CHAPTER 10
TRAFFIC CONTROL DEVICES AND TRAFFIC BARRIERS

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CHAPTER 10
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10-1.0 INTRODUCTION

The purpose of traffic control is to promote highway safety by providing for orderly and predictable movement of all traffic throughout the State's highway transportation system. Traffic control devices, barriers, etc., are used to direct and assist vehicle operators in safely traversing any facility open to public travel. There are a number of behavioral characteristics and situations which can be controlled to enhance safety.

10-1.01 Vehicle Path

Vehicle path is controlled directly by the driver, aided visually by signs and markings and physically by curbs, islands and barriers.

10-1.02 Vehicle Speed

Vehicle speed is controlled by the driver, but is standardized to fit the location by regulatory and warning signs, laws and enforcement. While road segment speed is regulated by coordinated signs, road condition and enforcement generally prevail.

Speed regulations and speed limits restrain a driver's freedom to drive at any speed he wishes. If drivers do not recognize particular speed limits as being reasonable, the limits will be disregarded and will become ineffective.

10-1.03 Vehicle Conflict

Vehicle conflict areas occur when driver indecision, speed and traffic volume combine to raise the potential for collision. The objective of traffic control devices and roadway design is to minimize conflict.

10-1.04 Operational Controls

10-1.04.01 After Construction

After construction is completed, the control devices installed as part of the project should move traffic safely through intersections or on an open road. The operational characteristics of the completed project should be observed and adjustments made to signal timing or signing, as necessary. These latter functions are the responsibility of the District Traffic Engineer.

10-1.04.02 During Construction

During construction, traffic control devices are generally the responsibility of the Contractor, or the Maintenance Engineer if the project is being constructed by maintenance forces. The control devices used during the construction phase are prescribed by the references listed in Section 10-10.0.

10-1.05 Traffic Laws and Regulations

Laws are official statutes of the State and are necessary for the proper functioning of traffic control devices. A regulation is an enforceable rule promulgated by the Commissioner. Specific laws pertaining to traffic control can be found in the revised Minnesota Code.

10-1.05.01 Rules and Regulations

The most common rules and regulations of concern to the Department are those regarding;

1. Signs, signals and markings,
2. Speed restrictions,
3. Passing restrictions,
4. Parking prohibitions,
5. Through highways,
6. Load limits,
7. Lane-use controls,
8. Advertising restrictions,
9. Restrictions of certain classes of traffic such as pedestrians, bicycles and animals,
10. Right-of-way and access control, and
11. Rules of the road.

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10-1.06 Warranting Procedure for the Use of Explicit Controls

To be effective, a traffic control device should meet five basic requirements. They are to:

1. Fulfill a reasonable need,
2. Command attention,
3. Convey a clear, simple message,
4. Command respect, and
5. Give adequate time for a proper response.

For regulatory devices, the actions required of vehicle operators and pedestrians are specified by State statute, local ordinances or resolutions that are consistent with national standards. Specific warrants for installation of explicit controls are prescribed in the *Minnesota Manual on Uniform Traffic Control Devices* (*MN MUTCD*).

10-2.0 RULES OF THE ROAD

In addition to explicit controls, there are driver behavior patterns which have become typical in this country. Most drivers expect other drivers to behave in a predictable manner according to the rules of the road. Designers should be aware that the rules of the road influence driver expectancy, and the use of traffic control devices should reinforce that expectancy.

10-2.01 Vehicle Position

The running position for a vehicle on a two-lane roadway will be in the right-hand lane except for maneuvers. A maneuver is a passing maneuver, change in direction at an intersection or an evasive movement to avoid contact with anything in its path. On a multi-lane facility the usual running position for a vehicle will be in the right-hand lane except for passing maneuvers.

10-2.02 Yield Conditions

A driver will normally yield the right-of-way to:

1. Vehicles approaching from the right at uncontrolled intersections,
2. Overtaking vehicles,
3. Pedestrians in crosswalks, and
4. Emergency vehicles.

10-2.03 Speed Factors

The driver's choice of speed will be affected by:

1. Roadway geometrics,
2. Weather,
3. Traffic (motor vehicular, pedestrians and other modes),
4. Roadway conditions,
5. Vehicle characteristics, and
6. Posted speed zones.

