact Attenuation System (NCIAS) has been developed recently. This system, shown in Figure 8.31, applies the same principles of the CIAS to a narrow site. The NCIAS consists of eight steel cylinders bolted together in a straight line. Steel tension cables are located along the sides to keep the cylinders in place and provide redirection to vehicles impacting the sides of the system. The last four cylinders are reinforced with pipe stiffeners and retainers to help redirect vehicles hitting close to the rear of the unit, while not interfering with the collapsibility of frontal impact. The NCIAS has all the same performance characteristics as the standard CIAS.

A typical application of the NCIAS is for protection of bridge piers in a narrow median. Special configurations of CIAS units can be designed for shielding wider objects.

A temporary version of the CIAS with a portable backup block, appropriate for work zone application, is described in Chapter 9.

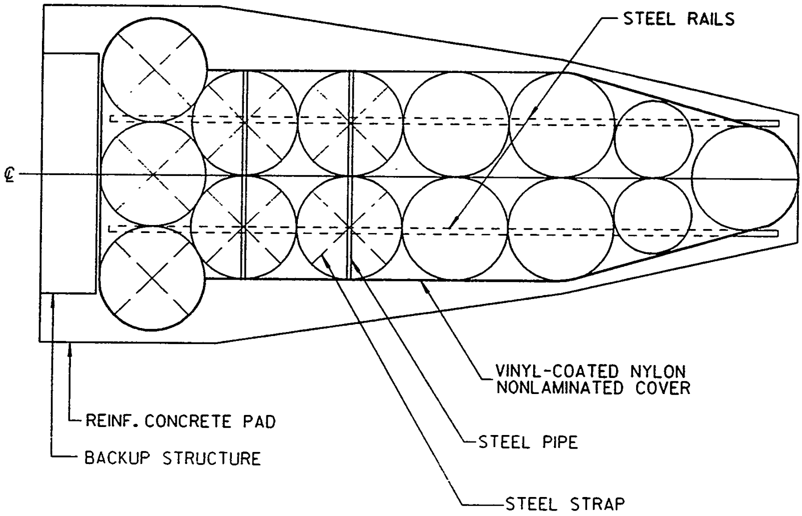


FIGURE 8.29 Schematic Drawing of a Connecticut Impact Attenuation System

8.3.3.7 Bullnose Attenuator

Several highway agencies use a w-beam guardrail envelope to shield specific obstacles. This treatment is most commonly referred to as a "bullnose attenuator" and was first installed in Minnesota in the mid-1960s in gore areas and in medians to shield bridge piers or the opening between twin bridges. For end-on impacts, the guardrail wraps around the front end of the vehicle which is gradually decelerated as it penetrates the envelope and successive posts on each side of the guardrail envelope snap off. For side impacts, the bullnose attenuator is designed to work as a longitudinal barrier to redirect an impacting vehicle away from the shielded obstacle.

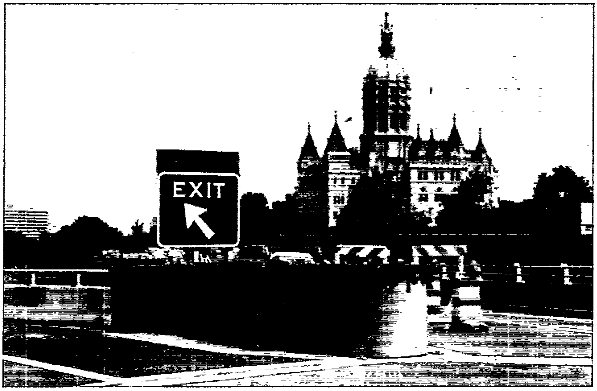


FIGURE 8.30 Completed CIAS Unit

FIGURE 8.31 Narrow Connecticut Impact Attenuation System (NCIAS)

There are several design variations in use throughout the country. Some systems use cable anchorages to minimize deflection for side impacts; some specify that the posts in the nose section be set in concrete to ensure a clean breakaway upon impact. If the posts push back in the soil, a vehicle could ramp up and over the barrier. Typical installations are shown in Figures 8.32 and 8.33. Field experience indicates that both systems work effectively, but that site grading is critical for proper performance. If the approach terrain is not flat and unobstructed, a vehicle could go over or under the w-beam rather than striking it head-on.

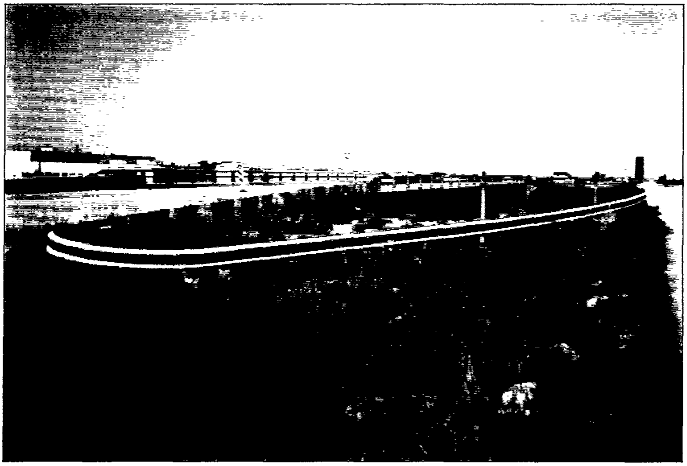


FIGURE 8.32 Bullnose Attenuator

Recent research efforts have been directed toward development of a bullnose attenuator which uses thrie-beam guardrail. This deeper metal beam railing can accommodate vehicles with above or below average centers of gravity and can counteract to some extent vehicle trajectories caused by uneven terrain. It is also significantly stiffer than w-beam and is capable of restraining or redirecting larger vehicles under certain impact conditions. The designer should keep abreast of further developments in this area.

8.3.3.8 Dragnet

The Dragnet or chain link fence vehicle attenuator is a proprietary device. Designed to stop a 2000-kg passenger car impacting head-on at 100 km/h, the Dragnet consists of anchor posts, energy-absorbing reels of steel tape, and a net assembly. A drawing of these component parts is shown in Figure 8.34. When hit, the chain-link fence wraps around the front of the impacting vehicle and the kinetic energy of the car is absorbed as the metal tape is pulled through a series of rollers in its casing. The stopping distance for a 2000-kg passenger car is approximately 20 m with an average deceleration rate of less than 2 g's. The system is repaired by replacing the steel tape in the casings and resetting the chain-link fence and cable.

This type of attenuator may be considered at locations where impacts are expected to be head-on and the results of vehicle penetration are severe. Typical locations might be for temporary road and ramp closures or in conjunction with a longitudinal barrier to shield the opening between twin bridges. Since the Dragnet is designed to deflect significantly, it can be used effectively only at locations where a clear area exists behind it. Because the Dragnet produces low deceleration rates, very little damage is done to impacting vehicles and serious injuries to vehicle occupants are unlikely.

8.3.3.9 Crash Cushion Attenuating Terminal (CAT)

The CAT system can also be used as an impact attenuator. See Subsection 8.2.7 for discussion.

8.3.3.10 Brakemaster

This system can be used as an impact attenuator in addition to functioning as a barrier end treatment. See Subsection 8.2.11 for discussion.

8.3.3.11 Low Maintenance Attenuator (LMA)

The Low Maintenance Attenuator (LMA) is a proprietary crash cushion which is designed to protect narrow obstacles in locations where a high frequency of impacts is anticipated. Repair costs for end-on impacts of this system are low due to the use of highly reusable parts. For most design impacts the main structural elements and energy absorbing materials do not require replacement and can be placed back into service in a short time.

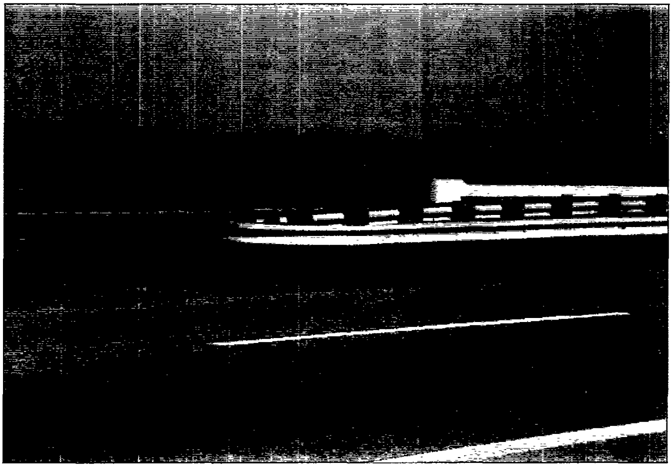


FIGURE 8.33 Bullnose Attenuator without Separate Anchorage

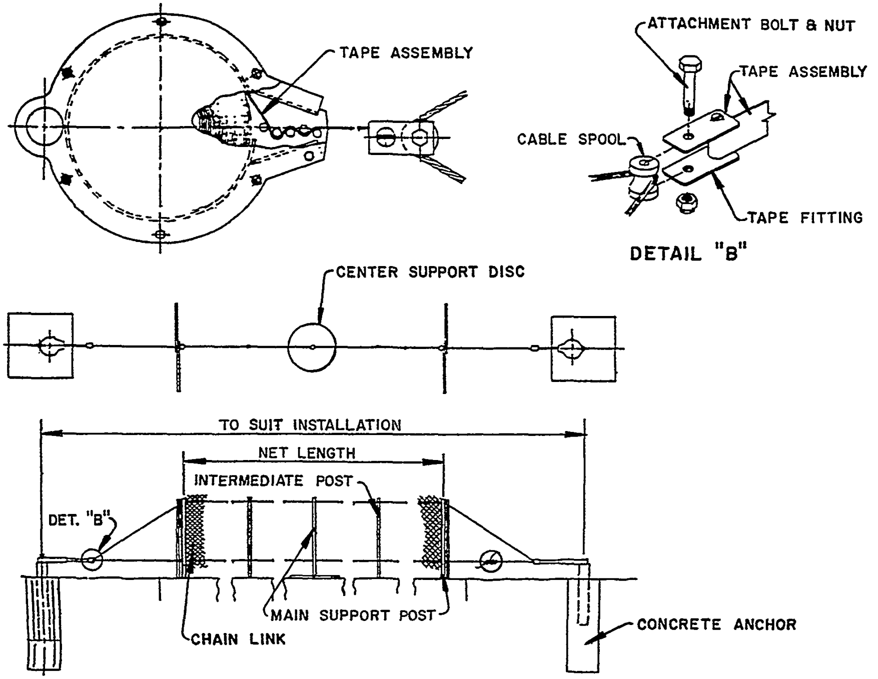


FIGURE 8.34 Dragnet Assembly

The LMA (shown in Figure 8.35) is composed of 12 modular bays which consist of elastomeric cylinders surrounded by a framework of triple corrugated steel diaphragms and thrie-beam guardrail. A flexible, reusable nose section is fastened to the end. When impacted end-on, the kinetic energy is absorbed by the telescoping movements of the guardrail and compression of the elastomeric cylinders. Longitudinal stiffness for side impact resistance is attained by use of restraining chains and a restraining cable.

Impact Performance: The LMA has been fully tested and found to stop passenger cars in the 820-kg to 2000-kg range at speeds up to 100 km/h within the guidelines of NCHRP Report 230. Side angle impacts can result in damage to the unit which can result in high-maintenance cost.

8.3.3.12 Advanced Dynamic Impact Extension Module (ADIEM)

In certain locations the Advanced Dynamic Impact Extension Module (ADIEM) can be used as a crash cushion. See Subsection 8.2.12 for discussion.

8.3.3.13 Gravel-Bed Attenuator

All of the previously identified crash cushions are designed for use for passenger cars and are not applicable to large vehicles. Although an impact attenuator capable of safely decelerating trucks or buses may be desirable, both the space and energy dissipation requirements for large vehicles are excessive. However, one velocity attenuating de-

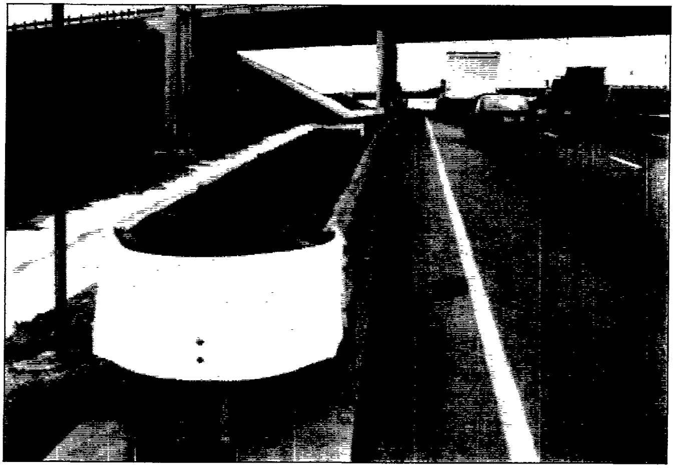


FIGURE 8.35 Low Maintenance Attenuator (LMA)

vice suitable for trucks is a gravel-bed attenuator. This design feature is most typically used on truck escape ramps along descending highway grades where runaway vehicles have been or are likely to be a problem.

Detailed design guidelines for this type of vehicle attenuating device are contained in the AASHTO publication *A Policy on Geometric Design of Highways and Streets.*

8.3.4 Selection Guidelines

The number and complexity of factors which enter the selection process for crash cushions preclude the development of a simple selection procedure. Each operational system has its own unique physical and functional characteristics. In some cases, one crash cushion will stand out as the most appropriate, but in most instances two or more types of impact attenuators will provide satisfactory protection to an errant motorist and the designer must choose between them. Once a decision has been made that a roadside feature warrants shielding and that a crash cushion is the best way to shield it, the design engineer should consider the following factors before making a final selection:

- Site Characteristics
- Structural and Safety Characteristics of Candidate Systems
- Cost
- Maintenance Characteristics

Each of these factors is discussed in the following subsections.

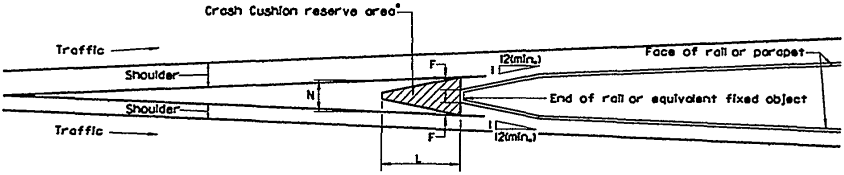
8.3.4.1 Site Characteristics

During the preliminary design stages for new construction and for rehabilitation or reconstruction of existing highways, the need for and space requirements of crash cushions to shield non-removable fixed objects should be considered. This will ensure compatibility with the final design and the crash cushion that is to be installed. Table 8.2 suggests the area that should be made available for crash cushion installation. Although it depicts a gore location, the same recommendations will generally apply to other types of fixed objects that require shielding. The unrestricted conditions represent the minimum dimensions for all locations except for those sites where it can be demonstrated that the increased costs for obtaining these dimensions (as opposed to those for restricted conditions) will be unreasonable. The preferred condition dimensions should be considered optimum. The information provided in this table is generic and may not be adequate for some systems. Therefore, it is recommended that the designer look at the various available systems which will adequately protect the obstacle and determine the space requirements from the manufacturer's specifications.

The designer should be aware that site conditions may dictate the type of attenuator needed. For example, fixed objects such as barrier ends which are less than one meter

TABLE 8.2 Reserve Area of Gores

Design Speed on Mainline (km/h)	Dimensions for Crash Cushion Reserve Area (meters)								
	Minimum						Preferred		
	Restricted Conditions			Unrestricted Conditions					
	N	L	F	N	L	F	N	L	F
50	2	2.5	0.5	2.5	3.5	1	3.5	5	1.5
80	2	5	0.5	2.5	7.5	1	3.5	10	1.5
110	2	8.5	0.5	2.5	13.5	1	3.5	17	1.5
130	2	11	0.5	2.5	17	1	3.5	21	1.5



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

wide should be shielded by a narrow crash cushion. Similarly, wide obstacles, e.g., those greater than 5 m, can be effectively shielded best by sand barrel arrays, by custom designed CIAS, or by the metal-beam "bullnose" attenuator.

8.3.4.2 Structural and Safety Characteristics of Available Systems

When more than one system is under consideration, the designer should carefully evaluate the structural and safety characteristics of each candidate system. These include such factors as impact decelerations, redirection capabilities, anchorage and backup structure requirements, and debris produced by impact.

Virtually all of the systems described in this chapter have the capability to stop both compact and full-sized passenger cars impacting head-on at 100 km/h within tolerable deceleration levels. The one exception is the Hi-Dro Cell Cluster, which is effective only for impact speeds up to 70 km/h.

Most systems described in Section 8.3.3 may also be designed to accommodate lesser impact speeds where site and operational conditions permit. Both sand barrels and Hi-Dro Cell Clusters may be used as a partial or temporary solution at locations where physical space is not adequate to install a 100-km/h system. It should also be noted that additional lower-mass sand barrel modules can oftentimes be added to an array to reduce the expected deceleration forces to lower levels. This is especially true when the shielded object is well off the roadway and the additional modules do not significantly reduce a motorist's ability to avoid a collision.

8.3.4.3 Costs

Table 8.3 summarizes approximate, comparative cost data for each of the operational systems. These figures include only material costs. Site preparation costs, which can be significant, and installation costs are not included. Except as noted, each system is based on the minimal design that will accommodate a head-on 100-km/h impact by a 2000-kg passenger car.

If an attenuator is located in an area where it is hit frequently, repair or replacement costs become significant over a long period of time and should be considered in the selection process as discussed in the next subsection.

TABLE 8.3 Comparative Cost Data

System	Cost
BCT	$1,000 – $1,200
Eccentric Loader BCT	$1,400
MELT	$1,400
ET-2000	$2,100 – $2,500
Turned Down Guardrail Terminal	$500 – $700
CAT	$3,000 – $4,500
SENTRE	$4,000 – $15,000
TREND	$6,000
Brakemaster	$12,000
ADIEM	$7,500
Hi-Dro Sandwich System	$20,000 – $50,000
G-R-E-A-T	$18,000 – $40,000
Sand-filled Plastic Barrels	$7,000 – $11,000
CIAS	$15,000 – $18,000
NCIAS	$14,000 – $17,000

Estimated cost of a unit that will accommodate a 100-km/h end-on impact by a 2000-kg vehicle. The costs are intended for comparative purposes only. Exact cost will vary depending on location and specific site conditions.

8.3.4.4 Maintenance Characteristics

Frequently, the most appropriate barrier will still not be evident after analyzing site requirements and the operational characteristics of candidate systems. Then, the maintenance characteristics of each attenuator may play an important role in the selection process. Pertinent maintenance characteristics of each crash cushion are summarized in Table 8.4. This information is based primarily on subjective evaluations. Where available, individual agency maintenance records should be used to establish costs associated with the types of crash cushions in actual use. Although the information in Table 8.4 will permit a designer to compare the relative maintenance characteristics of candidate systems, there is no substitute for knowing the actual maintenance requirements and costs for in-service installations. Each agency should document this information so it is available to the design engineer.

Maintenance characteristics can conveniently be categorized as regular (or routine) maintenance, collision maintenance, and material storage requirements. Each of these categories are discussed in this section.

Most systems described in this chapter require relatively little regular or routine maintenance. However, it is important that periodic maintenance checks be performed and recorded to ensure that each installed unit remains fully functional. If a crash cushion is located in an area that is accessible to pedestrians, vandalism may be a problem, particularly with a Hi-Dro Sandwich or Hi-Dro Cell Cluster unit where damage to the individual tubes may go unnoticed without a careful inspection. Regular checks are also needed on these systems to ensure that water has not been lost through leakage or evaporation or has not frozen.

Some cracking problems have occurred in the past with the plastic containers used in the inertial systems. These problems have been attributed in part to vibration (when the sand barrels were located on structures), calcium chloride (when mixed with sand to prevent freezing), and to design problems with the seam of some first-generation modules. It appears that these problems have been solved through improved designs.

Collision maintenance characteristics demand special consideration since they may require the most effort and expenditure over the life of an installation. If a particular site has a relatively high frequency of accidents, the use of a crash cushion having some degree of re-useability is recommended. Similarly, if nuisance hits are relatively common, an attenuator with redirection capability should reduce or eliminate the maintenance effort required for minor repairs or partial replacement of a system.

Closely associated with repair time and cost is the availability of the replacement parts needed to restore a damaged crash cushion to its original capacity. Thus, the type and amount of spare parts that must be on hand or quickly obtainable to repair each type of crash cushion in use by an agency may play an important role in the final selection process. The fewer different types of attenuators used by an agency, the easier it becomes to establish and maintain an adequate replacement parts inventory. Ideally, permanent repairs should be made very quickly. If this cannot be done, appropriate temporary measures should be taken to afford a reasonable level of protection or delineation until the original crash cushion can be restored.

8.3.5 Placement Recommendations

Most crash cushions and end treatments were designed and tested on relatively flat, level terrain. Consequently, one of these systems that is installed on or behind certain terrain conditions may perform unpredictably at best and ineffectively at worse. It is highly desirable that crash cushions and end treatments be placed on a relatively flat surface and that the path between the roadway and the attenuator be clear of any obstructions or irregularities. For optimal performance of any system, an impacting vehicle should strike the unit at normal height, with the vehicle's suspension system neither compressed nor extended.

Two prominent features with which the designer must often contend are roadside curbs and slopes. As noted in Chapter 3, both of these features can cause an impacting vehicle to become airborne and reach undesirable roll and pitch angles. For new construction, curbs should not be built where crash cushions are to be installed. Existing crash cushion locations should be reviewed to determine if the presence of a curb or a slope is likely to affect the performance of the unit, and if so, appropriate modifications should be made. In general, a mountable curb may be considered acceptable on existing construction and left in place unless it has contributed to poor attenuator performance in the past.

The surface on which a crash cushion is installed should be smooth, flat, and compacted. All of the energy absorbing attenuators must be placed on a hard, smooth pad or surface (usually concrete) to enable the unit to compress uniformly during an impact. In the case of inertial crash cushions, a paved surface provides uniform support for the sand barrels and, perhaps more importantly, provides a surface on which the pattern of the array and the required masses of the modules can be marked. This information must be readily available to maintenance personnel if a damaged or destroyed array is to be restored to its original capacity.

If a crash cushion is installed on a structure, the location of expansion joints may dictate the type of attenuator to use or require some modifications to the standard design. Non-anchored units (e.g., sand barrels) may be susceptible to vibration-induced movement.

Climatic conditions in a particular area should also be considered because some impact attenuators are affected by above or below average temperatures and may also be more susceptible to inadvertent damage caused by snow removal operations. Characteristics of specific impact attenuation systems are addressed under the sections on each system.

8.4 DELINEATION

Crash cushions and barrier end treatments are not intended to reduce accidents but rather to lessen their severity. Nevertheless, if a particular installation is struck frequently it is important to determine why the collisions are occurring. Frequently, improved signing, pavement markings, or delineation may result in fewer accidents. In this regard, conspicuous, well-delineated crash cushions and end terminals are significantly less likely to be hit than those which blend into the background, especially at night or during inclement weather. If a system is not reflective, standard object markers make it more conspicuous at night and under conditions of reduced visibility.

TABLE 8.4 Comparative Maintenance Requirements

Type Unit	Regular Maintenance	Collision Repair	Material Storage
Hi-Dro Sandwich System Hi-Dro Cell Cluster	Must be inspected on-site to determine if fluid level is adequate; unit is susceptible to vandalism; unit must be inspected more frequently during extreme high or low temperatures.	Unit is generally reusable after a collision; liquid on roadway may present a temporary problem in some cases.	Extra cells should be stored to replace any damaged by vandals or by collisions; antifreeze solution or liquid calcium chloride needed to prevent freezing in cold climates
Hex-Foam Sandwich/ G-R-E-A-T System	Can normally be inspected on a drive-by; missing or displaced Hex-Foam cartridges can be readily noted.	Unit is generally reusable after a collision; expendable Hex-Foam Cartridges must be replaced after unit is repositioned.	Hex-Foam cartridges and other replacement parts per manufacturers' recommendations
Sand Barrels	Can be inspected on drive-by for external damage. If lids are not riveted on, sand content should be checked periodically.	Individual sand barrels must be replaced after a collision; units damaged by nuisance hits must also be replaced. Debris must be removed from site.	Spare barrels sand support inserts and lids; supply of sand
CIAS	Can be inspected on drive-by.	Crushed units must be removed from site; minor damage can be repaired on-site by jacking.	Spare cylinders to replace badly damaged units
Bullnose Attenuator	Can be inspected on drive-by.	Similar to roadside barrier repair.	Standard barrier hardware, including posts
Dragnet	Can be inspected on drive-by.	Energy absorbing reels must be replaced; remainder of unit usually reusable. Spent reel casings can be refurbished and reused.	Energy absorbing reels of steel tape
LMA	Can be inspected on drive-by.	Unit generally reusable after collision.	Side fenders and other replacement parts per manufacturer's recommendation
CAT	Can be inspected on drive-by, except for cable tension which should be checked periodically.	Nose, rail elements and wood posts must be replaced. Foundation tubes are normally reusable.	Rail elements and wood posts
Brakemaster	Can be inspected on drive-by. Should be inspected on-site periodically.	Most above-ground components can be damaged and need replacement.	Breaking mechanism, fender panels, diaphragms, etc., per manufacturer's recommendation

CHAPTER 9: TRAFFIC BARRIERS, TRAFFIC CONTROL DEVICES, AND OTHER FEATURES FOR WORK ZONES

9.0 OVERVIEW

This chapter describes the safety, functional, and structural aspects of traffic barriers, traffic control devices, and safety features used in work zones and provides guidance on their application.

The AASHTO *Summary Report on Work Zone Accidents*[1] contained several conclusions: (1) accidents which occur in work zones are generally more severe, producing more injuries and fatalities than the national average for all accidents; (2) fixed-object accidents in both rural and urban areas more frequently result in injuries and fatalities than vehicle-to-vehicle collisions; and (3) about half of all work zone fixed-object accidents occur in darkness. Tractor-trailer injury and fatal accident involvement in work zones is considerably higher than the national average for other types of accidents involving these vehicles.

Previous chapters in this Guide provide criteria for safety performance of all features. Where warranted, this chapter adapts those criteria as necessary for application to work zones.

This chapter is not a stand-alone document on work zone safety, but must be used in conjunction with traffic control guidance. The *Manual on Uniform Traffic Control Devices* (MUTCD), Part VI[2], establishes the principles to be observed in the design, installation, and maintenance of traffic control devices in work zones and prescribes standards where possible. These principles and standards are aimed at the safe and efficient movement of traffic through work zones and the safety of the workers.

The design and selection of work zone safety features should be based on expected operating speeds and proximity of vehicles to the work and pedestrians. Actual operating speeds may be considerably higher than posted speed limits and as much as 30 to 40 km/h faster on freeways when temporary 60 km/h zones are established.

9.1 TRAFFIC BARRIERS

Work zone traffic barriers are designed either as permanent barriers as previously described in the Guide or as temporary barriers that can be easily relocated. They have several functions: (1) to protect traffic from entering work areas such as excavations or material storage sites, (2) to provide positive protection for workers, (3) to separate two-way traffic, (4) to protect construction such as falsework for bridges and other exposed objects, and (5) to separate pedestrians and vehicular traffic.

9.1.1 Temporary Longitudinal Barriers

Use of temporary longitudinal traffic barriers should be based on an engineering analysis. There are a number of factors such as traffic volumes, traffic operating speeds, offset, and duration, that affect barrier need within work zones. The Portable Concrete Barrier (PCB) is the option preferred by most State transportation agencies. Several other barrier designs are also available which may be appropriate for work zone applications. Although no consensus on specific warrants exists, barriers are usually justified for bridge widening, shielding of roadside structures, roadway widening (especially with edge dropoff) and to separate two-lane, two-way traffic on one roadway of a normally divided roadway.[3] (See Table 9.1.)

9.1.1.1 Portable Concrete Safety Shape

Portable concrete safety shape barriers, also known as portable concrete barriers (PCBs), are widely used in work zones to protect motorists as well as workers. However, improper use of these barriers can provide a "false sense of security" for both. Therefore, care must be taken in their design, installation, and maintenance.

PCBs are free-standing precast concrete sections 2.4 to 9 m in length with built-in connecting devices. Barrier weight varies from 600 to 750 kg/m depending on exact cross-section geometry and amount of reinforcement. The mass of individual segments can vary from 2000 to 7500 kg, thus requiring heavy equipment for installation and removal. Adequate longitudinal reinforcement and positive connections insure that the individual sections act as a smooth continuous unit.

The impact performance of PCB depends, among other factors, on segment length and mass, manner in which segments are joined, and manner in which segments are anchored.

The acceptable cross sections are the same as those described in Chapter 6. Corners of barriers may be beveled to minimize snagging of snowplows and to allow placement of the barrier sections in curves. A disadvantage is that, with the removal of the corners, resisting moment to lateral displacement is reduced.

When impacted, the mass of the PCB and friction between the PCB and the underlying surface tend to limit movement and overturning. Each section should be properly connected to the adjacent section to provide barrier continuity to resist movement, snagging, and/or instability of impacting vehicle. When lateral displacement of the barrier cannot be tolerated, it may be necessary to anchor the PCB to the underlying surface to prevent lateral movement. This can be done with drift pins or anchor bolts attached to the pavement or bridge deck. The pins or bolts should not protrude beyond the face of the PCB. Another method to limit sliding is to provide a mechanical interlock between the barrier and the pavement surface. This mechanical interlock can be provided by placing the PCB on a grout bed.

The designer should allow for adequate drainage through the PCB to prevent ponding.

Flare Rates

Flare rates for temporary barriers should be selected to provide the most cost-beneficial safety treatments possible. Low flare rates lead to longer flared sections and increase the number of impacts with the temporary barrier. Higher flare rates lead to shorter flared sections and fewer impacts but, for those impacts, increase the severity of redirection accidents and the number of barrier penetration accidents. Benefit/cost analyses of temporary concrete barriers indicate that total accident costs appear to be minimized for flare rates ranging from 4:1 to 8:1. A flare rate of 5:1 or 6:1 may be slightly more favorable for urban streets with high traffic volumes where speeds are lower and impact angles are higher.

Offset

A minimum offset of 0.6 m from the traveled lane to the PCB is desirable.

Types of Portable Concrete Barrier (PCB) Connectors[4]

To perform properly and redirect vehicles, the PCB system should be capable of withstanding severe impacts. A PCB system's weakest point is its joint which includes the physical connection and mating faces of adjoining segments. The methods for connecting PCB segments vary widely.

TABLE 9.1 Design for Temporary Barriers

Type	PCB	Quick Change	Low Profile	Triton
Structural adequacy	Variable depending on the type of joint	*	TL-2**	TL-2**
Deflection	0-1.5 m	1.5 m	.125 m	3.8 m
Typical Uses	Two-lane, two-way operation Shielding obstacles and false work Shielding edge	Shielding for changeable lanes	Work sites in urban and suburban areas where sight distance is a problem	Shielding where high portability is desired: i.e., rapidly changing and/or emergency traffic control measures. Protection in congested urban work sites.

* NCHRP Report 230 — 2000-kg passenger car at 25 degrees and 92 km/h

** NCHRP Report 350 — 2000-kg pickup at 25 degrees and 70 km/h

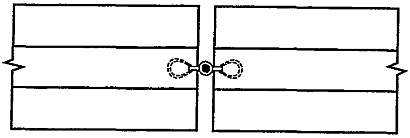
Many types of PCB connections have been crash tested and evaluated. (Refer to Chapter 5 for evaluation criteria.) Currently, the performance standards for temporary barriers are contained in NCHRP Report 350. Some versions of PCB connectors have been successfully crash tested with full-sized sedans impacting at 100 km/h and 25 degrees. Other connectors provide lower levels of performance.[4] Depending on site conditions, a temporary installation may not necessarily meet the same performance required of a permanently installed barrier system at the same site. Some existing joint connectors have provided adequate service when used at sites where the intent was to contain shallow impacts of passenger cars.

Tested and Operational Connections

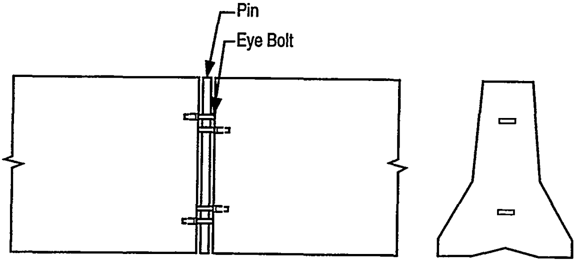
1. **Pin and Loop** (Figure 9.1) is constructed by casting steel loops into each end of the barrier segments. The loops are then positioned so that they overlap and a steel pin is inserted in the loops. There are several varieties of the pin and loop connectors. They differ according to gap width, pin diameter, manner in which the pin is secured, loop embedment length, and material used to form the loops. Such materials include steel eyebolts, smooth or deformed bars, and cable or wire rope. The wire rope may extend partially into the barrier or continue through the entire length of the segment.

   This joint can develop moderate strength in tension and torsion. The only successfully crash-tested version of this joint used steel rebar to form four loops (two loops in each barrier end). However, this joint design may allow significant lateral deflection before developing moment between two barrier segments. Therefore, this barrier design may allow large deflections under severe impact conditions, especially if short segments of barrier (less than 3 meters) are used. (Note: such shift can be reduced by placing a board on edge below the lower loops resting on the pavement surface with the ends formed to follow the 55-degree slope or by removing the slack from joint.)

   Pins should be secured at both ends of the barrier segment. Securing a pin by drilling a hole and inserting a cotter pin just below the upper loops or slotting the end will retard the pin from jumping out on impact. A



Typical Panel Plan With a View of Connection Detail



Typical Panel Elevation with a View of Connection Detail

Typical End View

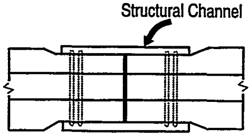
FIGURE 9.1 Pin and Loop

nut and washer will prevent a pin from being dislodged from the loops, although they may be difficult to install when the segments are in place, and salt corrosion can make them difficult to remove. Capacity of the joint could be improved over the pin and loop joint that was satisfactorily crash tested by making a more positive pin connection (nuts and washers at the top and bottom on the pin), by increasing the size of the pin, and by making the pin from a higher strength steel.

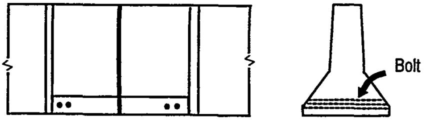
Problems encountered in using these connectors include: vertical steel pin for pin and loop connections may not remain installed since this pin is prone to removal by vandals; the loops may not be structurally adequate because of design deficiencies or previous damage; pin and loop connectors that are too close-fitting may restrict its installation on curves or at angles. As a result, smaller pins may be used or pins may be left out weakening the connection.

2. **Channel Splice** (Figure 9.2) is cast with two bolt holes at each end passing through the base of the barrier. Channel splice plates are then bolted to the sides of each adjoining segment. Important factors for this connector are the type of channel, channel length, number of bolts, bolt diameter, bolt hole diameter, spacing between bolt holes, and segment length. This joint design can generate moderately high tensile, moment, and shear strength and does not allow significant joint deflection before the moment resistance is generated. This barrier system has been successfully crash tested with a full-sized passenger car impacting at 100 km/h and 25 degrees.

   This design has numerous parts and limited tolerances, thus requiring relatively accurate alignment during placement and limited flexibility in accommodating changes in alignment, such as curves or flares.
3. **Vertical I-Beam** (Figure 9.3) is constructed with a slotted steel tube cast into each end of the barrier. The segments are then linked by inserting a steel I-beam down adjoining slotted tubes. This joint can develop very high tensile, moment, shear, and torsional strengths. It has been successfully crash tested with a 1980-kg passenger sedan impacting at 97 km/h at 25 degrees. The vertical I-beam joint also allows significant barrier movement before developing a restraining moment. Thus, to obtain optimal barrier performance, steps should be taken to reduce the amount of movement, such as removing slack from joints or using long barrier segments.
4. **Lapped Joint** (Figure 9.4) is fabricated such that each segment overlaps in a vertical plane. The joint is secured with a single steel bolt that passes through the overlapping segments. This joint provides moderate moment and tensile capacity with relatively low shear and torsional strengths.
5. **J-Hook Joint** (Figure 9.5) is a proprietary connection fabricated of two 254-mm high steel plates bent at the end in a J-hook.



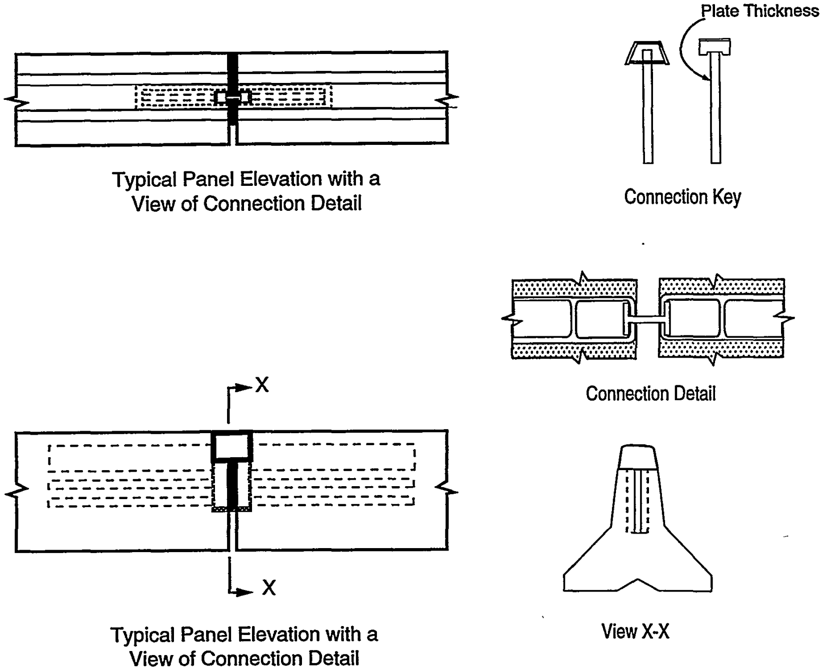
Typical Panel Plan with a View of Connection Detail



Typical Panel Elevation with a View of Connection Detail

Typical End View

FIGURE 9.2 Channel Splice



Typical Panel Elevation with a View of Connection Detail

Connection Key

Connection Detail

Typical Panel Elevation with a View of Connection Detail

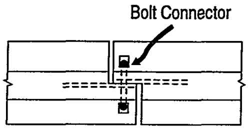
View X-X

FIGURE 9.3 Vertical I-Beam

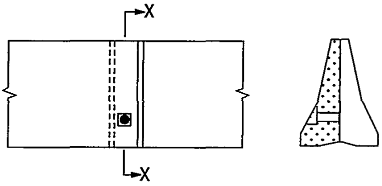
Other Connections in Use

6. **Tongue and Groove** consists of a vertical protrusion or tongue that is inserted into a groove in the end of an adjacent segment. This joint has no capacity to transfer tension or moment from one segment to the next. Further, the joint is capable of transferring only small torsion and shear loads between the segments. Another design includes the use of dowel bars which extend vertically from the base of the barrier into the underlying pavement.

   Design considerations are that tongue and groove systems may not be adequately interlocked. The barrier sections must be flush against one another. Neither the tongue nor the groove must be damaged to the point of reducing effectiveness. Tongue and groove are difficult to inspect after installation.
7. **Plate Insert** consists of a steel plate inserted in a vertical slot located in the lower center of each barrier end. The galvanized structural steel plate serves to prevent lateral movement of the two adjoining barriers during impact. The joint has limited application when the barriers are placed on a sharp curve or flare.
8. **Steel Dowel** has three steel dowels protruding from one end of each barrier segment. The steel dowels from one segment are inserted into holes of the next segment. This joint design has no tensile capacity, very low moment stiffness, low torsion capacity, and only moderate shear strength. A modified version (grouted joints) of this system has been tested successfully with full-sized sedans impacting at 100 km/h and 24 degrees; it is believed that the barrier (without grouting) may not be capable of meeting permanent barrier performance standards.
9. **Continuous Cable** consists of a cable running continuously through a hole cast the entire barrier length. A bearing plate is used at one end of the barrier as an anchoring device.



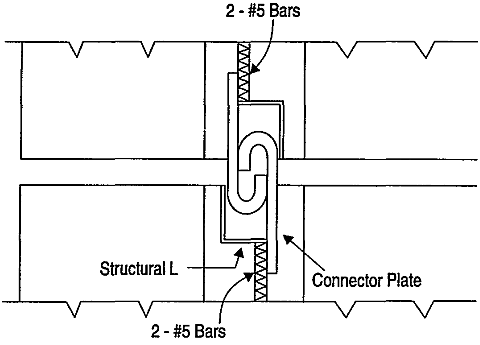
Typical Panel With a View Connection Detail



Typical Panel Elevation with a View of Connection Detail

View X-X

FIGURE 9.4 Lapped Joint



Positive Connector

FIGURE 9.5 J-Hook

Special Cases

Strengthened Barriers[4]

Most catastrophic accidents with PCBs involve heavy trucks or vehicles at high speeds and at high angles. High-angle secondary impacts may occur when barriers are located on both sides of the road or on curves. For these conditions or where minimal deflection distances are available, strengthened, stiffened, or anchored barriers and connectors may be used. Candidate sites include bridges, bridge approaches, excavations, lateral shifts or crossovers, or any roadway where there are two or three parallel runs of barrier.

Restricted Sites[5]

Because of restricted geometry, some sites may require the use of barriers where expected impacts could be substantially more than 25 degrees. One condition is when there are intersecting roadways that must be kept open near or within the work activity area. Detailed guidance to address this condition is found in the NCHRP Report 358, *Traffic Barriers and Control Treatments for Restricted Work Zones.*[5] Another condition is where work within an intersection may need PCB to protect workers from an errant vehicle or to protect the public from a hazard such as a deep excavation. If traffic must be maintained around the work site and the space is insufficient for a recommended PCB layout including the end treatment, flare rates sharper than previously recommended for the layout may be justified at the work site.

The following criteria should be considered when required to deploy the PCB at restricted sites:

- Use only at low speeds (60 km/h or less).
- All sections are to be adequately connected to adjacent sections.
- The end section must be anchored to prevent overturning and excessive sliding.
- Adequate clearance should be provided between the barrier and the work area to allow for sliding of the barrier. (If adequate clearance is not available, the PCB should be anchored.)
- Precautions must be taken to prevent the PCB from caving into an excavation. When placing a PCB around an excavation, the capability of the soil to withstand the load created by the PCB and any other objects near the cut face must be determined.

9.1.1.2 Other Concrete Barriers

"QUICK CHANGE" Barrier System (Figure 9.6)

The proprietary portable concrete barrier system is composed of a chain of modified F-shape concrete segments 1 m long which can be readily shifted laterally. Steel rods run the length of each segment and specially designed hinges are attached to either end, which are then joined by pins. The top of each system is "T" shaped to allow the

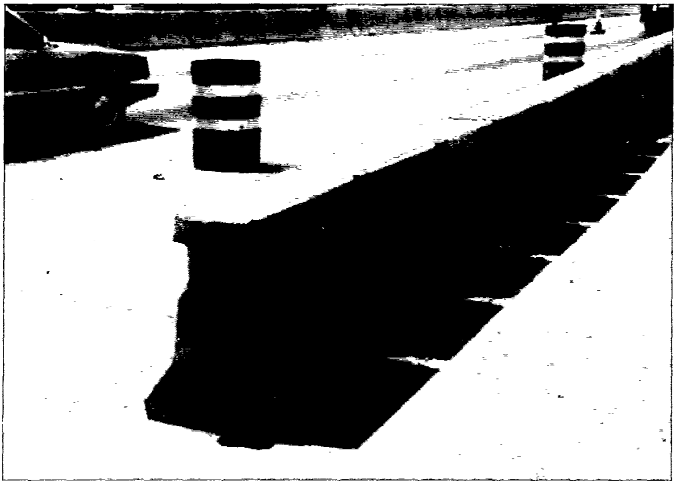


FIGURE 9.6 Quick Change Barrier System

segment to be picked up by a special vehicle and moved laterally up to 5.5 m. See Chapter 6 for more detail.

M.G.S. Barrier System

This proprietary portable concrete barrier system is composed of 6-m long precast segments which have concave sides with wide sawtooth striations angled downward at 45 degrees in the direction of traffic. It has been satisfactorily crash tested with a 2000-kg passenger car at 26 degrees and 100 km/h.

Low Profile Barrier System (Figure 9.7)[6]

This portable precast concrete system is composed of 510-mm high barrier segments. Each segment is 660 mm wide at the base, with a reverse batter of the barrier face at a 20:1.

The purpose of the barrier is to shield the work zone while improving the sight distance for drivers attempting to enter or exit the work zones from side roads or driveways.

The barrier was satisfactorily crash tested to the NCHRP 350 Test Level 2 conditions with a 2040-kg pickup at 70 km/h and 25 degrees and an 800-kg passenger car at 70 km/h and 20 degrees, resulting in a maximum deflection of 127 mm. It is being installed with a sloped end as the terminal.

9.1.1.3 Other Barriers

Triton Barrier (Figure 9.8)

This proprietary barrier is composed of 1981-mm long by 813-mm high by 533-mm wide segments of lightweight polyethylene plastic shells designed to use water as ballast. The plastic barrier shell is supplemented by an internal steel framework to provide additional rigidity during handling and impacts. There is also a cable along the top connecting the joints between barrier segments. This cable provides the barrier's tensile capacity during impacts.

It has been satisfactorily crash tested to the NCHRP 350 Test Level 2 conditions of a 2000-kg pickup at 70 km/h

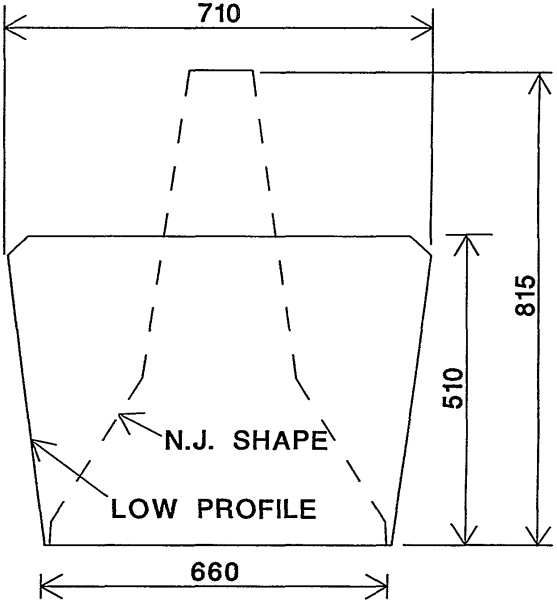


FIGURE 9.7 Low Profile Barrier

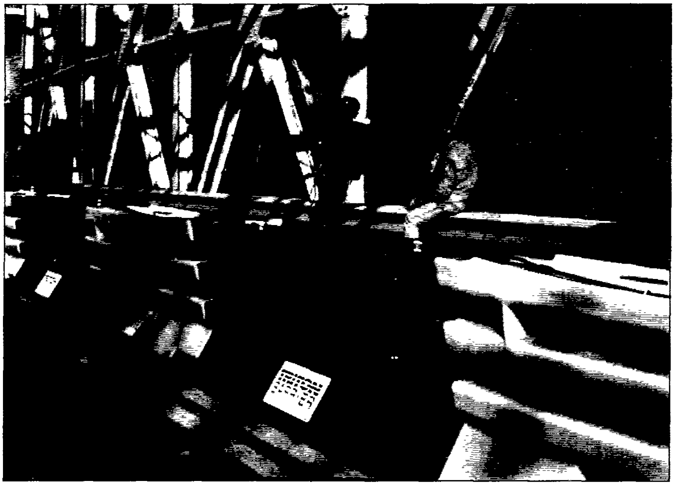


FIGURE 9.8 Triton Barrier

and 25 degrees and an 820-kg car at 70 km/h and 20 degrees with a maximum deflection of 3.8 m.

Timber Barrier Curb/Rail[7]

A 300-mm by 400-mm timber curb with a w-beam rail mounted on the 400-mm vertical face of the timber was tested. The curb redirected full-sized passenger cars at about 60 km/h and 15 degrees and displaced less than 300 mm. It may be used where speeds are 60 km/h or less.

A stacked timber barrier for use on a bridge deck consisting of 300-mm by 600-mm timbers has redirected a 2000-kg passenger car at 83 km/h and 13 degrees. It may be used where speeds are 80 km/h or less and the expected impact angle will be shallow (Figure 9.9).

No other timber barrier curb/rail should be used unless satisfactorily crash tested.[8]

9.1.1.4 End Treatments

The desirable treatments for exposed ends of barriers are:

- connecting to an existing barrier (Chapter 5), or
- attaching a crashworthy end treatment such as a crash cushion (Section 9.1.2), or
- flaring away to the edge of the clear zone appropriate for construction traffic conditions as determined by the transportation agency, or
- buried in the backslope.

For the PCB, either the buried in berm or the sloped end may be used for lower speeds:

- buried in berm (Chapter 5)—recommended for 30 km/h or less with a 1.8-m to 3-m end taper in case of soil settlement;
- sloped end—when other treatments are unfeasible, a sloped end may be used for speeds 45 km/h or less or conditions corresponding to Test Level 1 in NCHRP Report 350.[9] Generally, as the slope steepness increases, impact severity of this treatment will increase; but the probability of an impact in the sloped section will decrease as the slope increases.

For the Triton barrier, an empty section on the beginning of a length of Trition barrier run has been found satisfactory for use as an end treatment and/or crash cushion by crash testing.

Transitions

As for permanent barriers, adequate transitions should be made between barriers of differing flexibility or between a bridge rail and a temporary roadside barrier.

9.1.1.5 Applications

The length of barrier affects its redirective capability. Shorter lengths may not effectively decrease the hazard

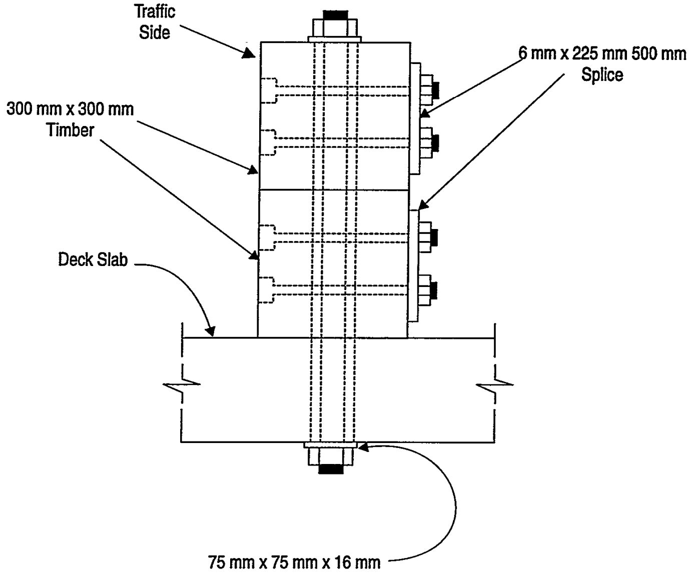


FIGURE 9.9 Timber Barrier Curb/Rail System

because they introduce a barrier end which can be hazardous and they may not prevent penetration or provide adequate redirective capability. For a short section (under 30 m), a tradeoff must be made as to which is worse, the hazard of the obstacle or the barrier to the motorist, or need to protect an innocent bystander such as a maintenance worker.

Barriers may be used to channelize traffic but should not be used as the primary tapering device. Lane tapers should be made of more forgiving channelizing devices such as barricades, barrels, or cones. Once the lane is closed, the barrier may be introduced. Barriers perform best when placed parallel to traffic flow.

When temporary barriers are installed on both sides of traffic, the beginnings of the barriers should be staggered to minimize the tendency of drivers to shy away from suddenly introduced objects near the traveled way.

Openings in barriers should be avoided if possible. Where necessary, the barrier ends should have an acceptable end treatment (Section 9.1.1.4) or offset.

For better night visibility, retroreflective devices or steady-burn warning lights may be mounted along the barrier. (See the MUTCD for guidance.) Under some conditions when horizontal curves are present, the lights may appear as a solid line of lights across the roadway. Under these conditions, it may be better to put lights only on the barriers on the outside of the curve and/or combine lights with chevrons. To locate these conditions, a site-specific review may be necessary to determine the optimum lighting setup. Also a solid edgeline may be placed on the pavement adjacent to the barrier to provide delineation.

9.1.2 Crash Cushions

Crash cushions are protective systems which prevent errant vehicles from impacting obstacles by either smoothly decelerating the vehicle to a stop when hit head-on or by redirecting it away from the obstacle for glancing impacts. Two types of crash cushions used in work zones are stationary and mobile (commonly called truck-mounted attenuators).

9.1.2.1 Stationary Crash Cushions

Crash cushions in work zones may be used in the same manner as at permanent highway installations, i.e., to protect the motorists from the exposed ends of barriers, fixed objects, or other obstacles. A number of stationary crash cushions are commonly used. Refer to Chapter 8 for detailed descriptions, installation requirements, and limitations.

One is the sand-filled plastic barrel system. If space is available, configurations of sand barrels designed for permanent installations should be used.

Because of restricted work zone site conditions and the lack of a feasible alternative in some instances, safety may be improved by using sand barrels in configurations that are not recommended for permanent installations. Because the sand barrel system has virtually no redirective capability, this system should be 750 mm wider than the fixed object. Where there is inadequate clearance between the crash cushion and work zone traffic, the following measures should be taken:

1. Redesign the barrier layout so the approach ends of temporary traffic barriers are offset to the edge of the clear zone appropriate for construction traffic conditions as determined by the transportation agency or shielded according to the recommendations in Section 9.1.1.4.
2. The lateral offset between the back corner of a sand barrel crash cushion and the corner of the obstacle may be reduced to a minimum of 375 mm where a greater offset would cause unacceptable interference with traffic.

For ease of moving, barrels may be installed on pallets or a skid 100 mm or less in height. A trailer with pallets called the "Portable Crash Cushion Trailer" has been developed to easily transport an array of sand barrels.

Barrels should be regularly inspected since they are susceptible to nuisance hits and provide little or no safety reserve after being hit.

Another stationary crash cushion is the G-R-E-A-T$^{®}_{cz}$. It is a redirective crash cushion which varies from the G-R-E-A-T mentioned in Chapter 8 by having an integral platform, backup structure, and anchor system instead of separate backup structure. Thus, it can be moved intact from one location to another. It should be located on a smooth surface for anchoring with either bolts or pins. Standard installation details, detailed design guides, and installation procedures are available from the manufacturer.

The Connecticut Impact Attenuation System (CIAS) (Figure 9.10) has been modified for use in construction zones as a temporary installation by the Ontario Ministry of Transportation. The modification is in the attachment to a free-standing, movable, reinforced concrete anchor block instead of the traditional cast-in-place concrete pad joined with the back wall. An advantage of this system when it is used in construction zones is that it can be separated easily into two or three component parts and relocated. It can also accommodate "nuisance" hits without requiring replacement. The system should be installed on a rigid surface;

FIGURE 9.10 Connecticut Impact Attenuation System

when used as a temporary system, such as in construction zones, an asphalt surface is suitable.

It is critical that the cylinders be able to slide freely on the steel rails; therefore, the installation surface must be smooth and the cylinders must not come in contact with the adjacent surface.

The CIAS may be installed on a 10-percent slope or less. To enable the system to perform as designed, the path from the traveled way to the system must be stable, relatively flat, and free of obstacles and irregularities. If curb in front of the system is required, only mountable type should be used. To prevent ice and snow buildup inside the cylinders, which will prevent free movement on the rails, cylinder covers should be installed.

The DRAGNET is used to provide closure of roads and ramps for construction and maintenance activities. It is useful for long term construction sites where the same closure is required repeatedly. An advantage is that, after the initial installation, it can be deployed; and if impacted, it can be repaired in a short time. The runout distance required varies depending on the design of the installation and the mass and impact velocity of the errant vehicle. For 100-km/h impacts, the approximate runouts for the 800-kg car will be 10 meters and about 20 meters for the 2000-kg vehicle. It can also withstand impacts by a 36,000-kg truck at 40 km/h with runouts of about 65 meters.

9.1.2.2 Truck-Mounted Attenuators (TMAs)

In many short-term, mobile, and moving work zones, trucks can be used as blocking vehicles to protect workers. Large trucks are effective in preventing vehicle encroachment into the work site; however, serious injury to occupants of the impacting vehicle and the truck can result.

Crash cushions called truck-mounted attenuators (TMAs) can be attached to the rear of these protective vehicles to reduce the severity of rear-end crashes. They are truck mounted and may be used for moving operations such as pavement marking, roadway sweeping, and maintenance activities in high-volume, high-speed areas or at long-term stationary construction sites. Suggested priorities for consideration for use are shown in Table 9.2.[10]

TMAs are used for three classes of protective vehicles in work zones:

- Shadow Vehicle: a moving truck spaced a short distance from a moving operation, giving physical protection to workers from traffic approaching from the rear.
- Barrier Vehicle: a truck parked upstream from a stationary operation and usually unoccupied.
- Advance Warning Truck: a truck parked a considerable distance upstream of a moving or stationary operation displaying an arrow panel and other signs as appropriate.

Shadow trucks and barrier vehicles may be equipped with a TMA. Advance sign trucks may use TMAs if they encroach on the traveled way. Protective vehicles usually are equipped with arrow panels, changeable message signs, or flashing amber lights. To increase the protection for the truck drivers, the trucks should have lap/shoulder restraints and headrests.

Existing TMAs are generally not suitable for specialized vehicles such as motor graders, mowers, and tow trucks; however, there are crash-tested interfaces for use between TMAs and some types of salt spreaders or street sweepers.

Layout

Buffer Distance

The buffer distance is the space between the protective vehicle and the work activity and provides for a roll-ahead, post-collision movement of the protective vehicle. This distance is typically a compromise between anticipated roll-ahead movement and excessive space that would permit traffic to move into the buffer zone. Some States report buffer distances ranged from 15 m to 60 m. Buffer distances should be based on horizontal/vertical geometrics, available sight distance, average speed of traffic, and type of operation. An example of a guideline is shown in Table 9.3.

When tested with a 2000-kg passenger car at 70 km/h, a truck with a TMA moved forward less than 10 m. Therefore, a minimum distance of 9 m between the truck and work zone is recommended. Based on the manufacturer's recommendation, if approach speeds are higher than 70 km/h, a longer distance should be used. The truck's parking brake should be set, the transmission placed in gear, and, when possible, the front wheels turned away from the work area. These recommendations are for trucks weighing 4500 kg or more.

Examples of TMAs are illustrated in Figures 9.11 through 9.14.

The Hex-Foam TMA shown in Figure 9.11 is an energy-absorbing cartridge mounted in a frame and encased in a fiberglass shell. The unit is cantilevered from the rear of the truck. The Hex-Foam energy-absorbing cartridges are made of hexagon-shaped paper honeycombed cells filled with polyurethane foam. Acceptable performance in several crash tests has been achieved on the Hex-Foam TMA with vehicles weighing up to 2450 kg and impact speeds up to 80 km/h.

California Department of Transportation (CALTRANS) developed a lightweight TMA consisting of "Hexcel" aluminum honeycombed sections for absorbing energy. The unit, shown in Figure 9.12, is cantilevered from the rear of a maintenance truck. This is one of the lightest available TMAs with a maximum total weight of 182 kg. It has performed adequately in tests at impact speeds of 70 km/h using vehicles weighing approximately 1000 kg and 2000 kg.

TABLE 9.2 Suggested Priorities for the Consideration for Use of Protective Vehicles and Truck-Mounted Attenuators

Closure/Exposure Condition	Examples of Typical Construction Maintenance Activities	Ranking* Freeway/Non-Freeway with Speed Limit			
			80 km/h	70 km/h	60 km/h
Mobile Activities:					
No Formal Lane Closure					
Shadow Vehicle for Operation Involving Exposed Personnel	Crack pouring, patching, utility work, striping, coning	A-1	A-2	A-3	A-4
Shadow Vehicle for Operation Not Involving Exposed Personnel	Sweeping, chemical spraying	E-1	E-2	E-3	E-4
No Formal Shoulder Closure					
Shadow Vehicle for Operation Involving Exposed Personnel	Pavement repair, pavement marking, delineator repair	B-2	B-3	C-3	C-3
Barrier Vehicle for Operation Not Involving Exposed Personnel	Open excavation, temporarily exposed bridge pier	E-2	E-3	E-4	E-5
Stationary Activities:					
Formal Lane Closure					
Barrier Vehicle for Operation Involving Exposed Personnel	Pavement repair, pavement marking	B-2	B-3	C-4	D-5
Barrier Vehicle for Condition Involving Significant Hazard	Open excavation	E-2	E-3	E-4	E-5
Formal Shoulder Closure					
Barrier Vehicle for Operation Involving Exposed Personnel	Pavement repair, pavement marking, guardrail repair	C-3	C-4	D-5	D-5
Barrier Vehicle for Condition Involving Significant Hazard	Open excavation	E-3	E-4	E-5	E-5

* The ranking letter indicates the priority assigned to the use of a protective vehicle. The use of protective vehicles is:

A - is very highly recommended
B - is highly recommended
C - is recommended
D - is desirable
E - may be justified on the basis of special conditions encountered on an individual project when an evaluation of the circumstances indicates that an impact with a protective vehicle is likely to result in less serious damage and/or injury than would impact with a working vehicle or the hazard

* The numerical rank indicates the level of priority assigned to the use of a TMA on an assigned protective vehicle.

The use of a TMA under the defined conditions:

1 - is very highly recommended
2 - is highly recommended
3 - is recommended
4 - is desirable
5 - may be justified on the basis of special conditions encountered on an individual project

TABLE 9.3 Examples of a Guideline for Spacing of Shadow Vehicles

For Shadow Vehicles Weighing 10,000 kg or More

Operating Speed/Speed Limit (km/h)[1]	**Recommended Spacing (m)[2]**	
	Stationary Operation	**Moving Operation[3]**
Greater than 90	45	52.5
70 - 90	30	45
Less than 70	22.5	30

For Shadow Vehicles Weighing Less than 10,000 kg but Greater than 4500 kg[4]

Operating Speed/Speed Limit (km/h)[1]	**Recommended Spacing (m)[2]**	
	Stationary Operation	**Moving Operation[3]**
Greater than 90	52.5	67.5
70 - 90	37.5	52.5
Less than 70	30	30

[1] Should use operating speed if higher than posted speed limit.

[2] Recommended spacing is distance between front of shadow vehicle and beginning of work area which is the first worker/operation/vehicle to be protected.

[3] Distances are appropriate for vehicle speeds up to 25 km/h.

[4] All Department CONSTRUCTION projects should refer to Section 619-1.02N of the Standard Specifications. Shadow Vehicles shall weigh 8000 kg to 9000 kg on all Department construction projects.

GENERAL NOTES:

1. The heaviest shadow vehicle should be used to optimize protection of our employees. Because roll-ahead is minimized with heavier shadow vehicles, they can be placed closer to the work space to minimize the risk of vehicles cutting in ahead of the shadow vehicles.
2. The spacing distance is good with or without a TMA. A vehicle equipped with a TMA may move less than a truck not equipped with a TMA. However, the recommended spacing is conservative enough to allow the same spacing for a TMA versus a vehicle without a TMA.
3. Distances are intended as guidelines. However, engineering judgement should be used to alter distance to take into effect traffic conditions, vehicle mix, sight distance, other site conditions, etc.

In a study for the Connecticut Department of Transportation, the University of Connecticut developed a TMA using a row of vertical steel pipe sections mounted on a sliding support frame. The assembly shown in Figure 9.13 is cantilevered from the rear of a maintenance truck. When struck by a vehicle, the frame slides forward. The collapse distance of the TMA is approximately 2.4 m. This design has performed well during crash testing with vehicles weighing up to 2000 kg and impact speeds up to 75 km/h.

The REN-GUARD Fibrous Honeycomb TMA is 2070 mm long, 2426 mm wide, 610 mm high and weighs 508 kg. It has been satisfactorily crash tested at 70 km/h with 2000-kg passenger cars and an 800-kg small car. (See Figure 9.14.)

The ALPHA 60 MD TMA consists of a crushable aluminum cartridge, a backup, and energy-absorbing strut support frame for attaching the system to the truck. It has been satisfactorily crash tested with a 2000-kg pickup and an 800-kg passenger car at 100 km/h.

9.2 TRAFFIC CONTROL DEVICES

Traffic control devices include signs, channelizing devices, lighting units, and signals which are used to warn, guide, or regulate traffic. They should be designed and installed to minimize the impact severity. This section discusses elements of design and installation for various devices used.

FIGURE 9.11 Hex-Foam TMA

FIGURE 9.12 Hexcel TMA

FIGURE 9.13 Connecticut Impact Attenuation System (CIAS) TMA

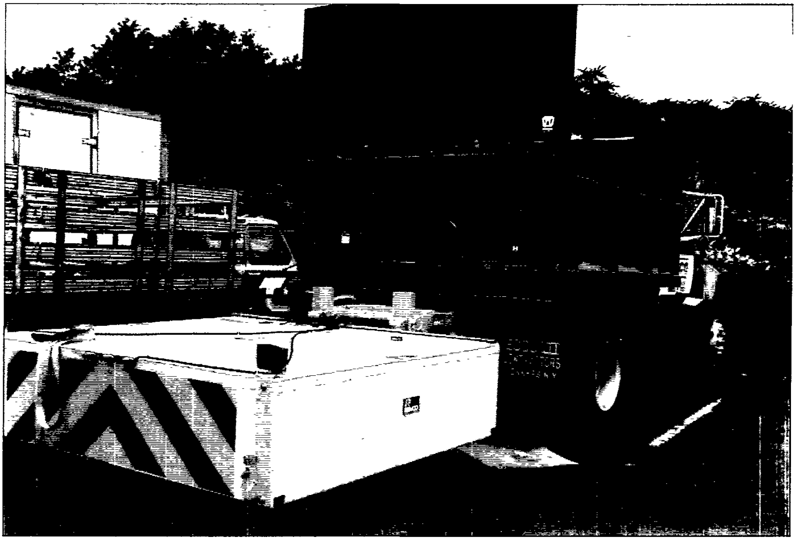


FIGURE 9.14 REN-GUARD TMA

9.2.1 Channelizing Devices

Devices used for channelization should provide a smooth and gradual transition in moving traffic from one lane to another, into a detour, or in reducing the width of the traveled way. Channelizing devices may also be used to separate traffic from the work area, pavement drop-offs, or storage areas. Where possible, they should be set 0.3 m to 0.6 m back from the edge of the traffic lane.

Common channelizing devices are cones and tubular markers, vertical panels, drums, barricades, and temporary raised islands. These devices should adhere to the size and shape requirements of the latest edition of the MUTCD.

Performance Evaluation Criteria

The performance evaluation of channelizing devices should be by crash testing using procedures found in NCHRP Report 350.[9]

The uses and crashworthiness of each channelizing device are discussed below. These devices are shown in Figure 9.15.

9.2.1.1 Cones and Tubular Markers

A traffic cone is conical with broadened base, from 450 mm to 1200 mm high. Tubular markers (tubes) are cylindrical with a broad base. They can be fastened to the pavement and can be made to be self-restoring when hit. Cones and tubes present minor impediments to traffic flow and generally will not damage a vehicle when hit. Cones are easily blown over or displaced unless their bases are ballasted or enlarged to increase stability. The ballast should not present a hazard if the cone is struck. Suggested ballasting includes doubling the cones, using heavier weighted cones, using special weighted bases, or using masses such as sandbag rings or ballast made out of recycled tire material.

9.2.1.2 Vertical Panels

A vertical panel consist of a post-mounted or free-standing sign 200 mm to 300 mm wide and 600 mm high minimum, striped downward in the direction of traffic flow.

A vertical panel design has been satisfactorily crash tested. It had a 300- to 450-mm by 90-mm plain concrete base; but the panel was 450 mm wide which exceeded MUTCD requirements. It is believed that vertical panels meeting the MUTCD with similar concrete bases may also be crashworthy. Other types of vertical panel bases such as hard rubber bases, square steel plates, and heavy steel rings are reportedly being used satisfactorily by some highway agencies. Vehicle wheel bases are not permitted.

9.2.1.3 Drums[11]

Drums may be either channelizing or warning devices.

Drums are roadway objects and may, in rare instances, cause a serious accident. Also, when located near the traffic lane, they may reduce capacity. Care should be used in placing the drums to reduce the likelihood of their being impacted.

Drums are commonly made of plastic. Many of the commercially available plastic drums have one or more flat sides to limit rolling and have recesses for warning lights.

Based on crash test results, neither steel 210-liter drums (which are not recommended for use) nor plastic drums performed without potential hazards.[12] The plastic drums, while being safer to ride down, had warning lights which could separate in high-speed impacts. Later crash tests of different plastic drums have shown that there are some type drums in which the warning light remained attached after impact. Therefore, the use of plastic drums which have been reinforced around the mounting hole or a similar precaution to prevent warning lights from separating upon impact is recommended.

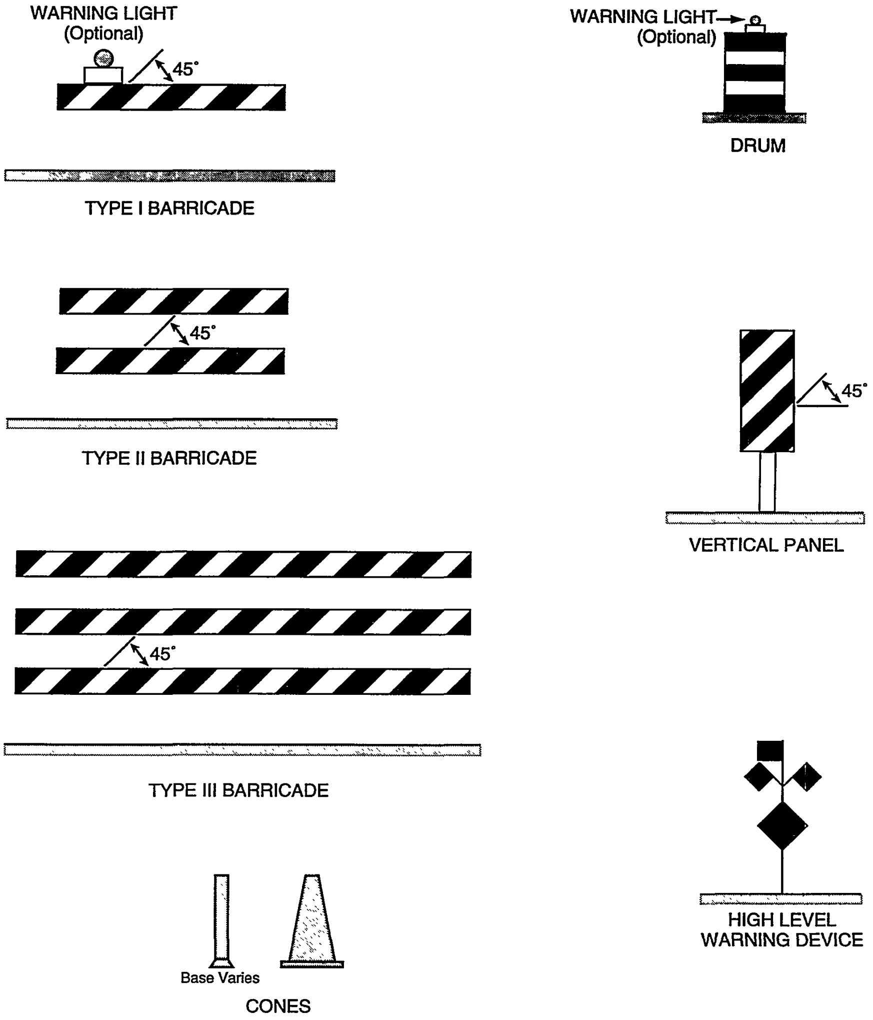
Single-piece plastic drums should be ballasted to the manufacturer's recommendation but not to exceed 25 kg of loose sand placed at the bottom, or recycled rubber tire sidewalls may be used. Two-piece drums with a base less than 100 mm high may be ballasted up to 34 kg.[13] Drums should not be ballasted with rocks, chunks of concrete, or similar objects. Ballast should not be placed at the top of the drums.

9.2.1.4 Barricades

Barricades function to warn of obstacles and/or channelize motorists through work zones. For daytime use, a barricade may be used where a collision with an object would be more severe than a collision with the barricade. Otherwise, cones or other types of channelization should be used. Barricades should not be ballasted by rocks or chunks of concrete. Sandbags or flat slabs of recycled rubber tire sidewalls are to be used as ballast. The bags should be placed on the bottom of the barricade.

According to the MUTCD, the three types of barricade are Type I, Type II, and Type III. Characteristics of barricades are shown in Figure 9.15.

Type I or Type II barricades are used where traffic is maintained through the work area. They may be used alone or in groups to mark a specific obstacle. Also, they may be used in a series for channelizing traffic. Type I barricades are normally used on urban or low-speed roads or streets or as a sign support on all types of roadway. Type II barricades are often used for expressways, freeways, and other high-speed roadways. Type III barricades have three



Note: Flashing or steady burn warning lights
should be used on barricades, panels,
and drums as needed.

FIGURE 9.15 Channelizing Devices

horizontal rails which are a minimum of 3000 mm long and a minimum of 2100 mm to the top of the highest rail. They may be used to block a road at the point of closure. Due to a potential for horizontal rails of barricades to penetrate a windshield, barricades should not be placed parallel to traffic within the clear zone. Barricades should be constructed of lightweight materials and have no rigid sway bracing for "A" frame designs.

Standard Type I barricades with which highway agencies have good and extensive operational experience and which are similar to the crash-tested barricade mentioned in the next paragraph are acceptable.[14]

A Type II barricade similar to one which was successfully crash tested is shown in Figure 9.16. Type III barricades which have been successfully crash tested are shown in Figures 9.17 through 9.19.

Attachment of the 150-mm x 150-mm vertical posts with the 150-mm x 150-mm base using a 300-mm x 150-mm x 13-mm piece of plywood is nailed to the sides of the vertical posts and base as shown in Figure 9.18.

9.2.1.5 Temporary Raised Islands[15,16]

To divide opposing traffic flows in two-lane, two-way (TLTW) operations, a device called a temporary raised island was developed. The island is used in combination with tubular markers and pavement striping material. It may also have application in other situations where barriers are not required. Islands may be of Portland cement concrete or bituminous concrete with a base width from 300 mm to 460 mm. One type of bituminous concrete island is shown in Figure 9.20.

General guidance on their use is:

1. There is not a consensus on the maximum traffic volumes for TLTW operations that would limit the use of the raised island. State highway agencies have guidelines for use that vary from a range of 4000 to 15,000 ADT, to allowing a range of use on freeways from under 22,000 ADT up to a maximum of 60,000 ADT.
2. Each location should use geometrics that provide an operating speed equal to that of the existing roadway, where possible, to minimize operational problems.
3. Special attention should be given to traffic control at an intersection that is within a TLTW operation, especially the side street approaches of the intersection. Special attention may include extensive warning signing, supplemental pavement markings, and intersection control beacons.[17]

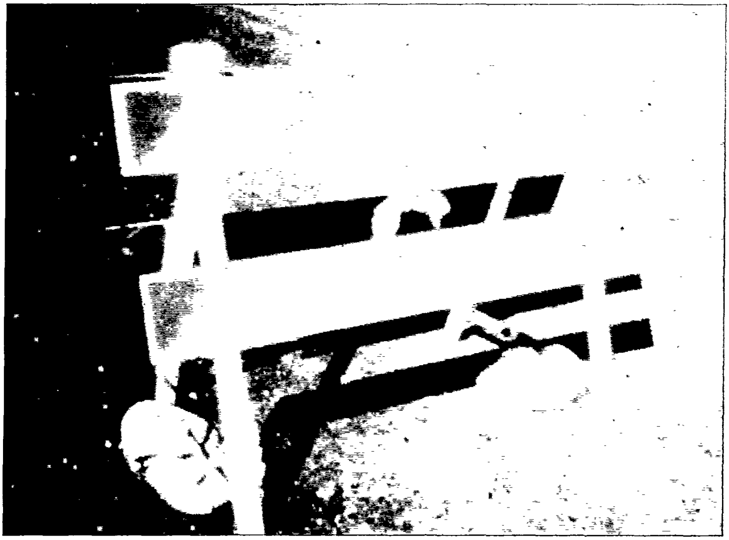


FIGURE 9.16 Standard Type II Barricade

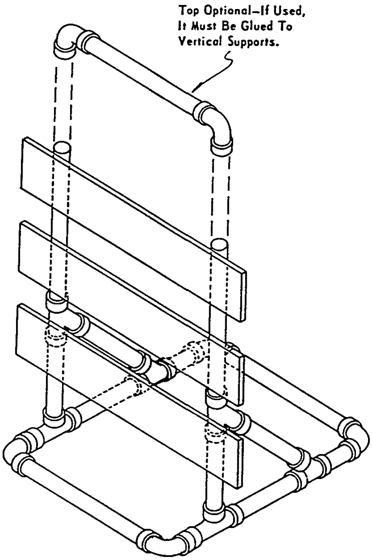
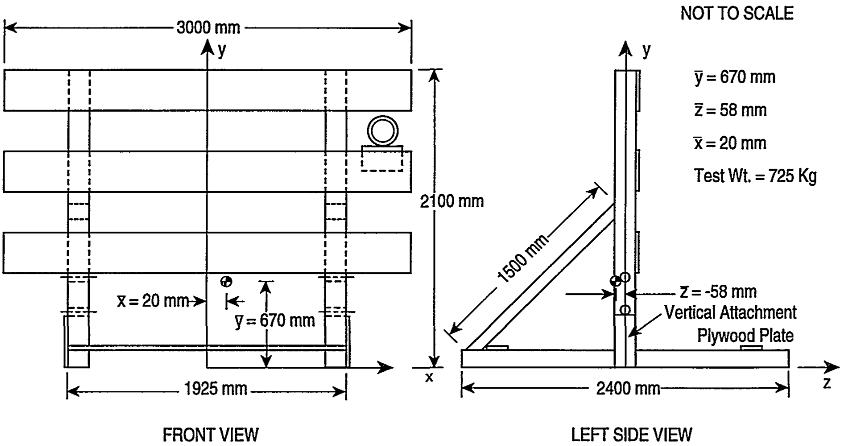


FIGURE 9.17 Type III PVC Breakaway Barricade



Attachment of the 150 x 150 vertical posts with the 150 x 150 base using a 3650 x 150 x 13 piece of plywood nailed to the sides of the vertical posts and base

FIGURE 9.18 Type III Wood Breakaway Barricade

9.2.2 Glare Screens[18]

Glare screens on barriers may be used in work zones to reduce glare and to block the driver's view of work zone activities which may distract from driving tasks. Crossovers, horizontal curves, restrictive lanes, and tapers adjacent to work areas such as a bridge deck repair site may warrant their use.

Installation of glare screens in work zones depends on many factors such as accident experience, high nighttime traffic volumes, complaints from the public, or highway geometry. Additional factors include distance between opposing traffic, lane width restrictions, delineation washout, work area distractions, and worker proximity. Design parameters for glare screens include distance between opposing traffic, barrier type, vertical curvature, and horizontal curvature.

Desirable characteristics of a work zone glare screen include the following:

- When hit, device shall not penetrate the passenger compartment or present an undue hazard to workers and other traffic;
- performs in predictable manner when hit;
- effectively reduces glare;
- resistant to vandalism and vehicle damage; and
- easy to repair.

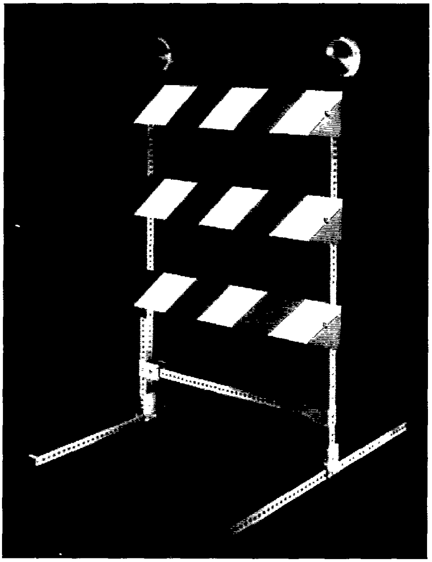


FIGURE 9.19 Unistrut Breakaway Barricade

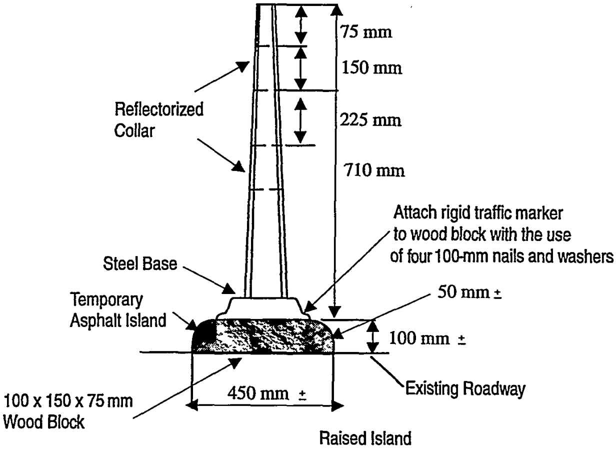


FIGURE 9.20 Raised Island

9.2.3 Signs and Supports

Guidance for design and placement of work zone signs is given in the MUTCD and in Chapter 4 of this Guide. Sign supports placed in the clear zone should yield or break away upon impact to minimize hazards to motorists and not present an undue hazard to workers.

Work zone signs may be mounted on fixed supports, temporary, or portable supports. Fixed supports are preferable for long-term projects. These supports should meet the breakaway requirements for permanent installations discussed in Chapter 4. Temporary supports are used for signs that are in place at night or for less than two weeks.

Signs mounted on portable low-level supports are suitable for conditions such as short-term operations (one work shift or less) or changing activities. These supports should be designed to be safe when impacted. Flexible sign panels for temporary or portable signs are more crashworthy than rigid panels. When crash tested at approximately 100 km/h, fiber glass chevron signs, 450 mm by 600 mm, weighing 1 kg, and bolted to the top of plastic drums performed well.[13] Plywood chevron signs tested under the same conditions did not perform acceptably.

If they are to be stored along the roadside when not in use but within clear zone appropriate for construction traffic conditions as determined by the transportation agency, they should be designed to fold down to a height of less than 100 mm.

Trailer-mounted devices such as signs, arrow panels, and special lighting units are often used in work zones. Since they are often located in the roadway, they should be crashworthy. A good design would be lightweight with the center of gravity of the unit, such as a self-contained power source, near or below the center of gravity of impacting vehicles. As result of an impact, detached elements, fragments, or other debris from the device should not penetrate or show potential for penetrating the passenger compartment or present undue hazard to the public.

9.2.4 Warning Lights

Work zone warning lights are portable, lens directed, enclosed lights commonly mounted on barricades, drums, vertical panels, or advanced warning signs. The MUTCD requires that they be installed to a minimum mounting height of 900 mm. This is windshield height. If the warning lights separate from the device upon impact, injury to vehicle occupants or workers may result. Tests have shown that the Type A and Type C warning lights can crack a windshield when impacted at 48 km/h and penetrate the windshield at 97 km/h.[19] To prevent the lighting device from separating and penetrating the vehicle compartment, it should be securely fastened to the traffic control device. Larger batteries that are typically used for high-intensity flashing warning lights should have separate battery cases which are mounted near the ground to prevent impacting the windshield.

9.3 PAVEMENT EDGE DROP-OFFS[20]

Pavement edge drop-offs may occur during highway work such as pavement repairs, resurfacing, or shoulder work. When not properly addressed, drop-offs may lead to an errant vehicle losing control with a high potential for a serious accident.

Desirably, no vertical differential greater than 50 mm should occur between adjacent lanes. However, when a vertical differential does occur, mitigating measures should be taken. The extent of the measures depend upon:

- shape of vertical differential;
- longitudinal length of differential;
- location of differential (centerline, lane line and/or edge-of-traveled way);
- duration;
- traffic volume and speed;
- geometrics; and
- relative location of on-coming traffic.

Research has found that loss of vehicle control can develop at speeds greater than 50 km/h under certain circumstances, where inattentive or inexperienced drivers return to the traffic lane by oversteering to overcome the resistance from a continuous pavement edge and tire-scrubbing condition.[20] Differentials can be mitigated satisfactorily with a 45-degree face or tapered at a rate of 150 mm horizontal per 25 mm of vertical. Pavement edge drop-offs greater than 75 mm immediately adjacent to traffic are not recommended to be left overnight. If they are higher than 75 mm and left overnight, mitigating measures should be considered.

Some mitigating measures are:

- Place a wedge of material along the face of the drop-off. The wedge should consist of stable material placed at a 45-degree or flatter slope. Warning signs should be placed in advance and throughout the treatment. Pavement markings are useful in delineating the edge of the travel lane.
- Place channelizing devices along the traffic side of the drop-off and maintain, if practical, a 1-m wide buffer between the edge of the travel lane and the drop-off. Warning signs should be placed in advance and throughout the treatment.
- Install portable concrete barriers or other acceptable positive barriers with a buffer between the barrier face

and the traveled way. An acceptable crashworthy terminal or flared barriers should be installed at the upstream end of the section. For nighttime use, the barriers must be supplemented by standard delineation devices.

- Where a trench exists adjacent and parallel to the pavement edge, if feasible, place steel plates to cover an excavation or trench. A wedge of material around the cover may be required in order to assure a smooth transition between the pavement and the plate. Steel plates shall be held in place with pins adjacent to the paving material to prevent lateral movement. Warning signs should be used to alert motorists of the presence of steel plates and that they may be slippery, particularly when the plates are on the travel lanes.

These recommendations may be modified by the results of other statistically significant and valid studies.

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CHAPTER 10: ROADSIDE SAFETY IN URBAN AND/OR RESTRICTED ENVIRONMENTS

10.0 OVERVIEW

Generally, the principals and guidelines for roadside design presented in all of the previous chapters of this Guide discuss many roadside safety considerations for rural highways, where vehicle speeds are on the high side (that is, approaching 80 km/h, and greater) and the highway is operating under free-flow conditions. This chapter is intended to present the designer with considerations to help enhance safety in urban and urban-like areas and restricted or special situations. When discussed in this chapter, "urban" and "urban-like" refer to highways or streets where the following type conditions may be found: lower speeds; dense abutting development; limited right-of-way; closely spaced intersections and access to properties; high traffic volumes; and the presence of special users including mass-transit vehicles, delivery trucks, bicycles, and pedestrians. These and other factors influence the design and operation of highways in these areas. Restricted environments are sections or segments along roads and streets where there is limited right-of-way, where pedestrians are present in close proximity to the street, and where there is the presence of facilities needing special consideration — such as playgrounds or schools, and/or varying vehicle speeds and volumes. These restricted areas are not limited to urban environments, as they may also be found in rural and suburban settings.

Often there is no clear demarcation between rural and urban conditions. The transition area between the two has been referred to as "suburban." This is the stretch of roadway where traffic is leaving a rural type setting and entering an urban type setting. It is the vicinity where travel speeds are reducing but in many cases tend to remain on the high side, where abutting property access points and intersections are becoming more frequent, and where bicycle and pedestrian activity are on the increase. Of course, when leaving the urban-like area, these conditions would be diminishing and operating speeds would generally be on the increase.

While not so much the case in rural areas, the areas immediately bordering urban roads and streets are likely places for pedestrian activities, along with close utility locations and landscaping. Roadside safety for **both** the motorists and pedestrians needs to be kept in mind. Protection for pedestrians from possible errant vehicles may be prudent. There may be situations whereby the design should include some sort of fencing or barrier to help keep pedestrians or objects from entering onto the roadway or street.

It is mentioned under Section 2.1.2, the highway engineer has a significant degree of control over roadside geometry and appurtenances. This statement is more correct for rural conditions, and especially so for new rural highways. However, in many urban type or restricted conditions, the roadside environment (houses, businesses, trees, utility poles, signals, walkways, etc.) is already established to a high degree, and thus, the designer has the challenge of providing roadside safety given the many pre-existing constraints.

In the usual case, existing road and street traffic volumes increase with the passage of time. This results in decisions regarding additional lanes to provide additional roadway capacity. Designers must be cognizant that this will increase the potential for vehicle interaction with pedestrians and bicyclists, etc., that are using the space immediately adjacent to the roadway facility. Appropriate measures should be considered to provide a desirable (maximum) level of safety. A safe, efficient, and economical design is the goal.

The various features (for example: benches, trash receptacles, bike racks, utility supports, etc.) that are associated with the urban roadsides, that accommodate pedestrians and bicyclists, may be undesirable from the errant motorist's point of view. Ideally, appurtenances should not be located where they can be hit by an errant vehicle. In cases where they are, they should be of a yielding nature in order to minimize damage to the striking vehicle and its occupants. It is not recommended that traditional breakaway/frangible devices be used where they are likely to fall on or become projectiles which could strike pedestrians in the area. All situations need individual analysis to determine the appropriate treatment, based on the relative risks to motorists and pedestrians/bicyclists.

10.1 NEED FOR INDIVIDUAL STUDY OF SITES

The clear roadside concept is still the goal of the designer; however, this is often not attainable and compromises may be necessary. The design options for treatment of fixed objects should be considered in each case; they are:

- Remove the obstacle or redesign it so it can be safely traversed.
- Relocate the obstacle to a point where it is less likely to be struck.
- Reduce impact severity by using an appropriate breakaway device.
- Redirect a vehicle by shielding the obstacle with a longitudinal traffic barrier and/or impact attenuator.
- Delineate the obstacle if the above alternatives are not appropriate.

Engineering judgement will play an important part in the determination of improvements which can reasonably be made within the constraints of the urban roadside. To a greater extent than when designing for roadside safety for high-speed rural highways, each site in a restricted road environment should be individually studied. Since the conditions and concerns may vary greatly from site to site, using standard approaches may not be the most effective process. Designers should consider many alternatives to achieve a safe and balanced design. A key consideration is the presence or absence of other close-proximity objects, and the repetitive nature of such. A very important consideration is the driver's awareness of such constraints. In other words, how does the road environment "look" to the driver? It can be assumed that when drivers "feel" they have entered a more restrictive environment, they match it with a corresponding reduction in operating speed and/or increased attention to the driving task. A similar analysis should consider the perception of risk from the viewpoint of the adjacent pedestrians and bicycle users. The designer needs to look for design methods/techniques that can help "protect" against and minimize the risks. Maintenance considerations must be addressed for whatever action is to be implemented.

10.2 DESIGN SPEED FOR ROADSIDE FEATURES IN URBAN AND RESTRICTED AREAS

The selection of a design speed for safety appurtenances and other roadside features on some urban and suburban roads and streets may differ from high-speed rural highways. It has been observed that, in general, on roadways where the design speed is 110 km/h and greater, the average vehicle operating speeds were less than the design speed. However, on low-speed roadways (design speed 70 km/h or less), the average operating speeds were greater than the design speed. Further, AASHTO's *A Policy on Geometric Design of Highways and Streets* states, "A design that satisfies the requirements for average running speed at low volume is adequate for traffic using the highway when the volumes are higher and the speeds are lower. ... For this reason low-volume conditions control certain highway elements, such as lane and shoulder widths, treatment of intersection curves, and speed-change lanes." This same rationale holds true for the design of safety appurtenances and features for urban/suburban roads and streets.

On urban and suburban roads, operating speeds have greater variation by time of day than rural roads. During free-flow conditions, and especially during late night periods, speeds are much higher than during the heavy traffic flow periods, often even beyond the speed limit. With higher speeds come more severe accidents, as indicated by the data shown in Table 10-1. During the lower volume and higher speed period of 7 p.m. to 7 a.m., there is a greater percentage of injury and fatal accidents than during the other half of the day. While other factors may contribute to this higher percentage, higher speeds and greater speed variance under free-flow conditions is likely to be a significant contributing factor. Consequently, roadside features should be designed for the higher operating speeds that occur during free-flow conditions. This may mean that the design speed for roadside features may be higher than for the roadway proper. A speed study may be appropriate to determine the speed to be used for roadside design at locations where these conditions apply.

TABLE 10.1 Percentage of Single Vehicle Run-off Road Accidents by Severity and Time Period for Urban Principal and Minor Arterials in Illinois

Time Period	Property Damage Only Accidents	Possible Injury and Non-incapacitating Injury Accidents	Incapacitating Injury and Fatal Accidents	Total
7 p.m. - 7 a.m.	34.6	13.6	6.8	55.0
7 a.m. - 7 p.m.	32.3	8.8	3.9	45.0
				100.0

10.3 ROADSIDE BARRIERS IN URBAN AND RESTRICTED AREAS

A roadside barrier is a longitudinal barrier used to shield motorists from natural or synthetic obstacles located along either side of a roadway. The primary purpose of all roadside barriers is to prevent a vehicle from leaving the roadway and striking a fixed object or roadside feature that is considered more objectionable than the barrier itself. This is accomplished by containing and redirecting the impacting vehicle. In urban settings, barriers are often used to separate bystanders, pedestrians, and bicyclists from vehicular traffic.

Refer to Chapter 5 for a discussion of performance, structural, and safety characteristics of standard roadside barriers.

An untreated end of a roadside barrier is not desirable since if hit it may penetrate the passenger compartment or stop the vehicle too abruptly. A crashworthy end treatment is therefore considered essential if the barrier terminates within the clear zone or in an area where it is likely to be hit head-on by an errant motorist. The selection of the proper treatment should be in accord with the proposed test levels, warrants, and availability of maintenance. To be crashworthy, the end treatment should not spear, vault, or roll a vehicle for head-on or angled impacts.

Street intersections and driveways complicate the selection and use of end treatments. A major factor in selecting and locating end treatments is obtaining the necessary corner sight distance at these locations. A subjective analysis of the installation site should be done to determine the likelihood and consequences of a vehicle striking an unprotected barrier end versus the need to achieve acceptable corner sight distance.

Aesthetic concerns are not usually a significant factor in the selection of a roadside barrier except in environmentally sensitive locations such as recreational areas, parks, or some urban environments. In these instances, a natural-looking barrier that blends in with its surroundings is often selected. It is important that the systems used be crashworthy as well as visually acceptable to the highway agency.

Having decided that a roadside barrier is warranted at a given location and having selected the type of barrier to be used, the designer must specify the exact layout required. The major factors that must be considered include the following:

- Lateral offset from the edge of pavement and deflection distance of the barrier
- Terrain effects
- Flare rate
- Length of need
- Corner sight distance

Generally, a roadside barrier should be placed as far from the traveled way as conditions permit. Such placement gives an errant motorist the best chance of regaining control of the vehicle without striking the barrier. It also provides better sight distance, particularly at nearby intersections.

It is desirable that a uniform clearance be provided between traffic and roadside features such as bridge railings, retaining walls, roadside barriers, utility poles, and trees, particularly in urban areas where there is a preponderance of these elements. The placement of roadside barriers is covered in Chapter 5.

10.3.1 Barrier Warrants

Barrier warrants are based on the premise that a traffic barrier should be installed only if it reduces the severity of potential accidents. It is important to note that the probability or frequency of run-off-the-road accidents is not directly related to the severity of potential accidents.

Typically, barrier warrants have been based on a subjective analysis of certain roadside elements or conditions. If the consequences of a vehicle striking a fixed object or running off the road are believed to be more serious than hitting a traffic barrier, then the barrier is considered warranted. While this approach can be used often, there are instances where it is not immediately obvious whether the barrier or the unshielded condition presents the greater risk. Appendix A presents an analysis procedure that can be used to compare several alternative safety treatments and provides guidance to the designer.

Highway conditions that warrant shielding by a roadside barrier can be placed in one of two basic categories: embankments or roadside obstacles. Warrants for the first category are found in previous chapters. Low profile barriers (600 mm high) for speeds 70 km/h or less have been developed. They shield without obstructing visibility. The presence of pedestrians or other "bystanders" may justify protection from errant vehicular traffic.

10.3.2 Barriers to Protect Adjacent Land Use

In urban and suburban areas, more consideration should be given to protecting innocent bystanders, who are using adjoining properties, from risks imposed upon them by errant vehicles. Schools, playgrounds, and parks located on the outside of sharp curves or across T-intersections are examples of where barrier systems may be appropriate. At these locations, the probability of a vehicle leaving the roadway and striking a person or persons in the area is greater than on tangent stretches of roadway.

.Barriers intended to protect adjacent land use must prevent an errant vehicle from entering a specific area. A barrier that is not structurally adequate may be less desirable for the people it was intended to protect than having no barrier at all. Flying debris resulting from the impact of a vehicle into a deficient barrier can injure people in the area. Standard longitudinal barrier designs may need to be modified, depending on the community interests and the site conditions.

Consideration should also be given to installing a barrier to shield businesses and/or residences which are near the right-of-way, particularly at locations having a history of run-off-the-road accidents.

10.3.3 Warrants for Pedestrian and Bicyclist Barriers

Pedestrians and bicyclists are another area of concern to highway engineers. The most desirable solution to this problem is to 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 are no objective criteria to draw on for pedestrian and bicyclist barrier warrants. On low-speed streets, a barrier curb will usually suffice to delineate/separate pedestrians and cyclists from vehicular traffic. However, at speeds significantly over 70 km/h, a vehicle may mount the curb at relatively flat approach angles. Hence, when sidewalks or bicycle paths are adjacent to the traveled way of high-speed facilities, some provision may need to be made for the safety of pedestrians and bicyclists. For additional information concerning bicycles, the reader is referred to AASHTO's *Guide for the Development of Bicycle Facilities.*

10.3.4 Pedestrian Restraint Systems

Accidents involving pedestrians account for almost one out of every five traffic fatalities. Pedestrian accidents in some cities have accounted for as many as one-half of the traffic fatalities.

A large percentage (almost 40 percent) of pedestrian deaths occur while crossing streets between intersections; the injury rate shows the same trend. A pedestrian barrier prevents these accidents. Fences or similar devices that separate pedestrian and vehicular traffic have been used successfully to channel pedestrians to safe crossing locations.

Median pedestrian barriers can significantly reduce the number of midblock crossings. Median barriers are frequently chain-link fences located along a median, which prevent pedestrians from crossing at non-intersection locations. They can be installed exclusively as pedestrian barriers or be incorporated with vehicle-separating median barriers.

Sidewalk barriers are located along or near the edge of a sidewalk to channel pedestrians to a crosswalk or grade-separated facility or to impede their crossing at undesirable locations.

Other barrier uses may be outside school entrances and playgrounds. Often it is advisable to contain pedestrians at public transportation stops in order to prevent pedestrians from encroaching onto the roadway.

Common construction materials include chain-link fencing, pipe and chain/cable, planters or other sidewalk furniture, and hedges. Planters are not recommended if they would be an additional fixed object in an otherwise clear zone. Planters are not recommended on narrow sidewalks, where they may impede pedestrian circulation.

Roadside pedestrian barriers are generally high chain-link fences located alongside a highway or freeway to prevent pedestrians from crossing the road. Pedestrian barriers should be crashworthy designs, for example, eliminating the top traverse pipe cross bracing for chain-link fence.

Useful guidance may be found in the latest version of the *Uniform Federal Accessibility Standards.* Additional guidance may also be found in the *British Standard Specification for Pedestrian Restraint Systems.*

10.4 MEDIAN BARRIERS IN URBAN AREAS

A median barrier is a longitudinal barrier most commonly used to separate opposing traffic on a divided highway. It is also used along heavily traveled roadways to separate through traffic from local traffic or to separate special use lanes from other highway users. By definition, any longitudinal barrier placed on the left side of a divided roadway may be considered a median barrier. For median barriers on high-speed, controlled-access roadways which have relatively flat and traversable medians, refer to Chapter 6.

The use of standard highway median barriers on urban facilities with a design speed of 70 km/h or less with street intersections, regardless of access control, generally is not warranted. Alternate methods of separating opposing traffic are encouraged, such as the use of medians (in some cases raised medians). Flush medians are preferred over raised medians on highways with design speeds of 60 km/h or more. Raised medians can cause errant vehicles to vault.

10.5 BRIDGE RAILINGS

The local variables regarding the placement of urban guardrail, bridge railing, and other barriers become more challenging. The primary reasons are the need to match intersecting streets, provide access to properties, and to maintain access for pedestrians including the physically challenged.

As detailed in Chapter 7, appropriate bridge railings need to be selected by considering roadway design, traffic volumes, percent of heavy vehicles in the traffic stream, and the volume of pedestrian traffic. The performance requirements of bridge railings for urban areas are no different than any other highway system. However, bridges carrying low traffic volumes at greatly reduced speeds may not need bridge railings designed to the same standard as railings used on high-speed, high-volume facilities. The railing shall have adequate strength to prevent penetration by passenger vehicles while the transition rail section approaching the bridge should be considered with the same selection considerations discussed in previous sections. Transitions which meet performance levels one and two in accordance with NCHRP 350 are generally acceptable for cases with low roadway speeds. The bridge rail and transition section, nevertheless, must function effectively for the location and conditions selected. Standardization of urban bridge rail systems improves availability of replacement parts for maintenance departments.

Highway structures, regardless of location and traffic volume, normally warrant rigid railing. A rigid bridge railing requires an approach guardrail and the transition section. When a bridge also serves pedestrians, a barrier to shield them from vehicular traffic may be warranted. Placement of the bridge railing between traffic and the sidewalk affords maximum pedestrian protection. A pedestrian railing would then be needed at the outer edge of the bridge structure. The need for a bridge railing adjacent to the pedestrian walkway should be based upon the volume of traffic and the speed of the roadway traffic. Other considerations are the number of pedestrians crossing the bridge, the accident statistics (if available), and the conditions on either end of the structure. This type of treatment, on the other hand, may create a problem unless the bridge railing is terminated in an acceptable manner. Flaring the end section away from the roadway is often not practical because it would encroach upon the sidewalk, requiring the walkway to meander around the transition section and terminal unit.

In some instances, a crash cushion or metal beam barrier terminal can be used to an advantage; however, the presence of a raised curb may adversely affect the performance of this type of end treatment. In many low-speed situations, a concrete tapered end section parallel to the roadway may be the best compromise. The taper of the end section should be of sufficient length from the end of the bridge so that an impacting vehicle is ramped on and over the sloped end treatment before reaching the outside edge of the structure, yet not extend so far as to intrude on the sight distance of adjacent intersection streets just off the end of the bridge (Figure 7.1). Recommended minimum taper length is 6 meters, with 10 to 13 meters desirable.

Retrofitting existing bridge railings is a challenge. Typically bridges designed to AASHO Specifications prior to 1964 may have deficient railings (based on current criteria). If the adequacy of a railing appears questionable, further evaluation should be made to ensure the design meets the current specifications. In many older railing systems the presence of curbs defines the walkway between the driving lane and the bridge railing. This curb may cause an impacting vehicle to go over the railing or to strike it from an unstable position causing possible roll over.

While some retrofit designs may not bring a bridge railing not meeting current guidelines to full AASHTO standards, significant improvements can nevertheless be obtained. Chapter 7 outlines a number of retrofit concepts that can be adopted to different types of deficient railings. The metal post and beam retrofit functions well as a traffic barrier separating motor vehicles from pedestrians using an adjacent sidewalk crossing the bridge (Figure 7.9). In most cases, the metal post and beam system allows the existing bridge railing on a wide raised walkway to be used or converted to a pedestrian rail. A Self-Restoring Bridge Rail (SERB) retrofit provides containment of large vehicles where serious consideration for this condition is needed (Figure 7.11). Other retrofit means are also available and should be reviewed to determine its appropriateness for the conditions that exist.

(For guidance information concerning "overpass structures" on bridges, the reader is referred to AASHTO's *A Guide for Protective Screening of Overpass Structures.*)

10.6 CRASH CUSHIONS

Crash cushions are ideally suited for use at many urban locations when fixed objects cannot be removed, relocated, or made breakaway and cannot be adequately shielded by a longitudinal barrier. In urban situations, the increase in roadway maintenance mileage, the tight right-of-way constraints, and varying traffic flow conditions creates situations that limit available options for removing or relocating fixed objects. Use of crash cushions as opposed to longitudinal barriers become more appropriate to shield fixed objects, such as at exit ramp gores, ends of median barriers, bridge piers and abutments, to name only a few.

The availability of adequate width for the placement of crash cushions is often more restricted in urban areas, creating narrow placement areas. The options for selection of a crash cushion can be limited, due to the narrow site characteristics. However, a number of crash cushions and impact attenuation systems are available for narrow width conditions. The Hi-Dro Sandwich system can be ordered in a minimum width of 900 mm. The Hi-Dro Cell Clusters provide good low-speed attenuation at gore areas, bridge piers or abutments; and at traffic control devices that require narrow width systems. The Guard Rail Energy Absorbing Terminal (G-R-E-A-T) is provided in standard widths of 610 mm, 760 mm, and 910 mm. These systems and others as outlined in Chapter 8 should be reviewed to determine the effectiveness of the system for the proposed site location.

If crash cushions are located in areas accessible to pedestrians, vandalism can be a problem, particularly with Hi-Dro Sandwich or Hi-Dro Cell Cluster units, where damage to the individual tubes may go unnoticed without careful inspection. Curbs can also reduce the effectiveness of the crash cushion. Curbs should not be built where crash cushions are installed. Where necessary for drainage, an existing curb no higher than 100 mm could be considered acceptable and left in place, unless it has contributed to poor performance in the past.

Crash cushions are not intended to reduce accidents but rather lessen the severity of the impact. If a particular crash cushion is struck frequently it is important to determine why the collisions are occurring. Improved use of signs, pavement markings, delineation, reflectors or luminaires may help to reduce the number of occurrences.

10.7 CURBS

Curbed sections are generally restricted to speeds of 70 km/h or less on roadways in urban or highly developed areas. Some things that need to be considered are: delineation of the pavement edge, delineation of pedestrian walkways, control of access points, retention of water on the roadway, and vaulting of vehicles.

When a vehicle strikes a curb, the trajectory of that vehicle depends upon several variables: the size and suspension characteristics of the vehicle, its impact speed and angle, and the height and shape of the curb itself. Crash tests have shown that the use of guardrail with 150-mm curb where high-speed, high-angle impacts are likely should not be considered. Where curb is needed for drainage, the use of a curb no higher than 100 mm is satisfactory. On low-speed facilities, a vaulting potential still exists but, since the risk of such an occurrence is lessened, the use of 150-mm curb in combination with guardrail can be tolerated. Each situation should be considered individually taking into account anticipated speeds and consequences of vehicular penetration of the barrier.

The common practice in urban settings is to utilize curbs adjacent to the highway shoulders in order to provide separation of pedestrians from the traffic flow. In low-speed situations, a vertical face curb may provide marginal protection for pedestrians and acts to prevent the mingling of vehicular traffic flow and pedestrians. Curbs alone may not always be considered as adequate protection for pedestrians on adjacent sidewalks, or for shielding utility poles. In some cases, other measures may need to be considered. Realistically, a non-mountable curb has only limited redirectional capabilities, and only at low speeds.

The 0.5-m minimum clear zone behind a curb should always be exceeded if room permits. Designers should strive for a greater clear zone — one more appropriate for the off-peak operating speeds. At the higher speed end of the suburban area or high-speed urban facilities, consideration should be given for providing a shoulder and offsetting any curbing to the back of the shoulder. This shoulder can be eliminated, if necessary, further into the suburban area, where off-peak speeds are lower. The shoulders may be used to accommodate bicyclists and even pedestrians when sidewalks are not warranted.

Curb/barrier combinations should be crash tested if possible to quantify expected barrier performance under typical impact conditions, if extensive use of the combination is planned.

Section 3.4.1 provides additional guidance for the use of curbs.

10.8 DRAINAGE

Because speeds are generally lower, ditches are less of a safety problem to the errant motorist. Where practical, a closed drainage system should be considered. Curbs and drop inlets are common drainage elements in these cases.

Drainage inlets, grates, etc., should be placed flush with the ground surface and must be capable of supporting vehicle wheel loads; slots should be spaced and oriented so they will not be an obstacle to pedestrians or bicyclists.

Even though drainage ditches may be located outside the nominal clear zones in suburban areas, there may be a likelihood that errant vehicles which reach the ditch could strike parallel culvert ends at driveways or intersecting roads. Traversable designs should be considered at these locations. Section 3.4.3.2 provides information on traversable designs.

10.9 LANDSCAPING

Along most urban streets some type of landscaping exists. Trees, shrubs, lawns, decorative rock, and other materials are used to provide a pleasing setting for drivers, pedestrians, bicyclists, and abutting land owners.

The designer should always be consulted in the decisions regarding landscaping, particularly as they relate to sight distance and possible future lane needs. Considerations in design of landscaping include:

- The mature size of trees and shrubs, and how this will affect safety, visibility, and maintenance cost.
- Sufficient border area to accommodate the type of landscaping planned. If parking is allowed along the curb, will the landscaping allow access to parked vehicles?
- Design landscaping with possible future changes in roadway cross section in mind. For example, the addition of a second left-turn lane at major intersections by taking approximately 3 additional meters from the median island is becoming a normal practice. Landscaping in the affected area should be minimal or should not be included in the plan.

In general, in urban areas with lower travel speeds, large trees should be kept at least 2 to 3 meters from the edge of the traveled way, certainly outside of the clear zone.

Visibility restrictions resulting from landscaping are of principal concern to the designer. Points which must be considered include:

- Border area landscaping should allow full visibility at driveways for drivers and pedestrians.
- A clear vision space from 1 to 3 meters above grade is desirable along all streets and at all intersections. This allows drivers in cars, trucks, and buses to have good sight distance. Many cities have ordinances for sight restrictions at corners which incorporate this "clear space" idea.
- Landscaping very small islands should be avoided, to reduce maintenance needs.
- Large trees or rocks should not be used at decision points (e.g., gore areas, island noses) to "protect" poles and other appurtenances. Rather, each of the design options (in the order listed) stated in Section 10.1 should be considered to improve safety.

With respect to pedestrians, it is desirable to have a grass strip separating the sidewalk from the curb, thus further separating the pedestrian from vehicular traffic.

10.10 WORK ZONES

Construction work zones in urban areas have varying conditions of traffic control and work zone protection needs. Conditions can vary from low-speed, low-volume urban streets to highway construction zones in high-volume arterial and interstate locations. The type of traffic control under consideration needs to be reviewed for the site conditions, operating speeds, and traffic flows within the construction zone. The *Manual on Uniform Traffic Control Devices* (MUTCD) establishes the principles to be observed in traffic control, design, installation, and maintenance of traffic control devices in work zones.

Chapter 9 details a number of available traffic barriers and traffic control devices. Effective use and implementation of these barriers and devices in urban conditions remains extremely important and must be given full consideration on an individual project basis.

REFERENCE:

1. British Standards Institute. *British Standard Specification for Pedestrian Restraint Systems.* 2 Park Street, London W1A2BS, United Kingdom.

APPENDIX A
A COST-EFFECTIVENESS SELECTION PROCEDURE

The “ROADSIDE” software enclosed was compiled by the Federal Highway Administration and represents one approach to utilizing the *Roadside Design Guide*, as described in Appendix A. It carries no guarantees or warranties from the American Association of State Highway and Transportation Officials. The Federal Highway Administration advises that it is not copyrighted and may be duplicated. It is provided to purchasers of the *Roadside Design Guide* as a matter of convenience.

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A COST-EFFECTIVENESS SELECTION PROCEDURE

A1.0 OVERVIEW

This appendix is basically a user's guide and documentation for the computer program ROADSIDE, which has been created to assist in the economic analysis of existing or proposed roadside conditions. On the other hand, the information presented will be sufficient to fully support a manual economic analysis.

The current version of the program, ROADSIDE 5.0, is a metricated and revised version of the ROADSIDE program described in Appendix A of the previous edition of this guide. Both versions have their genesis in the analysis procedure presented in Chapter VII of the AASHTO's 1977 *Guide for Selecting, Locating, and Designing Traffic Barriers.*

Copies of ROADSIDE can be purchased from:

McTrans Center: 512 Weil Hall
University of Florida
Gainesville, Florida 32611
Phone: 904-392-0378
FAX : 904-392-3224

or:

PC-Trans
Kansas University Transportation Center
2011 Learned Hall
Lawrence, Kansas 66045
Phone: 913-864-5655
FAX : 913-864-3199

A DOS file, ROADSIDE.DOC, is shipped with ROADSIDE. It is suggested that first-time users of ROADSIDE 5.0 call this file, after entering the appropriate drive and directory (path) information, by entering TYPE ROADSIDE.DOC|MORE. After reading this file it is further recommended that the user start the program (from the appropriate drive and directory) by entering ROADSIDE. When the program starts up the user will be asked to respond to a few questions. Pushing the Enter key has the effect of answering N (No) to the questions and will speed the user to the basic work screen where, after reading through the screen, the user should press the F4 key followed by Enter to access the program's help menu. Reading through all the screens accessible from the help menu and then returning to the work screen and pressing the appropriate number or function keys followed by **Enter** and reading the resulting screens related to the items or function keys shown on the work screen will give a good orientation to running the program. Note that, with a few exceptions pressing the Enter key will avoid the necessity of otherwise responding to the questions that will appear on most of the screens accessed from the basic work screen. Taking this shortcut, however, will bypass a few associated input screens.

The input cursor for the basic work screen appears in the lower right hand corner of the screen. Typed characters will appear at this location and can be revised in the usual way using the backspace key or the direction and delete keys. On the other hand, nothing will appear at the cursor when a function key is pressed. And, once pressed, the only way to change the input of a function key is to press another function key. Ultimately, the Enter key must be pressed to escape the function key input procedure.

For those who may find the program ROADSIDE tedious, old-fashioned, or of questionable validity, the National Cooperative Highway Research Program has projects underway that are expected to lead to a new analysis program based on a different accident cost prediction approach than that in ROADSIDE. This new program is expected to be available by 1996.

ROADSIDE calculates the total present worth (TPW) of accident costs and highway department costs incurred over a specified analysis period (the project life), using the following equation:

$$TPW = CA(KC) + CI + ARC + CM(KT) - CS(KJ)$$

Where: CA = Accident cost based on initial collision frequency
KC = Factor to account for project life, discount rate, and traffic growth rate
CI = Installation cost
ARC = Present worth of accident repair costs = $\sum$ KC(CDi)(CFi)
CDi = Average collision damage repair costs for sides, corners, and face
CFi = Initial collision frequencies for sides, corners, and face
CM = Annual maintenance cost
KT = Factor to account for the project life and the discount rate
CS = Salvage value of feature being studied
KJ = Factor to account for the project life and the discount rate

ROADSIDE also reports annualized costs, which are obtained by multiplying present worth values by a capital recovery factor (CRF).

At this point it should be pointed out that the precision with which ROADSIDE permits the user to input data and the precision of its output greatly exceed the certainty of the accuracy of its output. ROADSIDE's precision was set with two thoughts in mind, it removes, and permits the determination of, the effects of rounding and it allows the user to select the precision to be used. It should also be pointed out that, while the accuracy of ROADSIDE's results can easily be questioned because of the many assumptions and uncertainties it operates under, its results should be very useful for comparing alternative courses of action. In addition, its supporters and critics should recognize that, where moderate differences between the calculated effectivenesses of alternatives exist, the selection process should include engineering judgement based on past experience, maintenance expectations, future plans, budget, etc.

The remainder of the text in this appendix tracks the ROADSIDE user inputs to provide background and explanation of the ROADSIDE procedures and provides techniques for handling input adjustments that must be made external to the program. An example problem is also included.

A2.0 LATERAL EXTENT OF ENCROACHMENT PROBABILITY

When ROADSIDE starts up it asks the user to indicate whether a printer is to be enabled. (If the printer is enabled the user will have the option of sending a case study report to a printer or a computer file.) After a response to the question on enabling the printer is entered, a screen appears that says, "READING DATA FILES WITH LATERAL EXTENT OF ENCROACHMENT PROBABILITY," "PLEASE WAIT." There is an encroachment probability file for each of eight design speeds (50 km/h through 120 km/h at 10 km/h increments) giving estimated lateral extent of encroachment probabilities from zero (the edge of the traveled way) out to 45 m in 0.25 m increments.

Tables A.1.1 through A.1.8 show the data in the files, along with F(A) values. The F(A) values are the integral of the Lateral Offset - Lateral Extent Probability curves. They are not used in ROADSIDE but will be useful in manually making an economic analysis of a roadside condition. The lateral encroachment extent probability curves are shown in Figure A.1. Note that the lateral extent of encroachment in Tables A.1.1 through A.1.8 goes to 45 m for all design speeds but that after a certain point the probability remains at zero and the F(A) term remains constant. The point at which this occurs will be defined as the finite lateral extent of the roadside for a tangent roadway with a level roadside. Table A.2 is a tabulation of these finite extent of roadside distances versus design speeds.