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10-3.0 MARKINGS AND DELINEATORS

There are five general types of markings in-use;

1. Pavement markings,
2. Object markings,
3. Delineators,
4. Colored pavements, and
5. Barricades and channelizing devices.

The *Minnesota Manual on Uniform Traffic Control Devices* (*MN MUTCD*), the MnDOT *Traffic Engineering Manual* and Technical Memoranda set forth allowable limits, alternatives and specific standards for these markings. The District Traffic Engineer's office can provide guidance.

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10-4.0 SIGNS

Signing standards and guidelines for permanent and temporary signs are contained in the *Minnesota Manual on Uniform Traffic Control Devices* (*MN MUTCD*), the MnDOT *Traffic Engineering Manual* and the MnDOT *Standard Signs Manual*.

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10-5.0 SIGNALS

10-5.01 Vehicular Traffic Control

10-5.01.01 General

Highway traffic signals are generally grouped into traffic control signals, pedestrian signals and other highway traffic signals. Signals can operate to the advantage or disadvantage of the vehicles and persons controlled. Traffic control signals should control traffic only at the intersection or mid-block location where the installation is placed. There are two types of traffic control signals, pre-timed and traffic-actuated. Signal warrants are discussed in the *MN MUTCD* in the signal section.

10-5.01.02 Signal Design and Coordination

The selection, location and placement of traffic signals and related equipment such as loop detectors, cabinet and service equipment pads, hand holes, conduit and cable are determined by the use of manuals [*MN MUTCD*, MnDOT *Traffic Engineering Manual*, MnDOT *Signal Design Manual* (latest edition; web address: http://www.dot.state.mn.us/trafficeng/publ/index.html)] and by the expertise and current practices of traffic engineering design, operations and field personnel.

Signal equipment design, installation and maintenance are the responsibility of the Office of Traffic Engineering, the District Traffic Engineer, or the Electrical Services Section..

A thorough engineering study of roadway and traffic conditions, resulting in an Intersection Control Evaluation (ICE), is made prior to any signal installation.

Although road designers do not generally become involved in the selection and location of signals, they should keep the possibility or presence of signals in mind during the design process because:

1. The need for signalization at an intersection affects the design of islands, channelization, curb cuts (pedestrian ramps), corner radii and other features.
2. During construction, temporary signals may be needed to control traffic, either on the route being constructed or along a route to which traffic is being diverted.
3. Minor signal work may be required by mill and overlay, bridge re-deck and bridge approach panel projects. This normally consists of loop detector replacement and the possible adjustment or relocation of hand holes (pull boxes).
4. Roadway construction may provide the opportunity to lay conduit or place other signal equipment easily and inexpensively to meet future signalization needs.

Any questions regarding signalization should be referred to the District Traffic Engineer.

Designers must be in contact with signal design personnel in order to incorporate signal-related work into their plans.

10-5.02 Pedestrian Signals

Pedestrian signal indications are traffic signal indications used to control pedestrian traffic. They usually consist of pedestrian push buttons and indications with a steady walking person symbol, a flashing upraised hand with a countdown timer, and a steady upraised hand. MnDOT installs accessible pedestrian stations (APS) at all new and reconstructed signals to be ADA compliant. Pedestrian signals are usually installed in conjunction with vehicular traffic signals.

10-5.03 Other Signals

Other types of signals include flashing beacons, pedestrian hybrid beacons, advanced warning signals, lane-use control signals, movable bridge signals, emergency-traffic control signals, railroad crossing signals, one-lane, two-way facility signals, freeway entrance ramp control signals and portable signals.

10-5.03.01 Flashing Beacons

Flashing beacons can provide traffic control when used in an intersection, be used at mid-block crosswalks, at non-signalized intersection, to supplement certain regulatory signs, and to warn of obstructions in or adjacent to the roadway.

10-5.03.02 Advanced Warning Flashers (AWF)

AWF's are part of the intersecton traffic control signal and alert drivers when the green indication of the traffic control signal they are approaching is about to terminate.

10-5.03.03 Lane-Use Control Signals

Lane-use control signals are special overhead signals with indications used to permit or prohibit the use of specific lanes. Supplementary signs are often used to explain their meaning. The common indications are a downward green arrow, a yellow "X" and a red "X".