TABLE A.1.1 Lateral Extent of Encroachment Probabilities - Design Speed 50 km/h

A m	P	F(A) m	A m	P	F(A) m	A m	P	F(A) m
0.00	1.0000	0.0000	15.00	0.0015	1.9742	30.00	0.0000	1.9766
0.25	0.8058	0.2257	15.25	0.0013	1.9745	30.25	0.0000	1.9766
0.50	0.6798	0.4114	15.50	0.0012	1.9748	30.50	0.0000	1.9766
0.75	0.5893	0.5701	15.75	0.0010	1.9751	30.75	0.0000	1.9766
1.00	0.5203	0.7088	16.00	0.0009	1.9753	31.00	0.0000	1.9766
1.25	0.4622	0.8316	16.25	0.0007	1.9755	31.25	0.0000	1.9766
1.50	0.4132	0.9410	16.50	0.0006	1.9757	31.50	0.0000	1.9766
1.75	0.3695	1.0388	16.75	0.0005	1.9759	31.75	0.0000	1.9766
2.00	0.3319	1.1265	17.00	0.0005	1.9760	32.00	0.0000	1.9766
2.25	0.2990	1.2054	17.25	0.0004	1.9761	32.25	0.0000	1.9766
2.50	0.2698	1.2765	17.50	0.0003	1.9762	32.50	0.0000	1.9766
2.75	0.2438	1.3406	17.75	0.0003	1.9763	32.75	0.0000	1.9766
3.00	0.2209	1.3987	18.00	0.0002	1.9763	33.00	0.0000	1.9766
3.25	0.2007	1.4514	18.25	0.0002	1.9764	33.25	0.0000	1.9766
3.50	0.1822	1.4993	18.50	0.0002	1.9764	33.50	0.0000	1.9766
3.75	0.1656	1.5428	18.75	0.0001	1.9765	33.75	0.0000	1.9766
4.00	0.1506	1.5823	19.00	0.0001	1.9765	34.00	0.0000	1.9766
4.25	0.1370	1.6182	19.25	0.0001	1.9765	34.25	0.0000	1.9766
4.50	0.1248	1.6510	19.50	0.0001	1.9765	34.50	0.0000	1.9766
4.75	0.1137	1.6808	19.75	0.0001	1.9766	34.75	0.0000	1.9766
5.00	0.1035	1.7079	20.00	0.0000	1.9766	35.00	0.0000	1.9766
5.25	0.0943	1.7327	20.25	0.0000	1.9766	35.25	0.0000	1.9766
5.50	0.0860	1.7552	20.50	0.0000	1.9766	35.50	0.0000	1.9766
5.75	0.0785	1.7758	20.75	0.0000	1.9766	35.75	0.0000	1.9766
6.00	0.0716	1.7945	21.00	0.0000	1.9766	36.00	0.0000	1.9766
6.25	0.0652	1.8116	21.25	0.0000	1.9766	36.25	0.0000	1.9766
6.50	0.0594	1.8272	21.50	0.0000	1.9766	36.50	0.0000	1.9766
6.75	0.0541	1.8414	21.75	0.0000	1.9766	36.75	0.0000	1.9766
7.00	0.0493	1.8543	22.00	0.0000	1.9766	37.00	0.0000	1.9766
7.25	0.0449	1.8661	22.25	0.0000	1.9766	37.25	0.0000	1.9766
7.50	0.0409	1.8768	22.50	0.0000	1.9766	37.50	0.0000	1.9766
7.75	0.0371	1.8866	22.75	0.0000	1.9766	37.75	0.0000	1.9766
8.00	0.0338	1.8954	23.00	0.0000	1.9766	38.00	0.0000	1.9766
8.25	0.0307	1.9035	23.25	0.0000	1.9766	38.25	0.0000	1.9766
8.50	0.0279	1.9108	23.50	0.0000	1.9766	38.50	0.0000	1.9766
8.75	0.0253	1.9175	23.75	0.0000	1.9766	38.75	0.0000	1.9766
9.00	0.0230	1.9235	24.00	0.0000	1.9766	39.00	0.0000	1.9766
9.25	0.0208	1.9290	24.25	0.0000	1.9766	39.25	0.0000	1.9766
9.50	0.0189	1.9340	24.50	0.0000	1.9766	39.50	0.0000	1.9766
9.75	0.0171	1.9385	24.75	0.0000	1.9766	39.75	0.0000	1.9766
10.00	0.0154	1.9425	25.00	0.0000	1.9766	40.00	0.0000	1.9766
10.25	0.0140	1.9462	25.25	0.0000	1.9766	40.25	0.0000	1.9766
10.50	0.0126	1.9495	25.50	0.0000	1.9766	40.50	0.0000	1.9766
10.75	0.0113	1.9525	25.75	0.0000	1.9766	40.75	0.0000	1.9766
11.00	0.0102	1.9552	26.00	0.0000	1.9766	41.00	0.0000	1.9766
11.25	0.0092	1.9576	26.25	0.0000	1.9766	41.25	0.0000	1.9766
11.50	0.0082	1.9598	26.50	0.0000	1.9766	41.50	0.0000	1.9766
11.75	0.0074	1.9617	26.75	0.0000	1.9766	41.75	0.0000	1.9766
12.00	0.0066	1.9635	27.00	0.0000	1.9766	42.00	0.0000	1.9766
12.25	0.0059	1.9651	27.25	0.0000	1.9766	42.25	0.0000	1.9766
12.50	0.0053	1.9665	27.50	0.0000	1.9766	42.50	0.0000	1.9766
12.75	0.0047	1.9677	27.75	0.0000	1.9766	42.75	0.0000	1.9766
13.00	0.0042	1.9688	28.00	0.0000	1.9766	43.00	0.0000	1.9766
13.25	0.0037	1.9698	28.25	0.0000	1.9766	43.25	0.0000	1.9766
13.50	0.0033	1.9707	28.50	0.0000	1.9766	43.50	0.0000	1.9766
13.75	0.0029	1.9715	28.75	0.0000	1.9766	43.75	0.0000	1.9766
14.00	0.0026	1.9721	29.00	0.0000	1.9766	44.00	0.0000	1.9766
14.25	0.0023	1.9727	29.25	0.0000	1.9766	44.25	0.0000	1.9766
14.50	0.0020	1.9733	29.50	0.0000	1.9766	44.50	0.0000	1.9766
14.75	0.0017	1.9738	29.75	0.0000	1.9766	44.75	0.0000	1.9766
						45.00	0.0000	1.9766

A = Lateral Offset: P = Probability: $F(A) = \sum_{x=0}^{x=A} \left[\frac{P_{x-\Delta x} + P_x}{2} \right] \Delta x$; $F(A)_0 = 0$

TABLE A.1.2 Lateral Extent of Encroachment Probabilities - Design Speed 60 km/h

A m	P	F(A) m	A m	P	F(A) m	A m	P	F(A) m
0.00	1.0000	0.0000	15.00	0.0056	2.5520	30.00	0.0000	2.5634
0.25	0.8488	0.2311	15.25	0.0051	2.5533	30.25	0.0000	2.5634
0.50	0.7393	0.4296	15.50	0.0046	2.5545	30.50	0.0000	2.5634
0.75	0.6563	0.6041	15.75	0.0041	2.5556	30.75	0.0000	2.5634
1.00	0.5919	0.7601	16.00	0.0036	2.5566	31.00	0.0000	2.5634
1.25	0.5380	0.9013	16.25	0.0032	2.5574	31.25	0.0000	2.5634
1.50	0.4921	1.0301	16.50	0.0029	2.5582	31.50	0.0000	2.5634
1.75	0.4508	1.1480	16.75	0.0025	2.5589	31.75	0.0000	2.5634
2.00	0.4135	1.2560	17.00	0.0022	2.5595	32.00	0.0000	2.5634
2.25	0.3800	1.3552	17.25	0.0020	2.5600	32.25	0.0000	2.5634
2.50	0.3497	1.4464	17.50	0.0017	2.5605	32.50	0.0000	2.5634
2.75	0.3223	1.5304	17.75	0.0015	2.5609	32.75	0.0000	2.5634
3.00	0.2973	1.6078	18.00	0.0013	2.5612	33.00	0.0000	2.5634
3.25	0.2749	1.6794	18.25	0.0012	2.5615	33.25	0.0000	2.5634
3.50	0.2544	1.7455	18.50	0.0010	2.5618	33.50	0.0000	2.5634
3.75	0.2354	1.8067	18.75	0.0009	2.5621	33.75	0.0000	2.5634
4.00	0.2179	1.8634	19.00	0.0007	2.5623	34.00	0.0000	2.5634
4.25	0.2020	1.9159	19.25	0.0006	2.5624	34.25	0.0000	2.5634
4.50	0.1874	1.9646	19.50	0.0006	2.5626	34.50	0.0000	2.5634
4.75	0.1739	2.0097	19.75	0.0005	2.5627	34.75	0.0000	2.5634
5.00	0.1613	2.0516	20.00	0.0004	2.5628	35.00	0.0000	2.5634
5.25	0.1496	2.0905	20.25	0.0003	2.5629	35.25	0.0000	2.5634
5.50	0.1387	2.1265	20.50	0.0003	2.5630	35.50	0.0000	2.5634
5.75	0.1287	2.1599	20.75	0.0002	2.5631	35.75	0.0000	2.5634
6.00	0.1195	2.1910	21.00	0.0002	2.5631	36.00	0.0000	2.5634
6.25	0.1110	2.2198	21.25	0.0002	2.5632	36.25	0.0000	2.5634
6.50	0.1030	2.2465	21.50	0.0001	2.5632	36.50	0.0000	2.5634
6.75	0.0955	2.2713	21.75	0.0001	2.5632	36.75	0.0000	2.5634
7.00	0.0886	2.2943	22.00	0.0001	2.5633	37.00	0.0000	2.5634
7.25	0.0821	2.3157	22.25	0.0001	2.5633	37.25	0.0000	2.5634
7.50	0.0762	2.3355	22.50	0.0001	2.5633	37.50	0.0000	2.5634
7.75	0.0706	2.3538	22.75	0.0001	2.5633	37.75	0.0000	2.5634
8.00	0.0654	2.3708	23.00	0.0000	2.5633	38.00	0.0000	2.5634
8.25	0.0606	2.3866	23.25	0.0000	2.5633	38.25	0.0000	2.5634
8.50	0.0561	2.4012	23.50	0.0000	2.5633	38.50	0.0000	2.5634
8.75	0.0519	2.4147	23.75	0.0000	2.5634	38.75	0.0000	2.5634
9.00	0.0480	2.4272	24.00	0.0000	2.5634	39.00	0.0000	2.5634
9.25	0.0444	2.4387	24.25	0.0000	2.5634	39.25	0.0000	2.5634
9.50	0.0410	2.4494	24.50	0.0000	2.5634	39.50	0.0000	2.5634
9.75	0.0379	2.4593	24.75	0.0000	2.5634	39.75	0.0000	2.5634
10.00	0.0350	2.4684	25.00	0.0000	2.5634	40.00	0.0000	2.5634
10.25	0.0323	2.4768	25.25	0.0000	2.5634	40.25	0.0000	2.5634
10.50	0.0297	2.4846	25.50	0.0000	2.5634	40.50	0.0000	2.5634
10.75	0.0273	2.4917	25.75	0.0000	2.5634	40.75	0.0000	2.5634
11.00	0.0252	2.4982	26.00	0.0000	2.5634	41.00	0.0000	2.5634
11.25	0.0231	2.5043	26.25	0.0000	2.5634	41.25	0.0000	2.5634
11.50	0.0212	2.5098	26.50	0.0000	2.5634	41.50	0.0000	2.5634
11.75	0.0195	2.5149	26.75	0.0000	2.5634	41.75	0.0000	2.5634
12.00	0.0179	2.5196	27.00	0.0000	2.5634	42.00	0.0000	2.5634
12.25	0.0163	2.5239	27.25	0.0000	2.5634	42.25	0.0000	2.5634
12.50	0.0149	2.5278	27.50	0.0000	2.5634	42.50	0.0000	2.5634
12.75	0.0136	2.5313	27.75	0.0000	2.5634	42.75	0.0000	2.5634
13.00	0.0124	2.5346	28.00	0.0000	2.5634	43.00	0.0000	2.5634
13.25	0.0113	2.5376	28.25	0.0000	2.5634	43.25	0.0000	2.5634
13.50	0.0103	2.5403	28.50	0.0000	2.5634	43.50	0.0000	2.5634
13.75	0.0094	2.5427	28.75	0.0000	2.5634	43.75	0.0000	2.5634
14.00	0.0085	2.5450	29.00	0.0000	2.5634	44.00	0.0000	2.5634
14.25	0.0077	2.5470	29.25	0.0000	2.5634	44.25	0.0000	2.5634
14.50	0.0070	2.5488	29.50	0.0000	2.5634	44.50	0.0000	2.5634
14.75	0.0063	2.5505	29.75	0.0000	2.5634	44.75	0.0000	2.5634
						45.00	0.0000	2.5634

A = Lateral Offset: P = Probability: $F(A) = \sum_{x=0}^{x=A} \left[\frac{P_{x-\Delta x} + P_x}{2} \right] \Delta x; \quad F(A)_0 = 0$

TABLE A.1.3 Lateral Extent of Encroachment Probabilities - Design Speed 70 km/h

A m	P	F(A) m	A m	P	F(A) m	A m	P	F(A) m
0.00	1.0000	0.0000	15.00	0.0128	3.1086	30.00	0.0000	3.1404
0.25	0.8839	0.2355	15.25	0.0118	3.1116	30.25	0.0000	3.1404
0.50	0.7821	0.4437	15.50	0.0108	3.1145	30.50	0.0000	3.1404
0.75	0.7046	0.6296	15.75	0.0098	3.1170	30.75	0.0000	3.1404
1.00	0.6445	0.7982	16.00	0.0090	3.1194	31.00	0.0000	3.1404
1.25	0.5953	0.9532	16.25	0.0082	3.1215	31.25	0.0000	3.1404
1.50	0.5530	1.0967	16.50	0.0074	3.1235	31.50	0.0000	3.1404
1.75	0.5149	1.2302	16.75	0.0068	3.1253	31.75	0.0000	3.1404
2.00	0.4797	1.3546	17.00	0.0061	3.1269	32.00	0.0000	3.1404
2.25	0.4474	1.4705	17.25	0.0056	3.1283	32.25	0.0000	3.1404
2.50	0.4175	1.5786	17.50	0.0050	3.1297	32.50	0.0000	3.1404
2.75	0.3899	1.6795	17.75	0.0046	3.1309	32.75	0.0000	3.1404
3.00	0.3642	1.7738	18.00	0.0041	3.1319	33.00	0.0000	3.1404
3.25	0.3406	1.8619	18.25	0.0037	3.1329	33.25	0.0000	3.1404
3.50	0.3190	1.9443	18.50	0.0033	3.1338	33.50	0.0000	3.1404
3.75	0.2989	2.0215	18.75	0.0030	3.1346	33.75	0.0000	3.1404
4.00	0.2799	2.0939	19.00	0.0027	3.1353	34.00	0.0000	3.1404
4.25	0.2624	2.1617	19.25	0.0024	3.1359	34.25	0.0000	3.1404
4.50	0.2462	2.2253	19.50	0.0021	3.1365	34.50	0.0000	3.1404
4.75	0.2311	2.2849	19.75	0.0019	3.1370	34.75	0.0000	3.1404
5.00	0.2169	2.3409	20.00	0.0017	3.1374	35.00	0.0000	3.1404
5.25	0.2035	2.3935	20.25	0.0015	3.1378	35.25	0.0000	3.1404
5.50	0.1910	2.4428	20.50	0.0013	3.1382	35.50	0.0000	3.1404
5.75	0.1792	2.4891	20.75	0.0011	3.1385	35.75	0.0000	3.1404
6.00	0.1683	2.5325	21.00	0.0010	3.1387	36.00	0.0000	3.1404
6.25	0.1581	2.5733	21.25	0.0009	3.1390	36.25	0.0000	3.1404
6.50	0.1484	2.6116	21.50	0.0008	3.1392	36.50	0.0000	3.1404
6.75	0.1392	2.6476	21.75	0.0007	3.1393	36.75	0.0000	3.1404
7.00	0.1305	2.6813	22.00	0.0006	3.1395	37.00	0.0000	3.1404
7.25	0.1223	2.7129	22.25	0.0005	3.1396	37.25	0.0000	3.1404
7.50	0.1147	2.7425	22.50	0.0004	3.1398	37.50	0.0000	3.1404
7.75	0.1075	2.7703	22.75	0.0004	3.1399	37.75	0.0000	3.1404
8.00	0.1007	2.7963	23.00	0.0003	3.1399	38.00	0.0000	3.1404
8.25	0.0944	2.8207	23.25	0.0003	3.1400	38.25	0.0000	3.1404
8.50	0.0885	2.8435	23.50	0.0002	3.1401	38.50	0.0000	3.1404
8.75	0.0828	2.8650	23.75	0.0002	3.1401	38.75	0.0000	3.1404
9.00	0.0775	2.8850	24.00	0.0002	3.1402	39.00	0.0000	3.1404
9.25	0.0724	2.9037	24.25	0.0001	3.1402	39.25	0.0000	3.1404
9.50	0.0677	2.9212	24.50	0.0001	3.1402	39.50	0.0000	3.1404
9.75	0.0632	2.9376	24.75	0.0001	3.1403	39.75	0.0000	3.1404
10.00	0.0591	2.9529	25.00	0.0001	3.1403	40.00	0.0000	3.1404
10.25	0.0552	2.9672	25.25	0.0001	3.1403	40.25	0.0000	3.1404
10.50	0.0515	2.9805	25.50	0.0001	3.1403	40.50	0.0000	3.1404
10.75	0.0480	2.9929	25.75	0.0000	3.1403	40.75	0.0000	3.1404
11.00	0.0447	3.0045	26.00	0.0000	3.1403	41.00	0.0000	3.1404
11.25	0.0416	3.0153	26.25	0.0000	3.1404	41.25	0.0000	3.1404
11.50	0.0387	3.0253	26.50	0.0000	3.1404	41.50	0.0000	3.1404
11.75	0.0359	3.0347	26.75	0.0000	3.1404	41.75	0.0000	3.1404
12.00	0.0334	3.0433	27.00	0.0000	3.1404	42.00	0.0000	3.1404
12.25	0.0310	3.0514	27.25	0.0000	3.1404	42.25	0.0000	3.1404
12.50	0.0287	3.0588	27.50	0.0000	3.1404	42.50	0.0000	3.1404
12.75	0.0266	3.0658	27.75	0.0000	3.1404	42.75	0.0000	3.1404
13.00	0.0247	3.0722	28.00	0.0000	3.1404	43.00	0.0000	3.1404
13.25	0.0228	3.0781	28.25	0.0000	3.1404	43.25	0.0000	3.1404
13.50	0.0211	3.0836	28.50	0.0000	3.1404	43.50	0.0000	3.1404
13.75	0.0194	3.0886	28.75	0.0000	3.1404	43.75	0.0000	3.1404
14.00	0.0179	3.0933	29.00	0.0000	3.1404	44.00	0.0000	3.1404
14.25	0.0165	3.0976	29.25	0.0000	3.1404	44.25	0.0000	3.1404
14.50	0.0152	3.1016	29.50	0.0000	3.1404	44.50	0.0000	3.1404
14.75	0.0139	3.1052	29.75	0.0000	3.1404	44.75	0.0000	3.1404
						45.00	0.0000	3.1404

A = Lateral Offset: P = Probability: $F(A)=\sum_{x=0}^{x=A}\left[\frac{P_{x-\Delta x}+P_{x}}{2}\right]\Delta x$; $F(A)_0 = 0$

TABLE A.1.4 Lateral Extent of Encroachment Probabilities - Design Speed 80 km/h

A m	P	F(A) m	A m	P	F(A) m	A m	P	F(A) m
0.00	1.0000	0.0000	15.00	0.0249	3.6611	30.00	0.0000	3.7368
0.25	0.9137	0.2392	15.25	0.0232	3.6671	30.25	0.0000	3.7368
0.50	0.8242	0.4565	15.50	0.0216	3.6727	30.50	0.0000	3.7368
0.75	0.7492	0.6532	15.75	0.0201	3.6779	30.75	0.0000	3.7368
1.00	0.6877	0.8328	16.00	0.0187	3.6828	31.00	0.0000	3.7368
1.25	0.6375	0.9984	16.25	0.0173	3.6873	31.25	0.0000	3.7368
1.50	0.5956	1.1526	16.50	0.0161	3.6915	31.50	0.0000	3.7368
1.75	0.5601	1.2970	16.75	0.0149	3.6953	31.75	0.0000	3.7368
2.00	0.5283	1.4331	17.00	0.0138	3.6989	32.00	0.0000	3.7368
2.25	0.4992	1.5615	17.25	0.0128	3.7023	32.25	0.0000	3.7368
2.50	0.4720	1.6829	17.50	0.0118	3.7053	32.50	0.0000	3.7368
2.75	0.4461	1.7977	17.75	0.0109	3.7082	32.75	0.0000	3.7368
3.00	0.4217	1.9061	18.00	0.0100	3.7108	33.00	0.0000	3.7368
3.25	0.3984	2.0086	18.25	0.0092	3.7132	33.25	0.0000	3.7368
3.50	0.3766	2.1055	18.50	0.0085	3.7154	33.50	0.0000	3.7368
3.75	0.3562	2.1971	18.75	0.0078	3.7174	33.75	0.0000	3.7368
4.00	0.3367	2.2837	19.00	0.0071	3.7193	34.00	0.0000	3.7368
4.25	0.3183	2.3656	19.25	0.0066	3.7210	34.25	0.0000	3.7368
4.50	0.3012	2.4430	19.50	0.0060	3.7226	34.50	0.0000	3.7368
4.75	0.2851	2.5163	19.75	0.0055	3.7240	34.75	0.0000	3.7368
5.00	0.2700	2.5857	20.00	0.0050	3.7253	35.00	0.0000	3.7368
5.25	0.2556	2.6514	20.25	0.0045	3.7265	35.25	0.0000	3.7368
5.50	0.2419	2.7136	20.50	0.0041	3.7276	35.50	0.0000	3.7368
5.75	0.2290	2.7725	20.75	0.0037	3.7286	35.75	0.0000	3.7368
6.00	0.2169	2.8282	21.00	0.0034	3.7295	36.00	0.0000	3.7368
6.25	0.2055	2.8810	21.25	0.0031	3.7303	36.25	0.0000	3.7368
6.50	0.1947	2.9310	21.50	0.0028	3.7310	36.50	0.0000	3.7368
6.75	0.1843	2.9784	21.75	0.0025	3.7317	36.75	0.0000	3.7368
7.00	0.1745	3.0232	22.00	0.0022	3.7323	37.00	0.0000	3.7368
7.25	0.1651	3.0657	22.25	0.0020	3.7328	37.25	0.0000	3.7368
7.50	0.1562	3.1058	22.50	0.0018	3.7333	37.50	0.0000	3.7368
7.75	0.1478	3.1439	22.75	0.0016	3.7337	37.75	0.0000	3.7368
8.00	0.1398	3.1798	23.00	0.0015	3.7341	38.00	0.0000	3.7368
8.25	0.1323	3.2138	23.25	0.0013	3.7344	38.25	0.0000	3.7368
8.50	0.1251	3.2460	23.50	0.0011	3.7347	38.50	0.0000	3.7368
8.75	0.1183	3.2764	23.75	0.0010	3.7350	38.75	0.0000	3.7368
9.00	0.1117	3.3052	24.00	0.0009	3.7353	39.00	0.0000	3.7368
9.25	0.1055	3.3323	24.25	0.0008	3.7355	39.25	0.0000	3.7368
9.50	0.0996	3.3579	24.50	0.0007	3.7356	39.50	0.0000	3.7368
9.75	0.0940	3.3821	24.75	0.0006	3.7358	39.75	0.0000	3.7368
10.00	0.0886	3.4050	25.00	0.0005	3.7359	40.00	0.0000	3.7368
10.25	0.0836	3.4265	25.25	0.0005	3.7361	40.25	0.0000	3.7368
10.50	0.0789	3.4468	25.50	0.0004	3.7362	40.50	0.0000	3.7368
10.75	0.0744	3.4660	25.75	0.0004	3.7363	40.75	0.0000	3.7368
11.00	0.0701	3.4841	26.00	0.0003	3.7364	41.00	0.0000	3.7368
11.25	0.0660	3.5011	26.25	0.0003	3.7364	41.25	0.0000	3.7368
11.50	0.0621	3.5171	26.50	0.0002	3.7365	41.50	0.0000	3.7368
11.75	0.0584	3.5322	26.75	0.0002	3.7366	41.75	0.0000	3.7368
12.00	0.0549	3.5463	27.00	0.0002	3.7366	42.00	0.0000	3.7368
12.25	0.0516	3.5596	27.25	0.0001	3.7366	42.25	0.0000	3.7368
12.50	0.0484	3.5721	27.50	0.0001	3.7367	42.50	0.0000	3.7368
12.75	0.0454	3.5839	27.75	0.0001	3.7367	42.75	0.0000	3.7368
13.00	0.0426	3.5949	28.00	0.0001	3.7367	43.00	0.0000	3.7368
13.25	0.0400	3.6052	28.25	0.0001	3.7367	43.25	0.0000	3.7368
13.50	0.0375	3.6149	28.50	0.0001	3.7368	43.50	0.0000	3.7368
13.75	0.0351	3.6239	28.75	0.0000	3.7368	43.75	0.0000	3.7368
14.00	0.0328	3.6324	29.00	0.0000	3.7368	44.00	0.0000	3.7368
14.25	0.0307	3.6404	29.25	0.0000	3.7368	44.25	0.0000	3.7368
14.50	0.0286	3.6478	29.50	0.0000	3.7368	44.50	0.0000	3.7368
14.75	0.0267	3.6547	29.75	0.0000	3.7368	44.75	0.0000	3.7368
						45.00	0.0000	3.7368

A = Lateral Offset: P = Probability: $F(A) = \sum_{x=0}^{x=A} \left[\frac{P_{x-\Delta x} + P_x}{2} \right] \Delta x$: $F(A)_0 = 0$

TABLE A.1.5 Lateral Extent of Encroachment Probabilities - Design Speed 90 km/h

A	P	F(A)	A	P	F(A)	A	P	F(A)
m		m	m		m	m		m
0.00	1.0000	0.0000	15.00	0.0405	4.1780	30.00	0.0002	4.3238
0.25	0.9355	0.2419	15.25	0.0381	4.1878	30.25	0.0001	4.3238
0.50	0.8594	0.4663	15.50	0.0359	4.1970	30.50	0.0001	4.3239
0.75	0.7920	0.6727	15.75	0.0338	4.2057	30.75	0.0001	4.3239
1.00	0.7325	0.8633	16.00	0.0318	4.2139	31.00	0.0001	4.3239
1.25	0.6810	1.0400	16.25	0.0299	4.2216	31.25	0.0001	4.3239
1.50	0.6371	1.2047	16.50	0.0281	4.2289	31.50	0.0001	4.3239
1.75	0.5996	1.3593	16.75	0.0264	4.2357	31.75	0.0000	4.3240
2.00	0.5666	1.5051	17.00	0.0248	4.2421	32.00	0.0000	4.3240
2.25	0.5374	1.6431	17.25	0.0232	4.2481	32.25	0.0000	4.3240
2.50	0.5109	1.7742	17.50	0.0217	4.2537	32.50	0.0000	4.3240
2.75	0.4863	1.8988	17.75	0.0204	4.2589	32.75	0.0000	4.3240
3.00	0.4634	2.0175	18.00	0.0190	4.2639	33.00	0.0000	4.3240
3.25	0.4415	2.1306	18.25	0.0178	4.2685	33.25	0.0000	4.3240
3.50	0.4209	2.2384	18.50	0.0166	4.2728	33.50	0.0000	4.3240
3.75	0.4016	2.3412	18.75	0.0155	4.2768	33.75	0.0000	4.3240
4.00	0.3830	2.4393	19.00	0.0144	4.2805	34.00	0.0000	4.3240
4.25	0.3652	2.5328	19.25	0.0134	4.2840	34.25	0.0000	4.3240
4.50	0.3482	2.6220	19.50	0.0125	4.2872	34.50	0.0000	4.3240
4.75	0.3321	2.7071	19.75	0.0116	4.2903	34.75	0.0000	4.3240
5.00	0.3168	2.7882	20.00	0.0108	4.2931	35.00	0.0000	4.3240
5.25	0.3021	2.8655	20.25	0.0100	4.2957	35.25	0.0000	4.3240
5.50	0.2880	2.9393	20.50	0.0093	4.2981	35.50	0.0000	4.3240
5.75	0.2746	3.0096	20.75	0.0086	4.3003	35.75	0.0000	4.3240
6.00	0.2618	3.0767	21.00	0.0080	4.3024	36.00	0.0000	4.3240
6.25	0.2497	3.1406	21.25	0.0074	4.3043	36.25	0.0000	4.3240
6.50	0.2381	3.2016	21.50	0.0068	4.3061	36.50	0.0000	4.3240
6.75	0.2270	3.2597	21.75	0.0063	4.3077	36.75	0.0000	4.3240
7.00	0.2164	3.3151	22.00	0.0058	4.3092	37.00	0.0000	4.3240
7.25	0.2062	3.3680	22.25	0.0053	4.3106	37.25	0.0000	4.3240
7.50	0.1965	3.4183	22.50	0.0049	4.3119	37.50	0.0000	4.3240
7.75	0.1873	3.4663	22.75	0.0045	4.3131	37.75	0.0000	4.3240
8.00	0.1784	3.5120	23.00	0.0041	4.3141	38.00	0.0000	4.3240
8.25	0.1699	3.5555	23.25	0.0037	4.3151	38.25	0.0000	4.3240
8.50	0.1618	3.5970	23.50	0.0034	4.3160	38.50	0.0000	4.3240
8.75	0.1541	3.6365	23.75	0.0031	4.3168	38.75	0.0000	4.3240
9.00	0.1466	3.6741	24.00	0.0028	4.3176	39.00	0.0000	4.3240
9.25	0.1395	3.7098	24.25	0.0026	4.3183	39.25	0.0000	4.3240
9.50	0.1328	3.7439	24.50	0.0024	4.3189	39.50	0.0000	4.3240
9.75	0.1262	3.7762	24.75	0.0021	4.3194	39.75	0.0000	4.3240
10.00	0.1200	3.8070	25.00	0.0019	4.3199	40.00	0.0000	4.3240
10.25	0.1140	3.8363	25.25	0.0017	4.3204	40.25	0.0000	4.3240
10.50	0.1083	3.8641	25.50	0.0016	4.3208	40.50	0.0000	4.3240
10.75	0.1030	3.8905	25.75	0.0014	4.3212	40.75	0.0000	4.3240
11.00	0.0978	3.9156	26.00	0.0013	4.3215	41.00	0.0000	4.3240
11.25	0.0929	3.9394	26.25	0.0011	4.3218	41.25	0.0000	4.3240
11.50	0.0881	3.9620	26.50	0.0010	4.3221	41.50	0.0000	4.3240
11.75	0.0836	3.9835	26.75	0.0009	4.3223	41.75	0.0000	4.3240
12.00	0.0792	4.0038	27.00	0.0008	4.3226	42.00	0.0000	4.3240
12.25	0.0751	4.0231	27.25	0.0007	4.3227	42.25	0.0000	4.3240
12.50	0.0711	4.0414	27.50	0.0006	4.3229	42.50	0.0000	4.3240
12.75	0.0673	4.0587	27.75	0.0006	4.3231	42.75	0.0000	4.3240
13.00	0.0638	4.0751	28.00	0.0005	4.3232	43.00	0.0000	4.3240
13.25	0.0604	4.0906	28.25	0.0004	4.3233	43.25	0.0000	4.3240
13.50	0.0571	4.1053	28.50	0.0004	4.3234	43.50	0.0000	4.3240
13.75	0.0540	4.1192	28.75	0.0003	4.3235	43.75	0.0000	4.3240
14.00	0.0511	4.1323	29.00	0.0003	4.3236	44.00	0.0000	4.3240
14.25	0.0483	4.1448	29.25	0.0003	4.3237	44.25	0.0000	4.3240
14.50	0.0455	4.1565	29.50	0.0002	4.3237	44.50	0.0000	4.3240
14.75	0.0429	4.1675	29.75	0.0002	4.3238	44.75	0.0000	4.3240
						45.00	0.0000	4.3240

A = Lateral Offset: P = Probability: $F(A)=\sum_{x=0}^{x=A}\left[\frac{P_{x-\Delta x}+P_{x}}{2}\right]\Delta x$; $F(A)_0 = 0$

TABLE A.1.6 Lateral Extent of Encroachment Probabilities - Design Speed 100 km/h

A m	P	F(A) m	A m	P	F(A) m	A m	P	F(A) m
0.00	1.0000	0.0000	15.00	0.0561	4.6257	30.00	0.0006	4.8510
0.25	0.9460	0.2433	15.25	0.0532	4.6393	30.25	0.0005	4.8512
0.50	0.8901	0.4728	15.50	0.0504	4.6523	30.50	0.0004	4.8513
0.75	0.8274	0.6875	15.75	0.0478	4.6646	30.75	0.0004	4.8514
1.00	0.7731	0.8875	16.00	0.0452	4.6762	31.00	0.0003	4.8515
1.25	0.7232	1.0746	16.25	0.0428	4.6872	31.25	0.0003	4.8516
1.50	0.6794	1.2499	16.50	0.0405	4.6976	31.50	0.0003	4.8516
1.75	0.6403	1.4148	16.75	0.0383	4.7075	31.75	0.0002	4.8517
2.00	0.6056	1.5706	17.00	0.0363	4.7168	32.00	0.0002	4.8518
2.25	0.5749	1.7181	17.25	0.0343	4.7256	32.25	0.0002	4.8518
2.50	0.5472	1.8584	17.50	0.0324	4.7340	32.50	0.0001	4.8518
2.75	0.5219	1.9920	17.75	0.0305	4.7418	32.75	0.0001	4.8519
3.00	0.4983	2.1195	18.00	0.0288	4.7492	33.00	0.0001	4.8519
3.25	0.4763	2.2414	18.25	0.0271	4.7562	33.25	0.0001	4.8519
3.50	0.4555	2.3578	18.50	0.0255	4.7628	33.50	0.0001	4.8519
3.75	0.4359	2.4693	18.75	0.0240	4.7690	33.75	0.0001	4.8520
4.00	0.4174	2.5759	19.00	0.0225	4.7748	34.00	0.0000	4.8520
4.25	0.3996	2.6781	19.25	0.0212	4.7802	34.25	0.0000	4.8520
4.50	0.3828	2.7759	19.50	0.0198	4.7854	34.50	0.0000	4.8520
4.75	0.3668	2.8695	19.75	0.0186	4.7902	34.75	0.0000	4.8520
5.00	0.3516	2.9593	20.00	0.0175	4.7947	35.00	0.0000	4.8520
5.25	0.3371	3.0454	20.25	0.0164	4.7989	35.25	0.0000	4.8520
5.50	0.3232	3.1280	20.50	0.0153	4.8029	35.50	0.0000	4.8520
5.75	0.3099	3.2071	20.75	0.0144	4.8066	35.75	0.0000	4.8520
6.00	0.2972	3.2830	21.00	0.0134	4.8101	36.00	0.0000	4.8520
6.25	0.2849	3.3558	21.25	0.0126	4.8133	36.25	0.0000	4.8520
6.50	0.2732	3.4255	21.50	0.0117	4.8164	36.50	0.0000	4.8520
6.75	0.2619	3.4924	21.75	0.0109	4.8192	36.75	0.0000	4.8520
7.00	0.2512	3.5566	22.00	0.0102	4.8218	37.00	0.0000	4.8520
7.25	0.2407	3.6180	22.25	0.0095	4.8243	37.25	0.0000	4.8520
7.50	0.2307	3.6770	22.50	0.0088	4.8266	37.50	0.0000	4.8520
7.75	0.2210	3.7334	22.75	0.0081	4.8287	37.75	0.0000	4.8520
8.00	0.2117	3.7875	23.00	0.0076	4.8306	38.00	0.0000	4.8520
8.25	0.2028	3.8393	23.25	0.0070	4.8325	38.25	0.0000	4.8520
8.50	0.1941	3.8889	23.50	0.0065	4.8341	38.50	0.0000	4.8520
8.75	0.1858	3.9364	23.75	0.0060	4.8357	38.75	0.0000	4.8520
9.00	0.1779	3.9819	24.00	0.0055	4.8371	39.00	0.0000	4.8520
9.25	0.1702	4.0254	24.25	0.0051	4.8385	39.25	0.0000	4.8520
9.50	0.1628	4.0670	24.50	0.0047	4.8397	39.50	0.0000	4.8520
9.75	0.1557	4.1068	24.75	0.0043	4.8408	39.75	0.0000	4.8520
10.00	0.1488	4.1449	25.00	0.0040	4.8419	40.00	0.0000	4.8520
10.25	0.1421	4.1813	25.25	0.0037	4.8428	40.25	0.0000	4.8520
10.50	0.1357	4.2160	25.50	0.0034	4.8437	40.50	0.0000	4.8520
10.75	0.1296	4.2491	25.75	0.0031	4.8445	40.75	0.0000	4.8520
11.00	0.1237	4.2808	26.00	0.0028	4.8453	41.00	0.0000	4.8520
11.25	0.1181	4.3110	26.25	0.0026	4.8460	41.25	0.0000	4.8520
11.50	0.1127	4.3399	26.50	0.0024	4.8466	41.50	0.0000	4.8520
11.75	0.1075	4.3674	26.75	0.0021	4.8471	41.75	0.0000	4.8520
12.00	0.1025	4.3937	27.00	0.0019	4.8476	42.00	0.0000	4.8520
12.25	0.0976	4.4187	27.25	0.0018	4.8481	42.25	0.0000	4.8520
12.50	0.0930	4.4425	27.50	0.0016	4.8485	42.50	0.0000	4.8520
12.75	0.0885	4.4652	27.75	0.0014	4.8489	42.75	0.0000	4.8520
13.00	0.0843	4.4868	28.00	0.0013	4.8493	43.00	0.0000	4.8520
13.25	0.0802	4.5074	28.25	0.0012	4.8496	43.25	0.0000	4.8520
13.50	0.0763	4.5270	28.50	0.0011	4.8498	43.50	0.0000	4.8520
13.75	0.0726	4.5456	28.75	0.0010	4.8501	43.75	0.0000	4.8520
14.00	0.0690	4.5633	29.00	0.0009	4.8503	44.00	0.0000	4.8520
14.25	0.0656	4.5801	29.25	0.0008	4.8505	44.25	0.0000	4.8520
14.50	0.0623	4.5961	29.50	0.0007	4.8507	44.50	0.0000	4.8520
14.75	0.0591	4.6113	29.75	0.0006	4.8509	44.75	0.0000	4.8520
						45.00	0.0000	4.8520

A = Lateral Offset: P = Probability: $F(A)=\sum_{x=0}^{x=A}\left[\frac{P_{x-\Delta x}+P_x}{2}\right]\Delta x$; $F(A)_0 = 0$

TABLE A.1.7 Lateral Extent of Encroachment Probabilities - Design Speed 110 km/h

A m	P	F(A) m	A m	P	F(A) m	A m	P	F(A) m
0.00	1.0000	0.0000	15.00	0.0747	5.0520	30.00	0.0018	5.3931
0.25	0.9592	0.2449	15.25	0.0713	5.0703	30.25	0.0016	5.3935
0.50	0.9102	0.4786	15.50	0.0680	5.0877	30.50	0.0015	5.3939
0.75	0.8597	0.6998	15.75	0.0648	5.1043	30.75	0.0014	5.3943
1.00	0.8073	0.9082	16.00	0.0618	5.1201	31.00	0.0013	5.3946
1.25	0.7612	1.1043	16.25	0.0589	5.1352	31.25	0.0011	5.3949
1.50	0.7192	1.2893	16.50	0.0561	5.1496	31.50	0.0010	5.3952
1.75	0.6803	1.4643	16.75	0.0535	5.1633	31.75	0.0009	5.3955
2.00	0.6454	1.6300	17.00	0.0509	5.1763	32.00	0.0009	5.3957
2.25	0.6139	1.7874	17.25	0.0485	5.1888	32.25	0.0008	5.3959
2.50	0.5849	1.9373	17.50	0.0461	5.2006	32.50	0.0007	5.3961
2.75	0.5585	2.0802	17.75	0.0439	5.2118	32.75	0.0006	5.3962
3.00	0.5344	2.2168	18.00	0.0417	5.2225	33.00	0.0005	5.3964
3.25	0.5119	2.3476	18.25	0.0396	5.2327	33.25	0.0005	5.3965
3.50	0.4906	2.4729	18.50	0.0376	5.2424	33.50	0.0004	5.3966
3.75	0.4706	2.5931	18.75	0.0357	5.2515	33.75	0.0004	5.3967
4.00	0.4515	2.7083	19.00	0.0339	5.2602	34.00	0.0003	5.3968
4.25	0.4332	2.8189	19.25	0.0321	5.2685	34.25	0.0003	5.3969
4.50	0.4158	2.9250	19.50	0.0305	5.2763	34.50	0.0003	5.3970
4.75	0.3992	3.0269	19.75	0.0289	5.2837	34.75	0.0002	5.3970
5.00	0.3834	3.1247	20.00	0.0273	5.2908	35.00	0.0002	5.3971
5.25	0.3683	3.2187	20.25	0.0259	5.2974	35.25	0.0002	5.3971
5.50	0.3539	3.3090	20.50	0.0245	5.3037	35.50	0.0002	5.3972
5.75	0.3401	3.3957	20.75	0.0231	5.3097	35.75	0.0002	5.3972
6.00	0.3270	3.4791	21.00	0.0219	5.3153	36.00	0.0001	5.3973
6.25	0.3144	3.5593	21.25	0.0207	5.3206	36.25	0.0001	5.3973
6.50	0.3024	3.6364	21.50	0.0195	5.3256	36.50	0.0001	5.3973
6.75	0.2909	3.7105	21.75	0.0184	5.3304	36.75	0.0001	5.3974
7.00	0.2799	3.7819	22.00	0.0174	5.3348	37.00	0.0001	5.3974
7.25	0.2694	3.8505	22.25	0.0164	5.3391	37.25	0.0001	5.3974
7.50	0.2592	3.9166	22.50	0.0154	5.3430	37.50	0.0001	5.3974
7.75	0.2495	3.9802	22.75	0.0145	5.3468	37.75	0.0001	5.3974
8.00	0.2401	4.0414	23.00	0.0136	5.3503	38.00	0.0001	5.3975
8.25	0.2311	4.1003	23.25	0.0128	5.3536	38.25	0.0000	5.3975
8.50	0.2224	4.1570	23.50	0.0120	5.3567	38.50	0.0000	5.3975
8.75	0.2140	4.2115	23.75	0.0112	5.3596	38.75	0.0000	5.3975
9.00	0.2059	4.2640	24.00	0.0105	5.3623	39.00	0.0000	5.3975
9.25	0.1980	4.3145	24.25	0.0099	5.3648	39.25	0.0000	5.3975
9.50	0.1905	4.3631	24.50	0.0093	5.3672	39.50	0.0000	5.3975
9.75	0.1832	4.4098	24.75	0.0087	5.3695	39.75	0.0000	5.3975
10.00	0.1761	4.4547	25.00	0.0081	5.3716	40.00	0.0000	5.3975
10.25	0.1692	4.4978	25.25	0.0076	5.3735	40.25	0.0000	5.3975
10.50	0.1625	4.5393	25.50	0.0071	5.3754	40.50	0.0000	5.3975
10.75	0.1560	4.5791	25.75	0.0066	5.3771	40.75	0.0000	5.3975
11.00	0.1498	4.6173	26.00	0.0062	5.3787	41.00	0.0000	5.3975
11.25	0.1438	4.6540	26.25	0.0058	5.3802	41.25	0.0000	5.3975
11.50	0.1380	4.6892	26.50	0.0054	5.3816	41.50	0.0000	5.3975
11.75	0.1324	4.7230	26.75	0.0050	5.3829	41.75	0.0000	5.3975
12.00	0.1269	4.7554	27.00	0.0046	5.3841	42.00	0.0000	5.3975
12.25	0.1217	4.7865	27.25	0.0043	5.3852	42.25	0.0000	5.3975
12.50	0.1165	4.8163	27.50	0.0040	5.3863	42.50	0.0000	5.3975
12.75	0.1116	4.8448	27.75	0.0037	5.3872	42.75	0.0000	5.3975
13.00	0.1068	4.8721	28.00	0.0034	5.3881	43.00	0.0000	5.3975
13.25	0.1022	4.8982	28.25	0.0031	5.3889	43.25	0.0000	5.3975
13.50	0.0978	4.9232	28.50	0.0029	5.3897	43.50	0.0000	5.3975
13.75	0.0936	4.9472	28.75	0.0027	5.3904	43.75	0.0000	5.3975
14.00	0.0896	4.9701	29.00	0.0025	5.3910	44.00	0.0000	5.3975
14.25	0.0856	4.9920	29.25	0.0023	5.3916	44.25	0.0000	5.3975
14.50	0.0818	5.0129	29.50	0.0021	5.3922	44.50	0.0000	5.3975
14.75	0.0782	5.0329	29.75	0.0019	5.3927	44.75	0.0000	5.3975
						45.00	0.0000	5.3975

A = Lateral Offset: P = Probability: $F(A) = \sum_{x=0}^{x=A} \left[\frac{P_{x-\Delta x} + P_x}{2} \right] \Delta x$; $F(A)_0 = 0$

TABLE A.1.8 Lateral Extent of Encroachment Probabilities - Design Speed 120 km/h

A m	P	F(A) m	A m	P	F(A) m	A m	P	F(A) m
0.00	1.0000	0.0000	15.00	0.0957	5.4835	30.00	0.0042	5.9771
0.25	0.9707	0.2463	15.25	0.0919	5.5070	30.25	0.0039	5.9781
0.50	0.9213	0.4828	15.50	0.0883	5.5295	30.50	0.0036	5.9790
0.75	0.8837	0.7085	15.75	0.0847	5.5511	30.75	0.0034	5.9799
1.00	0.8397	0.9239	16.00	0.0813	5.5719	31.00	0.0032	5.9807
1.25	0.7950	1.1282	16.25	0.0780	5.5918	31.25	0.0029	5.9815
1.50	0.7542	1.3219	16.50	0.0748	5.6109	31.50	0.0027	5.9822
1.75	0.7182	1.5060	16.75	0.0717	5.6292	31.75	0.0025	5.9829
2.00	0.6842	1.6813	17.00	0.0687	5.6467	32.00	0.0023	5.9835
2.25	0.6524	1.8483	17.25	0.0658	5.6635	32.25	0.0022	5.9840
2.50	0.6233	2.0078	17.50	0.0631	5.6796	32.50	0.0020	5.9846
2.75	0.5969	2.1603	17.75	0.0604	5.6951	32.75	0.0018	5.9850
3.00	0.5723	2.3065	18.00	0.0578	5.7098	33.00	0.0017	5.9855
3.25	0.5491	2.4466	18.25	0.0553	5.7240	33.25	0.0015	5.9859
3.50	0.5274	2.5812	18.50	0.0529	5.7375	33.50	0.0014	5.9862
3.75	0.5072	2.7105	18.75	0.0506	5.7504	33.75	0.0013	5.9866
4.00	0.4881	2.8349	19.00	0.0483	5.7628	34.00	0.0012	5.9869
4.25	0.4697	2.9547	19.25	0.0462	5.7746	34.25	0.0011	5.9872
4.50	0.4520	3.0699	19.50	0.0441	5.7859	34.50	0.0010	5.9874
4.75	0.4351	3.1808	19.75	0.0421	5.7967	34.75	0.0009	5.9877
5.00	0.4189	3.2875	20.00	0.0402	5.8070	35.00	0.0008	5.9879
5.25	0.4033	3.3903	20.25	0.0384	5.8168	35.25	0.0007	5.9881
5.50	0.3882	3.4892	20.50	0.0366	5.8262	35.50	0.0007	5.9883
5.75	0.3738	3.5844	20.75	0.0349	5.8351	35.75	0.0006	5.9884
6.00	0.3600	3.6762	21.00	0.0332	5.8436	36.00	0.0006	5.9886
6.25	0.3468	3.7645	21.25	0.0317	5.8517	36.25	0.0005	5.9887
6.50	0.3341	3.8496	21.50	0.0302	5.8595	36.50	0.0005	5.9888
6.75	0.3219	3.9316	21.75	0.0287	5.8668	36.75	0.0004	5.9889
7.00	0.3103	4.0106	22.00	0.0273	5.8738	37.00	0.0004	5.9890
7.25	0.2992	4.0868	22.25	0.0260	5.8805	37.25	0.0004	5.9891
7.50	0.2884	4.1603	22.50	0.0247	5.8868	37.50	0.0003	5.9892
7.75	0.2781	4.2311	22.75	0.0235	5.8929	37.75	0.0003	5.9893
8.00	0.2682	4.2994	23.00	0.0223	5.8986	38.00	0.0003	5.9894
8.25	0.2588	4.3653	23.25	0.0212	5.9040	38.25	0.0002	5.9894
8.50	0.2497	4.4288	23.50	0.0201	5.9092	38.50	0.0002	5.9895
8.75	0.2409	4.4901	23.75	0.0190	5.9141	38.75	0.0002	5.9895
9.00	0.2325	4.5493	24.00	0.0180	5.9187	39.00	0.0002	5.9896
9.25	0.2244	4.6064	24.25	0.0171	5.9231	39.25	0.0001	5.9896
9.50	0.2166	4.6616	24.50	0.0161	5.9272	39.50	0.0001	5.9896
9.75	0.2091	4.7148	24.75	0.0153	5.9312	39.75	0.0001	5.9897
10.00	0.2019	4.7662	25.00	0.0144	5.9349	40.00	0.0001	5.9897
10.25	0.1949	4.8158	25.25	0.0137	5.9384	40.25	0.0001	5.9897
10.50	0.1881	4.8636	25.50	0.0129	5.9417	40.50	0.0001	5.9897
10.75	0.1815	4.9098	25.75	0.0122	5.9449	40.75	0.0001	5.9897
11.00	0.1751	4.9544	26.00	0.0115	5.9478	41.00	0.0000	5.9897
11.25	0.1690	4.9974	26.25	0.0109	5.9506	41.25	0.0000	5.9898
11.50	0.1630	5.0389	26.50	0.0102	5.9533	41.50	0.0000	5.9898
11.75	0.1572	5.0790	26.75	0.0096	5.9557	41.75	0.0000	5.9898
12.00	0.1516	5.1176	27.00	0.0091	5.9581	42.00	0.0000	5.9898
12.25	0.1462	5.1548	27.25	0.0085	5.9603	42.25	0.0000	5.9898
12.50	0.1409	5.1907	27.50	0.0080	5.9624	42.50	0.0000	5.9898
12.75	0.1357	5.2253	27.75	0.0075	5.9643	42.75	0.0000	5.9898
13.00	0.1307	5.2586	28.00	0.0070	5.9661	43.00	0.0000	5.9898
13.25	0.1258	5.2906	28.25	0.0066	5.9678	43.25	0.0000	5.9898
13.50	0.1211	5.3215	28.50	0.0062	5.9694	43.50	0.0000	5.9898
13.75	0.1165	5.3512	28.75	0.0058	5.9709	43.75	0.0000	5.9898
14.00	0.1121	5.3798	29.00	0.0054	5.9723	44.00	0.0000	5.9898
14.25	0.1078	5.4073	29.25	0.0051	5.9736	44.25	0.0000	5.9898
14.50	0.1037	5.4337	29.50	0.0048	5.9749	44.50	0.0000	5.9898
14.75	0.0996	5.4591	29.75	0.0045	5.9760	44.75	0.0000	5.9898
						45.00	0.0000	5.9898

A = Lateral Offset: P = Probability: $F(A) = \sum_{x=0}^{x=A} \left[\frac{P_{x-\Delta x} + P_x}{2} \right] \Delta x$; $F(A)_0 = 0$

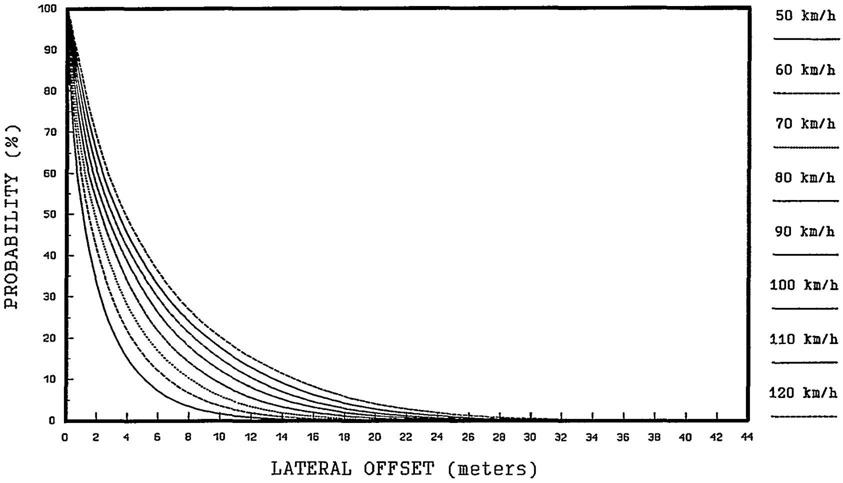


FIGURE A.1 Lateral Extent of Encroachment vs. Probability

Based on the input of a design speed and a traffic mix, the program (LATX-45) that was used to develop the lateral extent of encroachment probability curves integrates the lateral extent of encroachment for a combination of 13 different vehicles, encroaching on the roadside at 12 speeds and up to 13 angles for each of the 12 speeds. There are eight traffic mixes, defined by percent trucks, built in to the program. Mix number 1 is defined as having 2% trucks. Mixes 2 through 8 vary from 5% to 35% trucks in 5% increments, respectively. Selecting a traffic mix (% trucks) establishes the probabilities for each of the 13 vehicles. These mixes are quantified in Table A.3. (In reality, there are only 7 different vehicles considered because the differences between the various vehicles is in the cornering coefficient of friction assigned to each and the first seven vehicles all have the same cornering coefficient of friction. This is a vestige of a past effort that had a different objective and that did ascribed unique parameters to each of the 13 vehicles.) Figure A.2 illustrates the estimated distribution of vehicle types.

For each design speed a probability density curve is estimated. (See Figure A.3.) The area under the curve is equal to 1. The shape of the curve is such that the probability of a given speed is maximum between ±8 km/h from 0.9 of the design speed (DS). From 0 to (0.9DS - 8) km/h the probability rises linearly to the maximum. From (0.9DS + 8) km/h the probability decreases linearly from the maximum to zero at (0.9DS + 28) km/h. The probability density curve is divided into 12 cells, the area

TABLE A.2 "Finite" Lateral Extent of Roadside vs. Design Speed

Design Speed km/h	Finite Lateral Extent of Roadside* m
50	20.00
60	23.75
70	26.25
80	28.75
90	31.75
100	34.00
110	38.25
120	41.25

* Values are for a tangent highway with a level roadside.

TABLE A.3 Estimated Traffic Mix Characteristics

Vehicle Types	Vehicle Number	Percent in Class	Cornering Coefficient of Friction	Traffic Mix (Percent)							
				Percent Trucks							
				2	5	10	15	20	25	30	35
Automobiles	1	17	0.80	11.7	11.3	10.7	10.1	9.5	8.9	8.3	7.7
	2	31	0.80	21.2	20.6	19.5	18.4	17.3	16.1	15.0	13.9
	3	30	0.80	20.6	19.9	18.9	17.8	16.7	15.6	14.6	13.5
	4	22	0.80	15.1	14.6	13.8	13.0	12.2	11.5	10.7	9.9
Vans and Pickups	5	29	0.80	8.5	8.3	7.9	7.5	7.0	6.7	6.2	5.8
	6	39	0.80	11.5	11.1	10.5	10.0	9.5	8.9	8.3	7.8
	7	32	0.80	9.4	9.2	8.7	8.2	7.8	7.3	6.9	6.4
Single-unit Trucks	8	34	0.75	0.6	1.4	1.4	1.4	1.4	1.4	1.4	1.4
	9	38	0.61	0.8	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	10	28	0.41	0.6	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Combination Trucks	11	33	0.62	0.0	0.3	2.0	3.6	5.3	6.9	8.6	10.2
	12	33	0.46	0.0	0.3	2.0	3.6	5.3	6.9	8.6	10.2
	13	34	0.32	0.0	0.4	2.0	3.8	5.4	7.2	8.8	10.6

of each is taken as the probability of the speed at the center of the cell for all cells except the lowest speed cell, where the area of the cell is taken as the probability of the speed equal to two-thirds of the width of the cell, which is the nominal speed assigned to that cell. Between (0.9DS - 40) km/h to (0.9DS + 8) km/h there are six cells, each 8 km/h wide. Above (0.9DS + 8) km/h there are five cells, each 4 km/h wide. The width of the lowest speed cell is (0.9DS - 40) km/h. (Note: To avoid having a negative cell width the design speed cannot be less than 40/0.9, or 44.44 km/h.)

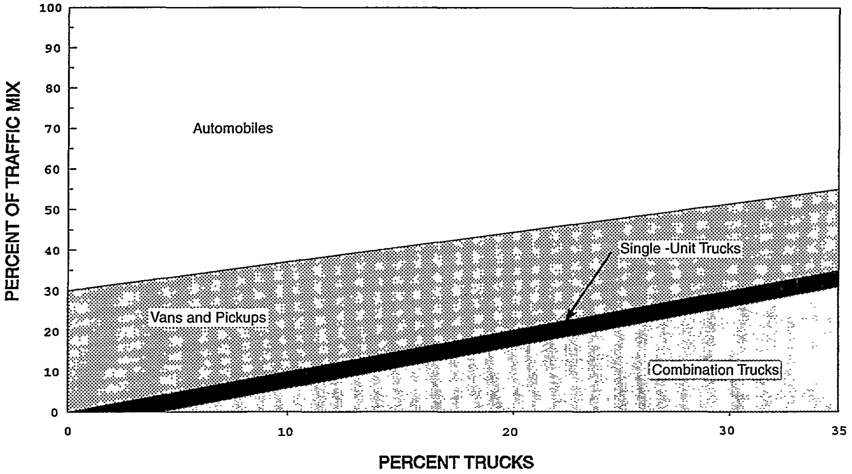


FIGURE A.2 Vehicle Mix Related to Percent Trucks in Traffic Stream

The predicted angles and the probabilities of the angles at which a vehicle encroaches on the roadside are defined by the shape of a basic encroachment angle probability density curve and the nominal speeds for each of the probability cells in the speed probability density curve. The basic shape of the angle probability density curve is such that the maximum probability occurs at zero degrees and the probability decreases linearly to zero at 39 degrees. The area under the curve is equal to one and is divided into 13 3-degree-wide cells. (See Figure A.4.) The nominal angle for an angle cell is the angle at the center of the cell. Thus, the minimum nominal encroachment angle is 1.5 degrees and the maximum is 37.5 degrees.

The lateral extent of encroachment probability program checks each vehicle at each of the nominal speeds for each of the cells in the speed probability density curve to determine the maximum angle the vehicle (as a point mass with its assigned coefficient of friction) would exit the traveled way, assuming it starts from a specified offset from the edge of the traveled way and turns at the minimum radius achievable without skidding at the nominal cell speed. (See Figure A.5.) The offset distance between the edge of the traveled way and the initial velocity vector of the point mass is set at 5.5 m. If the maximum achievable encroachment angle for a nominal cell speed equals or exceeds 36 degrees (39 - 3) the program analyzes encroachments for all the encroachment angle cells in the probability density curve. If, on the other hand, the maximum achievable angle is less than 36 degrees, the program determines in which cell the maximum achievable encroachment angle falls and takes the area of all cells with angles greater than the maximum angle in that cell and evenly distributes that area to all the remaining cells, thus increasing the encroachment probabilities for the angles represented by those cells. (See Figure A.6.)

For each angle-speed combination a maximum lateral extent of encroachment is calculated assuming the vehicle slows at a constant acceleration of -3.9 m/s^2, which is equivalent to a braking coefficient of friction of 0.4. (See Figure A.7.) Given this maximum encroachment distance, the program uses a cosine distribution rule to assign a probability to lateral encroachment distances between the edge of the traveled way and the maximum encroachment distance. The rule can be written:

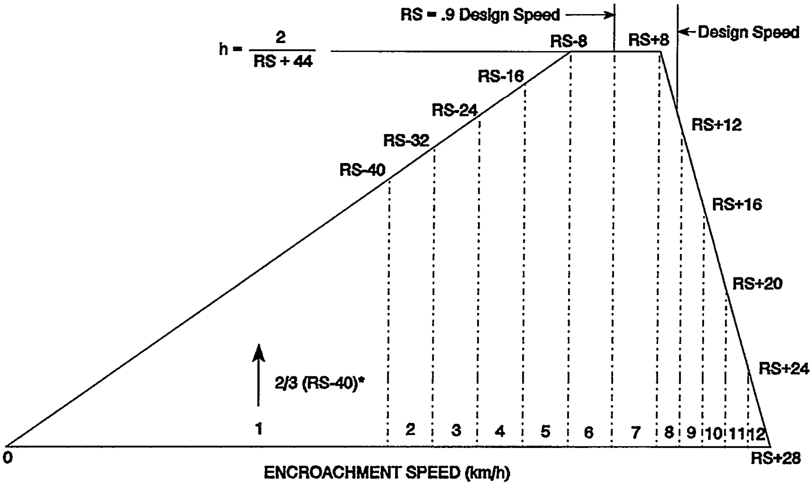
$$\begin{aligned} P(Y>Yd) &= 0.5 + 0.5\cos(\pi Yd/Ym) && \text{for } Yd<Ym \\ &= 0 && \text{for } Yd\geq Ym \end{aligned}$$

Where: Y = lateral extent of encroachment
Ym = maximum calculated lateral extent of encroachment
Yd = lateral distance from the edge of the traveled way
(πYd/Ym) is in radians. Note: π rad = 180°

To create tables of lateral extent of encroachment probabilities for a given design speed and traffic mix, the lateral extent of encroachment probability program sums, for all vehicles, the products of each vehicle's probability by all its encroachment speed-angle combination probabilities by the lateral extent of encroachment probabilities for the associated encroachment speed-angle combination at 0.25 m encroachment increments out to 45 m. The traffic mixes (% trucks) used in calculating the tables in files LATXT50.DAT through LATXT120.DAT, respectively, are shown in Table A.4. The lateral extent of encroachment probability tables used by ROADSIDE can only be changed by creating new tables to replace the supplied tables. It should be noted, however, that, because of the dominance of automobiles and light trucks (pickups and vans) on the values in the tables, the values in the tables are not very sensitive to changes in traffic mix.

TABLE A.4 Assumed Traffic Mixes for Various Design Speeds

Design Speed (km/h)	Traffic Mix (% Trucks)
50	2
60	5
70	5
80	10
90	15
100	20
110	25
120	25



* The nominal speed assigned to a cell is the middle of the speed range of the cell for all cells except cell number 1, which is assigned a speed equal to two-thirds its width.

FIGURE A.3 Speed Distribution Probability Density Curve

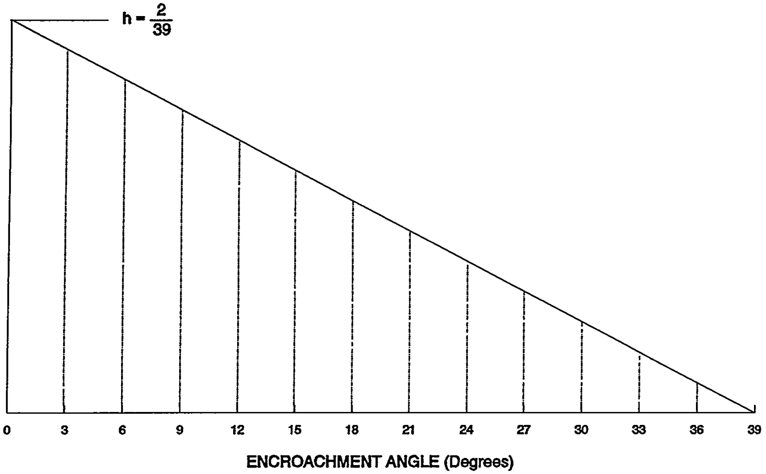
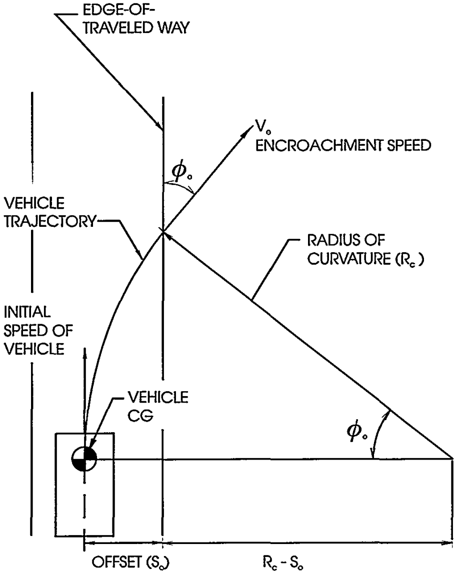


FIGURE A.4 Basic Encroachment Angle Probability Density Curve



$R_c = V_e^2 / gf_m = S_o/(1 - \cos\phi_e)$

$\phi_e = \cos^{-1}(1 - S_o g f_m / V_e^2)$
= Maximum encroachment angle

V_e = Encroachment speed = Initial speed of vehicle

S_o = Vehicle offset from edge-of-traveled way

f_m = Maximum available friction coefficient

R_c = Minimum radius of curvature

g = Acceleration of gravity = 9.80665 m/sec^2

FIGURE A.5 Encroachment Angle Model

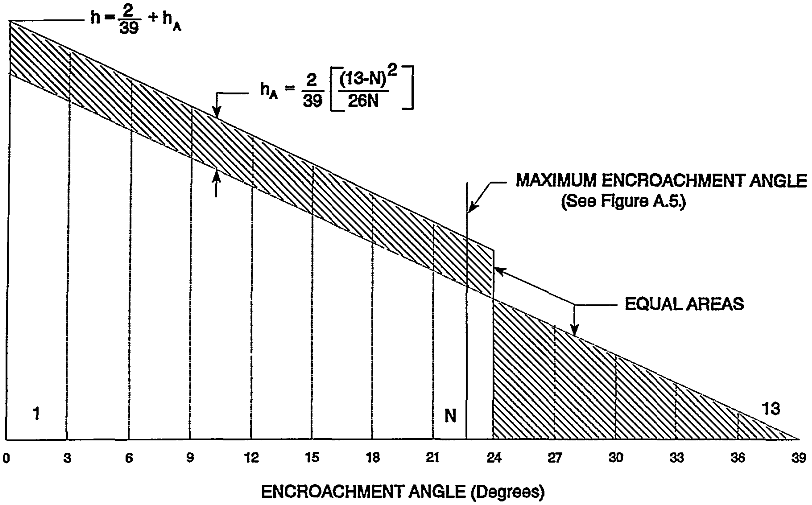
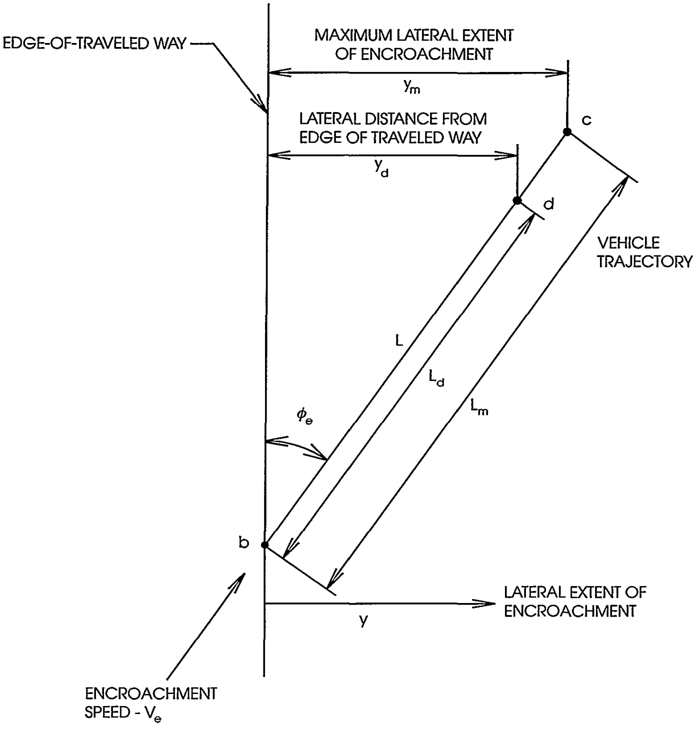


FIGURE A.6 Adjusted Encroachment Angle Probability Density Curve



MAXIMUM TRAJECTORY LENGTH $L_m = L_{bc}$

$L_m = V_e^2 / 2a$

WHERE: V_e = ENCROACHMENT SPEED

a = DECELERATION RATE

MAXIMUM LATERAL EXTENT OF ENCROACHMENT

$y_m = L_m \sin \phi_e$

FIGURE A.7 Geometry for Computing Lateral Extent of Encroachment

A3.0 GLOBAL VALUES

After the lateral extent of encroachment data files are read into memory, a screen containing “Global Parameter Values” will appear. These are the start-up global parameter values. They are always the same when the program is started. These values can be changed from this start-up screen or retrieved and changed later by using Function Key F5.

There are 16 global parameters, which divide into four categories—the accident costs associated with each of six accident severity levels, the frequency rate at which vehicles encroach on the roadside, the encroachment angles and traffic volume caps assigned to each of eight design speeds, and a “swath width” assumed to be swept by an encroaching vehicle. Each of these categories is described more fully below.

A3.1 ACCIDENT SEVERITY LEVEL COSTS (GLOBAL PARAMETERS 1 THROUGH 6)

ROADSIDE recognizes six accident severity levels and assigns dollar values to each. There are many philosophical, economic, and political issues that can be debated relative to assigning dollar values to traffic accidents. The most controversial values are those for life and pain and suffering. To arrive at the $1,000,000 shown below for a fatal accident, the following approach, which might be called the "moment-of-truth-maximum-amount approach," was used.

The first step was to determine the per capita Gross National Product, estimated to be $24,011 for 1994. The next was to determine the average age of persons killed in traffic accidents (38.4 years). The third step was to determine the average life expectancy (39.1 years) of a person that age. Next the life expectancy was multiplied by the per capita GNP, obtaining $938,830. This value was multiplied by 1.1, the estimated number of fatalities per fatal accident, obtaining $1,032,713. Finally, this value was rounded to $1,000,000. It was also assumed that the economic activity—domestic chores, do-it-yourself projects, unpaid child care, etc.—that is not included in the GNP would offset expenditures to provide minimum necessities for a spared accident victim. The other proposed values shown below for the various accident severities are a reflection of the assigned value of a life and known expenses incurred in traffic accidents. The resulting "societal costs" are believed to be reasonable values to use, both from the standpoint of public acceptance and the ability of the economy to support expenditures based on analyses using the values.

The severity levels and the default (start-up) values assigned to each are shown in Table A.5.

TABLE A.5 Estimated Costs for Various Traffic Accident Severity Levels

Fatal Accident = $1,000,000
Severe Injury Accident = 200,000
Moderate Injury Accident = 12,500
Slight Injury Accident = 3,750
Property Damage Only Accident Level 2 = 3,125
Property Damage Only Accident Level 1 = 625

For any case study these values can be revised. It is recommended, however, that a highway agency choosing to base its analyses on a different set of values do so on a consistent, established policy. (An agency making such a change may wish to obtain the source code and change the default values.)

The accident cost values are used in developing the costs assigned to accident severity index (SI) values. Severity indices are based on a zero to ten scale as defined in the Table A.6a and illustrated in the Figure A.8. Multiplying the data in Table A.6a for the proportion each accident severity level is assumed to exist at each severity index level by the appropriate costs in Table A.5 yields the severity index-cost relationships shown in Table A.6b.