10-5.03.04 Movable Bridge Signals

Movable bridge signals and gates are used to stop traffic for temporary roadway closures, rather than to alternately assign right-of-way to conflicting traffic movements. They are controlled by the bridge tender in coordination with the movable span.

10-5.03.05 Emergency Traffic Signals and Hybrid Beacons

Emergency traffic signals is typically in front of or near a building where there wouldn't normally be a signal, but where one is needed to allow emergency vehicles to safely access to the road by giving them the right-of-way. An emergency hybrid beacon is a special type of traffic signal system used to warn travelers and assist the emergency vehicles with safely entering the roadway. These systems are typically installed mid-block and because they go dark when at rest, they are not considered a traffic control systems.

10-5.03.06 Railroad Crossing Signals

Railroad crossing signals and gates are used to stop traffic at railroad-highway grade crossings during the approach or presence of a train. These signals may be coordinated with nearby intersection control signals.

10-5.03.07 One-Lane, Two-Way Facilities

One-lane, two-way facility signals are used to alternately allow opposing flow vehicular movements onto a shared single lane. Some permanent locations exist, but many are temporarily created due to construction or maintenance activities on bridges or other roadway sections.

10-5.03.08 Freeway Entrance Ramp Control

Freeway entrance ramp control signals (ramp meters) are used on ramps to limit or meter the rate at which vehicles are allowed onto the freeway and to provide bypass advantages to buses and car pools. The purpose is to increase freeway capacity and flow and to reduce merging accidents.

10-5.03.09 Portable Signals

Portable signals are used for temporary conditions such as in a construction zone where a temporary bypass is located.

10-5.04 Emergency Road Closing Gates

Emergency road closing gates are being employed in some areas of the State to be used in the event of major winter storms or natural disasters such as floods and tornados. MnDOT has not established standards for these devices. Contact the Office of Maintenance for guidelines on emergency road closings and for information on areas using emergency road closing gates.

10-6.0 LIGHTING

10-6.01 Roadway Lighting

Roadway lighting guidelines are found in the *Traffic Engineering Manual*, Chapter 10.

10-6.02 Pedestrian and Pedestrian/Roadway Illumination

Pedestrian walkway and bikeway lighting may not increase the capacity of pedestrian facilities, but its value to the safety and security of pedestrians is considerable. Pedestrian walkway and bikeway illumination guidelines are found in *An Informational Guide for Roadway Lighting*, published by AASHTO and the *American National Standard Practice for Roadway Lighting*, published by the Illuminating Engineering Society of North America.

Consult the Office of Traffic Engineering or the District Traffic Engineer with questions regarding lighting.

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10-7.0 TRAFFIC BARRIERS

The following is a discussion of the MnDOT design guidelines for roadside and median barriers. For further information, refer to the current AASHTO *Roadside Design Guide*.

10-7.01 Roadside Barriers

10-7.01.01 Service Requirements and Performance Criteria

Roadside barriers are protective devices for redirecting an errant vehicle from a dangerous path. The term "guardrail" refers to those barriers normally installed along the side of the road to prevent a vehicle from colliding with an obstruction or taking a perilous, off-roadway course where recovery of vehicle control is not reasonably possible. Briefly summarized, guardrails should effectively perform the following functions:

1. Prevent a "standard" vehicle from climbing over, breaking through or wedging under the installation.
2. Prevent or reduce the severity of a collision with a fixed object.
3. Minimize the departure angle of a redirected errant vehicle to reduce the likelihood of a secondary collision with following or adjacent vehicles.
4. Achieve these objectives while minimizing damage to the vehicle and injury to the occupants.
5. Protect abutting property owners and users from vehicle encroachment where there is a high likelihood of vehicles leaving the roadway.

Performance criteria for guardrail systems are established by AASHTO. The current criteria are found in the Manual for Assessing Safety Hardware (MASH) and National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. These reports establish the tests required to evaluate the occupant risk and structural integrity of the systems as well as the post-impact behavior of the vehicle for a variety of vehicle masses at various speeds and impact conditions. Systems must meet the current criteria in order to be used on our Trunk Highway System.

10-7.01.02 Project Considerations for Guardrail

There is no analytical way of precisely determining whether guardrail is needed in a given situation. Some guidelines and methodologies have been developed, but these must be supplemented with good engineering judgment. Remember that guardrail itself is a formidable hazard and should not be installed unless it will reduce accident severity. Guardrail should be installed discriminately and only when it is not feasible to remove or relocate the hazardous condition or when it is determined that the object is more of a hazard than the barrier itself.

When highway improvement projects are being designed for existing highways, an effort should be made to reduce the number of hazards in order to reduce the amount of guardrail. While it may not always be feasible to eliminate guardrail along existing highways by flattening side slopes to create a recovery area, this technique should receive consideration in designing safety improvement projects. Another suggested method for eliminating guardrail is to lengthen culverts so that the culvert end is outside of the clear zone. When considering the need for guardrail, the following questions should be considered:

1. Can the hazard be removed?
2. Can the hazard be relocated?
3. Can the hazard be made with a breakaway design?
4. Can a crash cushion be used rather than guardrail to protect the hazard?
5. Is the guardrail a greater hazard?

If the answer is "no" to all of these questions, then guardrail should be used.

Hazards that may warrant guardrail fall into these general categories: adverse geometrics such as sharp curves, high embankments and steep side slopes existing alone or in combination; fixed objects such as bridge piers, abutments, footings, walls, head walls, posts and trees; and other roadside hazards such as rock cuts, large boulders, permanent water over 2 ft deep, drop-offs and trees along the roadside. Where hazards exist within the median of divided highways, guardrail installations are as important as those along the outside of the roadway.

Guardrail is generally not required where speeds are less than 40 mph. Engineering judgment must be exercised in the application of this guideline with regard to hazardous locations in these areas.

The use of guardrail with curb is discouraged. Crash tests have shown that the use of guardrail over curb where high-angle, high-speed impacts are likely can result in a vehicle vaulting the guardrail due to the trajectory of the vehicle and the dynamic deflection of standard line barrier. Even at moderate speeds and shallow impact angles, these curbs can induce vehicle vaulting which can result in the vehicle striking the guardrail while it is airborne. If guardrail must be installed where there is a curb, the curb should be a mountable type, as defined by AASHTO, and not over 4 in. high, and the guardrail, ideally, should be placed parallel to the face of the curb with the front face of the barrier at the front face of the curb.