TABLE A.6a Proportions of Accident Severity Levels Estimated at Various Severity (SI) Levels

Accident Severity Level	*Proportion of Accident Severity Level (%)*											
	SI Level											
	0	0.5	1	2	3	4	5	6	7	8	9	10
PDO1	0.0	100.0	66.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PDO2	0.0	0.0	23.7	71.0	43.0	30.0	15.0	7.0	2.0	0.0	0.0	0.0
Slight Injury	0.0	0.0	7.3	22.0	34.0	30.0	22.0	16.0	10.0	4.0	0.0	0.0
Moderate Injury	0.0	0.0	2.3	7.0	21.0	32.0	45.0	39.0	28.0	19.0	7.0	0.0
Severe Injury	0.0	0.0	0.0	0.0	1.0	5.0	10.0	20.0	30.0	27.0	18.0	0.0
Fatal	0.0	0.0	0.0	0.0	1.0	3.0	8.0	18.0	30.0	50.0	75.0	100.0

TABLE A.6b Resulting Severity Index-Cost Relationships

Severity Index	Cost
0.0	$ 0
0.5	$ 625
1.0	$ 1,719
2.0	$ 3,919
3.0	$ 17,244
4.0	$ 46,063
5.0	$ 106,919
6.0	$ 225,694
7.0	$ 363,938
8.0	$ 556,525
9.0	$ 786,875
10.0	$ 1,000,000

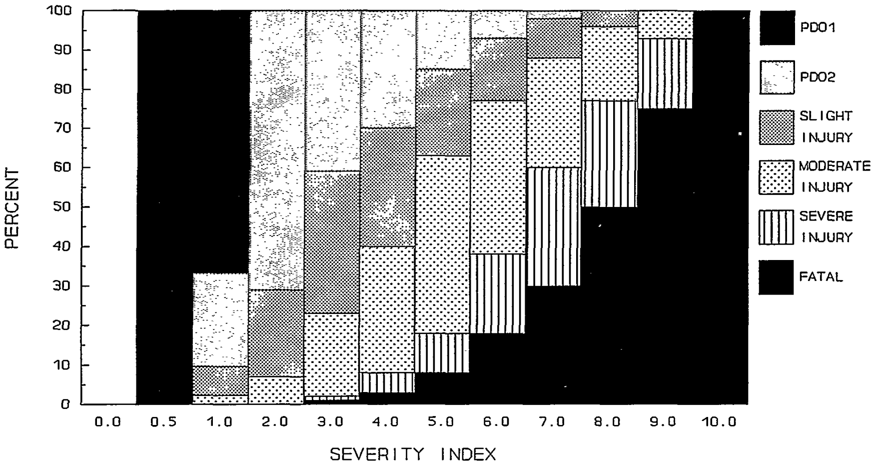


FIGURE A.8 Accident Type Distribution vs. Severity Index

A3.2 ENCROACHMENT RATE (GLOBAL PARAMETER 7)

The default encroachment rate in ROADSIDE is 0.0003000 encroachments/km/y/ vehicle per day (enc/km/y/vpd). This rate applies to encroachments to one side of a roadway from traffic going in one direction. The traffic entered into ROADSIDE is assumed to be the total average daily traffic for a highway at the beginning of an analysis period (the project life). This is two-way traffic for divided and undivided highways and one-way for one-way highways. The program divides two-way traffic by two to determine the directional traffic volumes. Then, for divided highways the opposing traffic is also considered; but, the offset to the feature under consideration is increased by half the total number of lanes times the width of a lane. (See Figure A.9.)

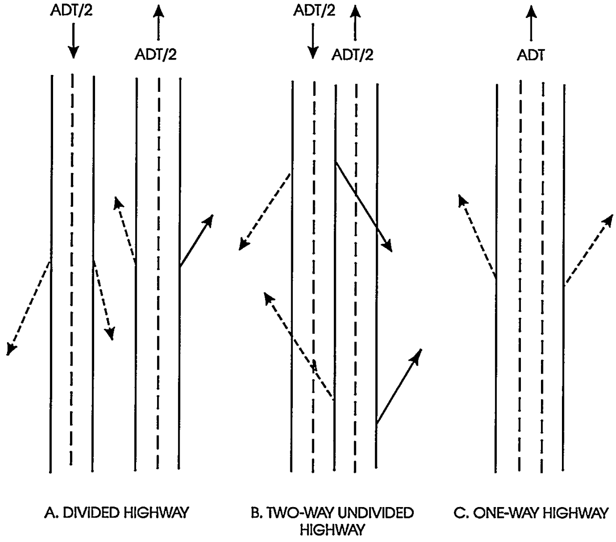


FIGURE A.9 Traffic Volume and Encroachment Distributions in ROADSIDE Program

A3.3 DESIGN SPEED, ENCROACHMENT ANGLE, AND TRAFFIC VOLUME CAP (GLOBAL PARAMETERS 8 THROUGH 15)

For each of the eight design speeds recognized by ROADSIDE, there is a unique encroachment angle and a unique traffic volume cap.

The default values for these parameters are shown in Table A.7. As with all the global parameter values, these values can be changed from the start-up global value screen or by later using the F5 function key.

A3.3.1 Encroachment Angle

While the lateral extent of encroachment probability curves are based on a model that examines many encroachment speed and angle combinations, the hazard model in ROADSIDE examines only one encroachment angle for each design speed, that in the "Global Parameter Values." The angle ϕ shown in Figure A.10 represents the encroachment angle used in the ROADSIDE analysis.

TABLE A.7 Encroachment Angle and Traffic Volume Cap Global Parameter Values

Design Speed km/h	Encroachment Angle degree	Traffic Volume Cap vpd/Lane
50	13.0	24000
60	12.8	23900
70	12.4	23700
80	12.0	23300
90	11.6	22800
100	11.1	22000
110	10.7	21000
120	10.3	20000

The default global encroachment angles were developed by running a computer program that, for a given vehicle and design speed, calculates an average encroachment angle resulting from the application of the encroachment speed and angle probability distributions and other applicable parameters used in creating the lateral extent of encroachment probability curve used with ROADSIDE for the given design speed. (See section A2.0.) The program was run to obtain an average encroachment angle for each design speed for each of the 13 design vehicles used in developing the lateral extent of encroachment curves. Then the products of each vehicle's specified proportion in the traffic mix for a given design speed times its average encroachment angle for the given design speed were summed to obtain the default global encroachment angle for the design speed.

The logic behind the recommended encroachment angles in the first edition of the *Roadside Design Guide* and earlier versions of ROADSIDE has been lost. However, the angles appear to be approximately midway between the average encroachment angle and the maximum angle achievable at the maximum encroachment speed associated with a given design speed. This approach, or whatever approach was used, yields significantly higher encroachment angles at the lower design speeds than does the approach recommended for ROADSIDE 5.0.

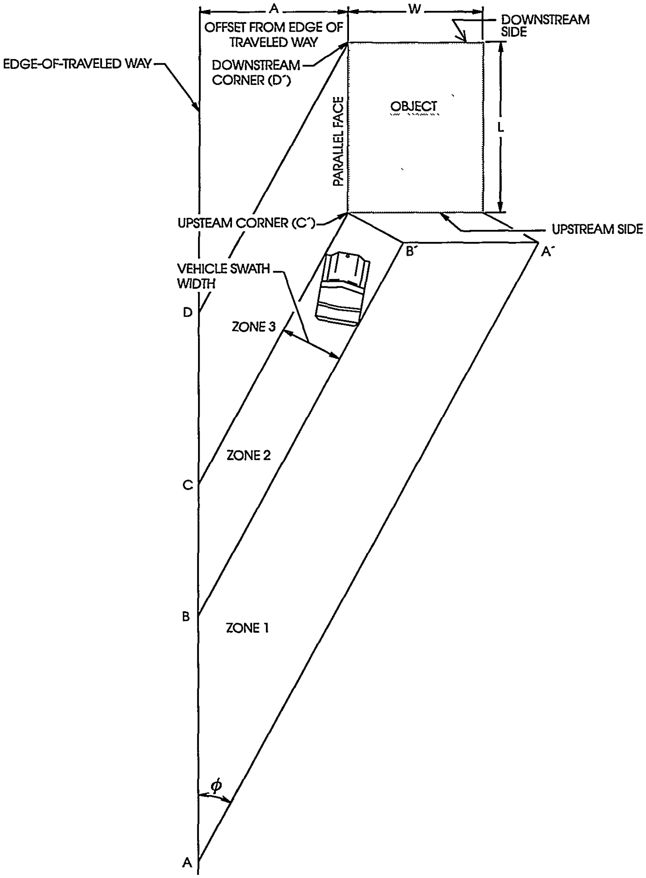


FIGURE A.10 Encroachment Model for Adjacent Traffic

The effect the encroachment angle has in the analysis approach upon which ROADSIDE is based is that an increase in the angle decreases the length of road that is assumed to contribute to impacts with the corners and the sides of an obstacle. The angles recommended in ROADSIDE 5.0 yield approximately a 20% reduction in the length of road contributing to encroachments in the zones related to obstacle corners and sides when comparing between a design speed of 120 km/h and one of 50 km/h. On the other hand, from the approach used with ROADSIDE 4.3 and earlier versions, the decrease in the lengths of the corner and side zones between a design speed of 113 km/h and 48 km/h is a little under 40%. Considering that ROADSIDE bases its calculations on average encroachment severities, the 20% reduction in encroachments headed for corners and sides from the highest to the lowest design speed seems rational since it results from a change in the predicted average encroachment angle. On the other hand, the greater reduction is not irrational, given the rather significant differences in braking and steering possible over the design speed range in ROADSIDE. For those who believe the greater variation in encroachments is appropriate, Table A.8 shows encroachment angles based on averaging the average encroachment angle calculated for a design speed and its assigned traffic mix and the maximum achievable encroachment angle at the maximum encroachment speed predicted for that design speed.

TABLE A.8 Alternative Encroachment Angle Values

Design Speed (km/h)	50	60	70	80	100	110	120
Encroachment Angle (Deg.)	21.1	18.5	17.1	15.8	14.8	13.9	13.1

A3.3.2 Traffic Volume Cap

To account for reduced speeds and other moderating effects on roadside accident losses that result from congestion, ROADSIDE places a cap on the per-lane average daily traffic volume used in economic analyses. If the initial input traffic volume exceeds the per-lane cap in ROADSIDE, ROADSIDE uses a traffic volume equal to the per-lane traffic volume cap times the number of lanes on the highway and the volume is held constant over the analysis period (project life). If the initial per-lane traffic volume is below the cap and during the project life, the per-lane traffic volume reaches the cap set; beyond the start of the year nearest the time the cap is reached, ROADSIDE holds the traffic volume constant at a value based on the per-lane cap. Of course, if the per-lane traffic volume starts below the cap and the traffic growth does not reach the per-lane cap during the project life, the cap has no effect. (Note: The way ROADSIDE 5.0 handles the traffic cap is significantly changed from the way earlier versions handled the cap. The earlier versions only adjusted the traffic volume if the initial per-lane volume exceeded the cap and then allowed the traffic volume to grow at the input traffic growth rate over the project life, thwarting the purpose of the cap.)

The default cap values are based on engineering judgement that included an examination of the hourly traffic volumes that result in significant reductions in free-flow highway speeds and the application of low, in the order of 6%, peak hour to average daily traffic ratios to arrive at the suggested cap values.

A3.4 SWATH WIDTH (GLOBAL PARAMETER 16)

Figure A.10 depicts three zones within which an encroaching vehicle has the potential to impact a hazard. Two of the zones, zones labeled 1 and 3 in the figure, are based on the length and width of the hazard, respectively. The third zone, zone 2, is based on the path assumed to be swept by an encroaching vehicle (swath width). The default swath width is 3.6 m and is intended to represent a non-tracking passenger car skidding toward the hazard.

One reason a user might want to change this value would be to set it, along with hazard width, to zero in order to examine elements of a hazard. For example, ROADSIDE can not directly analyze a flared hazard. Nevertheless, by breaking a flared hazard into a series of short parallel lengths of hazard with zero swath width and hazard width for all elements except the end element, it would be possible to make runs on all the elements and sum the results to evaluate the flared hazard.

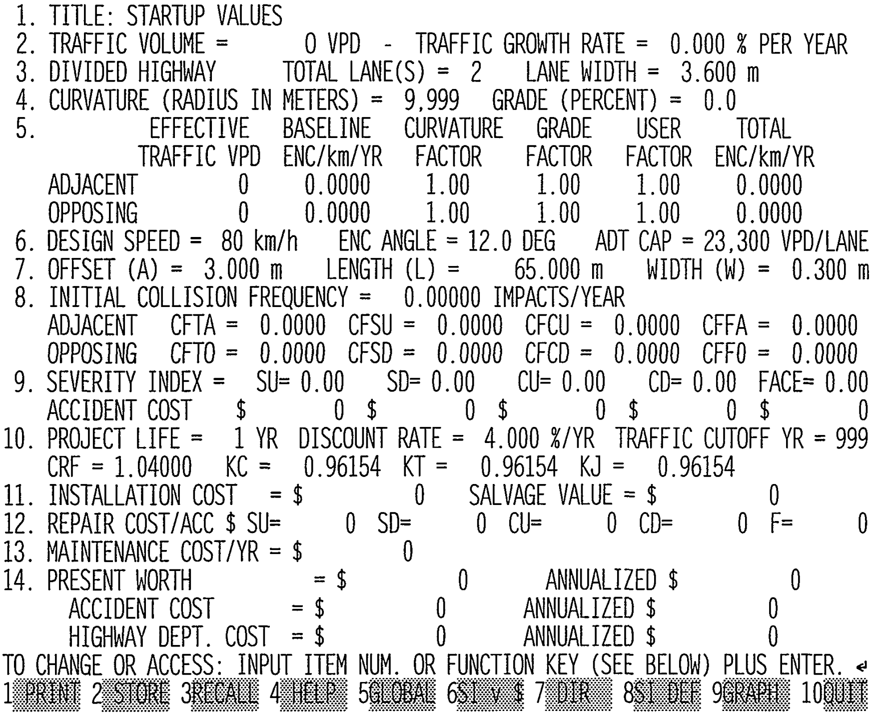
A3.5 RESETTING GLOBAL VALUES (GLOBAL PARAMETER Item 17)

The last item in the list of global parameter values is not a value but a means to, in one step, change any changed values back to the default start-up values.

A4.0 ROADSIDE DATA SELECTION AND ENTRY

After starting ROADSIDE and working through the preliminary setup screens the user reaches the basic work screen. (See Figure A.11.)

It is from this screen that a user inputs traffic, highway, and economic information for a case study of a roadside condition. The input cursor appears in the lower right corner of the screen. To input (or in some cases just review) data for any of the items numbered vertically on the screen, type the associated number, press enter, and follow the instructions on the screens that appear. Named across the bottom of the basic work screen are 10 program functions. They are activated by pressing the indicated function key, followed by pressing the enter key.



```
 1. TITLE: STARTUP VALUES
 2. TRAFFIC VOLUME =       0 VPD  -  TRAFFIC GROWTH RATE =  0.000 % PER YEAR
 3. DIVIDED HIGHWAY      TOTAL LANE(S) =  2    LANE WIDTH =  3.600 m
 4. CURVATURE (RADIUS IN METERS) =  9,999   GRADE (PERCENT) =  0.0
 5.          EFFECTIVE   BASELINE   CURVATURE   GRADE    USER     TOTAL
            TRAFFIC VPD  ENC/km/YR   FACTOR    FACTOR   FACTOR  ENC/km/YR
    ADJACENT        0     0.0000      1.00      1.00     1.00     0.0000
    OPPOSING        0     0.0000      1.00      1.00     1.00     0.0000
 6. DESIGN SPEED =  80 km/h    ENC ANGLE = 12.0 DEG    ADT CAP = 23,300 VPD/LANE
 7. OFFSET (A) =  3.000 m    LENGTH (L) =      65.000 m    WIDTH (W) =  0.300 m
 8. INITIAL COLLISION FREQUENCY =   0.00000 IMPACTS/YEAR
    ADJACENT   CFTA =  0.0000  CFSU =  0.0000  CFCU =  0.0000  CFFA =  0.0000
    OPPOSING   CFTO =  0.0000  CFSD =  0.0000  CFCD =  0.0000  CFFO =  0.0000
 9. SEVERITY INDEX =   SU= 0.00     SD= 0.00     CU= 0.00     CD= 0.00  FACE= 0.00
    ACCIDENT COST    $         0  $         0  $         0  $         0  $       0
10. PROJECT LIFE =   1 YR  DISCOUNT RATE =  4.000 %/YR  TRAFFIC CUTOFF YR = 999
    CRF = 1.04000   KC =   0.96154  KT =   0.96154  KJ =   0.96154
11. INSTALLATION COST   = $          0    SALVAGE VALUE = $           0
12. REPAIR COST/ACC $ SU=      0  SD=      0  CU=      0  CD=      0  F=      0
13. MAINTENANCE COST/YR = $         0
14. PRESENT WORTH           = $          0        ANNUALIZED $          0
      ACCIDENT COST       = $          0        ANNUALIZED $          0
      HIGHWAY DEPT. COST  = $          0        ANNUALIZED $          0
TO CHANGE OR ACCESS: INPUT ITEM NUM. OR FUNCTION KEY (SEE BELOW) PLUS ENTER. ↵
1 PRINT 2 STORE 3RECALL 4 HELP 5GLOBAL 6SI v $ 7 DIR  8SI DEF 9GRAPH 10QUIT
```

FIGURE A.11 ROADSIDE's Basic Work Screen

The basic work screen first appears with some of the items filled in with default start-up inputs. These inputs are only intended to start the program and have no other significance. They can all be changed by the user. Background and input guidance on each of the items listed in the basic work screen are given in the following subsections.

A4.1 ITEM 1: TITLE

The input screen for revising the title of a case study report describes two restrictions on the configuration of the title—the title length is limited to 69 characters and, if a title contains a comma (,) or commas, it must be enclosed entirely by quotation marks (" "). Violating the first restriction by adding 11 or fewer characters to the allowable number only knocks the word "Title:" off the screen. Exceeding the limitation further causes the first line of the title to roll off the top of the basic work screen. However, the input title information is not lost and can be viewed at the Item 1 input screen and will be included in the printed case study report. On the other hand, ignoring the restriction on the use of commas in the title will result in an error message, "Redo from start." This error message will be repeated so long as the user inputs a comma in the title without starting the title with quotation marks ("). On the other hand, a beginning quotation mark will not appear in the title and will prevent the use of a quotation mark at any other location in the title.

A4.2 ITEM 2: TRAFFIC VOLUME AND TRAFFIC GROWTH RATE

ROADSIDE assumes the input traffic is the total highway traffic. For two-way divided and undivided highways, it divides the input value by 2 to obtain the directional traffic volume. The traffic volume to be entered at the basic work screen is the estimated total traffic volume at the beginning of the analysis period. ROADSIDE assumes that traffic increases at a constant compounding rate. Thus, if, as is often true, a traffic volume has been estimated for some date in the future but the traffic at the start of the analysis period is not available, the value can be calculated by the following formula:

$$ADT_i = \frac{ADT_{dy}}{(1 + TGR)^T}$$

Where: ADT_i = initial traffic volume (volume at start of analysis period)

ADT_{dy} = traffic volume estimate for some future date (often for design year volume)

TGR = annual traffic growth rate

T = years between the start of the analysis period and the date for which a traffic volume has been estimated

While the traffic growth rate in the preceding formula is a ratio, the traffic growth rate entered in ROADSIDE is a percent per year. The program converts the percentage to a ratio.

A4.3 ITEM 3: HIGHWAY TYPE, NUMBER OF LANES, AND LANE WIDTH

ROADSIDE recognizes three highway types, divided, undivided, and one-way. For some applications, the user may wish to input a highway type different from that of the actual highway being studied. In doing so, care should be taken to ensure that appropriate adjustments in traffic volume are made and that the directionality of ROADSIDE is handled to properly account for curves and grades. For example, if a feature in the median of a divided highway is to be analyzed by treating the highway as two one-way highways, the total traffic and number of lanes for the divided highway will need to be divided by 2 to obtain the appropriate traffic volume and number of lanes to enter in the one-way analyses and, since ROADSIDE assumes encroachments are to the right side of the road, the curvature for encroachments into the median (to the left) will have to be entered under Item 4 opposite of what they are in the direction of the roadway being analyzed. The highway grade entered under Item 4 will be that of the roadway being analyzed, meaning a plus grade in one direction will be a minus in the opposite. Finally, care will be needed to ensure that various costs such as installation and maintenance are not double-counted.

The total lanes are just that, all lanes on the highways. A divided highway with four lanes in each direction has eight lanes. The number of lanes comes into play in determining if the per-lane traffic volume cap has been met and, along with lane width, in calculating the hazard offset distance for opposing traffic on undivided two-way highways.

A4.4 ITEM 4: CURVATURE AND GRADE

ROADSIDE checks the input highway grade and curvature and, for some conditions, adjusts the number of roadside encroachments on the basis of the adjustment factors shown in Figure A.12.

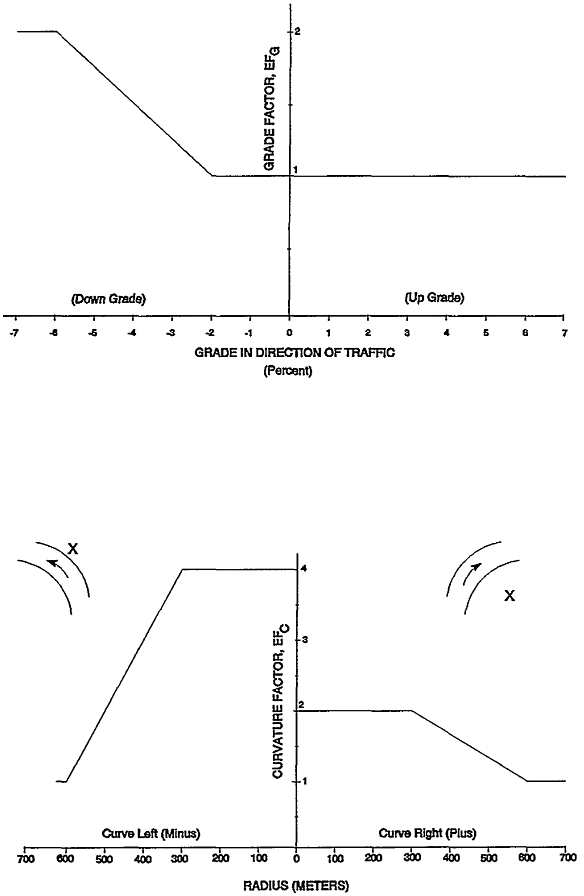


FIGURE A.12 Curvature and Grade Encroachment Adjustment Factors

A4.5 ITEM 5: USER SUPPLIED ENCROACHMENT MULTIPLICATION FACTORS

At Item 5, information is displayed that shows the effects the inputs at Items 2 through 5 have on the initial encroachment frequency for the roadside in the current case study. The only input items at Item 5 are the two "User Supplied Encroachment Multiplication Factors," one for each direction of traffic. These user supplied factors allow the user to further customize the analysis for a specific site. For example, while there is currently no guidance for how to do so, it is believed that the encroachment rate for a curve probably varies over the length of a curve, being highest at the beginning of the curve and diminishing to a constant rate at some point in the curve for one direction of traffic. Of course, for traffic going in the opposite direction, a different encroachment rate profile would exist. The user supplied factors can be used to account for such variations.

A4.6 ITEM 6: DESIGN SPEED

At Item 6, the user enters the case study highway design speed. Usually the design speed selected will be the nominal design speed for the highway. However, the user should consider whether site conditions suggest that another design speed should be used. The discussion in Section A2.0 on how speed is considered in determining the lateral extent of encroachment should be useful in determining the appropriateness of the nominal highway design speed for use in a case study analysis.

The other values reported, encroachment angle and the traffic volume cap, are global values associated with the selected design speed. (See Section A3.3.)

A4.7 ITEM 7: FEATURE LOCATION AND SIZE

There are three geometric attributes ROADSIDE recognizes for a roadside feature: its offset from the traveled way (A), its length parallel to the roadway (L), and its width perpendicular to the roadway (W). The input values for any or all of these values can be set to zero. This potential, along with being able to set the global value, swath width, to zero, allows the user to break a problem into elements. The example of a non-parallel feature has already been discussed in Section A3.4. Another possible condition requiring breaking the analysis of a feature into parts would be a culvert projecting from a fill, where the sides of the feature can be considered as being roadward of the feature's corners and face, meaning a different offset distance should be used with the sides than with the corners and face.

A4.7.1 Offset Distance Adjustments

With regard to lateral placement of a feature, ROADSIDE makes no adjustments for curvature or side slope. Since both of these highway characteristics will have an effect on the lateral extent of encroachment of an errant vehicle, some means of compensating for ROADSIDE's inability to adjust the lateral extent of encroachment for curvature or side slope is needed. Suggested means for making such adjustments are outlined below. They involve making adjustments to the offset distance to a feature before entering it in ROADSIDE.

A4.7.1.1 Adjusting Offset Distance for Side Slope

Roadside slopes affect encroaching vehicles in two basic ways. First, they influence the extent of encroachment and, second, they influence the severity of encroachments, usually as the result of their effect on rollover. It is the first influence that will be discussed here. The second comes into play in selecting a severity index value for a side slope, which is covered in Section A4.9. Under a given set of conditions, an errant vehicle is likely to encroach a given distance on a level roadside. Under the same conditions, except that the roadside has a positive upward slope, the distance is likely to be reduced because of the beneficial effect of the slope on braking and steering. Conversely, a negative slope would increase the encroachment distance. Since the lateral extent of encroachment probability tables in ROADSIDE are based on a level roadside, the distances to features on sloped roadsides need to be adjusted before being entered in ROADSIDE. It is recommended, in the absence of a better approach, that lateral distances be adjusted by multiplying the distance by a slope equivalency factor, E_S, where:

$$E_s = \frac{(f + s)}{f} = 1 + \frac{s}{f}$$

Where: f = braking and cornering coefficient of friction
s = slope of the roadside

It is further recommended that the value of f be assumed to be 0.4, the same as that used in creating the lateral extent of encroachment probability tables in ROADSIDE. Under this assumption a negative slope of 1 to 2.5 ($s = -0.4$) would have an $E_S = 0$ and a positive slope of 1 to 2.5 ($s = 0.4$) would have an $E_S = 2$. (Negative slopes greater than 1 to 2.5 should be assumed to have E_S values equal to zero.) Before applying an E_S adjustment a check is needed to see what portion of a slope is effective for braking and steering an encroaching vehicle. If an encroaching vehicle leaves the ground it will not be possible to brake or steer the vehicle over the distance it remains airborne. Any irregularity in the surface of the roadside holds the potential to cause an encroaching vehicle to become airborne. The only irregularity that will be addressed relative to adjusting the lateral offset to a feature in the roadside will be crest breaks in cross slope. Normally, some rounding will be provided between differing cross slopes. If the rounding is narrow or nonexistent at crest breaks in side slope, vehicles crossing such breaks will become airborne. The solution for preventing this occurrence is to provide a width of rounding great enough to ensure that the surface of roadside will always be higher than the projectile trajectory of a vehicle staring from any point along its path as it encroaches on the roadside.

To develop a recommendation for the width of rounding necessary to keep encroaching vehicles from becoming airborne and to ensure the effectiveness of the roadside for braking and steering, the following procedure was followed.

First, the average encroachment angle for the automobiles used in determining the lateral extent of encroachment probabilities tables was calculated for the various design speeds addressed in this appendix. Then the maximum encroachment angle estimated to be achieved by an automobile traveling at the maximum encroachment speed assumed for each design speed ($V_{max} = 0.9DS + (28\text{-}2)$ km/h) was calculated. In doing this, the encroaching vehicles were assumed to be point masses starting 5.5 m from the edge of the traveled way and turning at the minimum radius achievable without skidding at a coefficient of friction of 0.8.

The average encroachment angle and the maximum encroachment angle at maximum speed were then averaged to obtain an encroachment angle for each design speed to be used with the maximum speed assumed to be associated with that design speed. Using these speed and angle combinations, the distance between a point where an encroaching vehicle was assumed to start on a projectile trajectory on one slope and where that trajectory became tangent to the plane of an adjacent slope was calculated for various slope break combinations. These trajectory distances were then multiplied by 1.75 to account for the fact that the free projectile trajectory of a vehicle would not conform exactly to the circular rounding expected to be provided and to ensure an encroaching vehicle would exert a substantial force on the ground. These minimum widths of rounding were then arrayed by design speed and algebraic difference in slope. Upon this array the radii of circular rounding that would match the estimated needed rounding width was superimposed. By inspection it appeared reasonable to assign a single minimum radius rounding to each design speed.

The formula used for estimating the minimum width of rounding is:

$$W_{R_{min}} = 1.75V^2_{max}\frac{(s_1 - s_2)}{a_g}(\text{Sin}^2\phi_{\text{max avg}}) \quad \text{(meters)}$$

Where: s_1 and s_2 = slopes of intersecting side slopes
$V_{max} = 0.27778[0.9DS + (28\text{-}2)]$ (m/s)
(Note: 1000 m/km / 3600 s/h = 0.27778 m•h/km•s)
DS = design speed (km/h)
$\phi_{\text{max avg}} = (\phi_{avg} + \phi_{Vmax})/2$ (deg)
ϕ_{avg} = average automobile encroachment angle from the encroachment angle model
ϕ_{Vmax} = maximum encroachment angle at assumed maximum encroachment speed
$= \text{Cos}^{-1}[1 - (S_o a_g f/V^2_{max})]$ (deg)
S_o = offset from edge-of-traveled way (m)
a_g = acceleration of gravity = -9.80665 m/s^2
f = cornering coefficient of friction = 0.8

Table A.9 lists the recommended minimum rounding radii and summarizes the key input values in the process to arrive at the recommended radii.

TABLE A.9 Recommended Minimum Rounding Radii for Various Design Speeds and Related Development Information

Design Speed	Estimated Maximum Encroachment Speed	Estimated Maximum Encroachment Speed	Estimated Average Automobile Encroachment Angle	Estimated Max. Enc. Angle @ Maximum Encroachment Speed	Avg. of Avg. Angle Plus Max. Enc. Angle @ Max. Enc. Speed	Recommended Min. Rounding Radius
km/h	km/h	m/s	deg	deg	deg	m
50	71	19.72	19.95	27.24	20.10	9.0
60	80	22.22	12.81	24.13	18.47	9.5
70	89	24.72	12.46	21.66	17.06	10.0
80	98	27.22	12.15	19.65	15.90	10.5
90	107	29.72	11.82	17.98	14.90	11.0
100	116	32.22	11.40	16.58	13.99	11.5
110	125	34.72	11.04	15.38	13.21	12.0
120	134	37.22	10.68	14.34	12.51	12.5

Table A.10 shows, for various design speeds, the horizontal widths of rounding that would result from applying the recommended rounding radius for the given design speed to various breaks in side slopes.

To estimate the lateral extent of the effect a break in side slope, the lateral distance a vehicle, assumed to be a point mass, would travel on a projectile trajectory from the intercept of two slopes, starting in the plane of the first slope to touch down in the second, was calculated. The calculation was based on the vehicle traveling at the maximum speed assumed on a highway of a given design speed and traversing the roadside at the maximum encroachment angle assumed to be achievable by an automobile encroaching at the given maximum speed. This was done for each of various slope break combinations and for each of the various design speeds. It turned out that, because of the increase in encroachment angle that went with a reduction in encroachment speed, there was very little difference between the lateral trajectory distance for the various design speeds for a given combination of slope breaks. Table A.11 shows these "slope-break-effects widths" calculated for 120 km/h. The maximum distance shown in the table is 13.87 m for $s_1 = 0.4$ and $s_2 = - 0.4$ (an up slope of 1:2.5 breaking over without rounding to a down slope of 1:2.5). The comparable distance for a design speed of 50 km/h is 13.30 m, 4 percent less than for a design speed of 120 km/h. Thus, the one table is presented for all design speeds.

The procedure for determining the effective lateral offset to a roadside feature is as follows:

Step 1. Determine the lateral offset distances to all the critical points in a cross-section passing through the approach end of the feature under study or a surrogate cross-section established to account for changes in cross-section within a likely runout distance upstream of the feature. These will include all the physical points at which changes in slope and rounding occur plus the theoretical points at which slope-break effects end. These latter points apply only to crest breaks in side slope. The outer limit of a slope-break effect is determined by adding the appropriate distance from Table A.10 to the lateral offset to the beginning of the rounding or the distance to the slope break under consideration, if there is no rounding.

TABLE A.10 Rounding Widths

Rounding Width - meters

Design Speed = 50 km/h

S_2

S_1	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00	−0.05	−0.10	−0.15	−0.20	−0.25	−0.30	−0.35	−0.40
0.40	0.00	0.37	0.76	1.16	1.58	2.01	2.45	2.89	3.34	3.79	4.24	4.68	5.11	5.53	5.93	6.32	6.69
0.35	−0.37	0.00	0.39	0.79	1.21	1.64	2.08	2.52	2.97	3.42	3.87	4.31	4.74	5.16	5.56	5.95	6.32
0.30	−0.76	−0.39	0.00	0.40	0.82	1.25	1.69	2.14	2.59	3.04	3.48	3.92	4.35	4.77	5.17	5.56	5.93
0.25	−1.16	−0.79	−0.40	0.00	0.42	0.85	1.29	1.73	2.18	2.63	3.08	3.52	3.95	4.37	4.77	5.16	5.53
0.20	−1.58	−1.21	−0.82	−0.42	0.00	0.43	0.87	1.32	1.77	2.21	2.66	3.10	3.53	3.95	4.35	4.74	5.11
0.15	−2.01	−1.64	−1.25	−0.85	−0.43	0.00	0.44	0.89	1.34	1.78	2.23	2.67	3.10	3.52	3.92	4.31	4.68
0.10	−2.45	−2.08	−1.69	−1.29	−0.87	−0.44	0.00	0.45	0.90	1.34	1.79	2.23	2.66	3.08	3.48	3.87	4.24
0.05	−2.89	−2.52	−2.14	−1.73	−1.32	−0.89	−0.45	0.00	0.45	0.90	1.34	1.78	2.21	2.63	3.04	3.42	3.79
0.00	−3.34	−2.97	−2.59	−2.18	−1.77	−1.34	−0.90	−0.45	0.00	0.45	0.90	1.34	1.77	2.18	2.59	2.97	3.34
−0.05	−3.79	−3.42	−3.04	−2.63	−2.21	−1.78	−1.34	−0.90	−0.45	0.00	0.45	0.89	1.32	1.73	2.14	2.52	2.89
−0.10	−4.24	−3.87	−3.48	−3.08	−2.66	−2.23	−1.79	−1.34	−0.90	−0.45	0.00	0.44	0.87	1.29	1.69	2.08	2.45
−0.15	−4.68	−4.31	−3.92	−3.52	−3.10	−2.67	−2.23	−1.78	−1.34	−0.89	−0.44	0.00	0.43	0.85	1.25	1.64	2.01
−0.20	−5.11	−4.74	−4.35	−3.95	−3.53	−3.10	−2.66	−2.21	−1.77	−1.32	−0.87	−0.43	0.00	0.42	0.82	1.21	1.58
−0.25	−5.53	−5.16	−4.77	−4.37	−3.95	−3.52	−3.08	−2.63	−2.18	−1.73	−1.29	−0.85	−0.42	0.00	0.40	0.79	1.16
−0.30	−5.93	−5.56	−5.17	−4.77	−4.35	−3.92	−3.48	−3.04	−2.59	−2.14	−1.69	−1.25	−0.82	−0.40	0.00	0.39	0.76
−0.35	−6.32	−5.95	−5.56	−5.16	−4.74	−4.31	−3.87	−3.42	−2.97	−2.52	−2.08	−1.64	−1.21	−0.79	−0.39	0.00	0.37
−0.40	−6.69	−6.32	−5.93	−5.53	−5.11	−4.68	−4.24	−3.79	−3.34	−2.89	−2.45	−2.01	−1.58	−1.16	−0.76	−0.37	0.00

Rounding Width - meters

Design Speed = 60 km/h

S_2

S_1	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00	−0.05	−0.10	−0.15	−0.20	−0.25	−0.30	−0.35	−0.40
0.40	0.00	0.39	0.80	1.22	1.67	2.12	2.58	3.05	3.53	4.00	4.47	4.94	5.39	5.83	6.26	6.67	7.06
0.35	−0.39	0.00	0.41	0.83	1.28	1.73	2.19	2.66	3.14	3.61	4.08	4.55	5.00	5.44	5.87	6.28	6.67
0.30	−0.80	−0.41	0.00	0.43	0.87	1.32	1.78	2.26	2.73	3.20	3.68	4.14	4.59	5.03	5.46	5.87	6.26
0.25	−1.22	−0.83	−0.43	0.00	0.44	0.89	1.36	1.83	2.30	2.78	3.25	3.71	4.17	4.61	5.03	5.44	5.83
0.20	−1.67	−1.28	−0.87	−0.44	0.00	0.45	0.92	1.39	1.86	2.34	2.81	3.27	3.73	4.17	4.59	5.00	5.39
0.15	−2.12	−1.73	−1.32	−0.89	−0.45	0.00	0.46	0.93	1.41	1.88	2.35	2.82	3.27	3.71	4.14	4.55	4.94
0.10	−2.58	−2.19	−1.78	−1.36	−0.92	−0.46	0.00	0.47	0.95	1.42	1.89	2.35	2.81	3.25	3.68	4.08	4.47
0.05	−3.05	−2.66	−2.26	−1.83	−1.39	−0.93	−0.47	0.00	0.47	0.95	1.42	1.88	2.34	2.78	3.20	3.61	4.00
0.00	−3.53	−3.14	−2.73	−2.30	−1.86	−1.41	−0.95	−0.47	0.00	0.47	0.95	1.41	1.86	2.30	2.73	3.14	3.53
−0.05	−4.00	−3.61	−3.20	−2.78	−2.34	−1.88	−1.42	−0.95	−0.47	0.00	0.47	0.93	1.39	1.83	2.26	2.66	3.05
−0.10	−4.47	−4.08	−3.68	−3.25	−2.81	−2.35	−1.89	−1.42	−0.95	−0.47	0.00	0.46	0.92	1.36	1.78	2.19	2.58
−0.15	−4.94	−4.55	−4.14	−3.71	−3.27	−2.82	−2.35	−1.88	−1.41	−0.93	−0.46	0.00	0.45	0.89	1.32	1.73	2.12
−0.20	−5.39	−5.00	−4.59	−4.17	−3.73	−3.27	−2.81	−2.34	−1.86	−1.39	−0.92	−0.45	0.00	0.44	0.87	1.28	1.67
−0.25	−5.83	−5.44	−5.03	−4.61	−4.17	−3.71	−3.25	−2.78	−2.30	−1.83	−1.36	−0.89	−0.44	0.00	0.43	0.83	1.22
−0.30	−6.26	−5.87	−5.46	−5.03	−4.59	−4.14	−3.68	−3.20	−2.73	−2.26	−1.78	−1.32	−0.87	−0.43	0.00	0.41	0.80
−0.35	−6.67	−6.28	−5.87	−5.44	−5.00	−4.55	−4.08	−3.61	−3.14	−2.66	−2.19	−1.73	−1.28	−0.83	−0.41	0.00	0.39
−0.40	−7.06	−6.67	−6.26	−5.83	−5.39	−4.94	−4.47	−4.00	−3.53	−3.05	−2.58	−2.12	−1.67	−1.22	−0.80	−0.39	0.00

TABLE A.10 Rounding Widths (Continued)

Rounding Width - meters

Design Speed = 70 km/h

S_2

		0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00	−0.05	−0.10	−0.15	−0.20	−0.25	−0.30	−0.35	−0.40
	0.40	0.00	0.41	0.84	1.29	1.75	2.23	2.72	3.21	3.71	4.21	4.71	5.20	5.68	6.14	6.59	7.02	7.43
	0.35	−0.41	0.00	0.43	0.88	1.34	1.82	2.31	2.80	3.30	3.80	4.30	4.79	5.26	5.73	6.18	6.61	7.02
	0.30	−0.84	−0.43	0.00	0.45	0.91	1.39	1.88	2.37	2.87	3.37	3.87	4.36	4.83	5.30	5.75	6.18	6.59
	0.25	−1.29	−0.88	−0.45	0.00	0.46	0.94	1.43	1.93	2.43	2.92	3.42	3.91	4.39	4.85	5.30	5.73	6.14
	0.20	−1.75	−1.34	−0.91	−0.46	0.00	0.48	0.97	1.46	1.96	2.46	2.96	3.44	3.92	4.39	4.83	5.26	5.68
	0.15	−2.23	−1.82	−1.39	−0.94	−0.48	0.00	0.49	0.98	1.48	1.98	2.48	2.97	3.44	3.91	4.36	4.79	5.20
	0.10	−2.72	−2.31	−1.88	−1.43	−0.97	−0.49	0.00	0.50	1.00	1.49	1.99	2.48	2.96	3.42	3.87	4.30	4.71
	0.05	−3.21	−2.80	−2.37	−1.93	−1.46	−0.98	−0.50	0.00	0.50	1.00	1.49	1.98	2.46	2.92	3.37	3.80	4.21
S_1	0.00	−3.71	−3.30	−2.87	−2.43	−1.96	−1.48	−1.00	−0.50	0.00	0.50	1.00	1.48	1.96	2.43	2.87	3.30	3.71
	−0.05	−4.21	−3.80	−3.37	−2.92	−2.46	−1.98	−1.49	−1.00	−0.50	0.00	0.50	0.98	1.46	1.93	2.37	2.80	3.21
	−0.10	−4.71	−4.30	−3.87	−3.42	−2.96	−2.48	−1.99	−1.49	−1.00	−0.50	0.00	0.49	0.97	1.43	1.88	2.31	2.72
	−0.15	−5.20	−4.79	−4.36	−3.91	−3.44	−2.97	−2.48	−1.98	−1.48	−0.98	−0.49	0.00	0.48	0.94	1.39	1.82	2.23
	−0.20	−5.68	−5.26	−4.83	−4.39	−3.92	−3.44	−2.96	−2.46	−1.96	−1.46	−0.97	−0.48	0.00	0.46	0.91	1.34	1.75
	−0.25	−6.14	−5.73	−5.30	−4.85	−4.39	−3.91	−3.42	−2.92	−2.43	−1.93	−1.43	−0.94	−0.46	0.00	0.45	0.88	1.29
	−0.30	−6.59	−6.18	−5.75	−5.30	−4.83	−4.36	−3.87	−3.37	−2.87	−2.37	−1.88	−1.39	−0.91	−0.45	0.00	0.43	0.84
	−0.35	−7.02	−6.61	−6.18	−5.73	−5.26	−4.79	−4.30	−3.80	−3.30	−2.80	−2.31	−1.82	−1.34	−0.88	−0.43	0.00	0.41
	−0.40	−7.43	−7.02	−6.59	−6.14	−5.68	−5.20	−4.71	−4.21	−3.71	−3.21	−2.72	−2.23	−1.75	−1.29	−0.84	−0.41	0.00

Rounding Width - meters

Design Speed = 80 km/h

S_2

		0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00	−0.05	−0.10	−0.15	−0.20	−0.25	−0.30	−0.35	−0.40
	0.40	0.00	0.43	0.88	1.35	1.84	2.34	2.85	3.38	3.90	4.42	4.94	5.46	5.96	6.45	6.92	7.37	7.80
	0.35	−0.43	0.00	0.45	0.92	1.41	1.91	2.42	2.94	3.47	3.99	4.51	5.03	5.53	6.02	6.49	6.94	7.37
	0.30	−0.88	−0.45	0.00	0.47	0.96	1.46	1.97	2.49	3.02	3.54	4.06	4.57	5.08	5.56	6.03	6.49	6.92
	0.25	−1.35	−0.92	−0.47	0.00	0.49	0.99	1.50	2.02	2.55	3.07	3.59	4.10	4.61	5.09	5.56	6.02	6.45
	0.20	−1.84	−1.41	−0.96	−0.49	0.00	0.50	1.01	1.53	2.06	2.58	3.10	3.62	4.12	4.61	5.08	5.53	5.96
	0.15	−2.34	−1.91	−1.46	−0.99	−0.50	0.00	0.51	1.03	1.56	2.08	2.60	3.12	3.62	4.10	4.57	5.03	5.46
	0.10	−2.85	−2.42	−1.97	−1.50	−1.01	−0.51	0.00	0.52	1.04	1.57	2.09	2.60	3.10	3.59	4.06	4.51	4.94
	0.05	−3.38	−2.94	−2.49	−2.02	−1.53	−1.03	−0.52	0.00	0.52	1.05	1.57	2.08	2.58	3.07	3.54	3.99	4.42
S_1	0.00	−3.90	−3.47	−3.02	−2.55	−2.06	−1.56	−1.04	−0.52	0.00	0.52	1.04	1.56	2.06	2.55	3.02	3.47	3.90
	−0.05	−4.42	−3.99	−3.54	−3.07	−2.58	−2.08	−1.57	−1.05	−0.52	0.00	0.52	1.03	1.53	2.02	2.49	2.94	3.38
	−0.10	−4.94	−4.51	−4.06	−3.59	−3.10	−2.60	−2.09	−1.57	−1.04	−0.52	0.00	0.51	1.01	1.50	1.97	2.42	2.85
	−0.15	−5.46	−5.03	−4.57	−4.10	−3.62	−3.12	−2.60	−2.08	−1.56	−1.03	−0.51	0.00	0.50	0.99	1.46	1.91	2.34
	−0.20	−5.96	−5.53	−5.08	−4.61	−4.12	−3.62	−3.10	−2.58	−2.06	−1.53	−1.01	−0.50	0.00	0.49	0.96	1.41	1.84
	−0.25	−6.45	−6.02	−5.56	−5.09	−4.61	−4.10	−3.59	−3.07	−2.55	−2.02	−1.50	−0.99	−0.49	0.00	0.47	0.92	1.35
	−0.30	−6.92	−6.49	−6.03	−5.56	−5.08	−4.57	−4.06	−3.54	−3.02	−2.49	−1.97	−1.46	−0.96	−0.47	0.00	0.45	0.88
	−0.35	−7.37	−6.94	−6.49	−6.02	−5.53	−5.03	−4.51	−3.99	−3.47	−2.94	−2.42	−1.91	−1.41	−0.92	−0.45	0.00	0.43
	−0.40	−7.80	−7.37	−6.92	−6.45	−5.96	−5.46	−4.94	−4.42	−3.90	−3.38	−2.85	−2.34	−1.84	−1.35	−0.88	−0.43	0.00

TABLE A.10 Rounding Widths (Continued)

Rounding Width - meters

Design Speed = 90 km/h

										S_2								
		0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15	-0.20	-0.25	-0.30	-0.35	-0.40
	0.40	0.00	0.45	0.92	1.42	1.93	2.45	2.99	3.54	4.09	4.63	5.18	5.72	6.24	6.75	7.25	7.72	8.17
	0.35	-0.45	0.00	0.47	0.97	1.48	2.00	2.54	3.08	3.63	4.18	4.73	5.27	5.79	6.30	6.79	7.27	7.72
	0.30	-0.92	-0.47	0.00	0.49	1.00	1.53	2.07	2.61	3.16	3.71	4.26	4.79	5.32	5.83	6.32	6.79	7.25
	0.25	-1.42	-0.97	-0.49	0.00	0.51	1.04	1.57	2.12	2.67	3.22	3.76	4.30	4.83	5.34	5.83	6.30	6.75
	0.20	-1.93	-1.48	-1.00	-0.51	0.00	0.53	1.06	1.61	2.16	2.71	3.25	3.79	4.31	4.83	5.32	5.79	6.24
	0.15	-2.45	-2.00	-1.53	-1.04	-0.53	0.00	0.54	1.08	1.63	2.18	2.73	3.26	3.79	4.30	4.79	5.27	5.72
	0.10	-2.99	-2.54	-2.07	-1.57	-1.06	-0.54	0.00	0.55	1.09	1.64	2.19	2.73	3.25	3.76	4.26	4.73	5.18
	0.05	-3.54	-3.08	-2.61	-2.12	-1.61	-1.08	-0.55	0.00	0.55	1.10	1.64	2.18	2.71	3.22	3.71	4.18	4.63
S_1	0.00	-4.09	-3.63	-3.16	-2.67	-2.16	-1.63	-1.09	-0.55	0.00	0.55	1.09	1.63	2.16	2.67	3.16	3.63	4.09
	-0.05	-4.63	-4.18	-3.71	-3.22	-2.71	-2.18	-1.64	-1.10	-0.55	0.00	0.55	1.08	1.61	2.12	2.61	3.08	3.54
	-0.10	-5.18	-4.73	-4.26	-3.76	-3.25	-2.73	-2.19	-1.64	-1.09	-0.55	0.00	0.54	1.06	1.57	2.07	2.54	2.99
	-0.15	-5.72	-5.27	-4.79	-4.30	-3.79	-3.26	-2.73	-2.18	-1.63	-1.08	-0.54	0.00	0.53	1.04	1.53	2.00	2.45
	-0.20	-6.24	-5.79	-5.32	-4.83	-4.31	-3.79	-3.25	-2.71	-2.16	-1.61	-1.06	-0.53	0.00	0.51	1.00	1.48	1.93
	-0.25	-6.75	-6.30	-5.83	-5.34	-4.83	-4.30	-3.76	-3.22	-2.67	-2.12	-1.57	-1.04	-0.51	0.00	0.49	0.97	1.42
	-0.30	-7.25	-6.79	-6.32	-5.83	-5.32	-4.79	-4.26	-3.71	-3.16	-2.61	-2.07	-1.53	-1.00	-0.49	0.00	0.47	0.92
	-0.35	-7.72	-7.27	-6.79	-6.30	-5.79	-5.27	-4.73	-4.18	-3.63	-3.08	-2.54	-2.00	-1.48	-0.97	-0.47	0.00	0.45
	-0.40	-8.17	-7.72	-7.25	-6.75	-6.24	-5.72	-5.18	-4.63	-4.09	-3.54	-2.99	-2.45	-1.93	-1.42	-0.92	-0.45	0.00

Rounding Width - meters

Design Speed = 100 km/h

										S_2								
		0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15	-0.20	-0.25	-0.30	-0.35	-0.40
	0.40	0.00	0.47	0.97	1.48	2.02	2.57	3.13	3.70	4.27	4.85	5.42	5.98	6.53	7.06	7.58	8.07	8.54
	0.35	-0.47	0.00	0.49	1.01	1.54	2.09	2.65	3.22	3.80	4.37	4.94	5.50	6.05	6.59	7.10	7.60	8.07
	0.30	-0.97	-0.49	0.00	0.52	1.05	1.60	2.16	2.73	3.30	3.88	4.45	5.01	5.56	6.09	6.61	7.10	7.58
	0.25	-1.48	-1.01	-0.52	0.00	0.53	1.08	1.64	2.21	2.79	3.36	3.93	4.50	5.04	5.58	6.09	6.59	7.06
	0.20	-2.02	-1.54	-1.05	-0.53	0.00	0.55	1.11	1.68	2.26	2.83	3.40	3.96	4.51	5.04	5.56	6.05	6.53
	0.15	-2.57	-2.09	-1.60	-1.08	-0.55	0.00	0.56	1.13	1.71	2.28	2.85	3.41	3.96	4.50	5.01	5.50	5.98
	0.10	-3.13	-2.65	-2.16	-1.64	-1.11	-0.56	0.00	0.57	1.14	1.72	2.29	2.85	3.40	3.93	4.45	4.94	5.42
	0.05	-3.70	-3.22	-2.73	-2.21	-1.68	-1.13	-0.57	0.00	0.57	1.15	1.72	2.28	2.83	3.36	3.88	4.37	4.85
S_1	0.00	-4.27	-3.80	-3.30	-2.79	-2.26	-1.71	-1.14	-0.57	0.00	0.57	1.14	1.71	2.26	2.79	3.30	3.80	4.27
	-0.05	-4.85	-4.37	-3.88	-3.36	-2.83	-2.28	-1.72	-1.15	-0.57	0.00	0.57	1.13	1.68	2.21	2.73	3.22	3.70
	-0.10	-5.42	-4.94	-4.45	-3.93	-3.40	-2.85	-2.29	-1.72	-1.14	-0.57	0.00	0.56	1.11	1.64	2.16	2.65	3.13
	-0.15	-5.98	-5.50	-5.01	-4.50	-3.96	-3.41	-2.85	-2.28	-1.71	-1.13	-0.56	0.00	0.55	1.08	1.60	2.09	2.57
	-0.20	-6.53	-6.05	-5.56	-5.04	-4.51	-3.96	-3.40	-2.83	-2.26	-1.68	-1.11	-0.55	0.00	0.53	1.05	1.54	2.02
	-0.25	-7.06	-6.59	-6.09	-5.58	-5.04	-4.50	-3.93	-3.36	-2.79	-2.21	-1.64	-1.08	-0.53	0.00	0.52	1.01	1.48
	-0.30	-7.58	-7.10	-6.61	-6.09	-5.56	-5.01	-4.45	-3.88	-3.30	-2.73	-2.16	-1.60	-1.05	-0.52	0.00	0.49	0.97
	-0.35	-8.07	-7.60	-7.10	-6.59	-6.05	-5.50	-4.94	-4.37	-3.80	-3.22	-2.65	-2.09	-1.54	-1.01	-0.49	0.00	0.47
	-0.40	-8.54	-8.07	-7.58	-7.06	-6.53	-5.98	-5.42	-4.85	-4.27	-3.70	-3.13	-2.57	-2.02	-1.48	-0.97	-0.47	0.00

TABLE A.10 Rounding Widths (Continued)

Rounding Width - meters Design Speed = 110 km/h

S_2

	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00	−0.05	−0.10	−0.15	−0.20	−0.25	−0.30	−0.35	−0.40
0.40	0.00	0.49	1.01	1.55	2.10	2.68	3.26	3.86	4.46	5.06	5.65	6.24	6.81	7.37	7.90	8.42	8.91
0.35	−0.49	0.00	0.52	1.05	1.61	2.18	2.77	3.36	3.96	4.56	5.16	5.74	6.32	6.87	7.41	7.93	8.42
0.30	−1.01	−0.52	0.00	0.54	1.09	1.67	2.25	2.85	3.45	4.05	4.64	5.23	5.80	6.36	6.90	7.41	7.90
0.25	−1.55	−1.05	−0.54	0.00	0.56	1.13	1.72	2.31	2.91	3.51	4.10	4.69	5.26	5.82	6.36	6.87	7.37
0.20	−2.10	−1.61	−1.09	−0.56	0.00	0.57	1.16	1.75	2.35	2.95	3.55	4.13	4.71	5.26	5.80	6.32	6.81
0.15	−2.68	−2.18	−1.67	−1.13	−0.57	0.00	0.59	1.18	1.78	2.38	2.97	3.56	4.13	4.69	5.23	5.74	6.24
0.10	−3.26	−2.77	−2.25	−1.72	−1.16	−0.59	0.00	0.59	1.19	1.79	2.39	2.97	3.55	4.10	4.64	5.16	5.65
0.05	−3.86	−3.36	−2.85	−2.31	−1.75	−1.18	−0.59	0.00	0.60	1.20	1.79	2.38	2.95	3.51	4.05	4.56	5.06
S_1 0.00	−4.46	−3.96	−3.45	−2.91	−2.35	−1.78	−1.19	−0.60	0.00	0.60	1.19	1.78	2.35	2.91	3.45	3.96	4.46
−0.05	−5.06	−4.56	−4.05	−3.51	−2.95	−2.38	−1.79	−1.20	−0.60	0.00	0.59	1.18	1.75	2.31	2.85	3.36	3.86
−0.10	−5.65	−5.16	−4.64	−4.10	−3.55	−2.97	−2.39	−1.79	−1.19	−0.59	0.00	0.59	1.16	1.72	2.25	2.77	3.26
−0.15	−6.24	−5.74	−5.23	−4.69	−4.13	−3.56	−2.97	−2.38	−1.78	−1.18	−0.59	0.00	0.57	1.13	1.67	2.18	2.68
−0.20	−6.81	−6.32	−5.80	−5.26	−4.71	−4.13	−3.55	−2.95	−2.35	−1.75	−1.16	−0.57	0.00	0.56	1.09	1.61	2.10
−0.25	−7.37	−6.87	−6.36	−5.82	−5.26	−4.69	−4.10	−3.51	−2.91	−2.31	−1.72	−1.13	−0.56	0.00	0.54	1.05	1.55
−0.30	−7.90	−7.41	−6.90	−6.36	−5.80	−5.23	−4.64	−4.05	−3.45	−2.85	−2.25	−1.67	−1.09	−0.54	0.00	0.52	1.01
−0.35	−8.42	−7.93	−7.41	−6.87	−6.32	−5.74	−5.16	−4.56	−3.96	−3.36	−2.77	−2.18	−1.61	−1.05	−0.52	0.00	0.49
−0.40	−8.91	−8.42	−7.90	−7.37	−6.81	−6.24	−5.65	−5.06	−4.46	−3.86	−3.26	−2.68	−2.10	−1.55	−1.01	−0.49	0.00

Rounding Width - meters Design Speed = 120 km/h

S_2

	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00	−0.05	−0.10	−0.15	−0.20	−0.25	−0.30	−0.35	−0.40
0.40	0.00	0.51	1.05	1.61	2.19	2.79	3.40	4.02	4.64	5.27	5.89	6.50	7.09	7.67	8.23	8.77	9.28
0.35	−0.51	0.00	0.54	1.10	1.68	2.28	2.89	3.51	4.13	4.75	5.37	5.98	6.58	7.16	7.72	8.26	8.77
0.30	−1.05	−0.54	0.00	0.56	1.14	1.74	2.35	2.97	3.59	4.22	4.84	5.45	6.04	6.62	7.18	7.72	8.23
0.25	−1.61	−1.10	−0.56	0.00	0.58	1.18	1.79	2.41	3.03	3.66	4.28	4.89	5.48	6.06	6.62	7.16	7.67
0.20	−2.19	−1.68	−1.14	−0.58	0.00	0.60	1.21	1.83	2.45	3.08	3.70	4.31	4.90	5.48	6.04	6.58	7.09
0.15	−2.79	−2.28	−1.74	−1.18	−0.60	0.00	0.61	1.23	1.85	2.48	3.10	3.71	4.31	4.89	5.45	5.98	6.50
0.10	−3.40	−2.89	−2.35	−1.79	−1.21	−0.61	0.00	0.62	1.24	1.87	2.49	3.10	3.70	4.28	4.84	5.37	5.89
0.05	−4.02	−3.51	−2.97	−2.41	−1.83	−1.23	−0.62	0.00	0.62	1.25	1.87	2.48	3.08	3.66	4.22	4.75	5.27
S_1 0.00	−4.64	−4.13	−3.59	−3.03	−2.45	−1.85	−1.24	−0.62	0.00	0.62	1.24	1.85	2.45	3.03	3.59	4.13	4.64
−0.05	−5.27	−4.75	−4.22	−3.66	−3.08	−2.48	−1.87	−1.25	−0.62	0.00	0.62	1.23	1.83	2.41	2.97	3.51	4.02
−0.10	−5.89	−5.37	−4.84	−4.28	−3.70	−3.10	−2.49	−1.87	−1.24	−0.62	0.00	0.61	1.21	1.79	2.35	2.89	3.40
−0.15	−6.50	−5.98	−5.45	−4.89	−4.31	−3.71	−3.10	−2.48	−1.85	−1.23	−0.61	0.00	0.60	1.18	1.74	2.28	2.79
−0.20	−7.09	−6.58	−6.04	−5.48	−4.90	−4.31	−3.70	−3.08	−2.45	−1.83	−1.21	−0.60	0.00	0.58	1.14	1.68	2.19
−0.25	−7.67	−7.16	−6.62	−6.06	−5.48	−4.89	−4.28	−3.66	−3.03	−2.41	−1.79	−1.18	−0.58	0.00	0.56	1.10	1.61
−0.30	−8.23	−7.72	−7.18	−6.62	−6.04	−5.45	−4.84	−4.22	−3.59	−2.97	−2.35	−1.74	−1.14	−0.56	0.00	0.54	1.05
−0.35	−8.77	−8.26	−7.72	−7.16	−6.58	−5.98	−5.37	−4.75	−4.13	−3.51	−2.89	−2.28	−1.68	−1.10	−0.54	0.00	0.51
−0.40	−9.28	−8.77	−8.23	−7.67	−7.09	−6.50	−5.89	−5.27	−4.64	−4.02	−3.40	−2.79	−2.19	−1.61	−1.05	−0.51	0.00

TABLE A.11 Slope-break Effects Widths

Slope-break Effects Widths - meters

s_2

		0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00	-0.05	-0.10	-0.15	-0.20	-0.25	-0.30	-0.35	-0.40
	0.40	0.00	0.87	1.73	2.60	3.47	4.33	5.20	6.07	6.93	7.80	8.67	9.53	10.40	11.27	12.13	13.00	13.87
	0.35	------	0.00	0.87	1.73	2.60	3.47	4.33	5.20	6.07	6.93	7.80	8.67	9.53	10.40	11.27	12.13	13.00
	0.30	------	------	0.00	0.87	1.73	2.60	3.47	4.33	5.20	6.07	6.93	7.80	8.67	9.53	10.40	11.27	12.13
	0.25	------	------	------	0.00	0.87	1.73	2.60	3.47	4.33	5.20	6.07	6.93	7.80	8.67	9.53	10.40	11.27
	0.20	------	------	------	------	0.00	0.87	1.73	2.60	3.47	4.33	5.20	6.07	6.93	7.80	8.67	9.53	10.40
	0.15	------	------	------	------	------	0.00	0.87	1.73	2.60	3.47	4.33	5.20	6.07	6.93	7.80	8.67	9.53
	0.10	------	------	------	------	------	------	0.00	0.87	1.73	2.60	3.47	4.33	5.20	6.07	6.93	7.80	8.67
	0.05	------	------	------	------	------	------	------	0.00	0.87	1.73	2.60	3.47	4.33	5.20	6.07	6.93	7.80
s_1	0.00	------	------	------	------	------	------	------	------	0.00	0.87	1.73	2.60	3.47	4.33	5.20	6.07	6.93
	-0.05	------	------	------	------	------	------	------	------	------	0.00	0.87	1.73	2.60	3.47	4.33	5.20	6.07
	-0.10	------	------	------	------	------	------	------	------	------	------	0.00	0.87	1.73	2.60	3.47	4.33	5.20
	-0.15	------	------	------	------	------	------	------	------	------	------	------	0.00	0.87	1.73	2.60	3.47	4.33
	-0.20	------	------	------	------	------	------	------	------	------	------	------	------	0.00	0.87	1.73	2.60	3.47
	-0.25	------	------	------	------	------	------	------	------	------	------	------	------	------	0.00	0.87	1.73	2.60
	-0.30	------	------	------	------	------	------	------	------	------	------	------	------	------	------	0.00	0.87	1.73
	-0.35	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	0.00	0.87
	-0.40	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	0.00

The slope-break effects width (W_{se}) is defined as the distance from a break in slope a point mass traveling in a straight line in the plane of one slope would travel on a projectile trajectory from the break in slope to contact with the second slope. The formula for the width is:

$$W_{se} = \left(\frac{s_2 - s_1}{a_g}\right) 2V^2 \sin^2 \phi$$

Where:
s_1 = slope of first side slope
s_2 = slope of second side slope
V = speed of point mass
ϕ = encroachment angle (assumes slope break is parallel to roadway)

The values in this table are based on an encroachment speed of 134 km/h, the assumed maximum encroachment speed on a 120-km/h design speed highway, and an encroachment angle of 14.34°, the maximum encroachment angle achievable at the encroachment speed, given a coefficient of friction of 0.8 and an offset from the edge of the traveled way of 5.5 meters. The values in this table are only slightly more than those that result from similar calculations using lower design speeds.