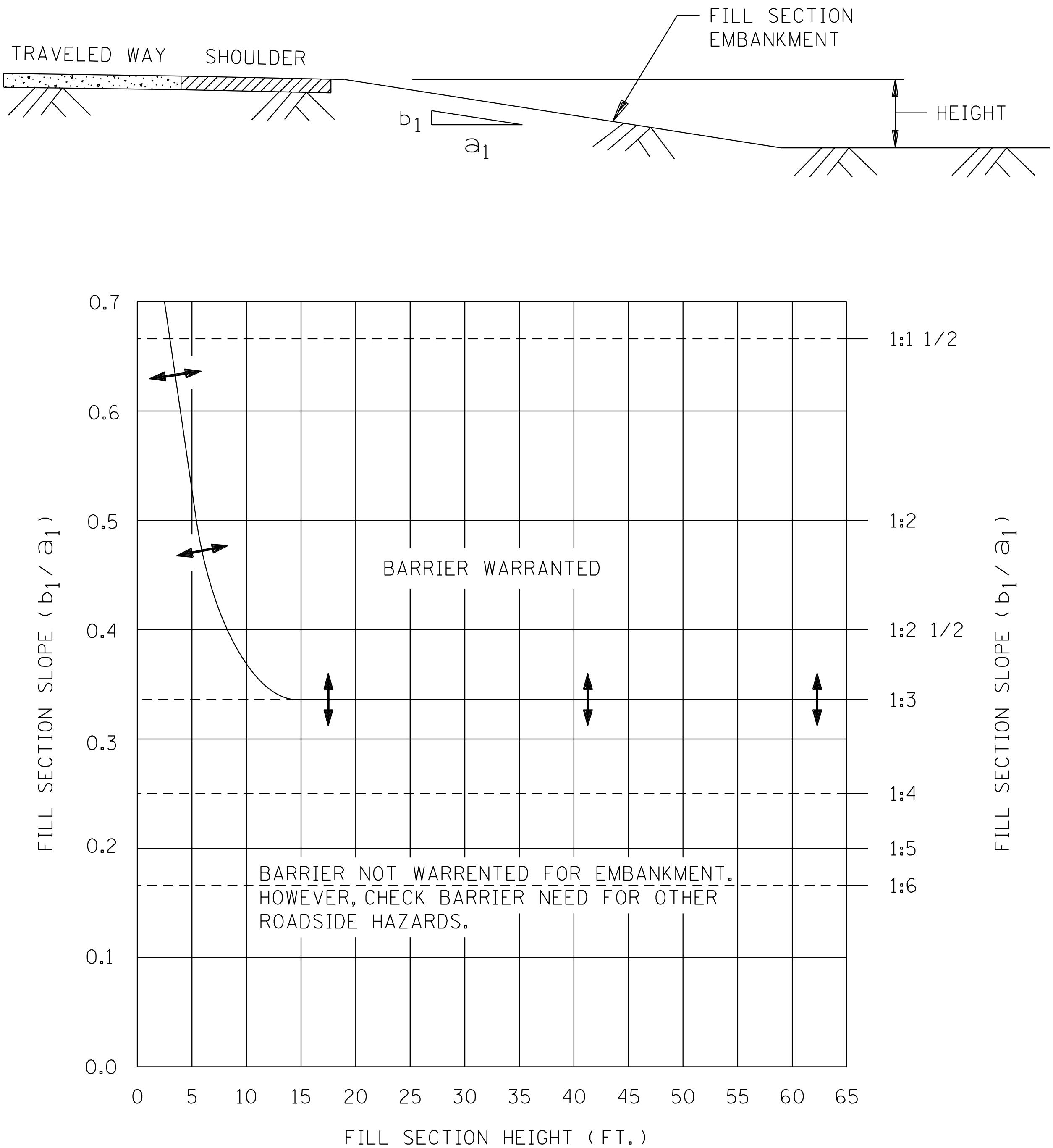
Guardrail should be located as close to the hazard as possible while maintaining the required distance between the guardrail and the hazard. See Section 10-7.02 for design deflections or working widths for various barriers. In addition, the slope criteria in Section 10-7.01.03 and 10-7.03 should be maintained in front of the guardrail.