Step 2. Using the following formula, calculate a rounding adjustment factor to be applied to slopes within the slope-break-effects widths.

$$F_{RND} = \text{Rounding adjustment factor}$$
$$= (1 - s_{\Delta}) + s_{\Delta}(\frac{RND_A}{RND_T}). \text{ If } RND_A > RND_T \text{, then: } F_{RND} = 1$$

Where: RND_A = Width of rounding provided

RND_T = Width of rounding suggested in Table A.10

$s_{\Delta} = |s_2 - s_1|$

s_1 and s_2 = intersecting cross slopes

Step 3. Divide the widths of rounding by 4 and assign a slope = s_1 to the first quarter, a slope = $(s_2 + s_1)/2$ to the second and third quarters, and a slope = s_2 to the fourth.

Step 4. Starting from the edge of the traveled way, adjust each of the horizontal widths of slope segments by multiplying by the slope equivalency factor, E_s, appropriate for the slope.

Step 5. Further adjust the slopes within the slope-break-effects widths by multiplying the adjusted width from step 4 by the rounding adjustment factor, F_{RND}. Where slope-break-effects widths overlap the lower value of F_{RND} applies.

Step 6. Sum all the adjusted slope widths from the edge of the traveled way to the face of the feature being studied and, if within a section of highway where the curvature correction discussed in Section A4.7.1.2 applies, multiply the sum by the appropriate correction factor. This is the offset value, A, to input to ROADSIDE.

Note that while no rounding correction is to be applied to sag breaks in grade, it is suggested that, for traversability, the minimum radius rounding for such breaks be 12 m.

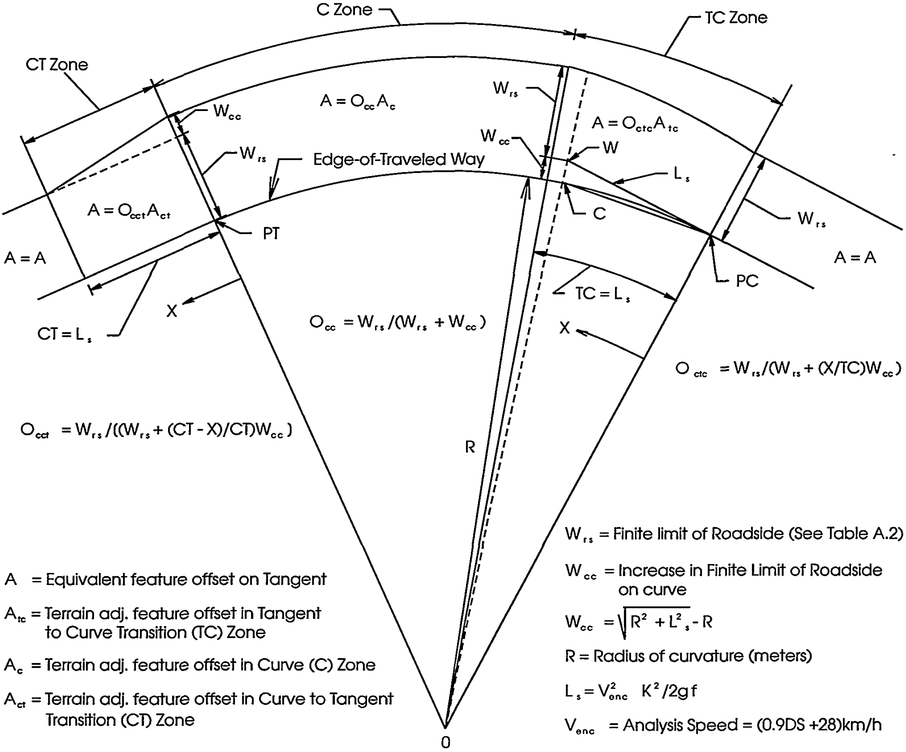
A4.7.1.2 Adjusting Offset Distance for Curvature

The formulas and rationale for the suggested curvature offset adjustment are illustrated in Figure A.13. It is assumed that the finite limit of the roadside on a curve will increase over that on tangent by an amount equal the radial offset between the curve and the end of a line tangent to the curve and of a length from the point of tangency to its end equal to the stopping distance (L_s) of a vehicle with an initial speed equal 0.9 the design speed plus 28 km/h and stopped under an assumed constant coefficient of friction of 0.4. This increase in the finite width of the roadside is W_{cc} in Figure A.13 and is equal to C,W in the triangle W,C,PC. W_{cc} values for eight design speeds from 50 through 120 km/h for various radii of curvature are given in Table A.12. The table was constructed so that, in nearly all instances, the given increments in radius of curvature do not result in increments in W_{cc} exceeding 0.5 m. Given the many estimations and assumptions that these procedures include, the precision of the values in the table greatly exceed the certainty of the procedure results.

The preceding adjustment procedures provide guidance for outsides of curves. It would be reasonable to apply the same approach to reduce the finite limit on the inside of curves. In the interest of greater safety it is suggested that this not be done. However, if it is used on the inside of curves it is suggested that adjustments in TC zone be based on the following formula:

$$O_{ctc_{ic}} = \frac{W_{rs}}{W_{rs} - (\frac{X}{TC})^2 W_{cc}}$$

, rather than the formula that would result from simply changing the sign of W_{cc} in the suggested TC zone adjustment formula for the outside of curves.



A = Equivalent feature offset on Tangent

A_{tc} = Terrain adj. feature offset in Tangent to Curve Transition (TC) Zone

A_c = Terrain adj. feature offset in Curve (C) Zone

A_{ct} = Terrain adj. feature offset in Curve to Tangent Transition (CT) Zone

W_{rs} = Finite limit of Roadside (See Table A.2)

W_{cc} = Increase in Finite Limit of Roadside on curve

$W_{cc} = \sqrt{R^2 + L^2_s} - R$

R = Radius of curvature (meters)

$L_s = V^2_{enc}\ K^2/2gf$

V_{enc} = Analysis Speed = (0.9DS +28)km/h

DS = Design Speed (km/h)

g = Acceleration of Gravity = 9.80665 m/s^2

f = Coefficient of Friction = 0.4

K = 0.277778 (m/s)/(km/h)

FIGURE A.13 Offset Dimension Adjustment Guidance for Features on Curves

TABLE A.12 W_{cc} - Increase in Finite Width of Roadside on Curves

Design Speed (km/h)	50 00		60 00		70 00		80 00		90 0		100.0		110.0		120.0	
L_s (meters)	52.41		66.13		81.45		98.35		116 9		137.0		158.6		181.9	
W_{rs} (meters)	20 00		23.75		26.75		28 75		31.75		34.00		38.25		41.28	
	Radius (meters)	W_{cc} (meters)	Radius (meters)	W_{cc} (meters)	Radius (meters)	W_{cc} (meters)	Radius (meters)	W_{cc} (meters)	Radius (meters)	W_{cc} (meters)	Radius (meters)	W_{cc} (meters)	Radius (meters)	W_{cc} (meters)	Radius (meters)	W_{cc} (meters)
	50	22.44	80	23.80	110	26.87	150	29.37	190	33.08	250	35.05	300	39.36	425	37.30
	52	21.83	82	23.34	112	26.48	152	29.04	192	32.79	252	34.81	305	38.79	430	36.90
	54	21.25	84	22.91	114	26.10	154	28.73	194	32.50	254	34.57	310	38.23	435	36.51
	56	20.70	86	22.49	116	25.74	156	28 42	196	32.21	256	34.33	315	37.69	440	36.12
	58	20.17	88	22.08	118	25.38	158	28.11	198	31.93	258	34.09	320	37.16	445	35.75
	60	19.67	90	21 68	120	25.03	160	27.81	200	31.66	260	33.86	325	36.65	450	35.38
	62	19.19	92	21.30	122	24.69	162	27.52	202	31.39	262	33.63	330	36.15	455	35.02
	64	18.72	94	20.93	124	24 36	164	27.23	204	31.12	264	33.41	335	35.66	460	34.66
	66	18 28	96	20.57	126	24.03	166	26.95	206	30.86	266	33.18	340	35.19	465	34.32
	68	17.85	98	20.23	128	23.71	168	26.67	208	30.60	268	32.96	345	34.72	470	33.98
	70	17.45	100	19.89	130	23.41	170	26.40	210	30.34	270	32.75	350	34.27	475	33.64
	72	17.06	105	19.09	132	23 10	172	26.13	212	30.09	272	32.53	355	33.83	480	33.31
	74	16.68	110	18.35	134	22.81	174	25.87	214	29.85	274	32.32	360	33.40	485	32.99
	76	16.32	115	17.66	136	22.52	176	25.62	216	29.60	276	32.11	365	32.98	490	32.68
	78	15.97	120	17.02	138	22.24	178	25.36	218	29.37	278	31.90	370	32.57	495	32.37
	80	15.64	125	16.42	140	21.97	180	25.12	220	29.13	280	31.70	375	32.17	500	32.06
	82	15.32	130	15.85	142	21.70	182	24.87	222	28.90	282	31.50	380	31.78	505	31.77
	84	15 01	135	15.33	144	21.44	184	24.64	224	28.67	284	31.30	385	31.40	510	31.47
	86	14.71	140	14.83	146	21.18	186	24.40	226	28.44	286	31.10	390	31.03	515	31.18
	88	14.43	145	14.37	148	20.93	188	24.17	228	28.22	288	30.90	395	30.66	520	30.90
	90	14.15	150	13.93	150	20.69	190	23.95	230	28.00	290	30.71	400	30.31	525	30.62
	92	13.88	155	13.52	155	20.10	192	23.72	232	27.79	292	30.52	405	29.96	530	30.35
	94	13.62	160	13.13	160	19.54	194	23.51	234	27.58	294	30.33	410	29.62	535	30.08
	96	13.38	165	12.76	156	19.98	196	23.29	236	27.37	296	30.15	415	29.29	540	29.82
	98	13.14	170	12.41	170	18.50	198	23.08	238	27.16	298	29.96	420	28.96	545	29.56
	100	12.90	175	12.08	175	18.02	200	22.87	240	26.96	300	29.78	425	28.64	550	29.30
	105	12.35	180	11.76	180	17.57	205	22.37	242	26.76	305	29.34	460	26.58	560	28.81
	110	11.85	185	11.46	185	17.13	210	21.89	244	26 56	310	28.90	465	26.31	570	28.32
	115	11.38	190	11.18	190	16.72	215	21.43	246	26.36	315	28.48	440	27.72	580	27.86
	120	10.95	195	10.91	195	16.33	220	20.98	248	26.17	320	28.07	445	27.43	590	27.41
	125	10.54	200	10.65	200	15.95	225	20.56	250	25.98	325	27.68	450	27.14	600	26.97
	130	10.17	210	10.17	205	15.59	230	20.15	255	25.52	330	27.29	455	26.86	610	26.55
	135	9.82	220	9.72	210	15.24	235	19.75	260	25.07	335	26.91	460	26.58	620	26.14
	140	9.49	230	9.32	215	14.91	240	19.37	265	24.64	340	26.55	465	26.31	630	25.74
	145	9.18	240	8.94	220	14.59	245	19.00	270	24.22	345	26.19	470	26.05	640	25.35
	150	8.89	250	8.60	225	14.29	250	18.65	275	23.82	350	25.84	475	25.79	650	24.98
	160	8.37	260	8.28	250	12.93	255	18.31	280	23.42	355	25.50	480	25.53	660	24.61
	170	7 90	270	7.98	260	12.46	260	17.98	285	23.04	360	25.17	485	25.28	670	24.26
	180	7.48	300	7.20	270	12.02	265	17.66	290	22.67	365	24.85	490	25.04	680	23.91
	190	7.10	320	6.76	280	11.60	270	17.36	295	22.32	370	24.53	495	24.80	690	23.58
	200	6.75	340	6.37	290	11.22	280	16.77	300	21.97	375	24.22	500	24.56	700	23.25
	220	6.16	360	6.02	300	10.86	290	16.22	305	21.64	380	23.92	510	24.10	710	22.93
	240	5 66	380	5.71	310	10 52	300	15.71	310	21.31	385	23.63	520	23.66	720	22.63
	260	5.23	400	5.43	320	10.20	310	15.23	315	20.99	390	23.35	530	23.23	730	22.32
	280	4.86	425	5.11	340	9.62	320	14.77	320	20.68	395	23.07	540	22.82	740	22.03
	300	4.54	450	4.83	360	9.10	330	14.34	325	20.38	400	22.79	550	22.42	750	21.75
	320	4.26	500	4.35	380	8.63	340	13.94	330	20.09	405	22.53	560	22.03	760	21.47
	340	4.02	550	3.96	400	8.21	350	13.56	335	19.81	410	22.27	570	21.66	770	21.20

TABLE A.12 W_{cc} - Increase in Finite Width of Roadside on Curves (Continued)

Design Speed (km/h)	50 00		60 00		70 00		80 00		90 0		100.0		110 0		120 0	
L_s (meters)	52.41		66 13		81 45		98.35		116 9		137.0		158.6		181.9	
W_{rs} (meters)	20 00		23 75		26 75		28 75		31 75		34.00		38.25		41.28	
	Radius (meters)	W_{cc} (meters)	Radius (meters)	W_{cc} (meters)	Radius (meters)	W_{cc} (meters)	Radius (meters)	W_{cc} (meters)	Radius (meters)	Wcc (meters)	Radius (meters)	W_{cc} (meters)	Radius (meters)	W_{cc} (meters)	Radius (meters)	W_{cc} (meters)
	350	3.90	600	3.63	420	7.82	360	13.19	340	19.54	415	22.01	580	21.30	780	20.93
	400	3.42	700	3 12	440	7.47	370	12.85	345	19.27	420	21.76	590	20.95	790	20.67
	450	3.04	800	2 73	460	7.15	380	12 52	350	19.01	425	21.52	600	20.62	800	20.42
	500	2.74	900	2.43	480	6.86	390	12.21	360	18.50	430	21.28	610	20.29	820	19.94
	600	2.28	1000	2.18	500	6.59	400	11.91	370	18.03	440	20.82	620	19.97	840	19.47
	800	1 72	1200	1.82	550	6.00	420	11.36	380	17.57	450	20.38	630	19.66	860	19.03
	1000	1 37	1400	1.56	600	5.50	440	10.86	390	17.14	460	19.95	640	19.37	880	18.61
	1500	0.92	1600	1.37	650	5.08	460	10 40	400	16.73	470	19.55	650	19.08	900	18.20
	2000	0.69	2000	1.09	700	4.72	480	9.97	410	16.34	480	19.15	660	18.80	920	17.81
	2500	0.55	2500	0.87	750	4.41	500	9.58	420	15.97	490	18.78	670	18.52	940	17.44
	3000	0 46	3000	0.73	800	4.14	520	9.22	430	15.61	500	18.42	680	18.26	960	17.08
			3500	0.62	900	3.68	540	8.88	440	15.26	510	18.07	690	18.00	980	16.74
			4000	0.55	1000	3.31	560	8.57	450	14.94	520	17.73	700	17.75	1000	16.41
			4500	0.49	1200	2.76	580	8 28	460	14.62	530	17.41	720	17.27	1020	16.09
					1400	2.37	600	8.01	470	14.32	540	17.10	740	16.81	1040	15.79
					1600	2.07	620	7.75	480	14.03	550	16.79	760	16.38	1060	15.50
					1800	1.84	640	7.51	490	13.75	560	16.50	780	15.97	1080	15.21
					2000	1.66	650	7.40	500	13.48	570	16.22	800	15.58	1100	14.94
					2500	1.33	700	6.88	520	12.98	580	15.95	820	15.20	1120	14.68
					3000	1 11	750	6.42	540	12.51	590	15.69	840	14.85	1140	14.42
					4000	0.83	800	6.02	560	12.07	600	15.43	860	14.51	1160	14.18
					5000	0.66	850	5.67	580	11.66	620	14.95	880	14.18	1180	13.94
					6000	0.55	900	5.36	600	11.28	640	14.49	900	13.87	1200	13.71
					7000	0 47	1000	4.82	620	10.92	660	14.06	920	13.58	1220	13.49
							1100	4.39	640	10.59	680	13.65	940	13.29	1240	13.27
							1200	4.02	660	10.27	700	13.27	960	13.02	1260	13.06
							1400	3.45	680	9 98	720	12.91	980	12.76	1280	12.86
							1600	3.02	700	9.69	740	12.57	1000	12.50	1300	12.67
							1800	2.68	750	9.06	760	12.24	1020	12.26	1350	12.20
							2000	2.42	800	8.50	780	11.93	1040	12.03	1400	11.77
							2500	1.93	850	8.00	800	11.64	1060	11.80	1450	11.37
							3000	1.61	900	7.56	820	11.36	1080	11.59	1500	10.99
							4000	1.21	950	7.17	840	11.09	1100	11.38	1560	10.57
							5000	0.97	1000	6.81	860	10.84	1150	10.89	1600	10.31
							6000	0.81	1050	6.49	880	10.59	1200	10.44	1650	10.00
							8000	0.60	1100	6.19	900	10.36	1250	10.03	1700	9.71
							10000	0 48	1200	5.68	920	10.14	1300	9.64	1750	9.43
									1300	5.25	940	9.92	1350	9.29	1800	9.17
									1400	4.87	950	9.82	1400	8.96	1900	8.69
									1500	4.55	1000	9.33	1450	8.65	2000	8.26
									1600	4.26	1050	8.89	1500	8.36	2100	7.86
									1800	3.79	1100	8.49	1550	8.10	2200	7.51
									2000	3.41	1200	7.79	1600	7.84	2300	7.18
									2200	3.10	1250	7.48	1700	7.39	2400	6.88
									2500	2.73	1300	7.19	1800	6.98	2500	6.61
									3000	2.28	1350	6.93	1900	6.61	2600	6.36
									3500	1.95	1400	6.68	2000	6.28	2800	5.90
									4000	1.71	1500	6.24	2100	5.98	3000	5.51

TABLE A.12 W_{cc} - Increase in Finite Width of Roadside on Curves (Continued)

Design Speed (km/h)	50.00		60.00		70 00		80.00		90.0		100.0		110.0		120.0	
L_s (meters)	52.41		66.13		81.45		98.35		116.9		137.0		158.6		181.9	
W_{rs} (meters)	20.00		23.75		26.75		28.75		31.75		34.00		38.25		41.28	
	Radius (meters)	W_{cc} (meters)	Radius (meters)	W_{cc} (meters)	Radius (meters)	Wcc (meters)	Radius (meters)	W_{cc} (meters)	Radius (meters)	W_{cc} (meters)	Radius (meters)	W_{cc} (meters)	Radius (meters)	W_{cc} (meters)	Radius (meters)	W_{cc} (meters)
									4500	1.52	1600	5.85	2200	5.71	3200	5.17
									5000	1.37	1700	5.51	2400	5.24	3400	4.86
									6000	1.14	1800	5.20	2600	4.83	3600	4.59
									8000	0.85	1900	4.93	2800	4.49	3800	4.35
									10000	0.68	2000	4.68	3000	4.19	4000	4.13
									15000	0.46	2200	4.26	3200	3.93	4500	3.68
											2400	3.90	3400	3.70	5000	3.31
											2600	3.60	3500	3.59	5500	3.01
											2800	3.35	4000	3.14	6000	2.76
											3000	3.12	4500	2.80	7000	2.36
											3500	2.68	5000	2.52	8000	2.07
											4000	2.34	6000	2.10	10000	1.65
											5000	1.88	7000	1.80	12000	1.38
											6000	1.56	8000	1.57	15000	1.10
											8000	1.17	10000	1.26	20000	0.83
											10000	0.94	15000	0.84	25000	0.66
											15000	0.63	20000	0.63	30000	0.55
											20000	0.47	25000	0.50	40000	0.41
													30000	0.42		

A4.8 ITEM 8: INITIAL COLLISION FREQUENCIES

Initial collision frequencies are calculated values. For adjacent traffic, the initial collision frequencies are given by:

CFSU = collision frequency with side of feature

$$= (\mathrm{EF})(1/\tan\phi)[\sum_{i=1}^{W} \mathrm{LEP}(A + SW\cos\phi + \{i-1\})]/1000$$

CFCU = collision frequency with corner of feature

$$= (\mathrm{EF})(1/\sin\phi)[\sum_{i=1}^{SW} \mathrm{LEP}(A + \{i-1\}\cos\phi)]/1000$$

CFFA = collision frequency with face of feature

$$= (\mathrm{EF})\,(L)\,\mathrm{LEP}(A)/1000$$

LEP(Y) = Lateral extent probability for lateral extent Y

ϕ = enc. angle (deg)

SW = swath width (meters)

EF = initial adjusted encroachment frequency enc/km/y*

A, L, W, and Y are in meters. A, L, and W are shown in Figure A.10.

For opposing traffic, the offset to the feature (A) is replaced with:

A + (number of adjacent lanes)(lane width).

Adjacent lanes = total lanes/2 for divided and undivided highways.

CFTA is collision freq. for face plus upstream side and corner from adj. traf.
CFSU is collision freq. for upstream side (zone 1 adj).
CFCU is collision freq. for upstream corner (zone 2 adj).
CFFA is collision freq. for face from adjacent traffic (zone 3 adj).
CFTO is collision freq. for face plus downstream side and corner from opp. traf.
CFSD is collision freq. for downstream side (zone 1 opp.).
CFCD is collision freq. for downstream corner (zone 2 opp.).
CFFO is collision freq. for face from opposing traffic (zone 3 opp.).

Collision frequencies are collisions per year based on the adjusted initial encroachment frequency.

* The initial encroachment frequency (EF) is a calculated value based on the encroachment rate (ER), initial effective traffic volume (TV_{eff}), highway curvature and grade factors (EF_C and EF_G), and a user supplied factor (EF_U).

$$EF = (ER)(TV_{eff})(EF_C)(EF_G)(EF_U)$$

ER is an adjustable global value that can be reached for revision by pressing Function Key 5 (F5).
EF_C and EF_G are determined by the input curvature (radius in meters) and grade.
EF_U is a user specified adjustment for site specific or other conditions.

A4.9 ITEM 9: SEVERITY INDICES

Severity indices, (SIs) are estimates of the societal costs associated with an average accident with a given feature. Five values are called for by ROADSIDE. One for each: the upstream side, the upstream corner, the face, the downstream corner, and the downstream side of the feature. The locations of these feature elements are shown in Figure A.10. Tables A.13.1 to A.13.10 are offered as aids in selecting appropriate SI values.

TABLE A.13.1 SUGGESTED SEVERITY INDICES

1/9

Foreslopes

Object Type and Characteristics			**Object Surface (*)**	**Severity Index**							
Slope (V:H)	Height (m)	Surface Condition		**Design Speed - km/h**							
				50	**60**	**70**	**80**	**90**	**100**	**110**	**120**
Foreslope 1:∞	0.0	A	F	0.1	0.2	0.2	0.3	0.4	0.5	0.7	0.8
		B See Notes	F	0.3	0.4	0.4	0.5	0.6	0.8	1.0	1.1
		C at End	F	0.4	0.6	0.8	1.0	1.1	1.3	1.5	1.8
		D of Table	F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Foreslope 1:10	0.15	A	F	0.2	0.3	0.5	0.6	0.7	0.9	1.1	1.2
		B See Notes	F	0.4	0.5	0.7	0.8	0.9	1.1	1.3	1.6
		C at End	F	0.7	0.9	1.1	1.3	1.4	1.6	1.9	2.2
		D of Table	F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥0.30	A	F	0.4	0.5	0.7	0.8	1.0	1.2	1.4	1.5
		B See Notes	F	0.6	0.7	0.9	1.0	1.2	1.4	1.6	1.9
		C at End	F	0.9	1.1	1.3	1.5	1.7	1.9	2.2	2.5
		D of Table	F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Foreslope 1:8	0.15	A	F	0.3	0.4	0.6	0.7	0.8	1.0	1.2	1.3
		B See Notes	F	0.5	0.6	0.8	0.9	1.0	1.2	1.4	1.7
		C at End	F	0.8	1.0	1.2	1.4	1.5	1.7	2.0	2.3
		D of Table	F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥0.30	A	F	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.9
		B See Notes	F	0.6	0.8	1.0	1.2	1.4	1.6	1.9	2.2
		C at End	F	0.9	1.2	1.4	1.7	1.9	2.1	2.5	2.9
		D of Table	F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.1 SUGGESTED SEVERITY INDICES 2/9
Foreslopes (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Foreslope 1:6	0.15	A	F	0.5	0.8	1.0	1.3	1.5	1.7	1.9	2.0
		B See Notes	F	0.7	1.0	1.2	1.5	1.7	1.9	2.1	2.2
		C at End	F	1.1	1.4	1.7	2.0	2.2	2.4	2.6	2.9
		D of Table	F	2.9	3.4	3.9	4.4	4.9	5.5	5.9	6.3
		E	F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	6.9
	≥0.30	A	F	0.5	0.8	1.0	1.3	1.6	1.9	2.1	2.2
		B See Notes	F	0.7	1.0	1.2	1.5	1.8	2.1	2.3	2.6
		C at End	F	1.1	1.4	1.7	2.0	2.3	2.6	2.9	3.2
		D of Table	F	3.0	3.8	4.0	4.5	5.0	5.6	6.0	6.4
		E	F	3.4	3.8	4.2	4.7	5.3	5.9	6.5	7.0
Foreslope 1:4	0.15	A	F	0.5	0.7	0.9	1.1	1.3	1.5	1.7	2.0
		B See Notes	F	0.7	0.9	1.1	1.3	1.5	1.7	2.0	2.3
		C at End	F	1.0	1.3	1.5	1.8	2.0	2.2	2.6	3.0
		D of Table	F	3.0	3.5	4.0	4.5	5.0	5.6	6.0	6.4
		E	F	3.4	3.8	4.2	4.7	5.3	5.9	6.5	7.0
	0.30	A	F	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.5
		B See Notes	F	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.9
		C at End	F	1.7	2.0	2.2	2.5	2.7	2.9	3.2	3.5
		D of Table	F	3.2	3.6	4.0	4.5	5.0	5.6	6.0	6.4
		E	F	3.5	3.9	4.3	4.8	5.4	6.0	6.6	7.1
	≥2.0	A	F	1.3	1.6	1.8	2.1	2.3	2.5	2.7	2.8
		B See Notes	F	1.5	1.8	2.0	2.3	2.5	2.7	2.9	3.2
		C at End	F	1.9	2.2	2.5	2.8	3.0	3.2	3.5	3.8
		D of Table	F	3.2	3.6	4.0	4.5	5.0	5.6	6.0	6.4
		E	F	3.5	3.9	4.3	4.8	5.4	6.0	6.6	7.1

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.1 SUGGESTED SEVERITY INDICES

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Foreslopes (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Foreslope 1:3	0.15	A	F	0.7	0.9	1.1	1.3	1.5	1.8	2.0	2.3
		B See Notes	F	0.9	1.1	1.3	1.5	1.7	2.0	2.3	2.6
		C at End	F	1.2	1.5	1.7	2.0	2.2	2.5	2.9	3.3
		D of Table	F	3.2	3.6	4.0	4.5	5.0	5.6	6.0	6.4
		E	F	3.5	3.9	4.3	4.8	5.4	6.0	6.6	7.1
	0.30	A	F	1.6	1.8	2.0	2.2	2.4	2.6	2.8	2.9
		B See Notes	F	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.3
		C at End	F	2.1	2.4	2.6	2.9	3.1	3.3	3.6	3.9
		D of Table	F	3.3	3.7	4.1	4.6	5.1	5.7	6.1	6.5
		E	F	3.6	4.0	4.4	4.9	5.5	6.1	6.7	7.2
	2.0	A	F	2.0	2.3	2.5	2.8	3.0	3.3	3.5	3.6
		B See Notes	F	2.2	2.5	2.7	3.0	3.2	3.5	3.7	4.0
		C at End	F	2.6	2.9	3.2	3.5	3.7	4.0	4.3	4.6
		D of Table	F	3.4	3.8	4.2	4.7	5.2	5.8	6.2	6.6
		E	F	3.7	4.1	4.5	5.0	5.6	6.2	6.8	7.3
	4.0	A	F	2.0	2.3	2.6	2.9	3.1	3.4	3.6	3.9
		B See Notes	F	2.2	2.5	2.8	3.1	3.3	3.6	3.9	4.2
		C at End	F	2.5	2.8	3.2	3.6	3.8	4.1	4.5	4.9
		D of Table	F	3.5	3.9	4.3	4.8	5.3	5.9	6.3	6.7
		E	F	3.8	4.2	4.6	5.1	5.7	6.3	6.9	7.4
	6.0	A	F	2.0	2.3	2.6	2.9	3.1	3.5	3.7	4.0
		B See Notes	F	2.2	2.5	2.8	3.1	3.3	3.7	4.0	4.3
		C at End	F	2.5	2.8	3.2	3.6	3.8	4.2	4.6	5.0
		D Of Table	F	3.5	3.9	4.3	4.8	5.3	5.9	6.3	6.7
		E	F	3.8	4.2	4.6	5.1	5.7	6.3	6.9	7.4

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.1 SUGGESTED SEVERITY INDICES

Foreslopes (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition		Design Speed - km/h							
				50	60	70	80	90	100	100	120
Foreslope 1:3 (cont.)	8.0	A	F	2.0	2.3	2.6	2.9	3.2	3.5	3.8	4.1
		B See Notes	F	2.2	2.5	2.8	3.1	3.4	3.7	4.0	4.3
		C at End	F	2.5	2.8	3.2	3.6	3.9	4.2	4.6	5.0
		D of Table	F	3.5	3.9	4.3	4.8	5.3	5.9	6.3	6.7
		E	F	3.8	4.2	4.6	5.1	5.7	6.3	6.9	7.4
	≥ 10	A	F	2.0	2.3	2.6	2.9	3.2	3.5	3.9	4.3
		B See Notes	F	2.2	2.5	2.8	3.1	3.4	3.7	4.1	4.5
		C at End	F	2.5	2.8	3.2	3.6	3.9	4.3	4.7	5.1
		D Of Table	F	3.5	3.9	4.3	4.8	5.3	5.9	6.3	6.7
		E	F	3.8	4.2	4.3	5.1	5.7	6.3	6.9	7.4
Foreslope 1:2	0.15	A	F	0.9	1.2	1.5	1.8	2.0	2.3	2.6	2.9
		B See Notes	F	1.1	1.4	1.7	2.0	2.2	2.5	2.9	3.3
		C at End	F	1.4	1.7	2.1	2.5	2.7	3.1	3.5	3.9
		D of Table	F	3.3	3.7	4.1	4.6	5.1	5.7	6.1	6.5
		E	F	3.6	4.0	4.4	4.9	5.5	6.1	6.7	7.2
	0.30	A	F	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.6
		B See Notes	F	2.3	2.5	2.7	2.9	3.1	3.3	3.6	3.9
		C at End	F	2.6	2.9	3.1	3.4	3.6	3.8	4.2	4.6
		D of Table	F	3.4	3.8	4.2	4.7	5.2	5.8	6.2	6.6
		E	F	3.7	4.1	4.5	5.0	5.6	6.2	6.8	7.3
	2.0	A	F	2.9	3.2	3.5	3.8	4.0	4.3	4.5	4.8
		B See Notes	F	2.3	2.9	3.4	4.0	4.2	4.5	4.8	5.1
		C at End	F	2.6	3.2	3.9	4.5	4.7	5.0	5.4	5.8
		D of Table	F	3.5	3.9	4.3	4.8	5.3	5.9	6.3	6.7
		E	F	3.8	4.2	4.6	5.1	5.7	6.3	6.9	7.4

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.1 SUGGESTED SEVERITY INDICES 5/9
Foreslopes (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Foreslope 1:2 (cont.)	4.0	A	F	3.1	3.4	3.8	4.2	4.4	4.6	4.8	5.1
		B See Notes	F	2.5	3.1	3.8	4.4	4.6	4.8	5.1	5.4
		C at End	F	2.8	3.5	4.2	4.9	5.1	5.3	5.7	6.1
		D of Table	F	3.8	4.1	4.5	4.9	5.4	6.0	6.4	6.8
		E	F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5
	6.0	A	F	3.3	3.6	3.9	4.3	4.5	4.7	4.9	5.2
		B See Notes	F	3.2	3.6	4.1	4.5	4.7	4.9	5.2	5.5
		C at End	F	2.9	4.0	4.5	4.9	5.2	5.4	6.1	6.2
		D of Table	F	3.8	4.1	4.5	4.9	5.4	6.0	6.4	6.8
		E	F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5
	8.0	A	F	3.6	3.9	4.1	4.4	4.6	4.8	5.0	5.3
		B See Notes	F	3.8	4.1	4.3	4.6	4.8	5.0	5.3	5.6
		C at End	F	4.1	4.4	4.7	5.0	5.2	5.4	5.8	6.2
		D of Table	F	3.8	4.1	4.5	4.9	5.4	6.0	6.4	6.8
		E	F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5
	10.0	A	F	4.1	4.3	4.5	4.7	4.9	5.2	5.4	5.5
		B See Notes	F	4.2	4.4	4.6	4.8	5.0	5.3	5.5	5.8
		C at End	F	4.4	4.7	4.9	5.2	5.4	5.7	6.0	6.3
		D of Table	F	3.8	4.1	4.5	4.9	5.4	6.0	6.4	6.8
		E	F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5
	14.0	A	F	4.5	4.7	4.9	5.1	5.3	5.5	5.7	6.0
		B See Notes	F	4.6	4.8	5.0	5.2	5.4	5.6	5.9	6.2
		C at End	F	4.7	5.0	5.2	5.5	5.7	5.9	6.3	6.7
		D of Table	F	3.8	4.1	4.5	4.9	5.4	6.0	6.4	6.8
		E	F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.1 SUGGESTED SEVERITY INDICES 6/9
Foreslopes (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Foreslope 1:2 (cont)	18.0	A	F	4.8	5.0	5.2	5.4	5.6	5.8	6.0	6.3
		B See Notes	F	4.9	5.1	5.3	5.5	5.7	5.9	6.1	6.4
		C at End	F	4.9	5.2	5.4	5.7	5.9	6.1	6.4	6.7
		D of Table	F	3.8	4.1	4.5	4.9	5.4	6.0	6.4	6.8
		E	F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5
	22.0	A	F	4.9	5.1	5.3	5.5	5.7	5.9	6.1	6.4
		B See Notes	F	5.0	5.2	5.4	5.6	5.8	6.0	6.2	6.5
		C at End	F	5.1	5.3	5.5	5.7	5.9	6.2	6.5	6.8
		D of Table	F	3.8	4.1	4.5	4.9	5.4	6.0	6.4	6.8
		E	F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5
	26.0	A	F	4.8	5.1	5.3	5.6	5.8	6.1	6.3	6.4
		B See Notes	F	4.9	5.2	5.4	5.7	5.9	6.2	6.4	6.5
		C at End	F	5.0	5.3	5.5	5.8	6.0	6.3	6.6	6.9
		D of Table	F	3.8	4.1	4.5	4.9	5.4	6.0	6.4	6.8
		E	F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5
	30.0	A	F	4.8	5.1	5.3	5.6	5.9	6.2	6.4	6.5
		B See Notes	F	4.9	5.2	5.4	5.7	6.0	6.3	6.5	6.6
		C at End	F	5.0	5.3	5.5	5.8	6.1	6.4	6.6	6.9
		D of Table	F	3.8	4.1	4.5	4.9	5.4	6.0	6.4	6.8
		E	F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5
	≥34.0	A	F	4.8	5.1	5.3	5.6	5.9	6.2	6.4	6.7
		B See Notes	F	4.9	5.3	5.4	5.7	6.0	6.3	6.5	6.8
		C at End	F	5.0	5.3	5.5	5.8	6.1	6.4	6.6	6.9
		D of Table	F	3.8	4.1	4.5	4.9	5.4	6.0	6.6	7.3
		E	F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.1 SUGGESTED SEVERITY INDICES

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Foreslopes (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Foreslope 1 : 1½	0.15	A	F	0.9	1.3	1.7	2.2	2.4	2.7	3.0	3.3
		B See Notes	F	1.1	1.5	1.9	2.4	2.6	2.9	3.3	3.7
		C at End	F	1.4	1.9	2.4	2.9	3.1	3.5	3.9	4.3
		D of Table	F	3.3	3.8	4.3	4.8	5.3	5.9	6.3	6.7
		E	F	3.7	4.1	4.5	5.0	5.6	6.2	6.8	7.3
	0.30	A	F	2.4	2.6	2.8	3.0	3.2	3.5	3.7	4.0
		B See Notes	F	2.6	2.8	3.0	3.2	3.4	3.7	4.0	4.3
		C at End	F	2.9	3.2	3.4	3.7	3.9	4.2	4.6	5.0
		D of Table	F	3.3	3.8	4.3	4.8	5.3	5.9	6.4	6.9
		E	F	3.7	4.1	4.5	5.0	5.6	6.2	6.9	7.6
	2.0	A	F	3.3	3.6	3.9	4.2	4.5	4.8	5.0	5.3
		B See Notes	F	3.2	3.5	3.7	4.0	4.4	4.8	5.2	5.6
		C at End	F	3.6	3.9	4.2	4.5	4.9	5.3	5.8	6.3
		D of Table	F	3.4	3.9	4.4	4.9	5.4	6.0	6.5	7.0
		E	F	3.7	4.1	4.5	5.0	5.6	6.2	6.9	7.6
	4.0	A	F	3.8	4.1	4.4	4.7	4.9	5.2	5.4	5.7
		B See Notes	F	3.8	4.1	4.5	4.9	5.4	5.9	6.2	6.5
		C at End	F	4.8	5.0	5.2	5.4	5.8	6.3	6.8	7.3
		D of Table	F	3.8	4.1	4.5	4.9	5.4	6.0	6.5	7.0
		E	F	3.8	4.2	4.6	5.1	5.7	6.3	7.0	7.7
	6.0	A	F	4.1	4.4	4.7	5.0	5.2	5.5	5.7	6.0
		B See Notes	F	4.7	4.4	4.7	5.5	5.9	6.3	6.6	7.0
		C at End	F	5.3	5.4	5.7	5.9	6.2	6.7	7.2	7.6
		D of Table	F	3.9	4.2	4.6	5.0	5.5	6.0	6.6	7.2
		E	F	3.9	4.3	4.7	5.1	5.8	6.4	7.1	7.8

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.1 SUGGESTED SEVERITY INDICES

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Foreslopes (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
				Design Speed - km/h							
Slope (V:H)	Height (m)	Surface Condition		50	60	70	80	90	100	110	120
Foreslope 1:1½ (cont.)	8.0	A	F	4.3	4.6	4.9	5.2	5.4	5.7	5.9	6.2
		B See Notes	F	5.5	5.6	5.8	5.9	6.3	6.6	7.0	7.4
		C at End	F	5.7	5.9	6.1	6.3	6.6	7.0	7.5	8.0
		D of Table	F	3.9	4.2	4.6	5.0	5.5	6.0	6.6	7.3
		E	F	3.9	4.3	4.7	5.2	5.8	6.4	7.1	7.8
	10.0	A	F	4.9	5.2	5.4	5.7	6.0	6.3	6.6	6.9
		B See Notes	F	6.4	6.5	6.7	6.8	7.2	7.6	7.8	8.1
		C at End	F	6.8	6.9	7.1	7.2	7.6	8.0	8.2	8.5
		D of Table	F	4.0	4.3	4.7	5.1	5.6	6.1	6.7	7.4
		E	F	4.0	4.4	4.8	5.3	5.9	6.5	7.2	7.9
	14.0	A	F	5.4	5.7	5.9	6.2	6.6	6.9	7.2	7.5
		B See Notes	F	7.1	7.2	7.4	7.5	7.9	8.2	8.5	8.8
		C at End	F	7.5	7.6	7.8	7.9	8.2	8.5	8.8	9.1
		D of Table	F	4.0	4.3	4.7	5.1	5.6	6.1	6.7	7.4
		E	F	4.0	4.4	4.8	5.3	5.9	6.5	7.2	7.9
	18.0	A	F	5.8	6.1	6.4	6.7	7.1	7.4	7.7	8.0
		B See Notes	F	7.6	7.7	7.9	8.0	8.4	8.7	9.0	9.3
		C at End	F	7.9	8.0	8.2	8.3	8.6	8.9	9.2	9.5
		D of Table	F	4.0	4.3	4.7	5.1	5.6	6.1	6.7	7.4
		E	F	4.0	4.4	4.8	5.3	5.9	6.5	7.2	7.9
	22.0	A	F	6.2	6.5	6.8	7.1	7.4	7.7	8.0	8.3
		B See Notes	F	7.7	7.9	8.1	8.3	8.6	8.9	9.1	9.2
		C at End	F	8.0	8.2	8.4	8.6	8.8	9.1	9.3	9.4
		D of Table	F	4.0	4.3	4.7	5.1	5.6	6.1	6.7	7.4
		E	F	4.2	4.5	4.9	5.3	5.9	6.5	7.2	7.9

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.1 SUGGESTED SEVERITY INDICES

Foreslopes (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Foreslopes 1:1½ (cont.)	26.0	A	F	6.3	6.6	6.9	7.2	7.5	7.8	8.1	8.4
		B See Notes	F	7.9	8.1	8.3	8.5	8.8	9.1	9.3	9.6
		C at End	F	8.0	8.3	8.5	8.8	9.0	9.2	9.4	9.7
		D of Table	F	4.1	4.4	4.8	5.2	5.6	6.1	6.7	7.4
		E	F	4.2	4.5	4.9	5.3	5.9	6.5	7.2	7.9
	30.0	A	F	6.6	6.9	7.1	7.4	7.7	8.0	8.3	8.6
		B See Notes	F	7.8	8.1	8.3	8.6	8.8	9.1	9.4	9.7
		C at End	F	8.0	8.3	8.5	8.8	9.0	9.2	9.4	9.7
		D of Table	F	4.1	4.4	4.8	5.2	5.5	6.1	6.7	7.4
		E	F	4.2	4.5	4.9	5.3	5.9	6.5	7.2	7.9
	34.0	A	F	6.8	7.1	7.3	7.6	7.8	8.1	8.4	8.7
		B See Notes	F	7.9	8.2	8.4	8.7	8.9	9.2	9.4	9.7
		C at End	F	8.1	8.4	8.6	8.9	9.0	9.2	9.4	9.7
		D of Table	F	4.1	4.4	4.8	5.2	5.6	6.1	6.7	7.4
		E	F	4.2	4.5	4.9	5.3	5.9	6.5	7.2	7.9
	≥38.0	A	F	6.9	7.2	7.4	7.7	7.9	8.2	8.5	8.8
		B See Notes	F	8.0	8.3	8.5	8.8	9.0	9.3	9.5	9.8
		C at End	F	8.3	8.5	8.7	8.9	9.1	9.3	9.5	9.8
		D of Table	F	4.1	4.4	4.8	5.2	5.6	6.1	6.7	7.4
		E	F	4.2	4.5	4.9	5.3	5.9	6.5	7.2	7.9

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

Notes for Table A.13.1:

A: Smooth and firm all seasons

B: Smooth but subject to deep rutting by errant vehicles half of the year

C: Shallow gullies (100 to 200 mm deep), scattered small boulders (under 225-mm projections), scattered small trees (diameters 75 to 100 mm), or structurally substantial woody brush. Features spaced so that nearly all encroaching vehicles will encounter them.

D: Medium gullies (approximately 250 mm deep), boulders or riprap (projecting approximately 300 mm), or medium trees (diameters 175 to 225 mm). Features spaced so that they will be encountered by all encroaching vehicles. It is assumed that density of features will preclude deep penetration of roadside. If this assumption is not valid, SIs for high, steep slopes may be considerably higher than values shown.

E: Deep gullies (over 0.5 m deep), large boulders or heavy riprap (over 450-mm projecting), large trees (diameters over 350 mm). Features spaced so that they will be encountered by all encroaching vehicles. It is assumed that density of features will preclude deep penetration of roadside. If this assumption is not valid, SIs for high, steep slopes may be considerably higher than values shown.

TABLE A.13.2 SUGGESTED SEVERITY INDICES

Foreslope - Vertical with and without water present

Object Type and Characteristics			Object Surface (*)	Severity Index, SI							
				Design Speed - km/h							
Slope (V:H)	Height (m)	Water Depth (m)		50	60	70	80	90	100	110	120
Foreslope Vertical	0.0	0	F	0.1	0.2	0.2	0.3	0.4	0.5	0.7	0.8
		1	F	2.6	2.7	2.9	3.0	3.2	3.4	3.6	3.7
		2	F	4.4	4.7	4.9	5.2	5.4	5.7	5.9	6.2
		4	F	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.7
		≥6	F	7.9	8.1	8.3	8.5	8.7	8.8	9.0	9.1
	0.3	0	F	2.6	2.9	3.1	3.4	3.6	3.9	4.1	4.4
		1	F	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.7
		2	F	4.6	4.9	5.2	5.5	5.9	6.2	6.6	7.0
		4	F	6.3	6.6	6.9	7.2	7.4	7.7	7.9	8.2
		≥6	F	8.2	8.3	8.5	8.6	8.8	9.0	9.2	9.3
	2.0	0	F	3.8	4.1	4.3	4.6	4.8	5.1	5.3	5.6
		1	F	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.7
		2	F	6.7	6.8	7.0	7.1	7.3	7.5	7.7	7.8
		4	F	7.6	7.7	7.9	8.0	8.2	8.4	8.6	8.7
		≥6	F	8.4	8.5	8.7	8.8	9.0	9.2	9.4	9.5
	4.0	0	F	5.7	5.8	5.8	5.9	6.1	6.3	6.5	6.6
		1	F	5.7	5.9	6.1	6.3	6.5	6.7	6.9	7.0
		2	F	7.4	7.5	7.7	7.8	8.0	8.2	8.4	8.5
		4	F	8.0	8.1	8.3	8.4	8.6	8.8	9.0	9.1
		≥6	F	8.6	8.7	8.9	9.0	9.2	9.4	9.6	9.7
	6.0	0	F	6.6	6.7	6.8	6.9	7.0	7.2	7.4	7.5
		1	F	6.8	6.9	7.1	7.3	7.4	7.6	7.8	7.9
		2	F	7.8	7.9	8.1	8.2	8.4	8.6	8.8	8.9
		4	F	8.2	8.3	8.5	8.7	8.9	9.1	9.3	9.4
		≥6	F	8.7	8.8	9.0	9.1	9.3	9.5	9.7	9.8

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.2 SUGGESTED SEVERITY INDICES 2/2
Foreslope - Vertical with and without water present (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index, SI							
Slope (V:H)	Height (m)	Water Depth (m)		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Foreslope Vertical (cont.)	8.0	0	F	7.4	7.5	7.7	7.8	7.9	8.0	8.2	8.3
		1	F	7.8	7.9	8.1	8.2	8.3	8.4	8.6	8.7
		2	F	8.1	8.2	8.4	8.5	8.7	8.9	9.1	9.2
		4	F	8.3	8.5	8.7	8.9	9.1	9.3	9.5	9.6
		≥6	F	8.8	8.9	9.1	9.2	9.4	9.6	9.8	9.9
	10.0	0	F	8.6	8.8	9.0	9.2	9.2	9.2	9.3	9.3
		1	F	8.7	8.9	9.1	9.3	9.4	9.4	9.6	9.7
		2	F	9.2	9.3	9.3	9.4	9.5	9.6	9.8	9.9
		4	F	9.5	9.6	9.6	9.7	9.8	9.8	9.9	9.9
		≥6	F	9.7	9.8	9.8	9.9	10.0	10.0	10.0	10.0
	14.0	0	F	9.5	9.6	9.6	9.7	9.8	9.8	9.8	9.8
		1	F	9.6	9.7	9.7	9.8	9.8	9.8	9.9	9.9
		2	F	9.6	9.7	9.7	9.8	9.9	9.9	10.0	10.0
		4	F	9.8	9.9	9.9	10.0	10.0	10.0	10.0	10.0
		≥6	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	18.0	0	F	9.9	9.9	9.9	9.9	9.9	9.9	10.0	10.0
		1	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
		2	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
		4	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
		≥6	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	22.0	0	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
		1	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
		2	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
		4	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
		≥6	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.3 SUGGESTED SEVERITY INDICES 1/5
Backslopes

Object Type and Characteristics			Object Surface (*)	Severity Index, SI							
Slope (V:H)	Height (m)	Surface Condition		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Backslope 1:10	0.15	A	F	0.1	0.1	0.1	0.2	0.3	0.4	0.6	0.7
		B See notes	F	0.2	0.3	0.3	0.4	0.5	0.7	0.9	1.0
		C at End	F	0.6	0.7	0.9	1.0	1.1	1.3	1.5	1.8
		D of Table	F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥0.3	A	F	0.1	0.1	0.1	0.2	0.3	0.3	0.5	0.6
		B See Notes	F	0.1	0.1	0.3	0.4	0.5	0.6	0.8	0.9
		C at End	F	0.6	0.7	0.9	1.0	1.1	1.3	1.5	1.8
		D of Table	F	2.6	3.2	3.9	4.5	5.1	5.7	6.3	7.0
		E A.13.1	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Backslope 1:8	0.15	A	F	0.1	0.1	0.2	0.3	0.4	0.4	0.6	0.7
		B See Notes	F	0.1	0.2	0.4	0.5	0.6	0.7	0.9	1.0
		C at End	F	0.6	0.7	0.9	1.0	1.1	1.3	1.5	1.8
		D of Table	F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥0.3	A	F	0.1	0.1	0.1	0.2	0.3	0.3	0.5	0.6
		B See Notes	F	0.1	0.2	0.2	0.3	0.4	0.6	0.8	0.9
		C at End	F	0.6	0.7	0.9	1.0	1.1	1.3	1.5	1.8
		D of Table	F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Backslope 1:6	0.15	A	F	0.1	0.1	0.3	0.4	0.5	0.5	1.7	0.8
		B See Notes	F	0.3	0.4	0.4	0.5	0.6	0.8	1.0	1.1
		C at End	F	0.6	0.7	0.9	1.0	1.1	1.3	1.5	1.8
		D of Table	F	2.8	3.6	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.3 SUGGESTED SEVERITY INDICES 2/5

Backslopes (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index, SI							
				Design Speed - km/h							
Slope (V:H)	Height (m)	Surface Condition		50	60	70	80	90	100	110	120
Backslope 1:6 (cont.)	≥0.5	A	F	0.1	0.1	0.1	0.2	0.3	0.3	0.5	0.6
		B See notes	F	0.1	0.2	0.4	0.5	0.5	0.6	0.8	0.9
		C at End	F	0.6	0.7	0.9	1.0	1.1	1.3	1.5	1.8
		D of Table	F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Backslope 1:4	≥0.15	A	F	0.1	0.1	0.3	0.4	0.5	0.6	0.8	0.9
		B See Notes	F	0.4	0.5	0.5	0.6	0.7	0.9	1.1	1.2
		C at End	F	0.7	0.8	1.0	1.1	1.3	1.4	1.6	1.7
		D of Table	F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Backslope 1:3	0.15	A	F	0.2	0.3	0.5	0.6	0.7	0.7	0.9	1.0
		B See Notes	F	0.4	0.5	0.7	0.8	0.9	1.1	1.3	1.4
		C at End	F	0.8	0.9	1.1	1.2	1.4	1.6	1.8	1.9
		D of Table	F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥1.0	A	F	0.3	0.4	0.6	0.7	0.9	1.2	1.3	1.4
		B See Notes	F	0.7	0.8	1.0	1.1	1.3	1.5	1.7	1.8
		C at End	F	1.3	1.4	1.6	1.7	1.9	2.1	2.3	2.4
		D of Table	F	2.9	3.4	3.9	4.4	4.9	5.5	6.0	6.5
		E A.13.1	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Backslope 1:2	0.15	A	F	0.4	0.5	0.7	0.8	1.0	1.2	1.4	1.7
		B See Notes	F	0.7	0.8	1.0	1.1	1.3	1.5	1.7	2.0
		C at End	F	1.0	1.1	1.3	1.4	1.6	1.9	2.2	2.5
		D of Table	F	2.9	3.4	3.9	4.4	4.9	5.5	6.0	6.5
		E A.13.1	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.3 SUGGESTED SEVERITY INDICES

Backslopes (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index, SI							
Slope (V:H)	Height (m)	Surface Condition		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Backslope 1:2 (cont.)	0.3	A	F	0.5	0.6	0.8	0.9	1.1	1.3	1.6	1.9
		B See notes	F	0.9	1.0	1.2	1.3	1.4	1.6	1.9	2.2
		C at End	F	1.4	1.5	1.7	1.8	1.9	2.1	2.3	2.6
		D of Table	F	3.0	3.5	4.0	4.5	5.0	5.6	6.1	6.6
		E A.13.1	F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	7.1
	0.6	A	F	0.7	0.8	1.0	1.1	1.3	1.5	1.8	2.1
		B See Notes	F	1.1	1.2	1.4	1.5	1.7	1.9	2.1	2.4
		C at End	F	1.9	2.0	2.2	2.3	2.4	2.6	2.8	3.1
		D of Table	F	3.0	3.5	4.0	4.5	5.0	5.6	6.1	6.6
		E A.13.1	F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	7.1
	≥1.2	A	F	0.8	0.9	1.1	1.2	1.5	1.8	2.1	2.4
		B See Notes	F	1.2	1.3	1.5	1.6	1.8	2.1	2.3	2.6
		C at End	F	2.0	2.1	2.3	2.4	2.5	2.7	2.9	3.2
		D of Table	F	3.0	3.5	4.0	4.5	5.0	5.6	6.1	6.6
		E A.13.1	F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	7.1
Backslope 1:½	0.15	A	F	0.3	0.6	0.8	1.1	1.4	1.8	2.2	2.6
		B See Notes	F	0.6	0.9	1.1	1.4	1.7	2.1	2.5	2.9
		C at End	F	0.9	1.2	1.4	1.7	2.1	2.5	3.0	3.5
		D of Table	F	2.9	3.4	3.9	4.4	4.9	5.5	6.0	6.5
		E A.13.1	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥0.3	A	F	0.5	0.8	1.0	1.3	1.6	2.0	2.6	3.1
		B See Notes	F	0.9	1.2	1.4	1.7	1.9	2.3	2.9	3.4
		C at End	F	1.4	1.7	1.9	2.2	2.4	2.8	3.3	3.8
		D of Table	F	3.0	3.5	4.0	4.5	5.0	5.6	6.1	6.6
		E A.13.1	F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	7.1

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.3 SUGGESTED SEVERITY INDICES

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Backslopes (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index, SI							
Slope (V:H)	Height (m)	Surface Condition		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Backslope 1:1½ (cont.)	0.6	A	F	0.9	1.1	1.3	1.5	1.8	2.2	2.7	3.2
		B See notes	F	1.3	1.5	1.7	1.9	2.2	2.6	3.1	3.6
		C at End	F	2.1	2.3	2.5	2.7	2.9	3.2	3.8	4.3
		D of Table	F	3.0	3.5	4.0	4.5	5.0	5.6	6.1	6.6
		E A.13.1	F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	7.1
	≥1.2	A	F	1.0	1.2	1.4	1.6	2.0	2.4	2.8	3.2
		B See Notes	F	1.4	1.6	1.8	2.0	2.3	2.7	3.2	3.7
		C at End	F	2.2	2.4	2.6	2.8	3.0	3.4	3.9	4.4
		D of Table	F	3.1	3.6	4.1	4.6	5.1	5.7	6.2	6.7
		E A.13.1	F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	7.1
Backslope 1:1	0.15	A	F	0.4	0.7	1.0	1.3	1.7	2.2	2.8	3.3
		B See Notes	F	0.7	1.0	1.3	1.6	2.0	2.5	3.1	3.6
		C at End	F	1.0	1.3	1.6	1.9	2.4	2.9	3.5	4.2
		D of Table	F	2.9	3.4	3.9	4.4	4.9	5.5	6.0	6.5
		E A.13.1	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	F	0.7	1.0	1.3	1.6	2.0	2.4	3.1	3.8
		B See Notes	F	1.1	1.4	1.7	2.0	2.3	2.7	3.4	4.1
		C at End	F	1.6	1.9	2.2	2.5	2.8	3.2	3.8	4.5
		D of Table	F	3.0	3.5	4.0	4.5	5.0	5.6	6.1	6.6
		E A.13.1	F	3.3	3.7	4.1	4.6	5.1	5.8	6.4	7.1
	0.6	A	F	1.0	1.3	1.5	1.8	2.2	2.6	3.3	4.0
		B See Notes	F	1.4	1.7	1.9	2.2	2.6	3.0	3.6	4.1
		C at End	F	2.2	2.5	2.7	3.0	3.2	3.6	4.2	4.9
		D of Table	F	3.0	3.5	4.0	4.5	5.0	5.6	6.1	6.6
		E A.13.1	F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	7.1

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.3 SUGGESTED SEVERITY INDICES 5/5

Backslopes (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index, SI							
Slope (V:H)	Height (m)	Surface Condition		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Backslope 1:1 (cont.)	≥1.2	A	F	1.1	1.4	1.6	1.9	2.3	2.8	3.4	3.9
		B See notes	F	1.5	1.8	2.0	2.3	2.7	3.1	3.7	4.2
		C at End	F	2.3	2.6	2.8	3.1	3.4	3.8	4.4	4.9
		D of Table	F	3.1	3.6	4.1	4.6	5.1	5.7	6.2	6.7
		E A.13.1	F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	7.1
Backslope Vertical	0.15	A	F	0.5	0.8	1.1	1.4	1.9	2.4	3.0	3.7
		B See Notes	F	0.8	1.1	1.4	1.7	2.2	2.7	3.3	4.0
		C at End	F	1.1	1.4	1.7	2.0	2.5	3.1	3.8	4.5
		D of Table	F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	F	0.7	1.0	1.3	1.6	2.0	2.5	3.2	3.9
		B See Notes	F	1.1	1.4	1.7	2.0	2.4	2.8	3.5	4.2
		C at End	F	1.6	1.9	2.2	2.5	2.9	3.3	3.9	4.6
		D of Table	F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.6	A	F	0.7	1.0	1.3	1.6	2.0	2.4	3.0	3.7
		B See Notes	F	1.1	1.4	1.7	2.0	2.3	2.7	3.3	4.0
		C at End	F	1.6	1.9	2.2	2.5	2.8	3.2	3.8	4.3
		D of Table	F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥1.0	A	F	0.6	0.9	1.2	1.5	1.9	2.3	2.9	3.6
		B See Notes	F	1.0	1.3	1.6	1.9	2.2	2.6	3.2	3.9
		C at End	F	1.5	1.8	2.1	2.4	2.7	3.1	3.7	4.2
		D of Table	F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.4 SUGGESTED SEVERITY INDICES 1/3
Parallel Ditches

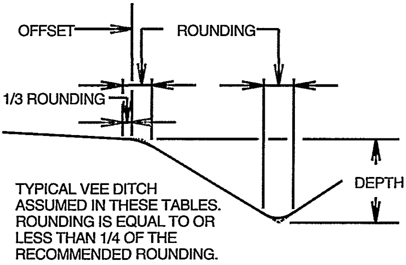
Object Type and Characteristics			Object Surface (*)	Severity Index							
				Design Speed - km/h							
Foreslope	Backslope	Depth (m)		50	60	70	80	90	100	110	120
1:2 Slope	1:2 Slope	0.15	F	1.2	1.5	1.7	2.0	2.4	2.8	3.4	3.9
		0.30	F	1.7	1.8	2.0	2.1	2.5	2.9	3.5	4.0
		0.60	F	1.9	2.0	2.2	2.3	2.7	3.1	3.6	4.1
		1.00	F	2.0	2.1	2.3	2.4	2.7	3.1	3.6	4.1
		1.20	F	2.1	2.2	2.4	2.5	2.8	3.2	3.7	4.2
	1:3 Slope	0.15	F	1.1	1.4	1.6	1.9	2.2	2.6	3.1	3.6
		0.30	F	1.5	1.7	1.9	2.1	2.4	2.8	3.2	3.6
		0.60	F	1.8	1.9	2.1	2.2	2.5	2.9	3.4	3.9
		1.00	F	1.9	2.0	2.2	2.3	2.5	2.9	3.5	4.0
		1.20	F	2.0	2.1	2.3	2.4	2.6	3.0	3.6	4.1
1:3 Slope	1:2 Slope	0.15	F	1.2	1.5	1.7	2.0	2.4	2.8	3.4	3.9
		0.30	F	1.6	1.7	1.9	2.0	2.4	2.8	3.4	3.9
		0.60	F	1.9	2.0	2.0	2.1	2.5	2.9	3.4	3.9
		1.00	F	2.0	2.1	2.1	2.2	2.5	2.9	3.4	3.9
		1.20	F	2.1	2.2	2.2	2.3	2.6	3.0	3.4	3.8
	1:3 Slope	0.15	F	1.1	1.4	1.6	1.9	2.2	2.6	3.1	3.6
		0.30	F	1.4	1.6	1.8	2.0	2.3	2.7	3.1	3.5
		0.60	F	1.7	1.8	2.0	2.1	2.3	2.7	3.1	3.5
		1.00	F	1.8	1.9	2.1	2.2	2.4	2.7	3.1	3.5
		1.20	F	2.0	2.1	2.1	2.2	2.4	2.8	3.2	3.6
	1:4 Slope	0.15	F	1.1	1.3	1.5	1.7	1.9	2.3	2.7	3.1
		0.30	F	1.3	1.5	1.7	1.9	2.1	2.4	2.8	3.2
		0.60	F	1.6	1.7	1.9	2.0	2.2	2.4	2.8	3.2
		1.00	F	1.9	2.0	2.0	2.1	2.2	2.5	2.9	3.3
		1.20	F	1.8	1.9	2.1	2.2	2.3	2.5	2.9	3.3

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.4 SUGGESTED SEVERITY INDICES 2/3
Parallel Ditches (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
				Design Speed - km/h							
Foreslope	Backslope	Depth (m)		50	60	70	80	90	100	110	120
1:4 Slope	1:2 Slope	0.15	F	1.1	1.4	1.6	1.9	2.3	2.7	3.2	3.7
		0.30	F	1.1	1.4	1.6	1.9	2.3	2.7	3.2	3.7
		0.60	F	1.2	1.5	1.7	2.0	2.3	2.7	3.2	3.7
		1.00	F	1.2	1.5	1.7	2.0	2.3	2.7	3.1	3.5
		1.20	F	1.2	1.5	1.7	2.0	2.3	2.7	3.1	3.5
	1:3 Slope	0.15	F	1.0	1.2	1.4	1.6	1.9	2.3	2.7	3.1
		0.30	F	1.1	1.3	1.5	1.7	1.9	2.3	2.7	3.1
		0.60	F	1.0	1.3	1.5	1.8	2.0	2.3	2.7	3.1
		1.00	F	1.1	1.4	1.6	1.9	2.1	2.3	2.7	3.1
		1.20	F	1.1	1.4	1.7	2.0	2.1	2.3	2.7	3.1
	1:4 Slope	0.15	F	0.9	1.1	1.3	1.5	1.7	2.0	2.3	2.6
		0.30	F	1.0	1.2	1.4	1.6	1.8	2.1	2.3	2.6
		0.60	F	1.1	1.3	1.5	1.7	1.9	2.2	2.4	2.5
		1.00	F	1.0	1.3	1.5	1.8	2.0	2.2	2.4	2.7
		1.20	F	1.1	1.4	1.6	1.9	2.1	2.3	2.5	2.6
1:6 Slope	1:2 Slope	0.15	F	0.8	1.1	1.3	1.6	2.0	2.4	2.9	3.4
		0.30	F	0.8	1.1	1.3	1.6	2.0	2.4	2.9	3.4
		0.60	F	0.7	1.0	1.2	1.5	1.9	2.3	2.7	3.1
		1.00	F	0.6	0.9	1.1	1.4	1.8	2.2	2.5	2.8
		1.20	F	0.6	0.9	1.1	1.4	1.8	2.2	2.4	2.7

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F



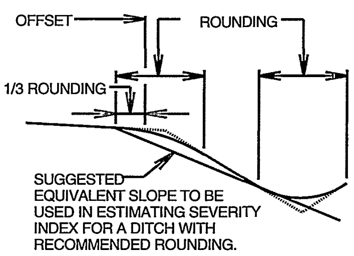


TABLE A.13.4 SUGGESTED SEVERITY INDICES

3/3

Parallel Ditches (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
				Design Speed - km/h							
Foreslope	Backslope	Depth (m)		50	60	70	80	90	100	110	120
1:6 Slope (cont.)	1:3 Slope	0.15	F	0.7	0.9	1.1	1.3	1.6	1.9	2.2	2.5
		0.30	F	0.7	0.9	1.1	1.3	1.6	1.9	2.2	2.5
		0.60	F	0.7	0.9	1.1	1.3	1.6	1.9	2.2	2.5
		1.00	F	0.5	0.8	1.0	1.3	1.6	1.9	2.1	2.4
		1.20	F	0.5	0.8	1.0	1.3	1.6	1.9	2.1	2.4
	1:4 Slope	0.15	F	0.5	0.7	0.9	1.1	1.3	1.6	1.9	2.2
		0.30	F	0.4	0.7	0.9	1.2	1.4	1.7	1.9	2.2
		0.60	F	0.6	0.8	1.0	1.2	1.4	1.7	1.9	2.2
		1.00	F	0.6	0.8	1.0	1.2	1.5	1.8	2.0	2.1
		1.20	F	0.6	0.8	1.0	1.2	1.5	1.8	2.0	2.1
	1:6 Slope	0.15	F	0.5	0.6	0.8	0.9	1.1	1.3	1.5	1.6
		0.30	F	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.7
		0.60	F	0.6	0.7	0.9	1.0	1.2	1.5	1.7	2.0
		1.00	F	0.5	0.7	0.9	1.1	1.3	1.6	1.8	2.1
		1.20	F	0.4	0.7	0.9	1.2	1.4	1.6	1.9	2.2

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

Note: For ditch configurations where the ditch bottom is 2.5 m wide or greater the foreslope and backslope should be treated as independent features with offsets adjusted for intervening slopes, and the cost of the features summed.

The estimated Severity Indices in this table assumes rounding is insufficient to have a beneficial effect. Where rounding approximating that recommended in Section A.4.7.1.1 is provided, the Severity Index of the ditch should be taken as that for a slope through the beginning and end of the hinge rounding and the offset to the feature measured to the beginning of rounding.

Where rounding is in between recommended and ineffective (say 1/4 of recommended) Severity Index estimates should be reduced to reflect more favorable conditions.

TABLE A.13.5 SUGGESTED SEVERITY INDICES 1/10
Intersecting Slopes - Negative (down)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition (**)		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Inter-secting Slopes (neg.) 1:10	0.3	A	S	0.7	0.8	1.0	1.1	1.4	1.7	2.0	2.3
		B See Notes	S	0.9	1.0	1.2	1.3	1.4	1.6	2.2	2.9
		C at End	S	1.2	1.4	1.6	1.8	1.9	2.1	2.8	3.5
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	>1.0	A	S	0.6	0.8	1.0	1.2	1.5	1.9	2.3	2.7
		B See Notes	S	0.8	1.0	1.2	1.4	1.7	2.1	2.6	3.1
		C at End	S	1.1	1.4	1.6	1.9	2.2	2.6	3.2	3.7
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Inter-secting Slope (neg.) 1:8	0.3	A	S	1.3	1.4	1.6	1.7	1.9	2.1	2.4	2.7
		B See Notes	S	1.5	1.6	1.8	1.9	2.1	2.3	2.7	3.1
		C at End	S	1.8	2.0	2.2	2.4	2.6	2.9	3.3	3.7
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	S	1.4	1.6	1.8	2.0	2.2	2.5	3.0	3.5
		B See Notes	S	1.6	1.8	2.0	2.2	2.4	2.7	3.3	3.8
		C at End	S	1.9	2.2	2.4	2.7	2.9	3.2	3.8	4.5
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	2	A	S	1.4	1.6	1.8	2.0	2.3	2.7	3.2	3.7
		B See Notes	S	1.6	1.8	2.0	2.2	2.5	2.9	3.5	4.0
		C at End	S	1.9	2.2	2.4	2.7	3.0	3.4	4.0	4.7
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

** Surface conditions are assumed to continue on surface beyond slope.

TABLE A.13.5 SUGGESTED SEVERITY INDICES

2/10

Intersecting Slopes - Negative (down) (continued)

Object Type and Characteristics			**Object Surface (*)**	**Severity Index**							
Slope (V:H)	Height (m)	Surface Condition (**)		**Design Speed - km/h**							
				50	**60**	**70**	**80**	**90**	**100**	**110**	**120**
Intersecting Slopes (neg.) 1:8 (cont.)	≥4	A	S	1.4	1.6	1.8	2.0	2.3	2.7	3.3	3.8
		B See Notes	S	1.6	1.8	2.0	2.2	2.5	2.9	3.5	4.2
		C at End	S	1.9	2.2	2.4	2.7	3.0	3.4	4.1	4.8
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Intersecting Slopes (neg.) 1:6	0.3	A	S	1.7	1.8	2.0	2.1	2.3	2.5	2.7	3.0
		B See Notes	S	1.9	2.0	2.2	2.3	2.5	2.7	3.0	3.3
		C at End	S	2.2	2.4	2.6	2.8	3.0	3.2	3.6	4.0
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	S	2.1	2.3	2.5	2.7	2.9	3.3	3.7	4.1
		B See Notes	S	2.3	2.5	2.7	2.9	3.1	3.5	4.0	4.5
		C at End	S	2.6	2.9	3.1	3.4	3.6	4.0	4.6	5.1
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	2	A	S	2.3	2.6	2.9	3.2	3.5	3.9	4.4	4.9
		B See Notes	S	2.5	2.8	3.1	3.4	3.7	4.1	4.7	5.2
		C at End	S	2.8	3.1	3.5	3.9	4.2	4.6	5.2	5.7
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	4	A	S	2.2	2.5	2.9	3.3	3.7	4.2	4.8	5.3
		B See Notes	S	2.4	2.7	3.1	3.5	3.9	4.4	5.0	5.5
		C at End	S	2.7	3.1	3.5	4.0	4.4	4.9	5.5	6.0
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

** Surface conditions are assumed to continue on surface beyond slope.

TABLE A.13.5 SUGGESTED SEVERITY INDICES 3/10
Intersecting Slopes - Negative (down) (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition (**)		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Inter-secting Slopes (neg) 1:6 (cont.)	6	A	S	2.2	2.5	2.9	3.3	3.7	4.2	4.9	5.5
		B See Notes	S	2.4	2.7	3.1	3.5	3.9	4.4	5.0	5.6
		C at End	S	2.7	3.1	3.5	4.0	4.4	4.9	5.5	6.0
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥8	A	S	2.2	2.5	2.9	3.3	3.7	4.2	4.9	5.6
		B See Notes	S	2.4	2.7	3.1	3.5	3.9	4.4	5.0	5.7
		C at End	S	2.7	3.1	3.5	4.0	4.4	4.9	5.5	6.0
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Inter-secting Slopes (neg.) 1:4	0.3	A	S	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
		B See Notes	S	2.1	2.2	2.4	2.5	2.7	2.9	3.2	3.5
		C at End	S	2.4	2.6	2.8	3.0	3.2	3.4	3.8	4.2
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	S	2.6	2.8	3.0	3.2	3.4	3.6	4.0	4.4
		B See Notes	S	2.8	3.0	3.2	3.4	3.6	3.9	4.3	4.7
		C at End	S	3.1	3.4	3.6	3.9	4.1	4.4	4.9	5.4
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	2	A	S	3.5	3.7	3.9	4.1	4.3	4.6	5.0	5.4
		B See Notes	S	3.6	3.8	4.0	4.2	4.5	4.8	5.2	5.6
		C at End	S	3.8	4.1	4.3	4.6	5.0	5.3	5.7	6.1
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F
** Surface conditions are assumed to continue on surface beyond slope.

TABLE A.13.5 SUGGESTED SEVERITY INDICES **4/10**
Intersecting Slopes - Negative (down) (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition (**)		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Intersecting Slopes (neg.) 1:4 (cont.)	4	A	S	3.7	4.1	4.5	5.0	5.2	5.5	5.9	6.3
		B See Notes	S	3.8	4.2	4.6	5.1	5.4	5.7	6.1	6.5
		C at End	S	4.0	4.5	5.0	5.5	5.8	6.2	6.6	7.0
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	6	A	S	3.7	4.2	4.7	5.2	5.6	6.0	6.4	6.8
		B See Notes	S	3.8	4.3	4.8	5.3	5.8	6.2	6.6	7.0
		C at End	S	3.9	4.5	5.1	5.7	6.1	6.6	7.0	7.4
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	8	A	S	3.7	4.3	4.8	5.4	5.9	6.4	6.8	7.2
		B See Notes	S	3.8	4.4	4.9	5.5	6.1	6.6	7.0	7.4
		C at End	S	3.9	4.5	5.2	5.8	6.4	7.0	7.4	7.8
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	10	A	S	3.7	4.3	4.8	5.4	6.0	6.6	7.2	7.7
		B See Notes	S	3.8	4.4	4.9	5.5	6.2	6.8	7.3	7.8
		C at End	S	3.9	4.5	5.2	5.8	6.5	7.1	7.5	7.9
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥14	A	S	3.7	4.3	4.8	5.4	6.0	6.6	7.2	7.9
		B See Notes	S	3.8	4.4	4.9	5.5	6.2	6.8	7.4	7.9
		C at End	S	3.9	4.5	5.2	5.8	6.5	7.1	7.5	7.9
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

** Surface conditions are assumed to continue on surface beyond slope.

TABLE A.13.5 SUGGESTED SEVERITY INDICES 5/10
Intersecting Slopes - Negative (down) (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition (**)		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Inter-secting Slopes (neg.) 1:3 (cont.)	0.3	A	S	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
		B See Notes	S	2.1	2.2	2.4	2.5	2.7	2.9	3.2	3.5
		C at End	S	2.4	2.6	2.8	3.0	3.2	3.4	3.8	4.2
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	S	2.7	2.9	3.1	3.3	3.5	3.7	4.0	4.3
		B See Notes	S	2.7	3.0	3.2	3.5	3.6	3.9	4.3	4.7
		C at End	S	3.1	3.4	3.6	3.9	4.1	4.4	4.9	5.4
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	2	A	S	3.8	4.0	4.2	4.4	4.6	4.8	5.1	5.4
		B See Notes	S	3.9	4.1	4.3	4.5	4.7	5.0	5.3	5.6
		C at End	S	4.2	4.4	4.6	4.8	5.0	5.3	5.6	5.9
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	4	A	S	4.8	5.0	5.2	5.4	5.7	6.0	6.2	6.5
		B See Notes	S	4.9	5.1	5.3	5.5	5.9	6.2	6.4	6.7
		C at End	S	5.1	5.3	5.5	5.7	6.1	6.4	6.8	7.2
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	6	A	S	4.9	5.3	5.7	6.1	6.4	6.7	6.9	7.2
		B See Notes	S	5.0	5.4	5.8	6.2	6.6	6.9	7.1	7.4
		C at End	S	5.2	5.6	5.9	6.3	6.7	7.0	7.3	7.7
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

** Surface conditions are assumed to continue on surface beyond slope.

TABLE A.13.5 SUGGESTED SEVERITY INDICES 6/10

Intersecting Slopes - Negative (down) (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition (**)		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Inter-secting Slopes (neg.) 1:3 (cont.)	8	A	S	5.0	5.6	6.1	6.7	7.0	7.3	7.5	7.8
		B See Notes	S	5.1	5.7	6.2	6.8	7.2	7.5	7.7	8.0
		C at End	S	5.2	5.8	6.3	6.9	7.3	7.6	7.8	8.1
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	10	A	S	4.9	5.6	6.3	7.0	7.4	7.8	8.2	8.6
		B See Notes	S	5.0	5.7	6.4	7.1	7.5	7.9	8.3	8.7
		C at End	S	5.1	5.8	6.5	7.2	7.6	8.0	8.4	8.8
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	14	A	S	4.9	5.6	6.3	7.0	7.5	7.9	8.3	8.7
		B See Notes	S	5.0	5.7	6.4	7.1	7.5	7.9	8.3	8.7
		C at End	S	5.1	5.8	6.5	7.2	7.6	8.0	8.4	8.8
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥18	A	S	4.9	5.6	6.3	7.0	7.5	8.0	8.4	8.8
		B See Notes	S	5.0	5.7	6.4	7.1	7.6	8.0	8.4	8.8
		C at End	S	5.1	5.8	6.5	7.2	7.6	8.0	8.4	8.8
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Inter-secting Slopes (neg.) 1:2	0.3	A	S	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
		B See Notes	S	2.1	2.2	2.4	2.5	2.7	2.9	3.2	3.5
		C at End	S	2.4	2.6	2.8	3.0	3.2	3.4	3.8	4.2
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

** *Surface conditions are assumed to continue on surface beyond slope.*

TABLE A.13.5 SUGGESTED SEVERITY INDICES 7/10

Intersecting Slopes - Negative (down) (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
				Design Speed - km/h							
Slope (V:H)	Height (m)	Surface Condition (**)		50	60	70	80	90	100	110	120
Inter-secting Slopes (neg.) 1:2 (cont.)	1	A	S	2.9	3.0	3.2	3.3	3.5	3.7	4.0	4.3
		B See Notes	S	2.9	3.1	3.3	3.5	3.6	3.9	4.3	4.7
		C at End	S	3.3	3.5	3.7	3.9	4.1	4.4	4.9	5.4
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	2	A	S	4.1	4.2	4.4	4.5	4.7	4.9	5.1	5.4
		B See Notes	S	4.1	4.2	4.4	4.5	4.7	5.0	5.3	5.6
		C at End	S	4.2	4.4	4.6	4.8	5.0	5.3	5.6	5.9
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	4	A	S	5.5	5.6	5.6	5.7	5.9	6.2	6.4	6.5
		B See Notes	S	5.5	5.6	5.6	5.7	6.0	6.3	6.5	6.6
		C at End	S	5.6	5.7	5.7	5.8	6.1	6.4	6.6	6.7
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	6	A	S	6.0	6.2	6.4	6.6	6.8	7.1	7.3	7.4
		B See Notes	S	6.0	6.2	6.4	6.6	6.9	7.2	7.4	7.5
		C at End	S	6.1	6.3	6.5	6.7	7.0	7.3	7.5	7.6
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	8	A	S	6.5	6.8	7.1	7.4	7.6	7.9	8.1	8.2
		B See Notes	S	6.5	6.8	7.1	7.4	7.7	8.0	8.2	8.3
		C at End	S	6.6	6.9	7.2	7.5	7.8	8.1	8.3	8.4
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

** Surface conditions are assumed to continue on surface beyond slope.

TABLE A.13.5 SUGGESTED SEVERITY INDICES **8/10**

Intersecting Slopes - Negative (down) (continued)

Object Type and Characteristics			**Object Surface (*)**	**Severity Index**							
Slope (V:H)	Height (m)	Surface Condition (**)		**Design Speed - km/h**							
				50	**60**	**70**	**80**	**90**	**100**	**110**	**120**
Inter-secting Slopes (neg.) 1:2 (cont.)	10	A	S	7.0	7.4	7.8	8.3	8.5	8.7	8.9	9.0
		B See Notes	S	7.0	7.4	7.8	8.3	8.5	8.8	9.0	9.1
		C at End	S	7.1	7.5	7.9	8.4	8.6	8.9	9.1	9.2
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	14	A	S	7.2	7.6	8.0	8.5	8.7	9.0	9.2	9.3
		B See Notes	S	7.2	7.6	8.0	8.5	8.7	9.0	9.2	9.3
		C at End	S	7.2	7.6	8.0	8.5	8.7	9.0	9.2	9.3
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	18	A	S	7.3	7.7	8.1	8.6	8.9	9.1	9.3	9.4
		B See Notes	S	7.3	7.7	8.1	8.6	8.9	9.1	9.3	9.4
		C at End	S	7.3	7.7	8.1	8.6	8.9	9.1	9.3	9.4
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	22	A	S	7.2	7.7	8.2	8.7	8.9	9.1	9.3	9.4
		B See Notes	S	7.2	7.7	8.2	8.7	8.9	9.1	9.3	9.4
		C at End	S	7.2	7.7	8.2	8.7	8.9	9.1	9.3	9.4
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

** Surface conditions are assumed to continue on surface beyond slope.

TABLE A.13.5 SUGGESTED SEVERITY INDICES **9/10**
Intersecting Slopes - Negative (down) (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
				Design Speed - km/h							
Slope (V:H)	Height (m)	Surface Condition (**)		50	60	70	80	90	100	110	120
Inter-secting Slopes (neg.) 1:1½	0.3	A	S	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
		B See Notes	S	2.1	2.2	2.4	2.5	2.7	2.9	3.2	3.5
		C at End	S	2.4	2.6	2.8	3.0	3.2	3.4	3.8	4.2
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	S	2.9	3.0	3.2	3.3	3.5	3.7	4.0	4.3
		B See Notes	S	2.9	3.1	3.3	3.5	3.6	3.9	4.3	4.7
		C at End	S	3.3	3.5	3.7	3.9	4.1	4.4	4.9	5.4
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	2	A	S	4.1	4.2	4.4	4.5	4.7	4.9	5.1	5.4
		B See Notes	S	4.1	4.2	4.4	4.5	4.7	5.0	5.3	5.6
		C at End	S	4.2	4.4	4.6	4.8	5.0	5.3	5.6	5.9
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	4	A	S	5.6	5.7	5.7	5.8	6.0	6.2	6.4	6.5
		B See Notes	S	5.6	5.7	5.7	5.8	6.0	6.3	6.5	6.6
		C at End	S	5.5	5.6	5.8	5.9	6.1	6.4	6.6	6.7
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	6	A	S	6.3	6.5	6.6	6.7	6.9	7.1	7.4	7.4
		B See Notes	S	6.3	6.5	6.6	6.7	6.9	7.2	7.4	7.5
		C at End	S	6.3	6.5	6.6	6.7	6.9	7.2	7.4	7.5
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F
** Surface conditions are assumed to continue on surface beyond slope.

TABLE A.13.5 SUGGESTED SEVERITY INDICES **10/10**
Intersecting Slopes - Negative (down) (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition (**)		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Inter-secting Slopes (neg.) 1:1½ (cont.)	8	A	S	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.3
		B See Notes	S	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.3
		C at End	S	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.3
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	10	A	S	7.9	8.2	8.5	8.8	8.9	8.9	9.1	9.2
		B See Notes	S	7.9	8.2	8.5	8.8	8.9	8.9	9.1	9.2
		C at End	S	7.9	8.2	8.5	8.8	8.9	8.9	9.1	9.2
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	14	A	S	8.3	8.6	8.8	9.1	9.2	9.3	9.5	9.6
		B See Notes	S	8.3	8.6	8.8	9.1	9.2	9.3	9.5	9.6
		C at End	S	8.3	8.6	8.8	9.1	9.2	9.3	9.5	9.6
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	18	A	S	8.5	8.8	9.0	9.3	9.4	9.5	9.5	9.5
		B See Notes	S	8.5	8.8	9.0	9.3	9.4	9.5	9.6	9.6
		C at End	S	8.5	8.8	9.0	9.3	9.4	9.5	9.6	9.6
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥22	A	S	8.6	8.9	9.1	9.4	9.5	9.5	9.6	9.6
		B See Notes	S	8.6	8.9	9.1	9.4	9.5	9.5	9.6	9.6
		C at End	S	8.6	8.9	9.1	9.4	9.5	9.5	9.6	9.6
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

** *Surface conditions are assumed to continue on surface beyond slope.*

TABLE A.13.6 SUGGESTED SEVERITY INDICES

Intersecting Slopes - Vertical Drop W/ and W/o Water Present

Object Type and Characteristics			Object Surface (*)	Severity Index							
				Design Speed - km/h							
Slope (V:H)	Height (m)	Water Depth (m)		50	60	70	80	90	100	110	120
Inter-secting Slope Vertical Drop	0	0	S	0.1	0.2	0.2	0.3	0.4	0.5	0.7	0.8
		1	S	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.7
		2	S	4.3	4.6	4.8	5.1	5.3	5.6	5.8	6.1
		4	S	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.5
		≥6	S	7.5	7.7	7.9	8.1	8.3	8.4	8.6	8.7
	0.3	0	S	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
		1	S	2.6	2.9	3.1	3.4	3.6	3.9	4.1	4.4
		2	S	4.3	4.6	4.9	5.2	5.6	5.9	6.3	6.7
		4	S	6.0	6.3	6.6	6.9	7.1	7.4	7.6	7.9
		≥6	S	7.9	8.0	8.2	8.3	8.5	8.7	8.9	9.0
	1.0	0	S	2.9	3.0	3.2	3.3	3.5	3.7	4.0	4.3
		1	S	3.2	3.4	3.6	3.8	4.0	4.2	4.5	4.8
		2	S	5.4	5.6	5.8	6.0	6.3	6.6	6.8	7.1
		4	S	6.5	6.8	7.0	7.3	7.5	7.7	7.9	8.2
		≥6	S	8.0	8.1	8.3	8.4	8.6	8.8	9.0	9.1
	2.0	0	S	4.1	4.2	4.4	4.5	4.7	4.9	5.1	5.4
		1	S	4.2	4.4	4.6	4.8	5.0	5.2	5.4	5.7
		2	S	6.5	6.6	6.8	6.9	7.1	7.3	7.5	7.6
		4	S	7.3	7.4	7.6	7.7	7.9	8.1	8.3	8.4
		≥6	S	8.1	8.2	8.4	8.5	8.7	8.9	9.1	9.2
	4.0	0	S	5.7	5.8	5.8	5.9	6.0	6.2	6.4	6.5
		1	S	5.7	5.8	6.0	6.1	6.2	6.4	6.7	7.0
		2	S	7.2	7.3	7.5	7.6	7.8	8.0	8.2	8.3
		4	S	7.8	7.9	8.1	8.2	8.4	8.6	8.8	8.9
		≥6	S	8.4	8.5	8.7	8.8	9.0	9.2	9.4	9.5
	≥8.0	Any Depth	S	Use Values From Foreslopes - Vertical							

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.7 SUGGESTED SEVERITY INDICES

Intersecting Slopes - Positive (up) **

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Intersecting Slopes (pos.) 1:10	0.15	A	S	0.3	0.4	0.6	0.7	0.9	1.1	1.3	1.6
		B See Notes	S	0.5	0.6	0.8	0.9	1.1	1.3	1.5	1.8
		C at End	S	0.9	1.0	1.2	1.3	1.5	1.7	2.0	2.3
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	S	0.4	0.5	0.7	0.8	1.2	1.5	1.9	2.3
		B See Notes	S	0.6	0.7	0.9	1.0	1.4	1.7	2.1	2.5
		C at End	S	0.8	1.0	1.2	1.4	1.8	2.1	2.5	2.9
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.6	A	S	0.4	0.5	0.7	0.8	1.2	1.6	2.0	2.4
		B See Notes	S	0.6	0.7	0.9	1.0	1.4	1.8	2.2	2.6
		C at End	S	0.8	1.0	1.2	1.4	1.8	2.2	2.6	3.0
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Intersecting Slopes (pos.) 1:8	0.15	A	S	0.3	0.4	0.6	0.7	0.9	1.1	1.3	1.6
		B See Notes	S	0.5	0.6	0.8	0.9	1.1	1.3	1.5	1.8
		C at End	S	0.9	1.0	1.2	1.3	1.5	1.7	2.0	2.3
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	S	0.4	0.6	0.8	1.0	1.5	2.0	2.2	2.5
		B See Notes	S	0.6	0.8	1.0	1.2	1.7	2.1	2.4	2.7
		C at End	S	0.8	1.1	1.3	1.6	2.1	2.5	2.8	3.1
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

** See note at end of this table for limitation and description of condition.

TABLE A.13.7 SUGGESTED SEVERITY INDICES
Intersecting Slopes - Positive (up) ** (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Inter-secting Slopes (pos.) 1:8 (cont.)	0.6	A	S	0.3	0.6	0.9	1.2	1.7	2.1	2.3	2.4
		B See Notes	S	0.5	0.8	1.0	1.3	1.8	2.2	2.4	2.7
		C at End	S	0.8	1.1	1.4	1.7	2.2	2.6	2.8	3.1
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	S	0.3	0.6	0.9	1.2	1.7	2.1	2.3	2.6
		B See Notes	S	0.5	0.8	1.1	1.4	1.8	2.2	2.5	2.8
		C at End	S	0.7	1.0	1.4	1.8	2.2	2.6	2.9	3.2
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Inter-secting Slopes (pos.) 1:6	0.15	A	S	0.3	0.4	0.6	0.7	0.9	1.1	1.3	1.6
		B See Notes	S	0.5	0.6	0.8	0.9	1.1	1.3	1.5	1.8
		C at End	S	0.7	0.9	1.1	1.3	1.5	1.8	2.0	2.3
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	S	0.5	0.8	1.2	1.6	2.0	2.3	2.6	2.9
		B See Notes	S	0.7	1.0	1.4	1.8	2.1	2.4	2.8	3.2
		C at End	S	1.0	1.3	1.7	2.1	2.4	2.7	3.1	3.5
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.6	A	S	0.5	0.9	1.3	1.8	2.1	2.4	2.7	3.0
		B See Notes	S	0.8	1.1	1.5	1.9	2.2	2.5	2.9	3.3
		C at End	S	1.0	1.4	1.8	2.3	2.5	2.8	3.2	3.6
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F
** See note at end of this table for limitation and description of condition.

TABLE A.13.7 SUGGESTED SEVERITY INDICES

Intersecting Slopes - Positive (up) ** (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Inter-secting Slopes (pos.) 1:6 (cont.)	1	A	S	0.4	0.9	1.4	1.9	2.2	2.5	2.8	3.1
		B See Notes	S	0.7	1.1	1.5	2.0	2.3	2.6	3.0	3.4
		C at End	S	0.9	1.4	1.9	2.4	2.6	2.9	3.3	3.7
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Inter-secting Slopes (pos.) 1:4	0.15	A	S	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.7
		B See Notes	S	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.9
		C at End	S	0.6	0.9	1.1	1.4	1.6	1.8	2.1	2.4
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	S	1.3	1.6	1.9	2.2	2.6	3.0	3.3	3.6
		B See Notes	S	1.5	1.8	2.0	2.3	2.7	3.1	3.5	3.9
		C at End	S	1.8	2.1	2.3	2.6	3.0	3.4	3.8	4.2
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.6	A	S	1.6	1.9	2.1	2.4	2.8	3.2	3.5	3.8
		B See Notes	S	1.7	2.0	2.2	2.5	2.9	3.3	3.6	3.9
		C at End	S	2.2	2.4	2.6	2.8	3.2	3.6	3.9	4.2
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	S	1.6	1.9	2.1	2.4	2.8	3.2	3.6	4.0
		B See Notes	S	1.7	2.0	2.2	2.5	2.9	3.3	3.7	4.1
		C at End	S	2.2	2.4	2.6	2.8	3.2	3.6	4.0	4.4
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

** See note at end of this table for limitation and description of condition.

TABLE A.13.7 SUGGESTED SEVERITY INDICES

Intersecting Slopes - Positive (up) ** (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Inter-secting Slopes (pos.) 1:3	0.15	A	S	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.7
		B See Notes	S	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.9
		C at End	S	0.6	0.9	1.1	1.4	1.6	1.8	2.1	2.4
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	S	1.8	2.1	2.4	2.7	3.1	3.5	3.9	4.3
		B See Notes	S	1.9	2.2	2.5	2.8	3.2	3.6	4.0	4.4
		C at End	S	2.2	2.5	2.8	3.1	3.5	3.9	4.2	4.5
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.6	A	S	1.8	2.1	2.5	2.9	3.3	3.7	4.1	4.5
		B See Notes	S	1.9	2.2	2.6	3.0	3.4	3.8	4.2	4.6
		C at End	S	2.2	2.5	2.9	3.3	3.7	4.0	4.4	4.8
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	S	1.9	2.2	2.6	3.0	3.4	3.8	4.2	4.6
		B See Notes	S	2.0	2.3	2.7	3.1	3.5	3.9	4.3	4.7
		C at End	S	2.1	2.5	2.9	3.4	3.8	4.1	4.5	4.9
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

** See note at end of this table for limitation and description of condition.

TABLE A.13.7 SUGGESTED SEVERITY INDICES Intersecting Slopes - Positive (up) ** (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Inter-secting Slopes (pos.) 1:2	0.15	A	S	0.4	0.5	0.7	0.8	1.0	1.2	1.4	1.7
		B See Notes	S	0.6	0.7	0.9	1.0	1.2	1.4	1.6	1.9
		C at End	S	0.8	1.0	1.2	1.4	1.6	1.8	2.1	2.4
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	S	2.1	2.5	2.9	3.4	3.9	4.4	4.8	5.2
		B See Notes	S	2.2	2.6	3.0	3.5	4.0	4.5	4.9	5.3
		C at End	S	2.3	2.8	3.3	3.8	4.2	4.7	5.1	5.5
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.6	A	S	2.5	2.8	3.2	3.6	4.1	4.6	5.0	5.4
		B See Notes	S	2.6	2.9	3.3	3.7	4.2	4.7	5.1	5.5
		C at End	S	2.8	3.1	3.5	3.9	4.4	4.9	5.3	5.7
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	S	2.6	2.9	3.3	3.7	4.2	4.7	5.1	5.5
		B See Notes	S	2.7	3.0	3.4	3.8	4.3	4.8	5.2	5.6
		C at End	S	2.9	3.2	3.6	4.0	4.5	4.9	5.3	5.7
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

** See note at end of this table for limitation and description of condition.

TABLE A.13.7 SUGGESTED SEVERITY INDICES 6/7

Intersecting Slopes - Positive (up) ** (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
Slope (V:H)	Height (m)	Surface Condition		Design Speed - km/h							
				50	60	70	80	90	100	110	120
Inter-secting Slopes (pos.) 1:½	0.15	A	S	0.4	0.5	0.7	0.8	1.0	1.3	1.5	1.8
		B See Notes	S	0.6	0.7	0.9	1.0	1.2	1.5	1.7	2.0
		C at End	S	0.8	1.0	1.2	1.4	1.6	1.9	2.1	2.4
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	S	2.4	2.9	3.4	3.9	4.3	4.8	5.3	5.8
		B See Notes	S	2.5	3.0	3.5	4.0	4.4	4.9	5.4	5.9
		C at End	S	2.7	3.2	3.7	4.2	4.6	5.1	5.5	5.9
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.6	A	S	2.6	3.1	3.6	4.1	4.6	5.2	5.6	6.0
		B See Notes	S	2.7	3.2	3.7	4.2	4.7	5.3	5.7	6.1
		C at End	S	2.9	3.4	3.9	4.4	4.9	5.4	5.8	6.2
		D of Table	S	2.9	3.4	3.9	4.4	4.9	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	S	2.7	3.2	3.7	4.2	4.7	5.3	5.7	6.1
		B See Notes	S	2.8	3.3	3.8	4.3	4.8	5.4	5.8	6.2
		C at End	S	3.0	3.5	4.0	4.5	5.0	5.5	5.9	6.3
		D of Table	S	3.0	3.5	4.0	4.5	5.0	5.5	5.9	6.3
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

** See note at end of this table for limitation and description of condition.

TABLE A.13.7 SUGGESTED SEVERITY INDICES

Intersecting Slopes - Positive (up) ** (continued)

Object Type and Characteristics			Object Surface (*)	Severity Index							
				Design Speed - km/h							
Slope (V:H)	Height (m)	Surface Condition		50	60	70	80	90	100	110	120
Inter-secting Slopes (pos.) 1:1	0.15	A	S	0.4	0.5	0.7	0.8	1.0	1.3	1.5	1.8
		B See Notes	S	0.6	0.7	0.9	1.0	1.2	1.5	1.7	2.0
		C at End	S	0.8	1.0	1.2	1.4	1.6	1.9	2.1	2.4
		D of Table	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	S	2.9	3.3	3.7	4.2	4.7	5.3	5.8	6.3
		B See Notes	S	3.0	3.4	3.8	4.3	4.8	5.4	5.8	6.2
		C at End	S	3.2	3.6	4.0	4.5	5.0	5.5	5.9	6.3
		D of Table	S	3.2	3.6	4.0	4.5	5.0	5.5	5.9	6.4
		E A.13.1	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.6	A	S	3.0	3.5	4.0	4.5	5.0	5.6	6.2	6.7
		B See Notes	S	3.1	3.6	4.1	4.6	5.1	5.6	6.2	6.7
		C at End	S	3.3	3.8	4.3	4.8	5.2	5.7	6.3	6.8
		D of Table	S	3.3	3.8	4.3	4.8	5.2	5.7	6.3	6.8
		E A.13.1	S	3.3	3.8	4.3	4.8	5.2	5.7	6.3	7.0
	1	A	S	3.1	3.6	4.1	4.6	5.1	5.7	6.3	6.8
		B See Notes	S	3.2	3.7	4.2	4.7	5.2	5.7	6.3	6.8
		C at End	S	3.4	3.9	4.4	4.9	5.3	5.8	6.4	6.9
		D of Table	S	3.4	3.9	4.4	4.9	5.3	5.8	6.4	6.9
		E A.13.1	S	3.4	3.9	4.4	4.9	5.3	5.8	6.4	6.9

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

** The condition addressed in this table is a relatively simple one where the vehicle encounters an intersecting upward slope that connects to a relatively level and wide surface at its upper limit. Transitions between foreslope or backslope and intersecting slopes are not addressed, nor is the condition where a vehicle might vault over a dike or a narrow intersecting roadway. Developing SIs for the conditions not addressed will require special analysis and engineering judgement.

TABLE A.13.8 SUGGESTED SEVERITY INDICES

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Traffic Barriers

Object Type and Characteristics	Object Surface (*)	Severity Index							
		Design Speed - km/h							
		50	60	70	80	90	100	110	120
Longitudinal Traffic Barriers									
Uniform Section									
Basic SI For all currently accepted barriers, guardrails, bridgerails, median barriers, apply the basic SI to that percentage of impacts estimated to be contained by the barrier. For that percentage of impacts estimated to penetrate an SI appropriate for the shielded hazard should be used to adjust the effective barrier SI.	F	1.9	2.0	2.2	2.3	2.5	2.7	3.0	3.3
Basic SI Non-blocked out w-beam on strong posts with 1.9-m post spacings (adjust for estimated penetrations)	F	2.0	2.1	2.3	2.4	2.7	3.0	3.3	3.6
Basic SI Cable on strong posts (adjust for estimated penetrations)	F	2.0	2.2	2.4	2.6	2.8	3.1	3.4	3.7
For walls and parapets with irregular surfaces estimate SIs by referring to vertical backslopes	F	-	-	-	-	-	-	-	-
Guardrail to Parapet Transitions									
Treat the same as currently acceptable longitudinal barriers if transition meets crash test acceptance requirements and adjust for estimated penetrations	F	1.9	2.0	2.2	2.3	2.5	2.7	3.0	3.3

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.8 SUGGESTED SEVERITY INDICES 2/4
Traffic Barriers (continued)

Object Type and Characteristics	Object Surface (*)	Severity Index							
		Design Speed - km/h							
		50	60	70	80	90	100	110	120
Guardrail to Parapet Transitions (cont.)									
For substandard transitions consider a section of the face of the approach guardrail as having the severity of a fixed object. This section of barrier would nominally be part of a continuous barrier face, thus the corner and side SIs would be zero.									
Examples: Standard, strong-post, w-beam guardrail, blocked out with two spaces at 0.95-m and full-strength attachment to parapet	F	0.1m @ 1.8**	0.1m @ 2.0	0.3m @ 2.2	0.4m @ 2.4	0.7m @ 2.6	1.1m @ 2.9	1.6m @ 3.2	2.0m @ 3.5
Standard, strong-post, w-beam guardrail, blocked out, with 1.9-m post spacing and no connection to parapet	F	0.4m @ 2.0	0.7m @ 2.3	1.1m @ 2.5	1.5m @ 2.8	2.1m @ 3.2	2.7m @ 3.5	3.5m @ 3.9	4.2m @ 4.3
Three cable guardrail, 4.88-m post spacing, attached to parapet end	F	2.4m @ 3.0	2.8m @ 3.4	3.3m @ 3.8	3.8m @ 4.3	4.5m @ 4.8	5.5m @ 5.4	6.9m @ 6.0	8.4m @ 6.5
Terminals (approach end except where noted)									
Stand-up w-beam, unanchored, with no safety treatment and no flare. The first few feet of the unanchored rail will have diminished effectiveness and have a higher SI than the remainder of the guardrail. The values given here for that section of guardrail may require adjustment for penetration to the shielded object.	C&S	4.1	4.3	4.5	4.7	5.0	5.3	5.6	5.9
	F	1.0m @ 2.2	1.6m @ 2.5	2.1m @ 2.7	2.7m @ 3.0	3.3m @ 3.2	4.1m @ 3.4	5.2m @ 3.8	6.3m @ 4.2
BCT <u>without</u> diaphragms (properly installed with recommended flare)	C&S	3.0	3.3	3.6	3.9	4.1	4.3	4.5	4.8
	F	1.8m @ 2.1	1.8m @ 2.3	1.8m @ 2.5	1.8m @ 2.7	1.8m @ 2.9	1.8m @ 3.2	1.8m @ 3.5	1.8m @ 3.8
Turned-down w-beam (7.5-m twist)	C&S	2.7	2.9	3.1	3.3	3.7	4.0	4.3	4.6
	F	5.5m @ 2.8	5.5m @ 3.0	5.5m @ 3.2	5.5m @ 3.4	5.5m @ 3.8	5.5m @ 4.1	5.5m @ 4.4	5.5m @ 4.7

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F
** Dimension above "@" sign is length of device to be analyzed using the noted severity index.

TABLE A.13.8 SUGGESTED SEVERITY INDICES 3/4
Traffic Barriers (continued)

Object Type and Characteristics	Object Surface (*)	Severity Index							
		Design Speed - km/h							
		50	60	70	80	90	100	110	120
Terminals (cont.)									
Three cable, wood post guardrail terminal with cables anchored to end post and end post restrained by rod attached to a deadman. Approach end.	C&S	3.0	3.3	3.5	3.8	4.2	4.6	5.0	5.4
Exit end (treat as fixed object)	C&S	2.7	3.1	3.5	4.0	4.5	5.0	5.5	6.0
BCT with diaphragm (properly installed with recommended flare)	C&S	2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.4
	F	2m @ 2.1	2m @ 2.3	2m @ 2.5	2m @ 2.7	2m @ 2.9	2m @ 3.2	2m @ 3.5	2m @ 3.8
CAT, ET2000, Brakemaster, MELT	C&S	2.0	2.2	2.4	2.6	2.9	3.2	3.5	3.8
	F	2m @ 2.1	2m @ 2.3	2m @ 2.5	2m @ 2.7	2m @ 2.9	2m @ 3.2	2m @ 3.5	2m @ 3.8
Buried in backslope - The SI components for this type of terminal will be dependent on the configuration of the backslope, the ditch cross section, the terminus flare rate, and the conditions reachable by vehicles penetrating the terminal area. Values given here assume a 1:3 backslope paralleling the roadway at the point of burial, top of guardrail parallels the roadway at point of burial, top of guardrail parallels the roadway grade, the ditch is modified to provide a berm for carrying the flaring guardrails, grading approaching the berm is sufficiently gentle to have minimal effect on approach vehicle trajectory, and the guardrail at flare rates for 50, 60, 70, 80, 90, 100, 110, and 120 km/h are 9:1, 10:1, 11:1, 12:1, 13:1, 14:1, 15:1, and 16:1 respectively.	C&S	0.6	0.7	0.9	1.0	1.2	1.5	1.7	2.0
	F	4m @ 2.0	4m @ 2.2	4m @ 2.4	4m @ 2.6	4m @ 2.8	4m @ 3.1	4m @ 3.3	4m @ 3.6

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

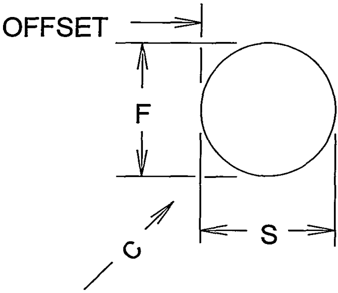
TABLE A.13.8 SUGGESTED SEVERITY INDICES 4/4

Traffic Barriers (continued)

Object Type and Characteristics	Object Surface (*)	Severity Index							
		Design Speed - km/h							
		50	60	70	80	90	100	110	120
Terminals (Approach end except where noted)(cont.)									
Three-cable, steel post guardrail terminal with 5.5-m turndown and non-snag release feature for exit end impacts	C&S	1.9	2.0	2.2	2.3	2.5	2.7	3.0	3.3
	F	3m @ 2.0	3m @ 2.1	3m @ 2.3	3m @ 2.4	3m @ 2.6	3m @ 2.8	3m @ 3.1	3m @ 3.4
Eccentric Loader Terminal	C&S	2.0	2.2	2.4	2.6	2.8	3.1	3.4	3.7
	F	2m @ 2.1	2m @ 2.3	2m @ 2.5	2m @ 2.7	2m @ 2.9	2m @ 3.2	2m @ 3.5	2m @ 3.8
SENTRE	C&S	2.1	2.2	2.4	2.5	2.7	3.0	3.3	3.6
	F	2m @ 1.9	2m @ 2.0	2m @ 2.2	2m @ 2.3	2m @ 2.5	2m @ 2.7	2m @ 2.9	2m @ 3.2
Crash Cushions									
Redirecting - Design meets recommended performance requirements.	C&S	2.1	2.2	2.4	2.5	2.7	3.0	3.3	3.6
	F	1.9	2.0	2.2	2.3	2.5	2.8	3.1	3.4
Non-Redirecting - Design meets recommended performance requirements, sand barrels have recommended 0.75-m shadow offset at rear of array - treat a section of the face at the rear of the array as having higher SI than that assigned to the remainder of the crash cushion. Consider section as part of a continuous barrier face. Thus the corner and side SIs of the section equal zero.	C&S	1.9	2.0	2.2	2.3	2.5	2.8	3.1	3.4
	F	0.2m @ 3.3	0.3m @ 3.6	0.5m @ 3.9	1.0m @ 4.2	1.5m @ 4.6	2.3m @ 5.1	2.7m @ 5.6	3.3m @ 6.1

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.9 SUGGESTED SEVERITY INDICES 1/4
Fixed Objects

Object Type and Characteristics		Object Surface (*)	Severity Index							
			Design Speed - km/h							
			50	60	70	80	90	100	110	120
Round  	Diameter equal to 0.5 m	S	3.0	3.4	3.8	4.3	4.8	5.4	6.0	6.5
		C	3.4	3.8	4.2	4.7	5.2	5.8	6.5	7.2
		F	2.6	3.0	3.4	3.9	4.4	4.9	5.3	5.7
	Diameter equal to 1 m	S	2.8	3.3	3.8	4.3	4.8	5.3	5.9	6.4
		C	3.3	3.7	4.1	4.6	5.1	5.7	6.4	7.1
		F	2.5	2.9	3.3	3.8	4.3	4.7	5.0	5.3
	Diameter equal to or greater than 2 m	S	2.7	3.2	3.7	4.2	4.7	5.3	5.9	6.4
		C	3.2	3.6	4.0	4.5	5.0	5.6	6.3	7.0
		F	2.6	2.9	3.3	3.7	4.2	4.7	5.2	5.7
Rectangular: Width of approach side equal to 0.5 m Face parallel to roadway, sides are perpendicular.	Height = 0.15 m	S	0.2	0.3	0.5	0.6	0.7	0.8	0.9	0.9
		C	0.2	0.3	0.5	0.6	0.7	0.8	0.9	0.9
		F	0.4	0.5	0.7	0.8	1.0	1.2	1.4	1.5
	Height = 0.3 m	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		C	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		F	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
	Height = 0.5 m	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	6.8
		C	3.2	3.6	4.0	4.5	5.1	5.7	6.3	6.8
		F	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
	Height = 0.6 m	S	3.4	3.8	4.2	4.7	5.2	5.8	6.5	7.2
		C	3.4	3.8	4.2	4.7	5.2	5.8	6.5	7.2
		F	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
	Height > 1.0 m	S	3.4	3.9	4.4	4.9	5.4	6.0	6.7	7.4
		C	3.4	3.9	4.4	4.9	5.4	6.0	6.7	7.4
		F	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.9 SUGGESTED SEVERITY INDICES

2/4

Fixed Objects (continued)

Object Type and Characteristics		Object Surface (*)	Severity Index							
			Design Speed - km/h							
			50	60	70	80	90	100	110	120
Rectangular: Width of approach side is 1.25 m. Face is parallel to roadway, sides are perpendicular.	Height = 0.15 m	S	0.5	0.6	0.8	0.9	1.1	1.3	1.5	1.8
		C	0.5	0.6	0.8	0.9	1.1	1.3	1.5	1.8
		F	0.4	0.5	0.7	0.8	1.0	1.2	1.4	1.5
	Height = 0.3 m	S	2.6	3.2	3.7	4.3	4.8	5.3	5.8	6.3
		C	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		F	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
	Height = 0.5 m	S	3.0	3.5	4.0	4.5	5.0	5.6	6.2	6.7
		C	3.2	3.6	4.0	4.5	5.1	5.7	6.3	6.8
		F	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
	Height = 0.6 m	S	3.1	3.6	4.1	4.6	5.1	5.7	6.4	7.1
		C	3.4	3.8	4.2	4.7	5.2	5.8	6.5	7.2
		F	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
	Height > 1.0 m	S	3.3	3.8	4.3	4.8	5.3	5.9	6.6	7.3
		C	3.4	3.9	4.4	4.9	5.4	6.0	6.7	7.4
		F	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.9 SUGGESTED SEVERITY INDICES 3/4
Fixed Objects (continued)

Object Type and Characteristics		Object Surface (*)	Severity Index							
			Design Speed - km/h							
			50	60	70	80	90	100	110	120
Rectangular: Width of approach side is 2 m or greater. Face is parallel to traffic and sides are perpendicular.	Height = 0.15 m	S	0.5	0.7	0.9	1.1	1.3	1.6	1.9	2.2
		C	0.5	0.7	0.9	1.1	1.3	1.6	1.9	2.2
		F	0.4	0.5	0.7	0.8	1.0	1.2	1.4	1.5
	Height = 0.3 m	S	2.5	3.1	3.6	4.2	4.7	5.3	5.8	6.3
		C	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		F	1.9	2.0	2.2	2.3	2.5	2.7	3.0	3.3
	Height = 0.5 m	S	2.9	3.4	3.9	4.4	4.9	5.5	6.1	6.6
		C	3.2	3.6	4.0	4.5	5.1	5.7	6.3	6.8
		F	1.9	2.0	2.2	2.3	2.5	2.7	3.0	3.3
	Height = 0.6 m	S	2.8	3.4	4.1	4.7	5.1	5.6	6.3	7.0
		C	3.5	3.8	4.2	4.6	5.2	5.8	6.5	7.2
		F	1.9	2.0	2.2	2.3	2.5	2.7	3.0	3.3
	Height > 1.0 m	S	3.2	3.7	4.2	4.7	5.2	5.8	6.5	7.2
		C	3.4	3.9	4.4	4.9	5.4	6.0	6.7	7.4
		F	1.9	2.0	2.2	2.3	2.5	2.7	3.0	3.3
Trees	Diameter = 50 mm	A	0.2	0.3	0.3	0.4	0.5	0.5	0.7	0.8
	Diameter = 100 mm	A	1.0	1.1	1.1	1.2	1.3	1.5	1.7	2.0
	Diameter = 150 mm	A	2.5	2.6	2.6	2.7	2.9	3.0	3.2	3.3
	Diameter = 200 mm	A	3.2	3.5	3.7	4.0	4.3	4.6	5.0	5.4
	Diameter = 250 mm	A	3.2	3.6	4.0	4.5	5.0	5.6	6.2	6.7
	Diameter = 300 mm	A	3.3	3.7	4.1	4.6	5.1	5.7	6.4	7.1
	Diameter > 300 mm	A	3.4	3.8	4.2	4.7	5.2	5.8	6.5	7.2

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.9 SUGGESTED SEVERITY INDICES 4/4

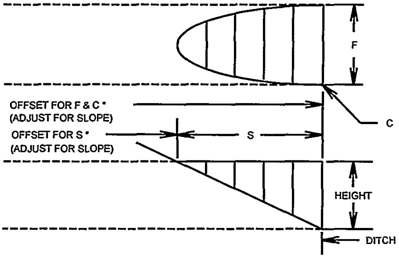
Fixed Objects (continued)

Object Type and Characteristics		Object Surface (*)	Severity Index							
			Design Speed - km/h							
			50	60	70	80	90	100	110	120
Utility Poles (Wooden)	Diameter = 200 mm	A	3.1	3.4	3.6	3.9	4.2	4.5	4.9	5.3
	Diameter = 250 mm	A	3.1	3.5	3.9	4.4	4.9	5.5	6.1	6.6
	Diameter = 300 mm	A	3.3	3.7	4.1	4.6	5.1	5.6	6.3	7.0
	Diameter > 300 mm	A	3.4	3.8	4.2	4.7	5.2	5.8	6.5	7.2
Breakaway Supports with 35 km/h crash test velocity change of:	1.5 meters/second	A	0.9	1.0	1.2	1.3	1.4	1.6	1.8	1.9
	3.0 meters/second	A	1.4	1.5	1.7	1.8	1.9	2.1	2.3	2.6
	4.5 meters/second	A	1.8	2.0	2.2	2.4	2.5	2.7	2.9	3.2
	6.1 meters/second	A	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.8
	7.6 meters/second	A	2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.4

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.10 SUGGESTED SEVERITY INDICES 1/5

Culverts

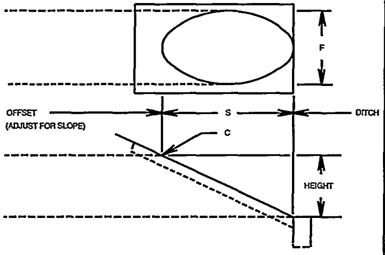
Object Type and Characteristics		Object Surface (*)	Severity Index							
			Design Speed - km/h							
Description	Height		50	60	70	80	90	100	110	120
Culvert Ends: Culvert Axis Transverse to traffic Culvert End Type A (See sketch below.)  * ANALYSIS SHOULD BE DONE IN TWO STEPS AND THE RESULTS COMBINED. (SEE TEXT)	0.3 m	S	0.4	0.5	0.7	0.8	0.9	1.1	1.3	1.4
		C	1.4	1.7	2.0	2.3	2.7	3.1	3.4	3.7
		F	2.3	2.6	2.9	3.2	3.4	3.7	4.0	4.3
	0.5 m	S	0.6	0.7	0.9	1.0	1.2	1.4	1.6	1.7
		C	1.7	2.1	2.5	3.0	3.4	3.8	4.3	4.8
		F	2.1	2.4	2.8	3.2	3.4	3.6	4.0	4.4
	0.6 m	S	1.5	1.8	2.2	2.6	2.9	3.2	3.6	4.0
		C	1.9	2.5	3.2	3.8	4.3	4.8	5.3	5.8
		F	2.2	2.5	2.8	3.1	3.3	3.6	4.0	4.4
	1.0 m	S	2.1	2.5	2.9	3.4	3.8	4.2	4.7	5.2
		C	2.0	2.6	3.1	3.7	4.3	4.9	5.5	6.0
		F	2.2	2.5	2.8	3.1	3.5	3.8	4.1	4.4
	1.2 m	S	2.6	3.0	3.4	3.9	4.3	4.8	5.4	5.9
		C	1.6	2.2	2.9	3.5	4.2	4.8	5.4	6.1
		F	2.1	2.5	2.9	3.4	3.8	4.1	4.3	4.6
	1.8 m	S	2.9	3.3	3.7	4.2	4.7	5.2	5.8	6.5
		C	1.1	1.8	2.5	3.2	3.9	4.5	5.1	5.8
		F	1.6	2.1	2.6	3.1	3.4	3.8	4.2	4.6
	2.4 m	S	3.0	3.5	4.0	4.5	5.0	5.6	6.2	6.7
		C	0.2	1.0	1.9	2.7	3.4	4.1	4.7	5.4
		F	1.5	1.9	2.3	2.8	3.3	3.7	4.1	4.5

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.10 SUGGESTED SEVERITY INDICES

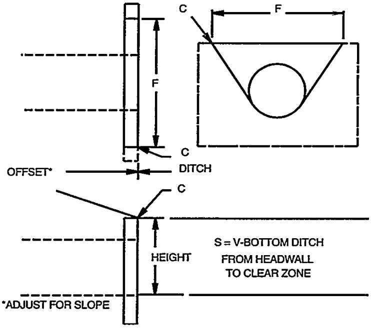
2/5

Culverts (continued)

Object Type and Characteristics		**Object Surface (*)**	**Severity Index**							
			Design Speed - km/h							
Description	Height		**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**
Culvert Ends: Culvert Axis Transverse to traffic (cont.) Culvert End Type B (See sketch below.)  	0.3 m	S,C,& F	0.2	0.3	0.5	0.6	0.8	1.0	1.3	1.6
	0.5 m	S,C,& F	0.4	0.5	0.7	0.8	1.2	1.6	2.0	2.4
	0.6 m	S,C,& F	0.3	0.6	0.9	1.2	1.7	2.1	2.3	2.6
	1.0 m	S,C,& F	0.5	1.0	1.5	2.0	2.3	2.6	3.0	3.4
	1.2 m	S,C,& F	1.5	1.8	2.1	2.4	2.8	3.2	3.6	4.0
	1.8 m	S,C,& F	1.9	2.3	2.7	3.2	3.7	4.1	4.5	4.9
	2.4 m	S,C,& F	2.5	2.9	3.3	3.8	4.3	4.8	5.3	5.8

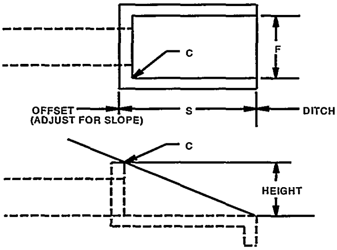
* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.10 SUGGESTED SEVERITY INDICES 3/5
Culverts (continued)

Object Type and Characteristics		Object Surface (*)	Severity Index							
			Design Speed - km/h							
Description	Height		50	60	70	80	90	100	110	120
Culvert Ends: Culvert Axis Transverse to traffic (cont.) Culvert End Type C (See sketch below.)  	0.3 m	C,S	2.4	2.7	3.0	3.3	3.6	3.9	4.3	4.7
		F	2.1	2.4	2.7	3.0	3.3	3.6	3.8	4.1
	0.5 m	C,S	3.0	3.3	3.5	3.8	4.1	4.4	4.6	4.9
		F	2.6	2.9	3.1	3.4	3.6	3.9	4.1	4.4
	0.6 m	C,S	3.2	3.5	3.8	4.1	4.4	4.7	5.0	5.3
		F	2.8	3.1	3.3	3.6	3.8	4.1	4.3	4.6
	1.0 m	C,S	3.9	4.2	4.5	4.8	5.0	5.3	5.5	5.8
		F	3.0	3.3	3.6	3.9	4.1	4.4	4.6	4.9
	1.2 m	C,S	4.3	4.5	4.7	4.9	5.2	5.5	5.8	6.1
		F	3.5	3.7	3.9	4.1	4.3	4.6	4.8	5.1
	1.8 m	C,S	4.8	5.0	5.2	5.4	5.7	6.0	6.3	6.6
		F	4.0	4.2	4.4	4.6	4.8	5.1	5.3	5.6
	2.4 m	C,S	5.2	5.4	5.6	5.8	6.0	6.3	6.6	6.9
		F	4.6	4.7	4.9	5.0	5.2	5.5	5.7	6.0

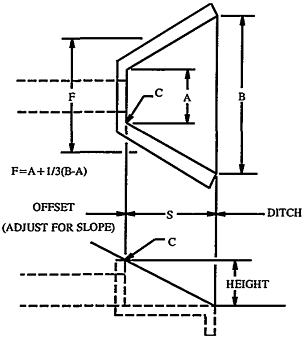
* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.10 SUGGESTED SEVERITY INDICES 4/5
Culverts (continued)

Object Type and Characteristics		Object Surface (*)	Severity Index							
			Design Speed - km/h							
Description	Height		50	60	70	80	90	100	110	120
Culvert Ends: Culvert Axis Transverse to traffic Culvert End Type D (See sketch below.) 	0.3 m	S,C,& F	1.2	1.4	1.6	1.8	2.0	2.3	2.6	2.9
	0.5 m	S,C,& F	1.5	1.7	1.9	2.1	2.4	2.8	3.5	4.2
	0.6 m	S,C,& F	1.6	1.9	2.1	2.4	2.8	3.1	3.3	3.6
	1.0 m	S,C,& F	1.7	2.1	2.5	3.0	3.2	3.5	3.8	4.1
	1.2 m	S,C,& F	2.4	2.7	3.0	3.3	3.6	3.9	4.2	4.5
	1.8 m	S,C,& F	3.0	3.3	3.6	3.9	4.3	4.6	4.9	5.2
	2.4 m	S,C,& F	3.3	3.6	4.0	4.4	4.8	5.1	5.5	5.9

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

TABLE A.13.10 SUGGESTED SEVERITY INDICES 5/5
Culverts (continued)

Object Type and Characteristics		Object Surface (*)	Severity Index							
			Design Speed - km/h							
Description	Height		50	60	70	80	90	100	110	120
Culvert Ends: Culvert Axis Transverse to traffic Culvert End Type E (See sketch below.) 	0.3 m	S	1.8	2.1	2.3	2.6	2.9	3.1	3.3	3.4
		C	2.2	2.5	2.8	3.1	3.4	3.7	3.9	4.2
		F	1.8	2.0	2.2	2.4	2.7	3.0	3.2	3.3
	0.5 m	S	2.5	2.7	2.9	3.1	3.2	3.4	3.7	4.0
		C	3.0	3.2	3.4	3.6	3.8	4.1	4.3	4.6
		F	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.8
	0.6 m	S	2.6	2.8	3.0	3.2	3.4	3.7	4.0	4.3
		C	3.0	3.3	3.5	3.8	4.0	4.3	4.6	4.9
		F	2.3	2.6	2.8	3.1	3.3	3.5	3.8	4.1
	1.0 m	S	2.7	3.0	3.4	3.8	4.0	4.2	4.4	4.5
		C	3.3	3.6	4.0	4.4	4.6	4.8	5.0	5.3
		F	2.7	3.0	3.3	3.6	3.8	4.0	4.2	4.3
	1.2 m	S	3.3	3.5	3.7	3.9	4.1	4.3	4.6	4.9
		C	3.9	4.1	4.3	4.5	4.7	5.0	5.3	5.6
		F	3.1	3.3	3.5	3.7	3.9	4.1	4.4	4.7
	1.8 m	S	3.9	4.0	4.2	4.3	4.5	4.8	5.1	5.4
		C	4.4	4.6	4.8	5.0	5.2	5.5	5.8	6.1
		F	3.7	3.8	4.0	4.1	4.3	4.6	4.9	5.2
	2.4 m	S	4.3	4.4	4.6	4.7	4.9	5.1	5.2	5.2
		C	5.0	5.1	5.3	5.4	5.6	5.8	6.0	6.1
		F	4.1	4.2	4.4	4.5	4.7	4.9	5.0	5.0

* S = Approach Side, C = Corner, F = Traffic Face, A = S,C, and F

Note: The ditch beyond the culvert end is also an obstacle and should be accounted for in an economic analysis and in locating guardrail.

A4.10 ITEM 10: PROJECT LIFE AND DISCOUNT RATE

The analysis period, or project life, will usually be taken as the expected service life of a feature. The unit is years. The minimum unit ROADSIDE recognizes is one year and only whole years are acceptable. If an analysis period of less than a year or fractional years is desired, the program can be used by converting all the time-dependent input variables and output results to a new unit of time—tenths of year, months, quarters, etc. Input items that must be converted are: 2- Traffic Growth, 10- Discount Rate, 13- Maintenance Cost, and Global Value 7- Encroachment Rate. Of course, the project life input at Item 10 would be in the selected units. The results for comparable times using different units will differ slightly because of the effect of compounding.

The discount rate is used to account for the time value of resources in calculating the present worth of highway department and accident costs. Many analysts of public investment believe the default 4.0 percent per year is a reasonable rate. Usually the interest rates in the financial markets are much too high because they include an inflation element that would need to be normalized out if they were to be used in the economic analyses performed by ROADSIDE.

The traffic cutoff year reported on the screen at this item location is the year at which the traffic will reach the per-lane traffic cap value set for the input design speed. It is a calculated value determined by the input traffic volume, number of lanes, the traffic growth rate, and, of course, the per-lane traffic cap. The formula for calculating the cap year is the following:

$\text{Cap Year} = \log(\text{ADT}_{\text{Limit}}/\text{ADT}_{\text{Initial}}/\text{Num Lanes})/\log(1+\text{TGR})$
$\text{ADT}_{\text{Limit}}$ = per-lane traffic volume cap (vpd)
$\text{ADT}_{\text{Initial}}$ = total initial traffic volume (vpd)
Num Lanes = total number of lanes

Four constants (CRF, KC, KT, and KJ) generated by ROADSIDE and used in the program in various calculations are also displayed at this item. These economic factors are calculated based on the project life, discount rate, and the traffic growth rate. These factors are:

$$\text{CRF} = \text{DR}/[(1-(1+\text{DR})^{-\text{PL}}]$$

CRF (capital recovery factor) converts present worth costs to annualized costs.

$$\text{KC} = \sum_{i=1}^{\text{PL}} \frac{(1+\text{TGR})^{(i+0.5)}}{(1+\text{DR})^{\text{PL}}}$$

KC converts initial accident and repair costs to project present worth costs.

$$\text{KT} = [1-(1+\text{DR})^{-\text{PL}}]/\text{DR}$$

KT converts fixed annual maintenance cost to present worth cost.

$$\text{KJ} = (1+\text{DR})^{-\text{PL}}$$

KJ converts salvage value (cost) to present worth (cost).

Where: DR = Discount rate
PL = Project life
TGR = Traffic growth rate

Note: If PL exceeds the traffic cap year, TGR = 0 in years beyond the traffic cap year and:

$$\text{KC} = \sum_{i=1}^{\text{CapYr}} \frac{(1+\text{TGR})^{(i+0.5)}}{(1+\text{DR})^{i}} + \sum_{i=\text{CapYr}+1}^{\text{PL}} \frac{(1+\text{TGR})^{\text{CapYr}}}{(1+\text{DR})^{i}}$$

Tables A.14 through A.17, respectively, present values for CRF, KC, KT, and KJ. These values are not needed as input to ROADSIDE but will be useful in performing manual economic analyses of roadside features.

To use Table A.15 to determine a KC value when the project life exceeds the cap year, do the following:

1. Using the table for 0% traffic growth rate, subtract the value for the appropriate discount rate and the cap year from the corresponding value at the project life.
2. Multiply the value calculated in step 1 by $(1+TGR)^{CapYr}$ Note: TGR is a ratio.
3. Using the table for the case study traffic growth rate, for the appropriate discount rate, determine the KC value for the cap year.
4. Add the values obtained in steps 2 and 3 to obtain the KC values for the case study.

Of course, if the initial per-lane traffic volume exceeds the per-lane traffic volume cap, the KC values can be read directly from Table 15 under the zero traffic growth rate section.

TABLE A.14 Capital Recovery Factor (CRF)

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

TABLE A.15 Values of KC

0 % Traffic Growth Rate

Project Life (Years)	Discount Rate (Percent)										
	0.000	1.000	2.000	3.000	4.000	5.000	6.000	7.000	8.000	9.000	10.000
1	1.000	0.990	0.980	0.971	0.962	0.952	0.943	0.935	0.926	0.917	0.909
2	2.000	1.970	1.942	1.913	1.886	1.859	1.833	1.808	1.783	1.759	1.736
3	3.000	2.941	2.884	2.829	2.775	2.723	2.673	2.624	2.577	2.531	2.487
4	4.000	3.902	3.808	3.717	3.630	3.546	3.465	3.387	3.312	3.240	3.170
5	5.000	4.853	4.713	4.580	4.452	4.329	4.212	4.100	3.993	3.890	3.791
6	6.000	5.795	5.601	5.417	5.242	5.076	4.917	4.767	4.623	4.486	4.355
7	7.000	6.728	6.472	6.230	6.002	5.786	5.582	5.389	5.206	5.033	4.868
8	8.000	7.652	7.325	7.020	6.733	6.463	6.210	5.971	5.747	5.535	5.335
9	9.000	8.566	8.162	7.786	7.435	7.108	6.802	6.515	6.247	5.995	5.759
10	10.000	9.471	8.983	8.530	8.111	7.722	7.360	7.024	6.710	6.418	6.145
11	11.000	10.368	9.787	9.253	8.760	8.306	7.887	7.499	7.139	6.805	6.495
12	12.000	11.255	10.575	9.954	9.385	8.863	8.384	7.943	7.536	7.161	6.814
13	13.000	12.134	11.348	10.635	9.986	9.394	8.853	8.358	7.904	7.487	7.103
14	14.000	13.004	12.106	11.296	10.563	9.899	9.295	8.745	8.244	7.786	7.367
15	15.000	13.865	12.849	11.938	11.118	10.380	9.712	9.108	8.559	8.061	7.606
16	16.000	14.718	13.578	12.561	11.652	10.838	10.106	9.447	8.851	8.313	7.824
17	17.000	15.562	14.292	13.166	12.166	11.274	10.477	9.763	9.122	8.544	8.022
18	18.000	16.398	14.992	13.754	12.659	11.690	10.828	10.059	9.372	8.756	8.201
19	19.000	17.226	15.678	14.324	13.134	12.085	11.158	10.336	9.604	8.950	8.365
20	20.000	18.046	16.351	14.877	13.590	12.462	11.470	10.594	9.818	9.129	8.514
21	21.000	18.857	17.011	15.415	14.029	12.821	11.764	10.836	10.017	9.292	8.649
22	22.000	19.660	17.658	15.937	14.451	13.163	12.042	11.061	10.201	9.442	8.772
23	23.000	20.456	18.292	16.444	14.857	13.489	12.303	11.272	10.371	9.580	8.883
24	24.000	21.243	18.914	16.936	15.247	13.799	12.550	11.469	10.529	9.707	8.985
25	25.000	22.023	19.523	17.413	15.622	14.094	12.783	11.654	10.675	9.823	9.077
26	26.000	22.795	20.121	17.877	15.983	14.375	13.003	11.826	10.810	9.929	9.161
27	27.000	23.560	20.707	18.327	16.330	14.643	13.211	11.987	10.935	10.027	9.237
28	28.000	24.316	21.281	18.764	16.663	14.898	13.406	12.137	11.051	10.116	9.307
29	29.000	25.066	21.844	19.188	16.984	15.141	13.591	12.278	11.158	10.198	9.370
30	30.000	25.808	22.396	19.600	17.292	15.372	13.765	12.409	11.258	10.274	9.427

2 % Traffic Growth Rate

Project Life (Years)	Discount Rate (Percent)										
	0.000	1.000	2.000	3.000	4.000	5.000	6.000	7.000	8.000	9.000	10.000
1	1.010	1.000	0.990	0.981	0.971	0.962	0.953	0.944	0.935	0.927	0.918
2	2.040	2.010	1.980	1.952	1.924	1.896	1.870	1.844	1.818	1.794	1.769
3	3.091	3.030	2.970	2.913	2.858	2.804	2.752	2.701	2.652	2.605	2.559
4	4.163	4.060	3.961	3.865	3.774	3.686	3.601	3.519	3.440	3.364	3.291
5	5.256	5.100	4.951	4.808	4.672	4.542	4.418	4.298	4.184	4.075	3.970
6	6.371	6.150	5.941	5.742	5.554	5.374	5.204	5.041	4.887	4.740	4.599
7	7.508	7.211	6.931	6.667	6.418	6.183	5.960	5.750	5.551	5.362	5.183
8	8.668	8.282	7.921	7.583	7.266	6.968	6.688	6.425	6.177	5.944	5.724
9	9.852	9.364	8.911	8.490	8.097	7.731	7.388	7.069	6.769	6.489	6.226
10	11.059	10.457	9.901	9.388	8.912	8.472	8.062	7.682	7.328	6.999	6.691
11	12.290	11.560	10.892	10.277	9.712	9.191	8.711	8.267	7.856	7.476	7.123
12	13.546	12.675	11.882	11.158	10.496	9.891	9.335	8.825	8.355	7.922	7.523
13	14.826	13.800	12.872	12.030	11.266	10.570	9.936	9.356	8.826	8.340	7.894
14	16.133	14.937	13.862	12.894	12.020	11.230	10.513	9.863	9.271	8.731	8.238
15	17.465	16.085	14.852	13.749	12.760	11.871	11.069	10.346	9.691	9.097	8.557
16	18.825	17.244	15.842	14.596	13.486	12.493	11.605	10.806	10.088	9.439	8.853
17	20.211	18.415	16.833	15.435	14.198	13.098	12.119	11.245	10.462	9.760	9.127
18	21.625	19.597	17.823	16.266	14.896	13.686	12.615	11.664	10.816	10.059	9.381
19	23.068	20.791	18.813	17.088	15.580	14.257	13.092	12.062	11.151	10.340	9.617
20	24.539	21.997	19.803	17.903	16.252	14.811	13.550	12.443	11.466	10.602	9.836
21	26.040	23.214	20.793	18.710	16.910	15.350	13.992	12.805	11.764	10.848	10.039
22	27.571	24.444	21.783	19.509	17.556	15.873	14.417	13.151	12.046	11.078	10.227
23	29.132	25.686	22.773	20.300	18.190	16.382	14.825	13.480	12.312	11.293	10.401
24	30.725	26.940	23.764	21.083	18.811	16.875	15.219	13.794	12.563	11.494	10.563
25	32.349	28.207	24.754	21.859	19.420	17.355	15.597	14.093	12.800	11.683	10.713
26	34.006	29.486	25.744	22.627	20.018	17.821	15.961	14.379	13.024	11.859	10.852
27	35.696	30.778	26.734	23.388	20.604	18.274	16.312	14.651	13.236	12.024	10.981
28	37.420	32.083	27.724	24.142	21.179	18.714	16.649	14.910	13.436	12.178	11.100
29	39.178	33.401	28.714	24.888	21.743	19.141	16.974	15.157	13.624	12.323	11.211
30	40.972	34.731	29.704	25.627	22.296	19.556	17.286	15.393	13.803	12.458	11.314

TABLE A.15 Values of KC (Continued)

4 % Traffic Growth Rate

Project Life (Years)	Discount Rate (Percent)										
	0.000	**1.000**	**2.000**	**3.000**	**4.000**	**5.000**	**6.000**	**7.000**	**8.000**	**9.000**	**10.000**
1	1.020	1.010	1.000	0.990	0.981	0.971	0.962	0.953	0.944	0.936	0.927
2	2.080	2.049	2.019	1.990	1.961	1.933	1.906	1.879	1.854	1.828	1.804
3	3.183	3.120	3.059	2.999	2.942	2.886	2.832	2.780	2.729	2.680	2.632
4	4.331	4.222	4.118	4.018	3.922	3.830	3.741	3.655	3.572	3.493	3.416
5	5.524	5.357	5.199	5.048	4.903	4.765	4.632	4.506	4.384	4.268	4.157
6	6.764	6.526	6.301	6.087	5.883	5.690	5.507	5.332	5.166	5.008	4.857
7	8.055	7.730	7.424	7.136	6.864	6.607	6.365	6.136	5.919	5.714	5.519
8	9.397	8.969	8.569	8.195	7.845	7.516	7.207	6.917	6.644	6.387	6.145
9	10.792	10.245	9.737	9.265	8.825	8.415	8.033	7.676	7.342	7.030	6.737
10	12.244	11.559	10.928	10.345	9.806	9.307	8.844	8.414	8.015	7.643	7.297
11	13.753	12.912	12.142	11.436	10.786	10.189	9.639	9.131	8.662	8.228	7.826
12	15.323	14.306	13.380	12.537	11.767	11.063	10.419	9.828	9.286	8.786	8.326
13	16.956	15.740	14.642	13.648	12.748	11.929	11.185	10.506	9.886	9.319	8.799
14	18.654	17.217	15.929	14.771	13.728	12.787	11.936	11.164	10.464	9.827	9.246
15	20.420	18.739	17.241	15.905	14.709	13.636	12.673	11.804	11.021	10.312	9.669
16	22.257	20.305	18.579	17.049	15.689	14.478	13.396	12.427	11.557	10.774	10.069
17	24.167	21.918	19.943	18.205	16.670	15.311	14.105	13.031	12.073	11.216	10.446
18	26.153	23.578	21.334	19.372	17.650	16.136	14.801	13.619	12.570	11.637	10.804
19	28.219	25.289	22.752	20.550	18.631	16.954	15.484	14.190	13.049	12.039	11.142
20	30.368	27.049	24.198	21.739	19.612	17.764	16.154	14.745	13.510	12.422	11.461
21	32.602	28.863	25.672	22.941	20.592	18.566	16.811	15.285	13.954	12.788	11.763
22	34.926	30.730	27.176	24.153	21.573	19.360	17.456	15.810	14.381	13.137	12.048
23	37.343	32.652	28.708	25.378	22.553	20.147	18.088	16.319	14.793	13.470	12.318
24	39.857	34.632	30.271	26.614	23.534	20.927	18.709	16.815	15.189	13.787	12.573
25	42.471	36.670	31.864	27.863	24.515	21.698	19.318	17.297	15.571	14.091	12.815
26	45.189	38.769	33.489	29.124	25.495	22.463	19.916	17.765	15.938	14.380	13.043
27	48.017	40.930	35.145	30.396	26.476	23.220	20.502	18.220	16.292	14.656	13.259
28	50.957	43.156	36.834	31.682	27.456	23.970	21.077	18.662	16.633	14.919	13.462
29	54.015	45.447	38.556	32.979	28.437	24.713	21.642	19.092	16.961	15.170	13.655
30	57.196	47.807	40.312	34.290	29.417	25.449	22.196	19.510	17.277	15.410	13.837

6 % Traffic Growth Rate

Project Life (Years)	Discount Rate (Percent)										
	0.000	**1.000**	**2.000**	**3.000**	**4.000**	**5.000**	**6.000**	**7.000**	**8.000**	**9.000**	**10.000**
1	1.030	1.019	1.009	1.000	0.990	0.981	0.971	0.962	0.953	0.945	0.936
2	2.121	2.089	2.058	2.028	1.999	1.970	1.943	1.915	1.889	1.863	1.838
3	3.278	3.212	3.148	3.087	3.027	2.970	2.914	2.860	2.807	2.756	2.707
4	4.504	4.390	4.281	4.176	4.076	3.979	3.885	3.795	3.709	3.625	3.545
5	5.804	5.627	5.459	5.298	5.144	4.997	4.856	4.722	4.593	4.470	4.352
6	7.182	6.925	6.682	6.451	6.233	6.025	5.828	5.640	5.461	5.291	5.129
7	8.642	8.287	7.953	7.639	7.343	7.063	6.799	6.550	6.314	6.090	5.879
8	10.190	9.717	9.275	8.861	8.474	8.111	7.770	7.451	7.150	6.867	6.601
9	11.831	11.217	10.648	10.119	9.627	9.169	8.742	8.343	7.971	7.623	7.297
10	13.570	12.792	12.075	11.413	10.802	10.236	9.713	9.227	8.777	8.358	7.968
11	15.414	14.445	13.558	12.745	11.999	11.314	10.684	10.103	9.567	9.072	8.614
12	17.369	16.179	15.099	14.116	13.220	12.403	11.655	10.971	10.343	9.767	9.237
13	19.440	17.999	16.700	15.527	14.464	13.501	12.627	11.831	11.105	10.443	9.837
14	21.636	19.910	18.364	16.978	15.733	14.611	13.598	12.682	11.853	11.100	10.415
15	23.964	21.915	20.094	18.472	17.025	15.730	14.569	13.526	12.587	11.739	10.972
16	26.431	24.019	21.891	20.010	18.342	16.861	15.541	14.362	13.307	12.360	11.509
17	29.047	26.227	23.759	21.592	19.685	18.002	16.512	15.190	14.014	12.965	12.027
18	31.819	28.545	25.700	23.221	21.054	19.154	17.483	16.010	14.708	13.552	12.525
19	34.758	30.978	27.717	24.897	22.448	20.317	18.454	16.823	15.388	14.124	13.006
20	37.873	33.531	29.814	26.622	23.870	21.491	19.426	17.628	16.057	14.680	13.469
21	41.175	36.210	31.992	28.396	25.319	22.676	20.397	18.425	16.713	15.220	13.915
22	44.675	39.022	34.256	30.223	26.796	23.872	21.368	19.215	17.357	15.746	14.345
23	48.385	41.973	36.609	32.103	28.301	25.080	22.340	19.998	17.988	16.257	14.759
24	52.318	45.070	39.054	34.038	29.836	26.300	23.311	20.773	18.609	16.754	15.158
25	56.486	48.321	41.595	36.029	31.399	27.531	24.282	21.541	19.217	17.238	15.543
26	60.905	51.732	44.236	38.078	32.993	28.773	25.253	22.302	19.815	17.708	15.914
27	65.589	55.313	46.980	40.186	34.617	30.028	26.225	23.056	20.401	18.165	16.271
28	70.554	59.070	49.831	42.356	36.273	31.294	27.196	23.803	20.977	18.610	16.616
29	75.817	63.014	52.795	44.589	37.961	32.573	28.167	24.542	21.541	19.042	16.947
30	81.395	67.153	55.875	46.888	39.681	33.864	29.139	25.275	22.096	19.462	17.267

TABLE A.15 Values of KC (Continued)

8 % Traffic Growth Rate

Project Life (Years)	Discount Rate (Percent)										
	0.000	1.000	2.000	3.000	4.000	5.000	6.000	7.000	8.000	9.000	10.000
1	1.039	1.029	1.019	1.009	0.999	0.990	0.980	0.971	0.962	0.953	0.945
2	2.162	2.129	2.098	2.067	2.037	2.008	1.979	1.952	1.925	1.898	1.872
3	3.374	3.306	3.240	3.176	3.115	3.055	2.997	2.941	2.887	2.834	2.783
4	4.683	4.564	4.449	4.339	4.234	4.132	4.034	3.940	3.849	3.762	3.677
5	6.097	5.909	5.730	5.559	5.396	5.240	5.091	4.948	4.811	4.680	4.555
6	7.624	7.347	7.086	6.838	6.602	6.379	6.167	5.965	5.774	5.591	5.417
7	9.273	8.886	8.521	8.179	7.856	7.551	7.264	6.992	6.736	6.493	6.263
8	11.054	10.530	10.042	9.585	9.157	8.757	8.381	8.029	7.698	7.387	7.094
9	12.977	12.289	11.651	11.059	10.509	9.997	9.520	9.075	8.660	8.273	7.910
10	15.055	14.170	13.355	12.605	11.912	11.272	10.680	10.131	9.623	9.150	8.711
11	17.299	16.181	15.160	14.226	13.369	12.584	11.862	11.197	10.585	10.020	9.497
12	19.722	18.331	17.070	15.925	14.883	13.933	13.066	12.273	11.547	10.881	10.269
13	22.339	20.631	19.093	17.707	16.455	15.321	14.293	13.359	12.509	11.735	11.027
14	25.165	23.089	21.235	19.576	18.087	16.748	15.543	14.455	13.472	12.580	11.772
15	28.217	25.719	23.503	21.535	19.782	18.217	16.817	15.561	14.434	13.418	12.502
16	31.514	28.530	25.905	23.589	21.542	19.727	18.114	16.678	15.396	14.249	13.220
17	35.074	31.536	28.447	25.743	23.369	21.280	19.436	17.805	16.358	15.071	13.924
18	38.919	34.751	31.140	28.002	25.268	22.878	20.784	18.943	17.321	15.887	14.616
19	43.072	38.188	33.990	30.370	27.239	24.521	22.156	20.091	18.283	16.694	15.295
20	47.557	41.864	37.009	32.853	29.286	26.212	23.555	21.250	19.245	17.495	15.961
21	52.401	45.795	40.204	35.457	31.411	27.950	24.979	22.420	20.207	18.287	16.616
22	57.632	49.997	43.588	38.187	33.619	29.739	26.431	23.601	32.170	19.073	17.259
23	63.282	54.491	47.171	41.050	35.911	31.578	27.910	24.793	22.132	19.852	17.890
24	69.384	59.297	50.965	44.052	38.291	33.470	29.417	25.996	23.094	20.623	18.509
25	75.974	64.436	54.982	47.199	40.763	35.416	30.953	27.210	24.056	21.387	19.117
26	83.091	69.930	59.235	50.499	43.330	37.418	32.517	28.435	25.019	22.144	19.715
27	90.778	75.806	63.738	53.960	45.996	39.477	34.111	29.672	25.981	22.895	20.301
28	99.079	82.089	68.506	57.588	48.765	41.594	35.735	30.921	26.943	23.638	20.876
29	108.045	88.807	73.555	61.393	51.639	43.772	37.390	32.181	27.905	24.374	21.442
30	117.727	95.991	78.900	65.382	54.625	46.013	39.076	33.453	28.868	25.104	21.997

10 % Traffic Growth Rate

Project Life (Years)	Discount Rate (Percent)										
	0.000	1.000	2.000	3.000	4.000	5.000	6.000	7.000	8.000	9.000	10.000
1	1.049	1.038	1.028	1.018	1.008	0.999	0.989	0.980	0.971	0.962	0.953
2	2.202	2.169	2.137	2.106	2.075	2.045	2.016	1.988	1.960	1.933	1.907
3	3.472	3.401	3.333	3.267	3.203	3.142	3.082	3.024	2.968	2.913	2.860
4	4.868	4.743	4.623	4.507	4.397	4.290	4.187	4.089	3.994	3.902	3.814
5	6.403	6.204	6.013	5.832	5.659	5.493	5.335	5.184	5.039	4.900	4.767
6	8.092	7.795	7.513	7.247	6.994	6.754	6.526	6.309	6.103	5.907	5.721
7	9.950	9.528	9.131	8.757	8.406	8.074	7.761	7.466	7.187	6.924	6.674
8	11.994	11.415	10.875	10.371	9.899	9.457	9.044	8.656	8.292	7.949	7.628
9	14.242	13.471	12.756	12.094	11.479	10.907	10.374	9.879	9.416	8.985	8.581
10	16.715	15.710	14.785	13.934	13.149	12.425	11.755	11.136	10.562	10.029	9.535
11	19.436	18.148	16.973	15.899	14.916	14.015	13.188	12.428	11.728	11.083	10.488
12	22.428	20.804	19.333	17.998	16.785	15.682	14.676	13.757	12.917	12.147	11.442
13	25.720	23.696	21.877	20.239	18.762	17.427	16.219	15.123	14.127	13.221	12.395
14	29.340	26.846	24.621	22.633	20.853	19.256	17.820	16.527	15.360	14.304	13.348
15	33.323	30.276	27.580	25.190	23.065	21.172	19.482	17.971	16.615	15.398	14.302
16	37.704	34.013	30.772	27.920	25.404	23.179	21.207	19.455	17.894	16.501	15.255
17	42.524	38.082	34.214	30.836	27.878	25.282	22.996	20.980	19.197	17.615	16.209
18	47.825	42.514	37.925	33.949	30.495	27.484	24.854	22.549	20.523	18.739	17.162
19	53.656	47.341	41.928	37.275	33.262	29.792	26.781	24.161	21.874	19.873	18.116
20	60.071	52.598	46.245	40.826	36.190	32.209	28.781	25.819	23.251	21.017	19.069
21	67.126	58.323	50.900	44.619	39.286	34.742	30.857	27.523	24.652	22.173	20.023
22	74.888	64.558	55.921	48.670	42.561	37.395	33.010	29.275	26.080	23.338	20.976
23	83.425	71.350	61.335	52.996	46.025	40.175	35.246	31.076	27.534	24.514	21.930
24	92.817	78.746	67.174	57.616	49.699	43.087	37.565	32.927	29.015	25.702	22.883
25	103.147	86.801	73.470	62.550	53.564	46.138	39.972	34.830	30.524	26.900	23.837
26	114.511	95.575	80.261	67.819	57.663	49.333	42.470	36.787	32.060	28.109	24.790
27	127.011	105.130	87.584	73.446	61.998	52.682	45.062	38.799	33.625	29.329	25.743
28	140.761	115.536	95.482	79.456	66.583	56.189	47.752	40.867	35.219	30.560	26.697
29	155.885	126.870	103.999	85.874	71.433	59.864	50.543	42.993	36.842	31.803	27.650
30	172.523	139.213	113.184	92.729	76.563	63.713	53.440	45.178	38.495	33.056	28.604

TABLE A.16 Values of KT

Project Life (Years)	Discount Rate (Percent) 0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
1	1.000	0.990	0.980	0.971	0.962	0.952	0.943	0.935	0.926	0.917	0.909
2	2.000	1.970	1.941	1.913	1.886	1.859	1.833	1.808	1.783	1.759	1.736
3	3.000	2.941	2.884	2.829	2.775	2.723	2.673	2.624	2.577	2.531	2.487
4	4.000	3.902	3.808	3.717	3.630	3.546	3.465	3.387	3.312	3.240	3.170
5	5.000	4.853	4.713	4.580	4.452	4.329	4.212	4.100	3.993	3.890	3.791
6	6.000	5.795	5.601	5.417	5.242	5.076	4.917	4.767	4.623	4.486	4.355
7	7.000	6.728	6.472	6.230	6.002	5.786	5.582	5.389	5.206	5.033	4.868
8	8.000	7.651	7.325	7.020	6.733	6.463	6.210	5.971	5.747	5.535	5.335
9	9.000	8.565	8.162	7.786	7.435	7.108	6.802	6.515	6.247	5.995	5.759
10	10.000	9.471	8.982	8.530	8.111	7.722	7.360	7.024	6.710	6.418	6.145
11	11.000	10.367	9.787	9.253	8.760	8.306	7.887	7.499	7.139	6.805	6.495
12	12.000	11.254	10.575	9.954	9.385	8.863	8.384	7.943	7.536	7.161	6.814
13	13.000	12.133	11.348	10.635	9.986	9.393	8.853	8.358	7.904	7.487	7.103
14	14.000	13.003	12.106	11.296	10.563	9.899	9.295	8.745	8.244	7.786	7.367
15	15.000	13.864	12.849	11.938	11.118	10.380	9.712	9.108	8.559	8.061	7.606
16	16.000	14.717	13.577	12.561	11.652	10.838	10.106	9.447	8.851	8.313	7.824
17	17.000	15.561	14.292	13.166	12.166	11.274	10.477	9.763	9.122	8.544	8.022
18	18.000	16.397	14.992	13.753	12.659	11.689	10.828	10.059	9.372	8.756	8.201
19	19.000	17.225	15.678	14.324	13.134	12.085	11.158	10.336	9.604	8.950	8.365
20	20.000	18.044	16.351	14.877	13.590	12.462	11.470	10.594	9.818	9.129	8.514
21	21.000	18.856	17.011	15.415	14.029	12.821	11.764	10.836	10.017	9.292	8.649
22	22.000	19.659	17.658	15.937	14.451	13.163	12.042	11.061	10.201	9.442	8.772
23	23.000	20.454	18.292	16.443	14.857	13.488	12.303	11.272	10.371	9.580	8.883
24	24.000	21.242	18.914	16.935	15.247	13.799	12.550	11.469	10.529	9.707	8.985
25	25.000	22.022	19.523	17.413	15.622	14.094	12.783	11.654	10.675	9.823	9.077
26	26.000	22.794	20.121	17.877	15.983	14.375	13.003	11.826	10.810	9.929	9.161
27	27.000	23.558	20.706	18.327	16.330	14.643	13.210	11.987	10.935	10.027	9.237
28	28.000	24.315	21.281	18.764	16.663	14.898	13.406	12.137	11.051	10.116	9.307
29	29.000	25.064	21.844	19.188	16.984	15.141	13.591	12.278	11.158	10.198	9.370
30	30.000	25.806	22.396	19.600	17.292	15.372	13.765	12.409	11.258	10.274	9.427

TABLE A.17 Values of KJ

Project Life (Years)	Discount Rate (Percent) 0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
1	1.0000	0.9901	0.9804	0.9709	0.9615	0.9524	0.9434	0.9346	0.9259	0.9174	0.9091
2	1.0000	0.9803	0.9612	0.9426	0.9246	0.9070	0.8900	0.8734	0.8573	0.8417	0.8264
3	1.0000	0.9706	0.9423	0.9151	0.8890	0.8638	0.8396	0.8163	0.7938	0.7722	0.7513
4	1.0000	0.9610	0.9238	0.8885	0.8548	0.8227	0.7921	0.7629	0.7350	0.7084	0.6830
5	1.0000	0.9515	0.9057	0.8626	0.8219	0.7835	0.7473	0.7130	0.6806	0.6499	0.6209
6	1.0000	0.9420	0.8880	0.8375	0.7903	0.7462	0.7050	0.6663	0.6302	0.5963	0.5645
7	1.0000	0.9327	0.8706	0.8131	0.7599	0.7107	0.6651	0.6227	0.5835	0.5470	0.5132
8	1.0000	0.9235	0.8535	0.7894	0.7307	0.6768	0.6274	0.5820	0.5403	0.5019	0.4665
9	1.0000	0.9143	0.8368	0.7664	0.7026	0.6446	0.5919	0.5439	0.5002	0.4604	0.4241
10	1.0000	0.9053	0.8203	0.7441	0.6756	0.6139	0.5584	0.5083	0.4632	0.4224	0.3855
11	1.0000	0.8963	0.8043	0.7224	0.6496	0.5847	0.5268	0.4751	0.4289	0.3875	0.3505
12	1.0000	0.8874	0.7885	0.7014	0.6246	0.5568	0.4970	0.4440	0.3971	0.3555	0.3186
13	1.0000	0.8787	0.7730	0.6810	0.6006	0.5303	0.4688	0.4150	0.3677	0.3262	0.2897
14	1.0000	0.8700	0.7579	0.6611	0.5775	0.5051	0.4423	0.3878	0.3405	0.2992	0.2633
15	1.0000	0.8613	0.7430	0.6419	0.5553	0.4810	0.4173	0.3624	0.3152	0.2745	0.2394
16	1.0000	0.8528	0.7284	0.6232	0.5339	0.4581	0.3936	0.3387	0.2919	0.2519	0.2176
17	1.0000	0.8444	0.7142	0.6050	0.5134	0.4363	0.3714	0.3166	0.2703	0.2311	0.1978
18	1.0000	0.8360	0.7002	0.5874	0.4936	0.4155	0.3503	0.2959	0.2502	0.2120	0.1799
19	1.0000	0.8277	0.6864	0.5703	0.4746	0.3957	0.3305	0.2765	0.2317	0.1945	0.1635
20	1.0000	0.8195	0.6730	0.5537	0.4564	0.3769	0.3118	0.2584	0.2145	0.1784	0.1486
21	1.0000	0.8114	0.6598	0.5375	0.4388	0.3589	0.2942	0.2415	0.1987	0.1637	0.1351
22	1.0000	0.8034	0.6468	0.5219	0.4220	0.3418	0.2775	0.2257	0.1839	0.1502	0.1228
23	1.0000	0.7954	0.6342	0.5067	0.4057	0.3256	0.2618	0.2109	0.1703	0.1378	0.1117
24	1.0000	0.7876	0.6217	0.4919	0.3901	0.3101	0.2470	0.1971	0.1577	0.1264	0.1015
25	1.0000	0.7798	0.6095	0.4776	0.3751	0.2953	0.2330	0.1842	0.1460	0.1160	0.0923
26	1.0000	0.7720	0.5976	0.4637	0.3607	0.2812	0.2198	0.1722	0.1352	0.1064	0.0839
27	1.0000	0.7644	0.5859	0.4502	0.3468	0.2678	0.2074	0.1609	0.1252	0.0976	0.0763
28	1.0000	0.7568	0.5744	0.4371	0.3335	0.2551	0.1956	0.1504	0.1159	0.0895	0.0693
29	1.0000	0.7493	0.5631	0.4243	0.3207	0.2529	0.1846	0.1406	0.1073	0.0822	0.0630
30	1.0000	0.7419	0.5521	0.4120	0.3083	0.2314	0.1741	0.1314	0.0994	0.0754	0.0573

A4.11 ITEM 11: INSTALLATION COST AND SALVAGE VALUE

The installation cost is the cost to install the feature being analyzed and will include any required site preparation. It is assumed to be incurred at the start of the project life. This cost will usually be zero for an existing feature to remain in place (a do-nothing analysis).

The salvage value is the net of the estimated value of the feature at the end of the analysis period (project life) and the estimated cost to remove the feature at the end of the project life, if that will be required. Thus, the value will be negative if the estimated cost of removal exceeds the estimated value of the feature at the end of the analysis period.

A4.12 ITEM 12: PER ACCIDENT REPAIR COSTS

There are five values to be input under this item, they are the estimated average costs to restore a feature after accidents involving each of the five contact areas of the feature under study—the upstream side and corner, the face, and the downstream side and corner.

A4.13 ITEM 13: ANNUAL MAINTENANCE COST

This is the average annual cost associated with keeping a feature in serviceable condition and could include less obvious costs such as added mowing or snow removal costs incurred because of the presence of the feature. These costs are **exclusive** of the accident repair costs.

A4.14 ITEM 14: CALCULATED COSTS

At Item 14 the user sees the results of the program's economic analysis based on the input values. There are three lines of data presented. The first is based on the total societal cost associated with the studied feature over the assigned project life. The cost is presented in two ways. The first is the present worth of all costs incurred over the life of the project. The second is the annualized value of the first, which is a constant amount that, if incurred at the ends of each of the years of the analysis period and discounted to the present at the assigned discount rate, would sum to the present worth value.

On the two lines below the first, the total values are divided into "Accident Costs" and "Highway Department Costs." Actually, these terms are a little misleading. The accident repair costs for the feature being studied are included in the Highway Department Costs. Entering this item number brings up a screen that repeats the values shown on the work screen, plus a breakdown of the Highway Department Cost—Installation Cost, Repair Cost, Maintenance Cost, and Salvage Value. The salvage value is the present worth (or annualized present worth) of the estimated value of the feature at the end of the study period. A negative salvage value indicates a net cost from removing the feature at the end of the study period.

A4.15 FUNCTION KEYS

At the bottom of the work screen is a line listing ten function keys. To initiate a function, press the function key followed by Enter. Function Keys F1, F2, and F3 are used to manage the files and printer outputs from the program and will be discussed further below. Function Key F4 provides access to the program's help screens. Function Key F5 allows the user to view and change the global values used in the program. This is the same process as that allowed when the program starts. Function Key F6 shows the calculated values for 12 severity indices: 0, 0.5, and 1 through 10. Function Key F7 shows the files in the directory from which ROADSIDE is running (the current directory). Function Key F8 shows the proportion of six accident severity levels, from a minor property-damage-only accident to a fatal accident, assigned to SI values of 0, 0.5, and 1 through 10.

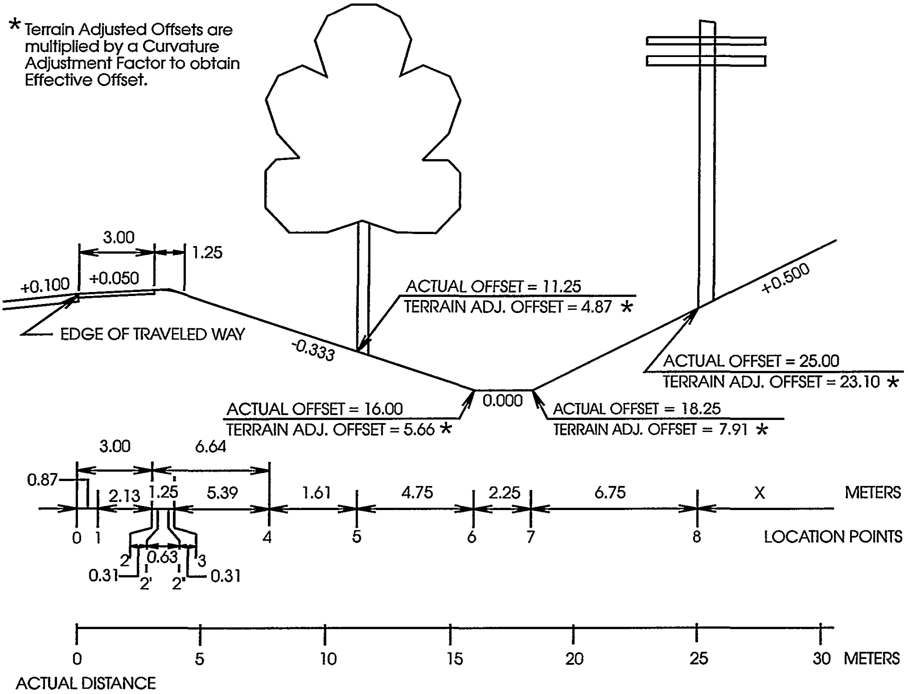
To save a record of an analysis of a feature, the user could, if the computer is connected to a printer, hit the "print screen" key. However, Function Key F1 provides two other options. If the computer is connected to a printer and the printer has been activated at the start up of the program, Function Key F1 allows the user to send an expanded and slightly rearranged version of the work screen directly to a printer. This function key also gives the option of saving this report to a file that can later be recalled and viewed or printed from DOS or a word processor.

Function Key F2 allows the user to save the essential input values from the current case study to a file that can later be recalled to the work screen for viewing or modification.

Function Key F3 allows the recall of files stored using Function Key F2.

A5.0 EXAMPLE PROBLEM

Problem: Determine the societal cost of a 500-mm tree and the benefit-cost ratio for removal of the tree. (See Figure A.14.)



* Terrain Adjusted Offsets are multiplied by a Curvature Adjustment Factor to obtain Effective Offset.

FIGURE A.14 Roadside Terrain for Example Problem
(Offsets from Adjacent Traffic)

Site:

Highway:
Type: Two-way, two lanes undivided
Lane width = 3.65 m
Grade for adjacent traffic = -3.0%
Curvature for adjacent traffic = -400 m (left) (measurement at edge-of-traveled way)
Superelevation = +10 %
Shoulder width = 3.0 m
Shoulder cross slope = +0.5%

Roadside:
1:3 foreslope, with the shoulder slope-foreslope hinge point 3.625 m from edge-of-traveled way
No rounding between pavement and shoulder slope
1.25-m rounding width between shoulder slope and side slope

Traffic:
Design Year (20 years out) traffic = 50,000 vpd
Traffic Growth Rate = 10% per year
Design Speed = 70 km/h
Basic Encroachment Rate = 0.0003 enc/km/y/vpd

Feature:
500-mm diameter, 50-year old oak tree located on the foreslope horizontally 11.25 m from the edge of the traveled way and 40 m into the curve from the PC and more than the TC distance from the PT.

Because the feature is located in the tangent to curve transition zone the problem will be worked as two one-way highways.

Entering data into ROADSIDE:

To obtain the needed outputs from ROADSIDE, six sets of data will need to be inputted. While these would be inputted serially, for convenience of presentation, in the following presentation, inputs for all six will be described together for each of the ROADSIDE input items.

1. Title:

I. **RDG Example Prob. Adjacent Traffic w/Tree (RDGADJWT)**
II. **RDG Example Prob. Opposing Traffic w/Tree (RDGOPPWT)**
III. **RDG Example Prob. Adjacent Traffic No Tree (RDGADJNT)**
IV. **RDG Example Prob. Opposing Traffic No Tree (RDGOPPNT)**
V. **RDG Ex. Prob. Adj. Traf. Backslope Tree Equiv. (RGADBSTE)**
VI. **RDG Ex. Prob. Opp. Traf. Backslope Tree Equiv. (RGOPBSTE)**

2. Traffic Volume and Traffic Growth Rate:

I, II, III, IV, V, and VI. The given traffic volume is for 20 years in the future.

To obtain the initial (beginning of project life) traffic volume the following formula is used. (See Section A4.2.)

$$\mathrm{ADT_i} = \frac{\mathrm{ADT_{dy}}}{(1+\mathrm{TGR})^{\mathrm{T}}}$$

The two-way design year ADT is given as 50,000 vpd and the traffic growth rate is given as 10% and the project life (analysis period) will be assumed to be 20 years. Thus, the initial two-way traffic volume is:

$$ADT_i = 50{,}000/(1 + 0.1)^{20}$$
$$= 7{,}432 \text{ vpd}$$

Divide the initial one-way traffic volume by 2 to obtain the initial one-way traffic volume, 3,716 vpd. Therefore, push **2** and **Enter**, then follow instructions to enter **3,716** (vpd) and **10** (% traffic growth rate, given).

3. Highway Type:

I, II, III, IV, V, and VI. Push **2** and **Enter,** then follow instructions to enter the letter **O** for one-way highway, **1** for number of lanes, and **3.6** for width of one lane.

4. Curvature and Grade:

For each case, push **4** and **Enter,** then follow the instructions for entering the curvature and grade.

I, III, and V. The curvature is **-400** (m) and the grade is **-3** (%).

II, IV, and VI. The curvature is **-396** (m) (400 - 4, the lane width) and the grade is **+3** (%).

Note that, while the curve is to the right for the opposing traffic, the sign remains minus because the feature is on the outside of the curve. On the other hand, the sign of grade does change from that for the adjacent traffic.

5. User-supplied Encroachment Multiplication Factors:

No user factors will be supplied. Therefore, this input item can be skipped unless these factors are not currently set to one. If they are not, press **5** and **Enter,** the follow the instructions to enter **1** for each of the two user-supplied encroachment multiplication factors.

6. Design Speed:

I, II, III, IV, V, and VI. Push **6** and **Enter,** then enter **70** (km/h).

Note that the global value swath width is reported at this item line. See item 7 for a discussion of setting this value to zero for data sets V and VI.

7. Feature location and size (See Section A.4.7.)

This can be the most laborious step in using ROADSIDE and should be considered for reduction to a computer program. However, one does not now exist. Therefore, the procedure described below should be followed to **determine the effective offsets, A(adj) and A(opp), to the tree and other features.** (Referring to Figure A.14 and Section A.4.7.1.1)

Calculate the effective offset distance to the tree and other features for adjacent traffic.

Table A.18 summarizes the effects of the roadside terrain on the effective offsets from adjacent traffic to various roadside features. The derivations of the values shown in Table A.18 are shown in the calculations below the table. The terrain adjusted offsets must be further adjusted by application of a curvature adjustment factor to obtain the effective offset distances.

TABLE A.18 Terrain Adjusted Offsets to Example Problems Features (Adjacent Traffic)

Point*	Offset m	Distance Between Points m	Terrain Correction Factor	Adjusted Distance m	Terrain Adjusted Offset m
0	0.00				0.00
		0.87	1.0688	0.930	
1	0.87				0.930
		2.13	1.1250	2.396	
2	3.00				3.326
		0.31	0.8412	0.261	
2’	3.31				3.587
		0.63	0.4829	0.304	
2"	3.94				3.891
		0.31	0.1247	0.039	
3	4.25				3.930
		5.39	0.1247	0.672	
4	9.64				4.602
		1.61	0.1667	0.268	
5	11.25				4.870
		4.75	0.1667	0.792	
6	16.00				5.662
		2.25	1.0000	2.25	
7	18.25				7.912
		6.75	2.2500	15.188	
8	25.00				23.098

* See Figure A.14.

Calculating Terrain Correction Factors (Adjacent Traffic)

0-1

From Table A.11, the slope-break-effects width for $s_1 = 0.1$ and $s_2 = 0.05$ is 0.87 m. Distances within this distance will be adjusted by multiplying the distance by the slope effectiveness factor, E_s, and the rounding effects factor, F_{RND}.

E_s for the shoulder slope is:

$$E_s = \frac{f+s}{f} = 1 + \frac{s}{f} \qquad f = 0.4$$

$$s = 0.05$$

$$= 1 + (0.05/0.4)$$

$$= 1.125$$

$$F_{RND} = (1 - s_\Delta) + s_\Delta\left(\frac{RND_A}{RND_T}\right) \qquad s_\Delta = |s_2 - s_1|$$

RND_A = the available rounding (given as zero)

$RND_T = 0.5$ m (from Table A.10 (70 km/h))

$$F_{RND} = 1 - 0.05 = 0.95$$

$$\text{Correction factor} = E_s(F_{RND})$$

$$= 1.125\ (0.95)$$

$$= 1.0688$$

1-2

The correction factor is the E_s calculated for 0-1, or 1.125.

2-4

The rounding effects distance for $s_1 = 0.05$ and $s_2 = -0.3333$ is, by interpolation from Table A.11, 6.64 m. Thus, 3-4 = (6.64-1.25) = 5.39 m.

2-2’

E_s = the same as 1-2 = 1.125.

$F_{RND} = (1 - 0.3833) + 0.3833\,(\frac{1.25}{3.6567})$

$= 0.7477$

Correction factor = 1.125(0.7477)

= 0.8412

$s_\Delta = |-0.3333 - 0.05|$

$= 0.3833$

$RND_T = 3.6567$ (from interpolation in Table A.10)

2’-2”

$s_{avg} = (s_2 + s_1)/2$ (from step 3 in section A4.7.1.1)

= (-0.3333 + 0.05)/2

= -0.14166

E_s = 1 + (-0.14166/0.4)

= 0.6459

F_{RND} = 0.7477, from 2-2’

Correction factor = 0.6459 (0.7477)

= 0.4829

2”-3

E_s = 1 + (-0.3333/0.4)

= 0.16675

F_{RND} = 0.7477, from 2-2’

Correction factor = 0.1667(0.7477)

= 0.1247

3-4

Correction factor = same as 2”-3 = 0.1247

4-5

E_s = same as 2”-3 = 0.1667

Correction factor = 0.1667 (no rounding or slope-break effects)

5-6

Correction factor = 0.1667, same as 4-5.

6-7

E_s = 1.0000

Correction factor = 1.0000

7-8

$E_s = 1 + (0.5/0.4)$

Correction factor = 2.25

From Table A.18 the terrain adjusted offset to the tree is 4.870 m, which is A_{TC} to be used in calculating the effective offset on a curve that is discussed below.

II, IV, and VI. **The terrain adjusted offsets to roadside features for opposing traffic** are equal the terrain adjusted offsets for adjacent traffic plus the terrain adjusted width of the adjacent lane(s), which, for this example problem, are determined as follows:

$E_s = 1 + (0.1/0.4)$ (Note that a coefficient of friction of 0.4 is used, not the 0.8 used in calculating encroachment angle.)

$= 1.25 =$ correction factor

Adjacent lanes = 1 @ 3.65 m

Adjusted offset = 1.25(3.65) = 4.563 (add to offsets from adjacent traffic)

Applying Curve Correction Factors to Terrain Adjusted Offsets

I, II, III, and IV. **Determine the curve correction factors.** Using Figure A.13 and Table A.12 (70 km/h) for:

$R_{adj} = 400$ m (given for adjacent traffic)

$R_{opp} = 396$ m (for opposing traffic (R_{adj} - lane width))

$L_s = 81.45$ m = TC

$W_{RS} = 26.75$ m

$W_{cc} = 8.21$ m (for $R_{adj} = 400$ m)

$W_{cc} = 8.29$ m ((by interpolation) for $R_{opp} = 396$ m)

I and III. Distance A from adjacent traffic to tree:

$$O_{CTC} = \frac{W_{RS}}{W_{RS} + \frac{X}{TC} W_{cc}}$$

(X = 40 m (given))

($R_{adj} = 400$ m (given))

$$= \frac{26.75}{26.75 + \frac{40}{81.45}(8.21)}$$

$$= 0.86902$$

$A = A_{TC}(O_{CTC}) = 4.87(0.86902)$ (A_{TC} from Table A.18)

$=$ **4.232** m (effective offset from adjacent traffic to tree)

II and IV. Distance A from opposing traffic to tree:

$$O_{cc} = \frac{W_{RS}}{W_{RS} + W_{cc}}$$

($R_{opp} = 396$ m)

$$= \frac{26.75}{26.75 + 8.29}$$

$$= 0.7634$$

$A = A_c(O_{cc})$ (From Table A.18 and calculations above, $A_c = 4.870 + 4.563 = 9.433$ m.)

$= 9.433(0.7634)$

$=$ **7.201** m (effective offset from opposing traffic to tree)

I, II, III, and IV. Determine length (L) and width (W) for the tree. The given diameter of the tree is 0.500 m. Conservatively, L and W could be taken as equivalent to the diameter of the tree. However, because the corners of the implied square are missing, lesser dimensions seem appropriate. The sides of a square with an area equal the cross-sectional area of the tree will be used. Thus:

$$L = W = \sqrt{\frac{\pi D^2}{4}}$$

$$= \frac{\sqrt{\pi (0.5)^2}}{2}$$

$$= \mathbf{0.4431}\text{ m} \qquad \text{(sides of a square with an area equal to cross section of tree)}$$

V and VI. Since the beginning of the backslope is beyond the feature and shaded by it, the analysis will be based on a section of slope equal to the length of highway contributing encroachments to contact with the feature. This is the length AD depicted in Figure A.10. This length can be calculated by using the geometry of the feature, width and length and encroachment angle. However, a much easier way to determine the length is to use information supplied in the case study printout obtainable from ROADSIDE. Figure A.15 is a printout for one part of this example problem. By summing the encroachments/year given under Item 7 for the 3 zones for adjacent traffic (0.0084 + 0.0701 + 0.0019 = 0.0804) and dividing by the total enc/km/y for adjacent traffic given under Item 5 (4.1805) one obtains 0.01923 km or L = **19.23** m.

In analyzing the cost of the tree-shielded backslope, the input for A is 7.91 (from Table A.18) times a curve adjustment factor. Because the feature is located in a tangent to curve transition zone, the curve adjustment factor is dependent on the feature's distance from the PC of the curve. Since the tree-shielded length of back slope will be down stream of the feature, its distance from the PC will differ from that of the shielding feature.

V. As an approximation of the longitudinal offset between the study feature and the shielded feature for the adjacent traffic, it is suggested that the actual lateral offset between the two features divided by the tangent of the global encroachment angle be used. Thus, the distance of the shielded backslope from the PC(X) is the sum of 40 m plus 7 m divided by the tangent of 12.4 degrees, or 71.838 m (40 + 31.838). Therefore, the tangent to curve correction factor (using values for TC, W_{rs}, and W_{cc} from above) is:

$$O_{ctc} = \frac{26.75}{26.75 + \frac{71.84}{81.45}(8.21)}$$

$$= 0.7870$$

This yields an effective lateral offset (A) to the backslope of:

0.7870(7.91) = **6.225** m from the adjacent traffic.

VI. The effective offset (A) from the opposing traffic, using the same curve correction factor (O_{cc}) as above for opposing traffic, is:

0.7634(4.563 + 7.91) = **9.522** m.

V and VI. Since L input for data sets V and VI is the total length of the slope assumed to be "shielded" by the tree, W will be input equal to **zero** and the global value for swath width will also be set to **zero**. To change the swath width, push the function key **F5** and **Enter** and follow instructions to change global parameter value number 16.

The utility pole on the backslope will be ignored even though it is within the "finite" limit of the roadside. However, were the pole a series of closely spaced trees, parallel to the highway, sufficiently far down stream of the tree to be shielded by the tree, it would be appropriate to take them into account.

Push **7** and **Enter**, then enter values for A, L, and W appropriate for the part of the problem being analyzed.

```
ROADSIDE - Version 5.0      11-02-1994    15:30:32      PAGE NUMBER   2
 1. TITLE: RDG Example Prob. Adjacent Traffic w/ Tree (RDGADJWT)

 2. INITIAL TRAFFIC VOLUME =   3,716 VEHICLES PER DAY
    TRAFFIC GROWTH RATE = 10.000 %/YEAR   UNCAPPED DES YR ADT =  24,999 VPD
    TRAFFIC VOLUME CAP =  23,700 VPD/LANE   AT  19.4 YR   RND TO  19 YR

 3. ONE-WAY HIGHWAY      TOTAL LANE(S) =  1    LANE WIDTH =  3.60 m

 4. CURVATURE (RADIUS IN METERS) =   -400  GRADE (PERCENT) = -3.0

 5. INITIAL ENCROACHMENT FREQUENCY = 0.0003000 * (TVeff) ENC/km/YR
             EFFECTIVE  BASELINE  CURVATURE   GRADE    USER     TOTAL
           TRAFFIC VPD  ENC/km/YR   FACTOR    FACTOR   FACTOR  ENC/km/YR
   ADJACENT     3,716     1.1148     3.00      1.25     1.00    4.1805
   OPPOSING         0     0.0000     3.00      1.00     1.00    0.0000

 6. DESIGN SPEED =  70 km/h  ENC ANGLE = 12.4 DEG  SWATH WIDTH =  3.60 m

 7. LATERAL OFFSET (A)       =        4.23 m
    LONGITUDINAL LENGTH (L) =        0.44 m
    WIDTH OF OBSTACLE (W)    =        0.44 m
                    ZONE 1        ZONE 2        ZONE 3
    ADJACENT        0.0084        0.0701        0.0019   ENCROACHMENTS/YEAR
    OPPOSING        0.0000        0.0000        0.0000   ENCROACHMENTS/YEAR

 8. INITIAL COLLISION FREQUENCY =    0.01357 IMPACTS PER YEAR
    ADJACENT    CFTA =  0.0136  CFSU =  0.0009  CFCU =  0.0122  CFFA =  0.0005
    OPPOSING    CFTO =  0.0000  CFSD =  0.0000  CFCD =  0.0000  CFFO =  0.0000
    EXPECTED IMPACTS OVER PROJECT LIFE =      0.811

 9. SEVERITY INDEX   SU =  3.80  SD =  3.80  CU =  4.20  CD =  4.20  FACE= 3.40
    ACCIDENT COST    $   40,299  $   40,299  $   58,234  $   58,234  $   28,771
      INITIAL COST/YEAR IMPACTS WITH UPSTREAM SIDE     OF FEATURE = $       34
      INITIAL COST/YEAR IMPACTS WITH DOWNSTREAM SIDE   OF FEATURE = $        0
      INITIAL COST/YEAR IMPACTS WITH UPSTREAM CORNER   OF FEATURE = $      712
      INITIAL COST/YEAR IMPACTS WITH DOWNSTREAM CORNER OF FEATURE = $        0
      INITIAL COST/YEAR IMPACTS WITH FACE              OF FEATURE = $       14
                              TOTAL INITIAL ANNUAL ACCIDENT COST = $      760

10. PROJECT LIFE =   20 YEARS        DISCOUNT RATE =  4.000 %/YR
  CRF =   0.07358   KC  =  36.05367   KT =   13.59033   KJ =    0.45639

11. INSTALLATION COST = $          0        SALVAGE VALUE = $    -1,200

12. REPAIR COST/ACC $ SU=       0  SD=       0  CU=       0  CD=       0  F=       0

13. MAINTENANCE COST PER YEAR       = $           0.

14. TOTAL PRESENT WORTH             = $       27,964        ANNUALIZED $       2,058
      ACCIDENT COST               = $       27,417        ANNUALIZED $       2,017
      HIGHWAY DEPARTMENT COST     = $          548        ANNUALIZED $          40
        INSTALLATION COST       = $            0       ANNUALIZED $             0
        REPAIR COST             = $            0       ANNUALIZED $             0
        MAINTENANCE COST        = $            0       ANNUALIZED $             0
        SALVAGE VALUE           = $         -548       ANNUALIZED $           -40
```

FIGURE A.15 Case Study Report Printout (Example Problem)

8. Collision Frequencies:

These are calculated values. Thus, no input is required.

9. Severity Indices:

I and II. From Table A.13.9 (1/4) (70 km/h), the SI values for a round fixed object are:

$\mathbf{SI_S = 3.8}$
$\mathbf{SI_C = 4.2}$
$\mathbf{SI_F = 3.4}$

III and IV. This step is to account for what would have happened to the encroaching vehicle were it not prevented from encroaching further by the feature under study, in this case, the tree. Beyond the tree is the continuation of the foreslope, a 2.5-m wide, flat-bottom ditch, and a 1:2 backslope. The height of the foreslope at the face of the tree is 1.58 m. Assume the SI for a foreslope includes the flat-bottom portion of the ditch and that the backslope of the ditch will be treated separately for data sets V and VI.

Thus, from Table A.13.1 (3/9), the recommended SI for a firm, smooth 1:3, 2-m high foreslope is 2.5, that for a 0.3-m high slope is 2.0. Since the table is based on the assumption that a vehicle will encroach on the foreslope by running off a relatively level shoulder, one can assume the SI is higher than that appropriate for the continuation of a slope beyond the slope-break-effects zone, where an encroaching vehicle will have become compliant with the slope. Therefore, assume an SI of **2.2** for the portion of the foreslope and ditch bottom shielded by the tree, which will be applicable to side, corner and face of the shielding tree.

V and VI. Table A13.3 (3/5) shows for a smooth firm 1:2 backslope an SI of **1.1**.

I, II, III, IV, V, and VI. Push **9** and **Enter** to enter severity index (SI) values.

10. Project Life and Discount Rate:

The analysis period or project life and discount rate are given as **20** years and **4** %/year, respectively. Push **1** and **zero** and **Enter** to enter these values.

11. Installation Cost and Salvage Value:

I and II. The existing or do-nothing condition leaves the tree in place. Thus, there is no installation cost. However, in 20 years the tree will have grown and its removal is estimated to cost $1200 at the end of the analysis period. This removal cost will be entered as a **-1200** salvage value. This value should be entered for only one direction of traffic. The choice of which direction is arbitrary. In this example, the cost of removal was assigned to data set I.

III and IV. In these two cases the tree is removed at an assumed cost of **$1000**. This will be treated as an installation cost. The salvage value will be zero. As with cases I and II, this installation cost should only be entered for one direction of traffic.

V and VI. These two cases are parts of cases III and IV and no input of either installation cost or salvage value are appropriate for these cases.

I, II, III, IV, V, and VI. Press **1** and **Enter** to enter the appropriate values or return values to zero if needed.

12. Per Accident Repair Costs:

It is possible that the highway department would have some clean-up expenses associated with an accident involving the subject tree. The assumption, however, is that there will be none. Therefore, the repair costs for each of the five elements of the study feature will be assumed to be zero. If these values are not currently set to zero, they should be changed by pressing **1** and **2** plus **Enter** and changing the values to **zero.**

13. Annual Maintenance Cost:

Fallen leaves and limbs could create an expense for a highway agency. However, the assumption will be made that they will not. Therefore, if this value is not set to zero, **1**, **3**, and **Enter** should be pressed and the maintenance value entered as **zero.**

14. Calculated Costs:

No inputs are made at this item. It is possible, however, by pressing 1,4, and enter to see the costs shown on the work screen plus see a breakdown of the highway department costs—installation, repair, and maintenance costs and salvage value, which may increase or reduce the highway department costs depending on whether it is minus (a net removal cost at the end of the project life) or plus (a net remaining value at the end of the project life). This is the same information shown under Item 14 in the case study report. (See Figure A.15.)

Summarizing the six case studies of the example problem:

I and II: With tree in place:

	I Adjacent Traffic	**II Opposing Traffic**	**Total I & II**
Total Present Worth	27,964	10,302	38,266
Accident Cost	27,417	10,302	37,719
Highway Dept. Cost	548	0	548
Installation Cost	0	0	0
Repair Cost	0	0	0
Maintenance Cost	0	0	0
Salvage Value	-548	0	-548

III, IV, V, VI: With tree removed:

	III (Foreslope) Adjacent Traffic	**IV (Foreslope) Opposing Traffic**	**V (Backslope) Adjacent Traffic**	**VI (Backslope) Opposing Traffic**	**Total III, IV, V, and VI**
Total Present Worth	4,221	1,210	894	307	6,632
Accident Cost	3,221	1,210	894	307	5,632
Highway Dept. Cost	1,000	0	0	0	1,000
Installation Cost	1,000	0	0	0	1,000
Repair Cost	0	0	0	0	0
Maintenance Cost	0	0	0	0	0
Salvage Value	0	0	0	0	0

Determining B/C Ratio for Example Problem:

$$B/C = \frac{\text{Accident cost with tree} - \text{Accident cost withouttree}}{\text{Hwy. Dept. cost without tree} - \text{Hwy. Dept. cost with tree}}$$

$$= \frac{37{,}719 - 5{,}632}{1{,}000 - 548} = \frac{32{,}087}{452}$$

$$= 71.0$$

Comment: This high benefit-cost ratio results from a very high traffic volume, moderately severe site conditions, and a relatively low cost to remove the tree. However, ROADSIDE only predicts 1.116 impacts with the tree (0.811 from adjacent traffic and 0.305 from opposing traffic) over the twenty-year study period. (This information is given under item 8 in the case study reports.) At a much lower traffic volume a high benefit-cost ratio would still exist, even though there would be a much smaller fraction of an impact predicted over the study period. Thus, it should be clear that favorable or non-existence accident data on a single isolated feature should not be taken as justification for doing nothing to enhance safety where known hazardous features exist.

Manual Calculations:

To illustrate the manual calculation alternative to using ROADSIDE, Data set I above will be evaluated here manually. The results of the manual calculations for inputs to ROADSIDE performed above will be used here without repeating the calculations.

Step 1: Determine the lengths of highway from which vehicles will be assumed to encroach with the potential for impacting a unit length of an element in the encroachment model. In Figure A.10 these would be a length between A and B corresponding to a unit length between A' and B', a length between B and C corresponding to a unit length along a line perpendicular to the traveled way projected onto B'C', and a length along CD corresponding to a unit length a long C'D'.

Zone 1:

$$\text{Enc. Factor}_{AB} = 1/\tan\phi$$
$$= 1/\tan 12.4^{\circ}$$
$$= 4.54826 \text{ m/m}$$

Zone 2:

$$\text{Enc. Factor}_{BC} = (1/\sin\phi)/\cos\phi$$
$$= 4.76813 \text{ m/m}$$

Zone 3:

$$\text{Enc. Factor}_{CD} = 1 \text{ m/m}$$

Step 2. Calculate initial encroachments per unit length of highway.

Zones 1, 2, & 3:

Initial Enc. Rate = (Enc. Rate)(EF_C)(EF_G)(Initial ADT)/1000 (Note: Division by 1000 converts encroachments per km to encroachment per m.)

Enc Rate = 0.00030 enc/km/y/vpd (given)

EF_C = 3.00 (Figure A.12, for given -400 m curvature)

EF_G = 1.25 (Figure A.12, for given -3% grade)

Initial ADT = 3,716 (calculated from given des. yr. traffic)

Initial Enc. Rate = (0.0003)(3.0)(1.25)(3,716)/1000

= 0.0041805 enc/y/m

Step 3: Calculate the Initial Impact Frequency (Initial Collision Frequency).

Zone 1:

First, determine effective offset of the far corner of the swath zone (B' in Figure A.10). The effective offset to the face of the tree was calculated above to be 4.23 m. Therefore:

$$\begin{aligned} B'_{off} &= 4.23 + SW \cos \phi \qquad\qquad SW = 3.6 \text{ (given)} \\ &= 4.23 + SW \cos 12.4^{\circ} \\ &= 7.7460 \text{ m} \end{aligned}$$

Second, determine the effective offset location of A', A'_{off}.

$$\begin{aligned} A'_{off} &= 7.7460 + W \\ &= 7.7460 + 0.443 \\ &= 8.1890 \text{ m} \end{aligned}$$

Third, determine impacts with upstream side of feature. Using Table A.1.3:

$$\begin{aligned} F(A)_{A'} &= 2.81475 \text{ m } (@\ 8.189 \text{ m}) \\ \text{less } F(A)_{B'} &= 2.76986 \text{ m } (@\ 7.746 \text{ m}) \\ F(A)_{B'A'} &= 0.04489 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{Initial impacts with side} = CF_{side} &= F(A)_{B'A'} \text{ (Enc. Factor}_{AB}\text{)(Initial Enc. Rate)} \\ &= 0.04489(4.54826)(0.0041805) \\ &= 0.00085 \text{ enc/y (Impacts/y)} \end{aligned}$$

Fourth, determine impacts with upstream corner (C') of feature. Using Table A.1.3:

$$\begin{aligned} F(A)_{B'} &= 2.76986 \text{ m } (@\ 7.746 \text{ m}) \\ \text{less } F(A)_{C'} &= \underline{2.15628} \text{ m } (@\ 4.23 \text{ m}) \\ F(A)_{C'B'} &= 0.61328 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{Initial impacts with C'} = CF_{corner} &= F(A)_{C'B'} \text{(Enc. Factor }_{BC}\text{)(Initial Enc. Rate)} \\ &= 0.61358(4.76813)(0.0041805) \\ &= 0.01223 \text{ enc/y (Impacts/y)} \end{aligned}$$

Fifth, determine impacts with face of feature. Using Table A.1.3:

$$P_{face} = 0.2636 \text{ m } (@\ 4.23 \text{ m})$$

$$\begin{aligned} \text{Initial impacts with face} = CF_{face} &= L(P_{face})\text{(Enc. Factor}_{CD}\text{)(Initial Enc. Rate)} \\ &= 0.443(0.2636)(1)(0.0041805) \\ &= 0.00049 \text{ enc/y (Impacts/y)} \end{aligned}$$

Step 4: Using the information in Section A3.1, calculate the average per accident cost with each of the elements of the feature—side, corner, and face. The severity index levels for each of these elements were determined above for input to ROADSIDE and are, respectively, 3.80, 4.20, and 3.40. Thus, by interpolation, the average cost per accident costs are:

for the side - $40,299:
for the corner - $58,234: and
for the face - $28,772.

Step 5: Calculate CA, annual accident cost at initial collision frequency (CF). This is the sum of the products of the initial collision frequencies calculated in Step 3 times the respective average accident cost (AAC) calculated in Step 4. Thus:

$$\begin{aligned} CA &= CF_{side}(ACC_{side}) + CF_{corner}(ACC_{corner}) + CF_{face}(ACC_{face}) \\ &= 0.00085(40{,}299) + 0.01223(58{,}234) + 0.00049(28{,}772) \\ &= 34.25415 + 712.20182 + 14.09828 \\ &= \$760.554 \end{aligned}$$

Step 6: Using the formula given in Section A.1.0, the guidance in Section A4.10 for making adjustments for the effects of cap year, and Tables A.14 through A.17, calculate the total present worth (TPW) and annualized costs for the case study feature.

First, determine if cap-year adjustments are needed using the following formula:

Cap Year = $\log(ADT_{limit}/ADT_{initial}/\text{Num Lanes})/\log(1+ TGR)$
ADT_{limit} = 23,700 vpd/lane (from Table A.7)
$ADT_{initial}$ = 3,716 vpd running in one lane (calculated above)
TGR = 10% (the traffic growth rate is given)
Cap Year = $\log(23{,}700/3{,}716/1)/\log(1 + (0.1))$
= 0.80467/0.04139 = 19.44 years

This is very close to the 20 years of the analysis period and one would be justified in skipping the adjustment that goes with the cap year's falling within the analysis period. However, to illustrate the process, the adjustment will be made. The KC value used in calculating costs is impacted by the cap year and could be calculated exactly by the formula given in Section A4.10. However, ROADSIDE rounds the cap year to an integer and Section A4.10 provides guidance for using KC values in Table A.15 to determine the cap-year-adjusted KC value, which is what will be done here.

Round the cap year to 19 and proceed as follows:

1. Using the 0% traffic growth rate and 4% discount rate portion of Table A.15, subtract the KC value for 19 years from the KC value for 20 years.

13.950	KC @ 4% discount rate & 20 years
13.134	KC @ 4% discount rate & 19 years
0.456	ΔKC 19 to 20 years

2. Multiply ΔKC by $(1 + TGR)^{\text{Cap Yr}}$
TGR (traffic growth rate) is given as 10%.

$$\Delta KC_{\text{to } 19} = 0.456(1.1)^{19} = 2.78885$$

3. Using the 10% traffic growth rate and 4% discount rate section of Table A.15, record the KC value for the cap year (19 years).

$$KC_{19\,yr} = 33.262$$

4. Add $\Delta KC_{\text{to } 19}$ and $KC_{19\,years}$ to obtain KC for project life.

$$\begin{aligned} KC_{PL} &= 2.789 + 33.262 \\ &= 36.051 \end{aligned}$$

From Section A.10:

$$TPW = (A(KC) + CI + ARC + CM(KT) - CS(KJ)$$

Total Present Worth of Accident Cost -

$$CA(KC) = \$760.554(36.051) \quad \text{(CA and KC from calculations above)}$$
$$= \$27{,}419$$

Total Present Worth of Installation Cost -

$$CI = 0 \quad \text{(given)}$$

Total Present Worth of Accident Repair Cost -

$$ARC = \Sigma KC(CD_i)(CF_i)$$

Where:

CD_i =Average collision damage repair costs for sides, corners, and face.
CF_i =Initial collision frequencies for sides, corners, and face.

For this analysis ARC is zero because there is assumed to be no repair cost associated with impacts on the tree. However, for illustrative purposes the form of the calculation would be as follows:

$$ARC = KC((CD_{side})(CF_{side}) + (CD_{corner})(CF_{corner}) + (CD_{face})(CF_{corner}))$$
$$= 36.051((0)(0.00085) + (0)(0.01223) + (0)(0.00049))$$
$$= 0$$

Total Present Worth of Maintenance Cost -

The annual maintenance cost (CM) is assumed to be zero. However to illustrate this step:

$$CM(KT) = (0)(13.590) \quad \text{(KT from Table A.16)}$$
$$= 0$$

Present Worth of Salvage Value -

The net cost to remove the tree at the end of the study period is estimated to be $1200. Thus, the salvage value (CS) is -$1200 and its present worth is:

$$CS(KJ) = -\$1200\ (0.4564) \quad \text{(KJ from Table 1.17)}$$
$$= -\ \$548$$

Summing:

$$TPW = \$27{,}419 + 0 + 0 + 0 - (-548)$$
$$= \$27,\ 967$$

To convert this number to an annualized cost, multiply by the capital recovery factor (CRF) found in Table A.14. This will give:

$$TPW(CRF) = 27{,}967(0.074)$$
$$= \$2{,}070$$

To recap the manual calculations, the results are given below in the same format as that in the case study report under item 14:

Total Present Worth	=$27,967	Annualized	$2,070
Accident Cost	=$27,419	Annualized	$2,029
Highway Dept. Cost	=$548	Annualized	$41
Installation Cost	=$0	Annualized	$0
Repair Cost	=$0	Annualized	$0
Maintenance Cost	=$0	Annualized	$0
Salvage Value	=$-548	Annualized	$-41

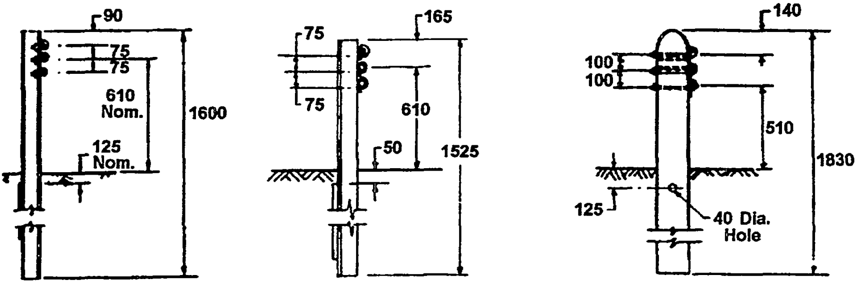
Note that the slight differences between the case study results report in Figure A.15 and the results above are because of rounding.

In this example problem, a two-lane, two-way highway was analyzed as two one-way highways to account for the feature being in a tangent to curve transition zone. Had the feature been on the curve, but out of the transition zone, the analysis could have been done without splitting the highway into two parts. However, the lane width entered into ROADSIDE would need to be adjusted by multiplying the lane width by the slope equivalency of the superelevated adjacent lane(s).

APPENDIX B
SELECTED ROADSIDE BARRIER DESIGN DETAILS

This appendix contains design details and additional information on the roadside barrier systems discussed in Section 5.4.1.

Note: All dimensions shown are in millimeters unless otherwise noted.



SGR01a SGR01b SGR01c

FIGURE B.1 3-Strand Cable

AASHTO Designation:	**SGR01a**	**SGR01b**	**SGR01c**
Post Type	S 75 x 8.5 steel	9 kg/m steel flanged channel	140 diameter modified wood
Post Spacing	5000	5000	3800
Beam Type	19 diameter steel cables	19 diameter steel cables	19 diameter steel cables
Maximum Dynamic Deflection	3.5 m	3.5 m	3.5 m

Remarks: For shallow angle impacts, barrier damage is usually limited to several posts, which must be replaced. Cable damage is rare except in severe crashes. A crashworthy end terminal is critical in each of the cable systems, both to provide adequate anchorage to develop full tensile strength in the cable and to minimize vehicle decelerations for impacts on either end of an installation.

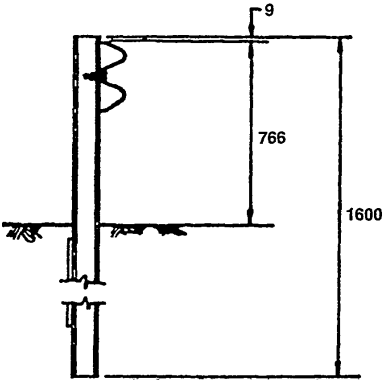


FIGURE B.2 W-Beam (Weak Post)

AASHTO Designation:	**SGR02**
Post Type	S 75 x 8.5 steel
Post Spacing	3810
Beam Type	2.67 w-section
Maximum Dynamic Deflection	approximately 2 m

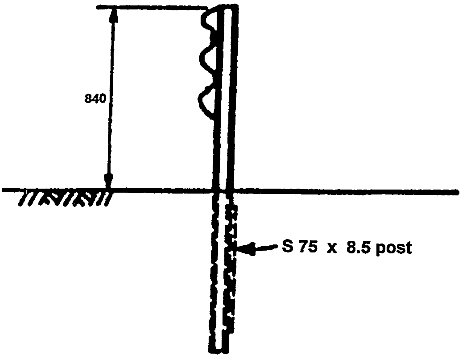


FIGURE B.3 Thrie-Beam (Weak Post)

AASHTO Designation:	**None**
Post Type	S 75 x 8.5 steel
Post Spacing	3810
Beam Type	3.43 thrie-beam
Maximum Dynamic Deflection	approximately 1.2 m

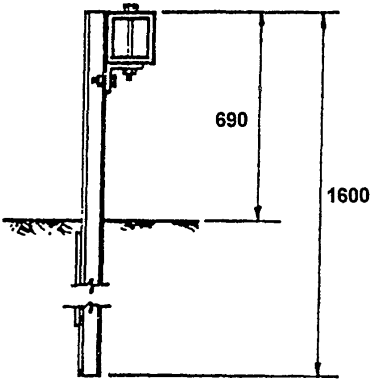
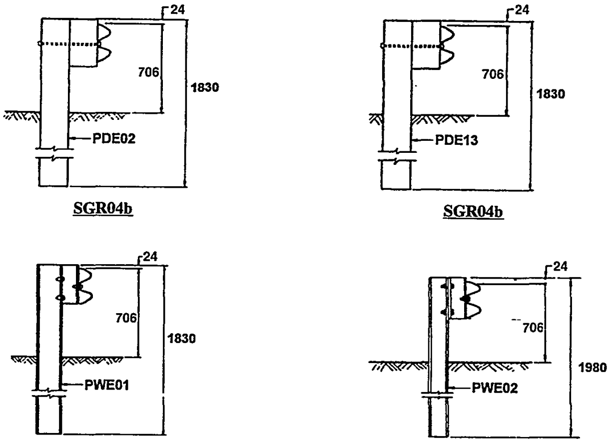


FIGURE B.4 Weak Post Box Beam

AASHTO Designation:	**SGR03**
Post Type	S 75 x 8.5 steel
Post Spacing	1830
Beam Type	152 x 152 x 4.78 steel tube
Maximum Dynamic Deflection	approximately 1.5 m



SGR04b SGR04b

SGR04a SGR04a

FIGURE B.5 Blocked-Out W-Beam (Strong Post)

AASHTO Designation varies with post type as noted below:

Post Type	PDE02 - 150 x 200 wood
	PDE13 - 180 Diameter wood
	PWE01 - W 150 x 13 steel
	PWE02 - W 150 x 13 steel
Post Spacing	1905
Beam Type	2.67 w-beam
Maximum Dynamic Deflection	approximately 0.9 m

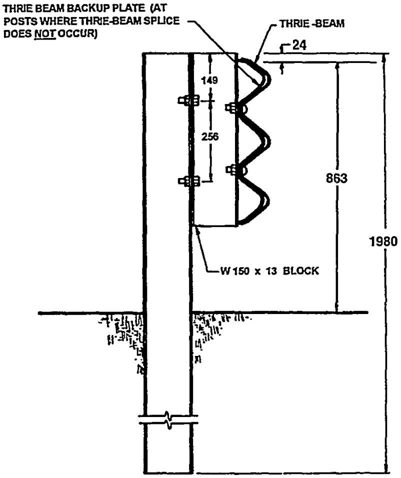


FIGURE B.6 Blocked-Out Thrie-Beam (Strong Post)

AASHTO Designation:	**SGR09a**
Post Type	W 150 x 13 steel or 150 x 200 wood
Post Spacing	1905
Beam Type	2.67 thrie-beam
Maximum Dynamic Deflection	approximately 0.6 m

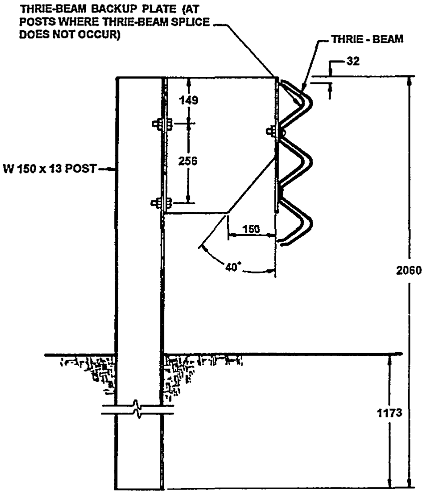


FIGURE B.7 Modified Thrie-Beam

AASHTO Designation:	**SGR09b**
Post Type	W 150 x 13 steel or 150 x 200 wood
Offset Block	M 369 x 26 steel
Post Spacing	1905
Beam Type	2.67 thrie-beam
Maximum Dynamic Deflection	approximately 0.9 m for a 9000-kg school bus (90 km/h, 15 degrees)

Remarks: Modified thrie-beam was first installed in Rhode Island, Colorado, Nebraska, and Michigan as an experimental barrier. Since that time, it has been re-classified as an operational system, requiring virtually no repair for shallow-angle hits. This barrier can accommodate vehicles ranging in size from 800-kg subcompacts to a 15,000-kg intercity bus.

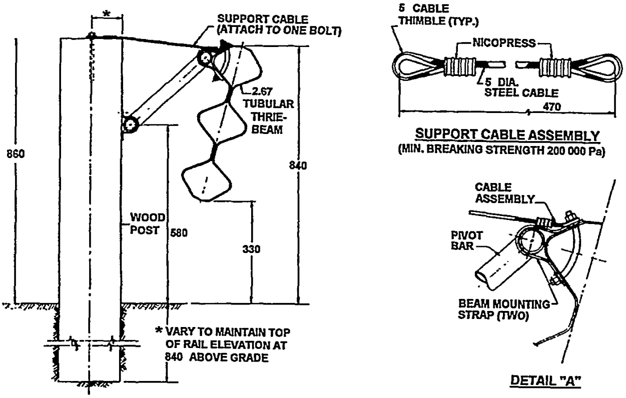


FIGURE B.8 Self-Restoring Barrier (SERB)

AASHTO Designation:	**None**
Post Type	200 x 200 wood
Post Spacing	1367
Beam Type	Welded tubular thrie-beam
Nominal Barrier Height	840
Maximum Dynamic Deflection	approximately 1.2 m with an 18,000-kg bus (90 km/h, 16 degrees)

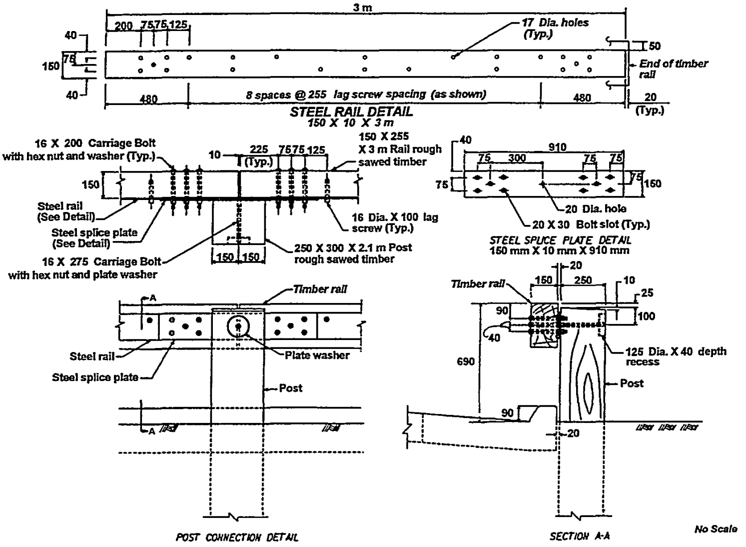


FIGURE B.9 Steel-Backed Wood Rail

AASHTO Designation:	**None**
Post Type	250 x 300 wood
Beam Type	150 x 250 wood with steel plate backing

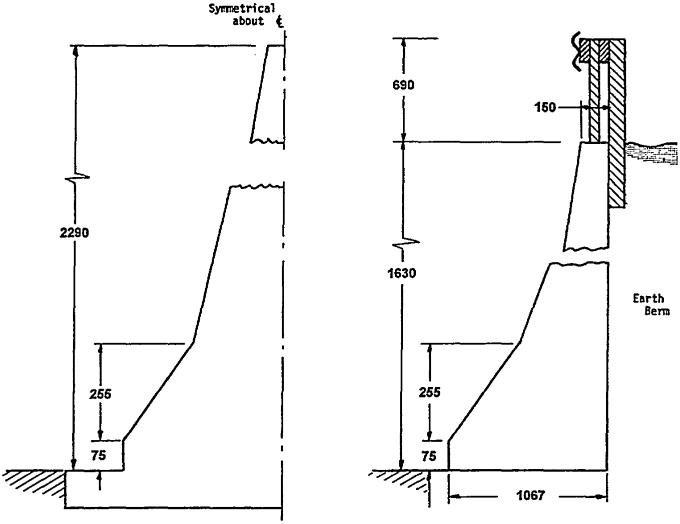


FIGURE B.10 Concrete Safety Shape

AASHTO Designation: MB5

The 810-mm high concrete safety shape was initially installed primarily as a median barrier, but has become commonly used as both a bridge railing and as a roadside barrier. Most of these barriers use the standard New Jersey shape; any extension in barrier height occurs above the slope break point. Several states extend the upper stem to serve as a maintenance-free glare screen. The two designs shown above are the extreme heights to which roadside barriers have been constructed—both along ramps with a history of truck accidents.

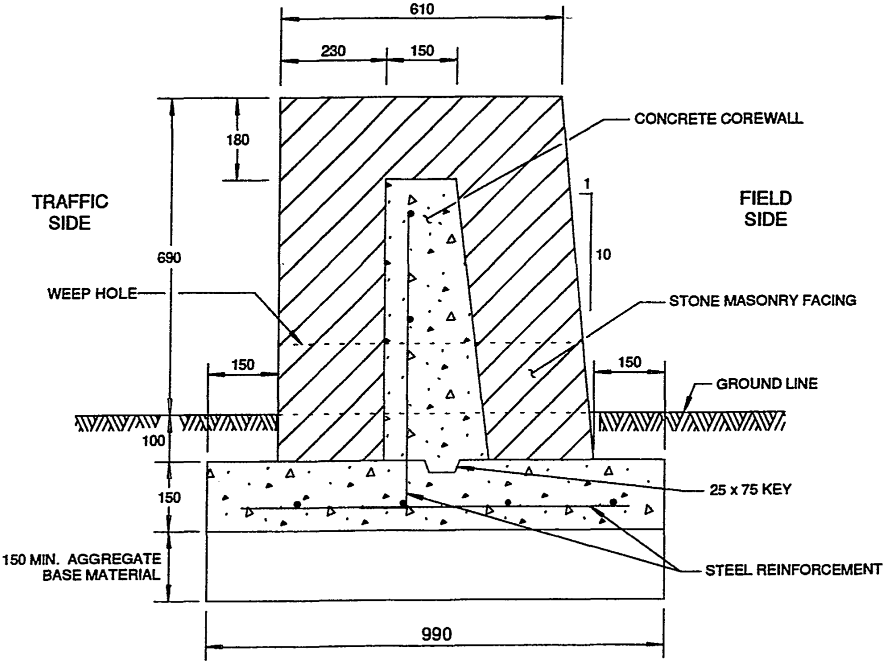


FIGURE B.11 Stone Masonry Wall

AASHTO Designation: None

This barrier consists of a reinforced concrete core faced with stone rubble masonry. Designed for use in scenic areas, its natural appearance and low height combine to make it an effective barrier for use on parkways and similar facilities.

APPENDIX C
SELECTED MEDIAN BARRIER DESIGN DETAILS

This appendix contains design details and additional information on the median barrier systems discussed in Section 6.4.1.

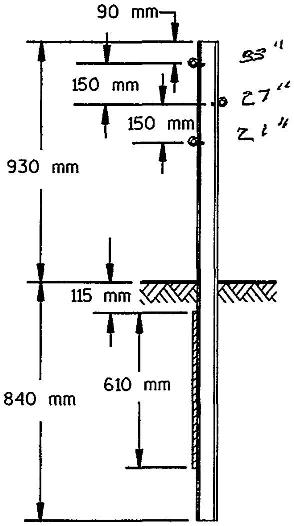


FIGURE C.1 3-Strand Cable

AASHTO Designation: **None (The former single-strand cable "MBI" is obsolete.)**

Post Type	S75 X 8.5
Post Spacing	4880 mm
Beam Type	19 mm diam steel cable
Nominal Barrier Height	760 mm
Maximum Dynamic Deflection	3500 mm

Remarks: Because of the high dynamic deflection for cable systems, they are not recommended for use in medians narrower than approximately 7 m. The extensive damage done during moderate to severe impacts leaves a significant length of barrier inoperative until repairs can be made. Cable median barrier systems are recommended for use on irregular terrain and on wider medians where the need is only to prevent infrequent potentially catastrophic cross-median accidents. For proper performances it is essential that this system be installed and maintained at the correct mounting height. This system is similar to the 3-strand cable roadside barrier, except that one of the cables is mounted on the opposite side of the post from the other two. See Figure B.1 for additional remarks.

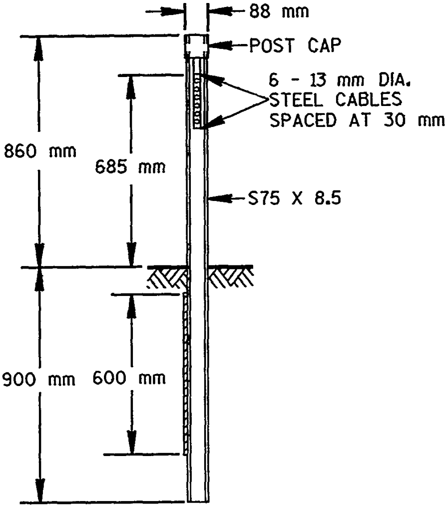


FIGURE C.2 6-Cable Guide Rail

AASHTO Designation:	**None**
Post Type	S75 x 8.5
Post Spacing	4000 mm
Beam Type	13 mm diam steel cable
Nominal Barrier Height	535 mm - 685 mm
Maximum Dynamic Deflection	3000 mm

Remarks: Because of the high dynamic deflections, this system is not recommended for use in medians narrower than approximately 6 m. The 6-cable guide rail has been successfully used by the Ontario Ministry of Transportation.

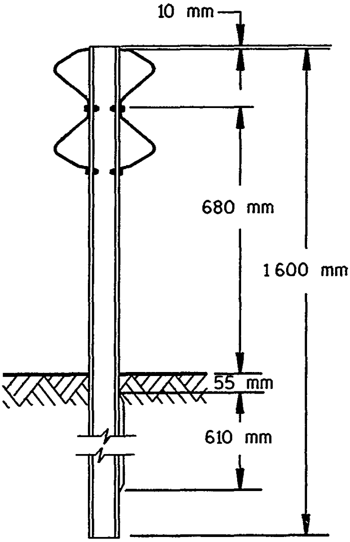


FIGURE C.3 Weak Post W-Beam

AASHTO Designation:	**SGM02**
Post Type	S75 x 8.5
Post Spacing	3810 mm
Beam Type	Two Steel "W" sections
Offset Brackets	None
Nominal Barrier Height	760 mm - 840 mm
Maximum Dynamic Deflection	Approximately 2100 mm

Remarks: This barrier system is suitable for wide flat medians where sufficient space is available to accommodate deflections. In order to place rigid objects within the median, the SGM02 must be divided into parallel SGR02 barriers with the object centered in 6.7-m plus gap or be transitioned to a semi-rigid system.

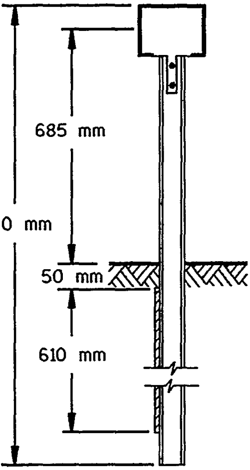
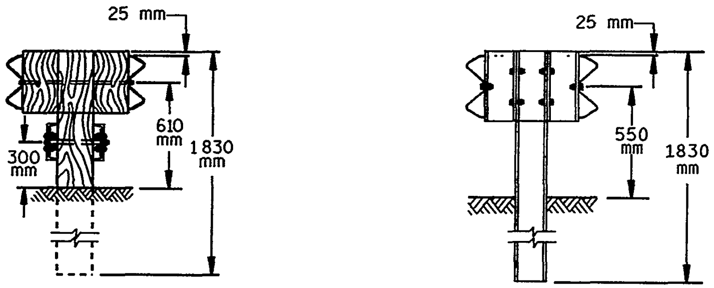


FIGURE C.4 Box Beam

AASHTO Designation:	**SGM03**
Post Type	S75 x 8.5
Post Spacing	1830 mm
Beam Type	TS-203 X 152 X 6.4
Offset Brackets	None
Mountings	Steel Paddles
Nominal Barrier Height	760 mm
Maximum Dynamic Deflection	1700 mm

Remarks: This barrier system is suitable for both wide and narrow medians and locations where the terrain is moderately irregular. Even moderate vehicle impacts cause a large number of posts to be damaged. Temporary supports may be used to maintain beam height until posts are replaced.



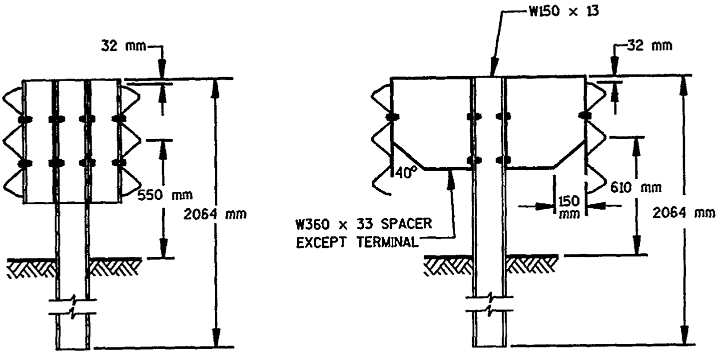
SGM06b **SGM04a**

FIGURE C.5 Strong Post W-Beam

AASHTO Designation:	**SGM06b**	**SGM04a**
Post Type	150 mm x 200 mm Timber*	W150 x 13
Post Spacing	1905 mm	1905 mm
Beam Type	Two Steel "W" Sections Two C150 x 12 Rub rails	Two Steel "W" Sections
Offset Brackets	Two 200 mm x 200 mm 360 mm Timber	Two W 150 x 13 x 360 mm
Nominal Barrier Height	760 mm	700 mm
Maximum Dynamic Deflection	approximately 600 mm	approximately 600 mm

Remarks: SGM06b and SBM04a systems are semi-rigid and are satisfactory for use in narrow medians. After typical impacts, the system remains serviceable. Some States use a "W" section as a rub rail, centered 250 mm above grade. This modification is appropriate for the SGM06b and a higher SGM04a. By dividing an SGM06b or SGM04a into parallel SGR04a-b rails (stiffened if deflection criteria cannot be met) objects in the median can be accommodated.

* 150 mm x 200 mm post and blockout is acceptable.



SGM09a

SGM09b

FIGURE C.6 Strong Post Thrie-Beam

AASHTO Designation:	**SGM09a**	**SGM09b**
Post Type	W150 x 13*	W150 x 13*
Post Spacing	1905 mm	1905 mm
Beam Type	Two Thrie-Beams	Two Thrie-Beams
Offset Brackets	W150 x 13*	M360 x 26 or W360 x 33
Nominal Barrier Height	810 mm	870 mm
Maximum Dynamic	approximately 500 mm	approximately 500 mm

Remarks: The SGM09 systems are satisfactory for use in narrow medians. Normal impacts do little damage to the rail. Under severe impact conditions, the rail of an SGM09b system remains upright and has the capability to redirect 18,000-kg vehicles impacting at 80 km/h and 15 degrees.

* 150 mm x 200 mm wood post is acceptable alternative (AASHTO Designation SGM09c).

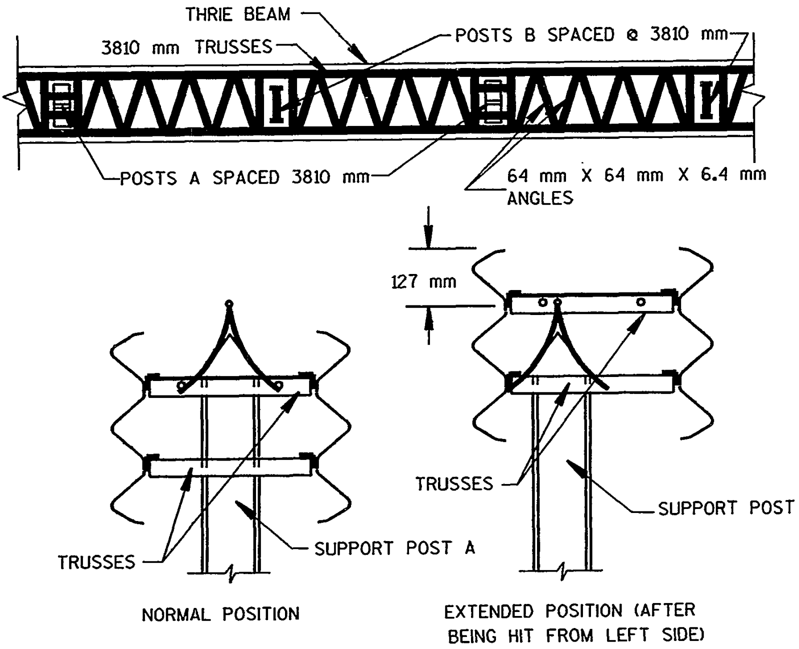
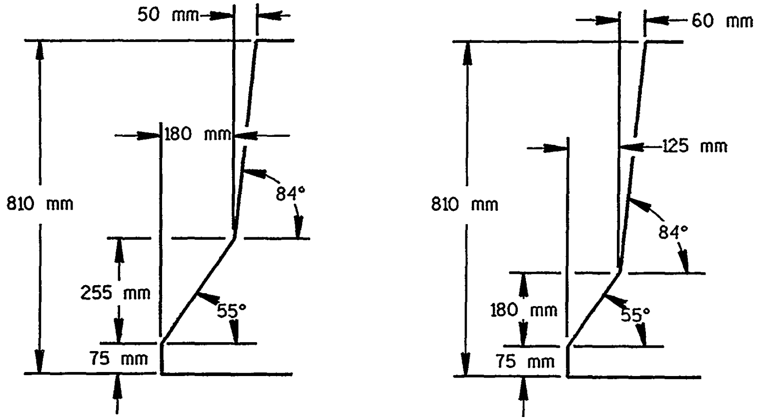


FIGURE C.7 Self-Restoring Median Barrier

AASHTO Designation:	**None**
Post Type	W150 x 29.8 x 2.1 m (A Posts); W150 x 29.8 x 2.4 m (B Posts)
Post Spacing	1900 mm
Beam Type	Two thrie-beams spaced at 500 mm by two steel trusses
Nominal Barrier Height	865 mm
Maximum Dynamic Deflection	730 mm (18,000-kg bus at 100 km/h and 15 degrees)

Remarks: This is a medium performance semi-flexible median barrier designed for use in narrow medians. The thrie-beam can deflect 90 mm laterally and 150 mm vertically and return to its original configuration without major damage. Transitions to end treatments have also been crash tested.



NJ-Shape **F-Shape**

FIGURE C.8 Concrete Safety Shape

AASHTO Designation:	**SGM11a**	**SGM10a**
Nominal Barrier Height	810 mm	810 mm
Maximum Dynamic Deflection*	0	0

Remarks: The lower sloped face redirects vehicles without damage under low-impact conditions. During moderate to severe impacts, some energy is dissipated when the vehicle is lifted off the pavement. The loss of tire contact with the pavement also aids redirection. In crash tests, the F-shape has proven to be more successful in preventing rollover of smaller vehicles.

The details of the shape are critical. The distance from the pavement to the break between the upper and lower slopes should be kept at 330 mm or below. Barrier performance under moderate to severe impact conditions is not significantly affected by overlays on the lower sloped face. The overall height of the barrier, however, needs to be maintained at a minimum of 740 mm.

The safety shape barrier is suitable for narrow medians. Both faces can be flared away from the centerline to provide room for rigid objects to be installed in the medians. (Flare rates should be as shown in Table 5.6.) Since this barrier requires a paved approach, its application in wide medians is less cost-effective.

* Very severe hits may destroy the barrier. Reinforcing is recommended to prevent shattering of concrete where the top of the barrier has a width less than 300 mm.

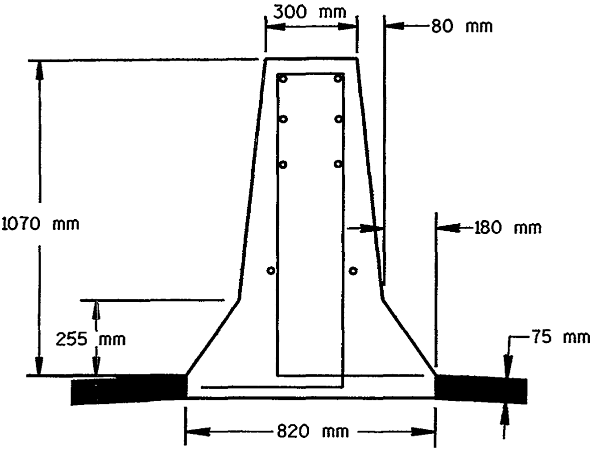


FIGURE C.9 Tall Wall Concrete Safety Shape (Reinforced)

AASHTO Designation:	**SGM12**
Nominal Barrier Height	1070 mm
Maximum Dynamic Deflection	0

Remarks: This tall wall concrete safety shaped barrier is used by the New Jersey Turnpike Authority.

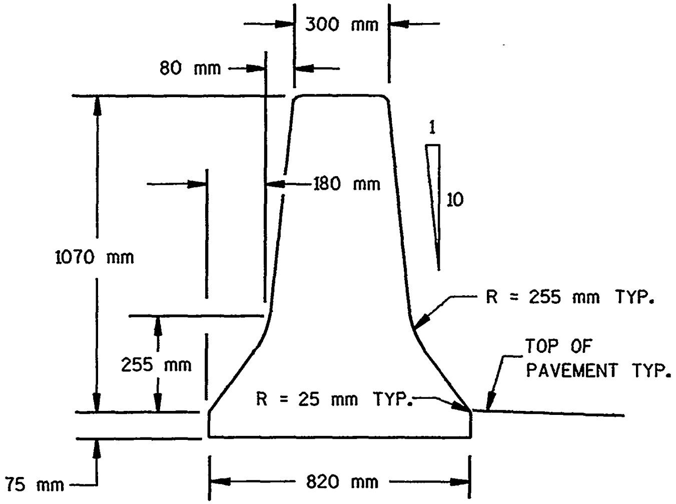


FIGURE C.10 Tall Wall Concrete Safety Shape (Non-Reinforced)

AASHTO Designation:	**None**
Nominal Barrier Height	1070 mm
Deflection	0

Remarks: This tall wall concrete safety shaped barrier is used by the Ontario Ministry of Transportation.

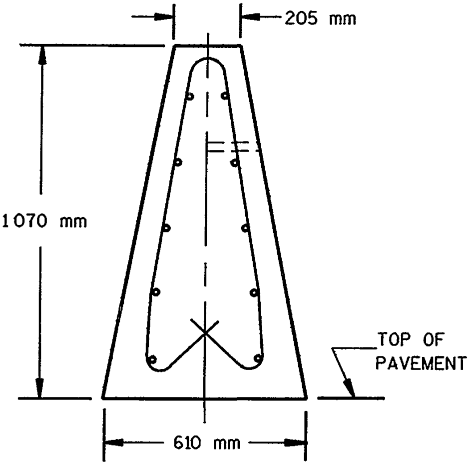


FIGURE C.11 Single-Slope Concrete Barrier

AASHTO Designation:	**None**
Nominal Barrier Height	1070 mm
Deflection	0

Remarks: This barrier is suitable for both permanent and temporary applications. The primary advantage is that the adjacent pavement can be overlaid several times without affecting the performance of the barrier. The disadvantage is that greater vehicle damage occurs at shallow impact angles compared to other safety-shaped barriers.

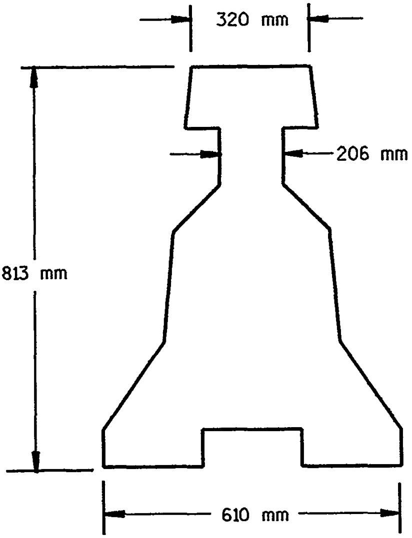


FIGURE C.12 Movable Concrete Barrier

AASHTO Designation:	**SWC01**
Nominal Barrier Height	813 mm
Deflection	1.2 meters

Remarks: This proprietary portable barrier system is suitable for both permanent (unbalanced traffic flow) and temporary application. It is composed of a chain of safety shaped concrete barrier segments 940 mm in length which can be shifted laterally. Even though the cost is relatively high, the system becomes cost-effective when frequent lateral movement of the temporary barrier is required while maintaining traffic.

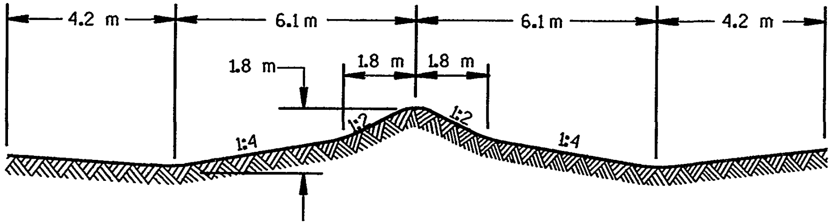


FIGURE C.13 Earth Berm

AASHTO Designation: **None**

Median is shaped to provide redirection.

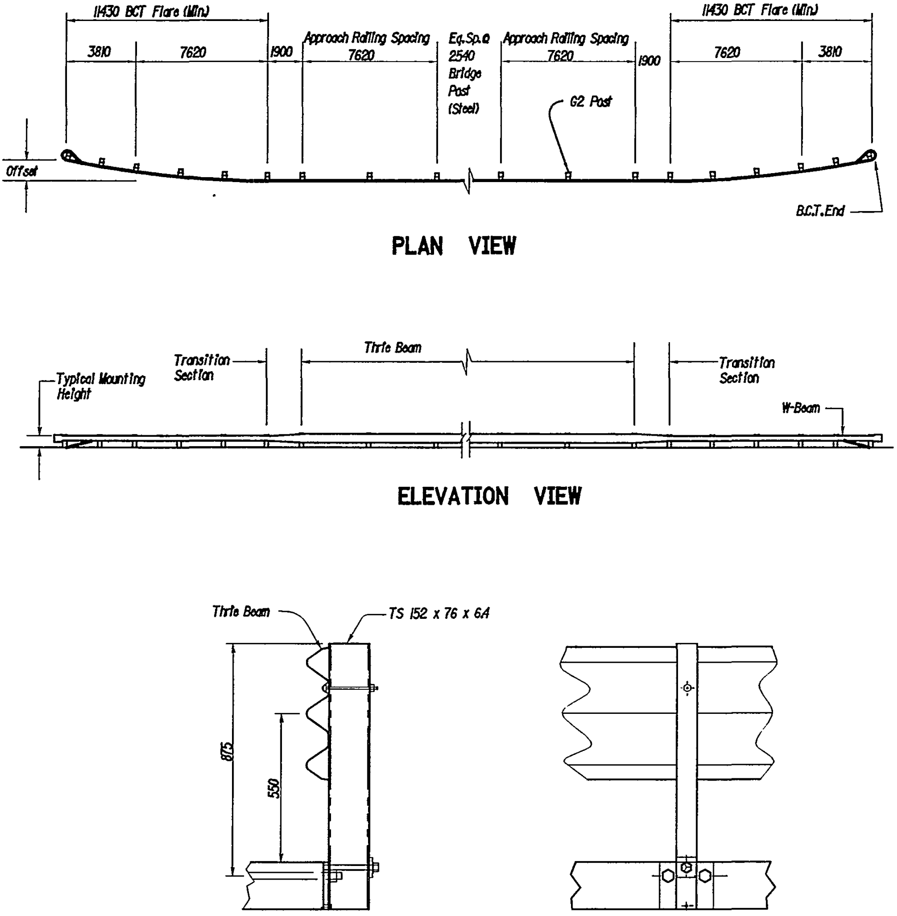
Height	1.2-m Minimum
Slope varies to suit field conditions	1:2 Desirable and maximum 1:3 Maximum for mowing 1:10 Minimum approach grade
Length	Minimum of full berm in advance of hazard

Remarks: This system provides redirection at low-impact angles (10 degrees or less) or low speeds (60 km/h or less). It may also be used in wide medians outside of the clear zone distance for both directions of travel.

APPENDIX D
SELECTED BRIDGE RAILING DESIGN DETAILS

This appendix contains design details and additional information on the crash-tested bridge railings described in Section 7.7.

Note: Some discrepencies exist between the information provided here and in Chapter 7 due to conversion to metric units and rounding off of numbers. The data given is for information only. For exact crash-test details, the reader is advised to refer to the original crash-test reports.

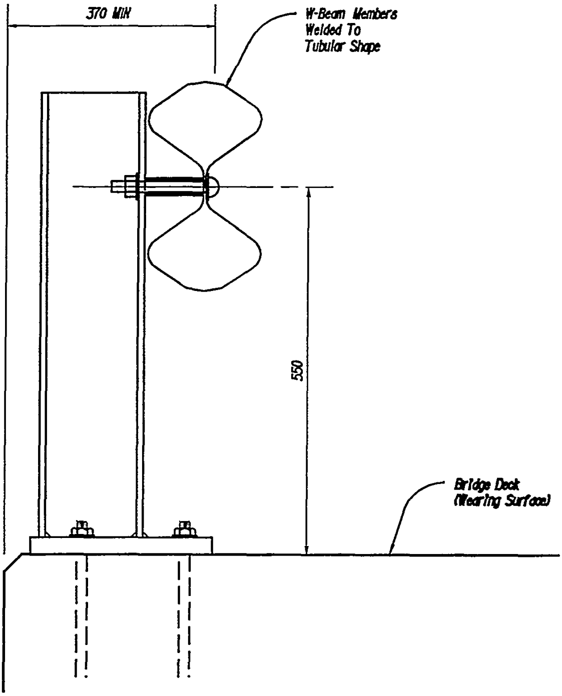


All Dimensions Shown Are mm unless Otherwise Noted.

FIGURE D.1 Side-Mounted Thrie-Beam Bridge Railing

Rail Height 810 mm

Test Vehicle	902-kg Car	1022-kg Car	1022-kg Car	9080-kg Bus
Impact Speed km/h	99	94	97	72
Impact Angle Degrees	14.1	16.0	16.0	7.7

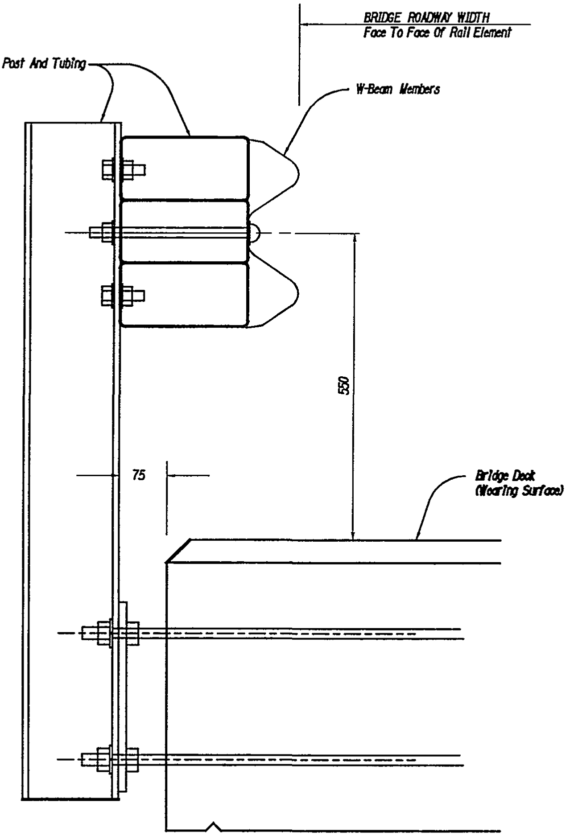


All Dimensions Shown Are mm unless Otherwise Noted.

ELEVATION OF POST

FIGURE D.2 Tubular W-Beam Bridge Railing

Rail Height	690 mm	
Test Vehicle	1035-kg Car	2043-kg Car
Impact Speed km/h	93	99
Impact Angle Degrees	14.0	27.5

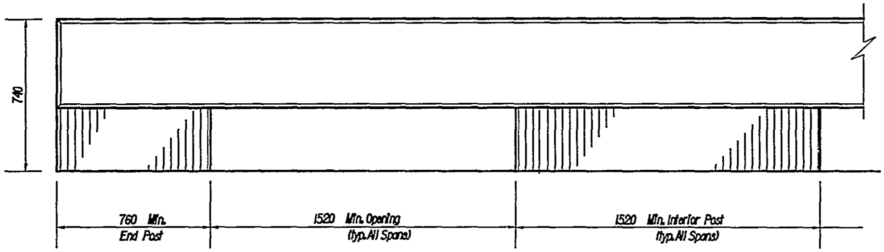


All Dimensions Shown Are mm unless Otherwise Noted.

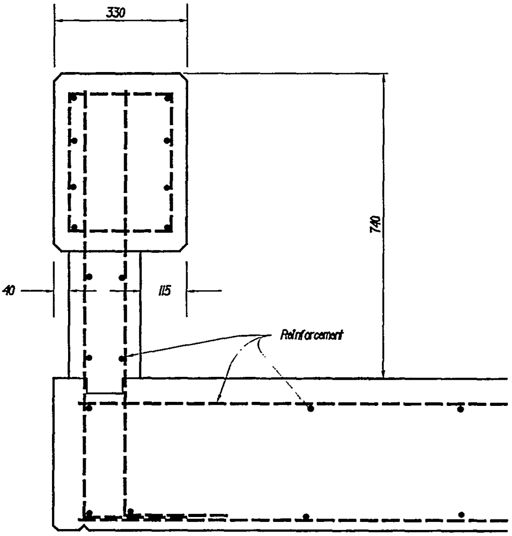
Type 1 POST

FIGURE D.3 Side-Mounted Rectangular Tube Bridge Railing

Rail Height	690 mm	
Test Vehicle	899-kg Car	2175-kg Car
Impact Speed km/h	98	97
Impact Angle Degrees	19.6	25.0



ELEVATION OF TRAFFIC RAIL

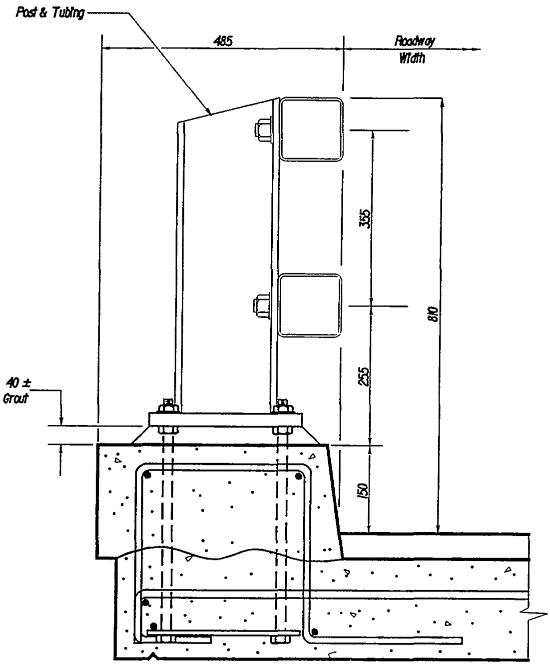


All Dimensions Shown Are mm unless Otherwise Noted.

SECTION 'B'

FIGURE D.4 Oklahoma TR-1 Bridge Railing

Rail Height	740 mm	
Test Vehicle	899-kg Car	2116-kg Car
Impact Speed km/h	95	95
Impact Angle Degrees	18.9	25.4

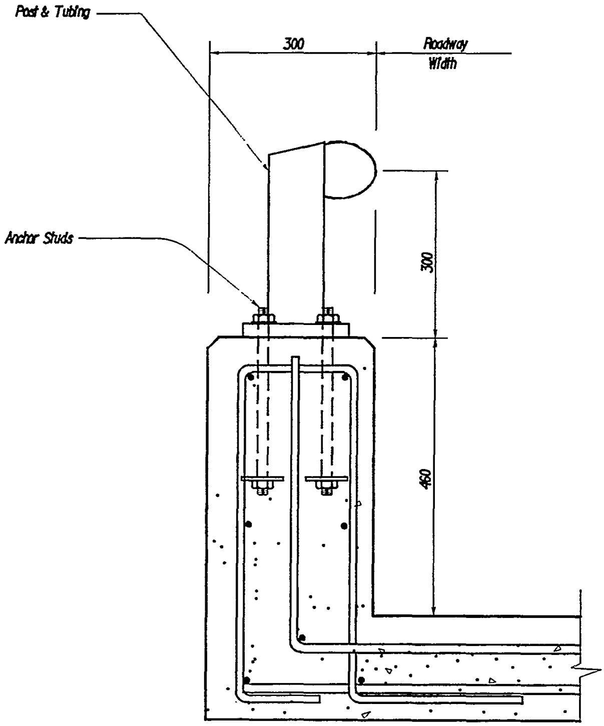


All Dimensions Shown Are mm unless Otherwise Noted.

CURB MOUNT-POST DETAIL

FIGURE D.5 2-Tube Curb-Mounted Bridge Railing

Rail Height	810 mm	
Test Vehicle	905-kg Car	2107-kg Car
Impact Speed km/h	94	97
Impact Angle Degrees	18.8	25

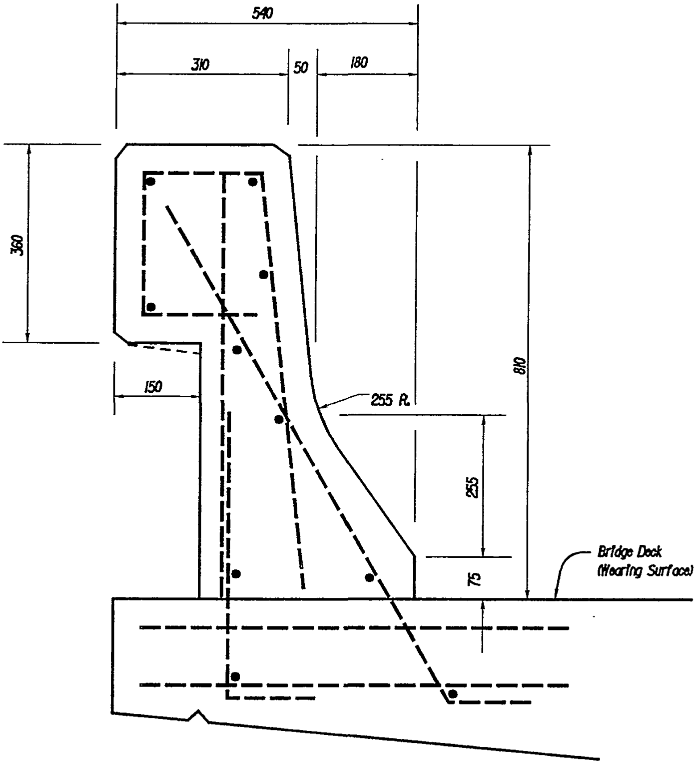


All Dimensions Shown Are mm unless Otherwise Noted.

SECTION THRU PARAPET & RAIL

FIGURE D.6 BR1 Type C Aluminum Bridge Railing

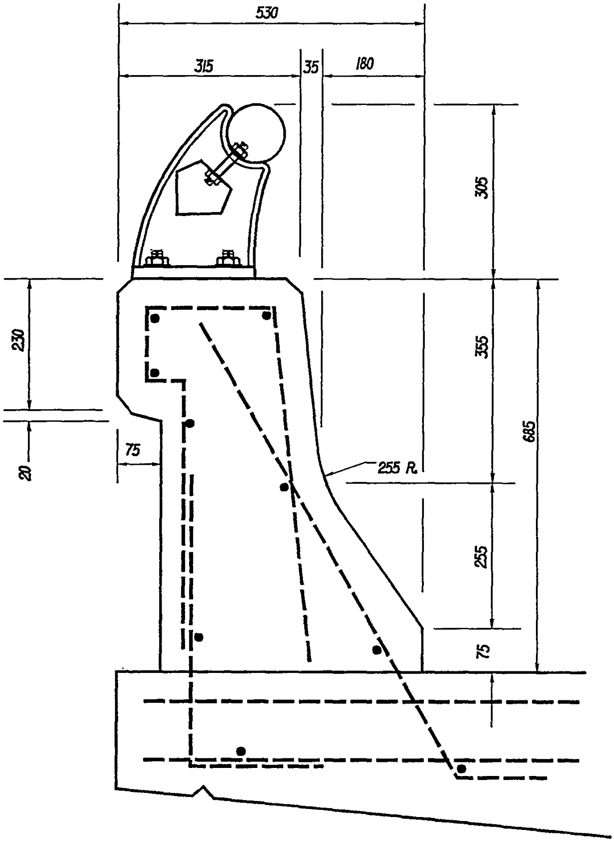
Rail Height	810 mm		
Test Vehicle	903-kg Car	2116-kg Car	9044-kg Bus
Impact Speed km/h	96	96	92
Impact Angle Degrees	18.8	25.0	14.8



All Dimensions Shown Are mm unless Otherwise Noted.

FIGURE D.7 Safety-Shaped Concrete Bridge Railing

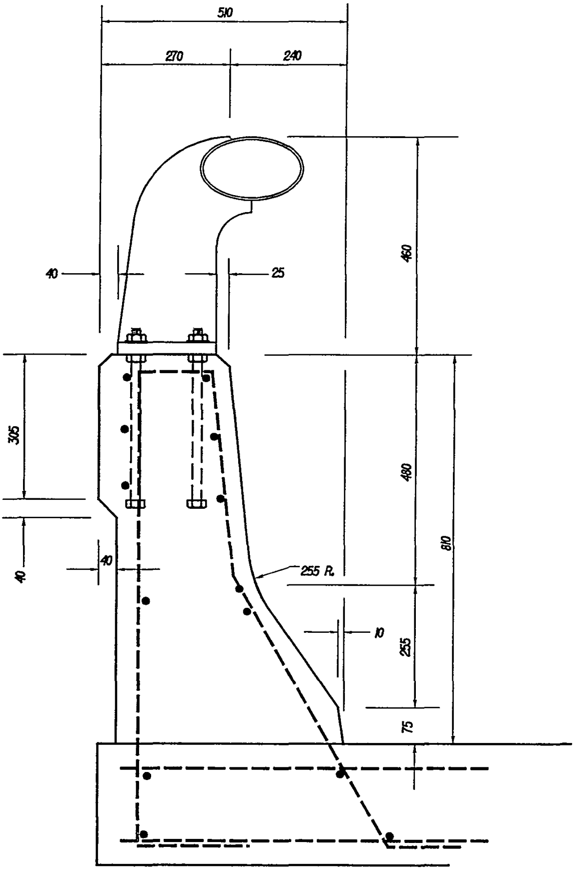
Rail Height	810 mm		
Test Vehicle	2061-kg Car	2061-kg Car	2061-kg Car
Impact Speed km/h	61	105	101
Impact Angle Degrees	7.0	7.0	25.0



All Dimensions Shown Are mm unless Otherwise Noted.

FIGURE D.8 Nevada Concrete Safety Shape

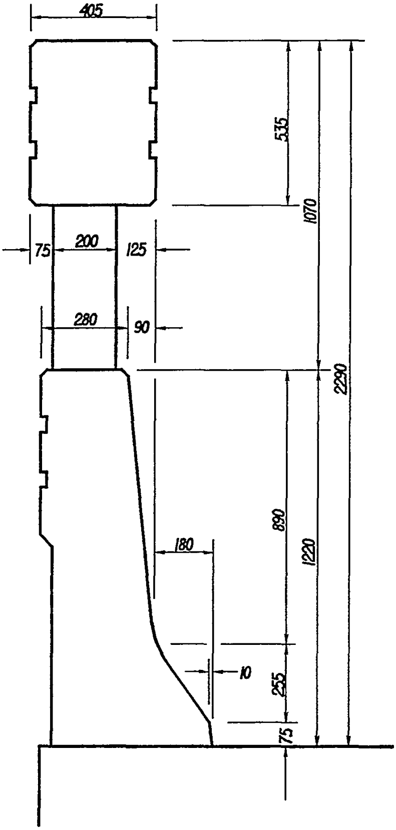
Rail Height	990 mm		
Test Vehicle	868-kg Car	2111-kg Car	18,160-kg Bus
Impact Speed km/h	98	99	95
Impact Angle Degrees	19.3	24.9	16.4



All Dimensions Shown Are mm unless Otherwise Noted.

FIGURE D.9 Texas Type HT

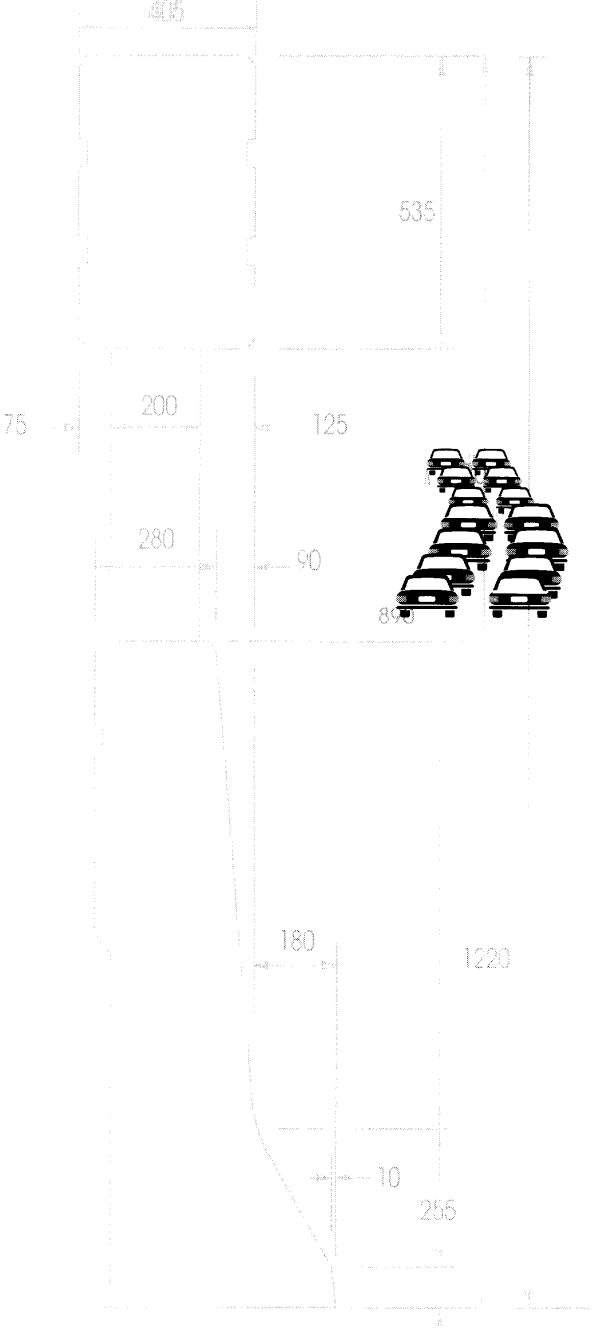
Rail Height	1270 mm
Test Vehicle	36,356-kg Truck
Impact Speed	78 km/h
Impact Angle Degrees	14.5



All Dimensions Shown Are mm unless Otherwise Noted.

FIGURE D.10 Texas Type TT

Rail Height	2290 mm
Test Vehicle	36,374-kg Tank Type Tractor-Trailer
Impact Speed	83 km/h
Impact Angle Degrees	15.0



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ERRATA

Inserted 3/28/96

To:

Roadside Design Guide Users

Due to the poor quality of several photographs in the attached Guide as initially printed, AASHTO has reprinted the following pages:

5-11
7-3
7-5
8-7
8-9
8-11
8-13
8-19

Due to an error in Figure A.9 on page A-19 and errors in three equations on page A-38, AASHTO has reprinted the corresponding pages:

A-19
A-38

Please note that the division by 1000 omitted in three equations on the original page A-38 was also omitted under Item 8 in the Help file of the ROADSIDE program; however, this omission was **not** made in the ROADSIDE program itself.

Please substitute these pages of the original text with the enclosed replacement pages.

We apologize for any inconvenience.

AASHTO Headquarters
February 1996

AASHTO Roadside Design Guide - 1996
ADOT Recieved 10 Copies

Distribution - initial (ask people to share)

* 1 - Louis (share with LeRoy)
1 - Bridge
1 - Traffic
4 - Design Managers
~~3~~1 - Predesign Managers (1 short)
10
1 - SPMG
1 - Utility Grp

I will ask FHWA for any extras they do not need.

We will need to issue a memo to designers to use as "Guide" only in concert with the info in Design Manual.

* Bob Miller is using one to be sure that we have proper referencing in Manual.

Need to have a coordinated request list for Roadway to see how many more to order and check $ availability in requesting ORGs.