10-7.01.03 Adverse Geometrics

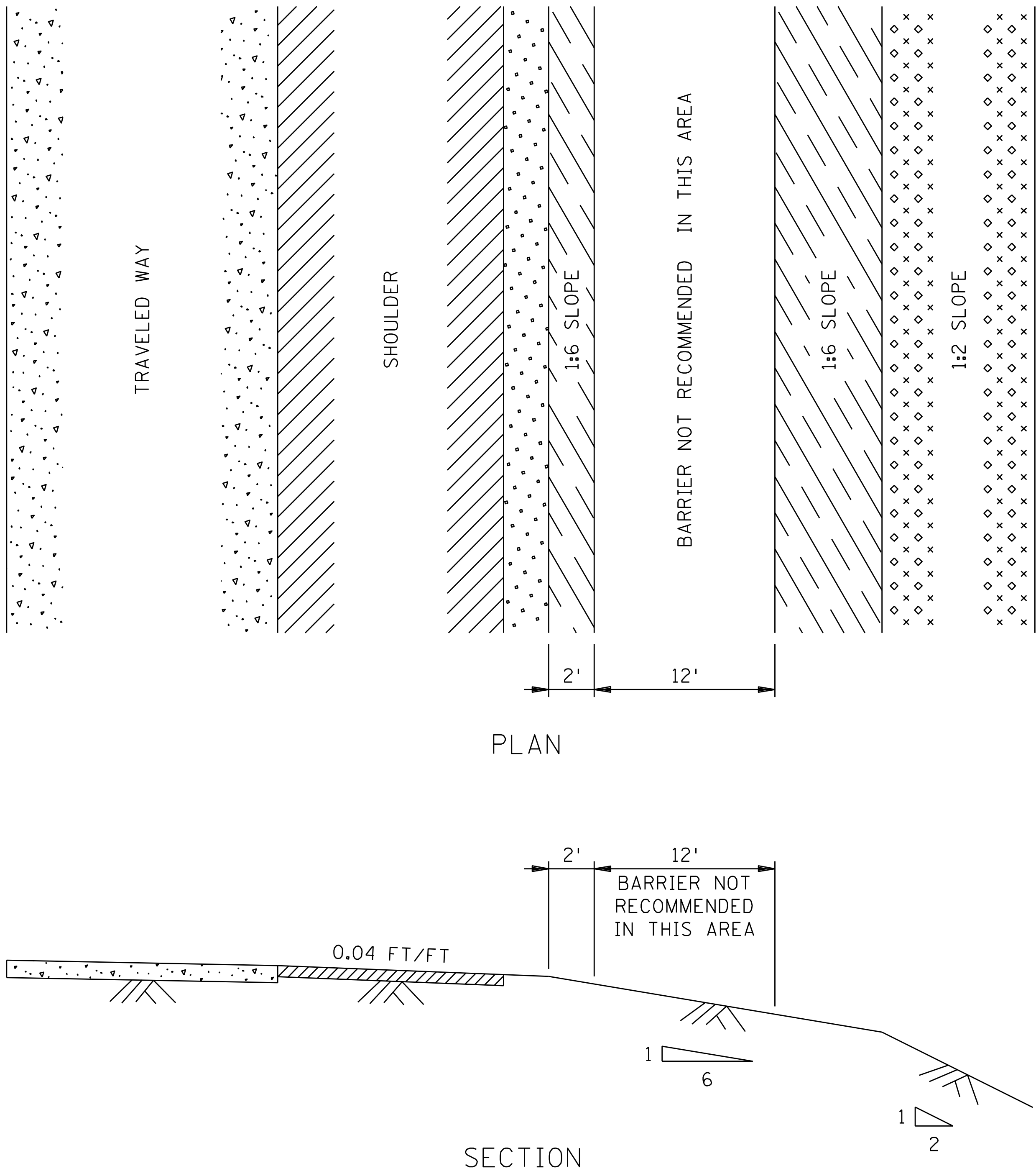
Height of embankments, steepness of side slopes and sharpness and direction of curvature are all elements contributing to the consequences of accidents involving vehicles inadvertently leaving the roadway. The need for guardrail depends on the extent to which these factors contribute to crash severity. The need for shoulder guardrail along embankments must be rationalized by evaluating whether the chance of "riding out" an over-the-embankment path would be less damaging than striking the guardrail. As a guideline, the equal severity curve shown in Figure 10-7.01A should be used for embankment slopes. Combinations of embankment height and slope plotting above and to the right of the curve indicate a need for guardrail. Combinations plotting below and to the left of the curve indicate conditions are less likely to be severe without guardrail. However, other factors contributing to accident severity, such as hazards located either on or at the toe of the slope, should be taken into consideration.

As a general rule, a roadside barrier should not be placed on slopes. However, it is acceptable if guardrail is warranted on broken-back or barn roof slopes (1:6 or flatter slopes and then a steeper slope) to locate the guardrail near the break point between 1:6 and steeper slopes to provide more recovery area. However, the barrier should not be located between 2 ft and 14 ft from the edge of the shoulder because of possible vaulting due to the slope break. See Figure 10-7.01B.

Horizontal curves alone normally do not warrant shoulder guardrail. Guardrail protection, however, should be considered along the outside edge of curves that are minimally acceptable for the design speed or for isolated curves of 3 degrees or sharper when there is an inadequate run-out area beyond these curves. Curves in conjunction with high embankments and steep slopes are potentially more dangerous than curves alone.



WARRANTS FOR GUARDRAIL ALONG FILL SECTIONS
Figure 10-7.01A



ROADSIDE BARRIER LOCATION ON TYPICAL BARN TOP SECTION
Figure 10-7.01B

10-7.01.04 Fixed Objects

Guardrail is warranted in advance of any fixed object located within the clear zone, provided the object is potentially more damaging than the guardrail if struck by a vehicle and the object cannot be feasibly removed or relocated. Objects such as supports for lights and sign posts equipped with breakaway devices do not require guardrail. Likewise, minor wood posts (less than 50 in^2) or other objects likely to inflict less damage than guardrail do not require a guardrail installation. Table 10-7.01A summarizes guidelines for protecting fixed objects.

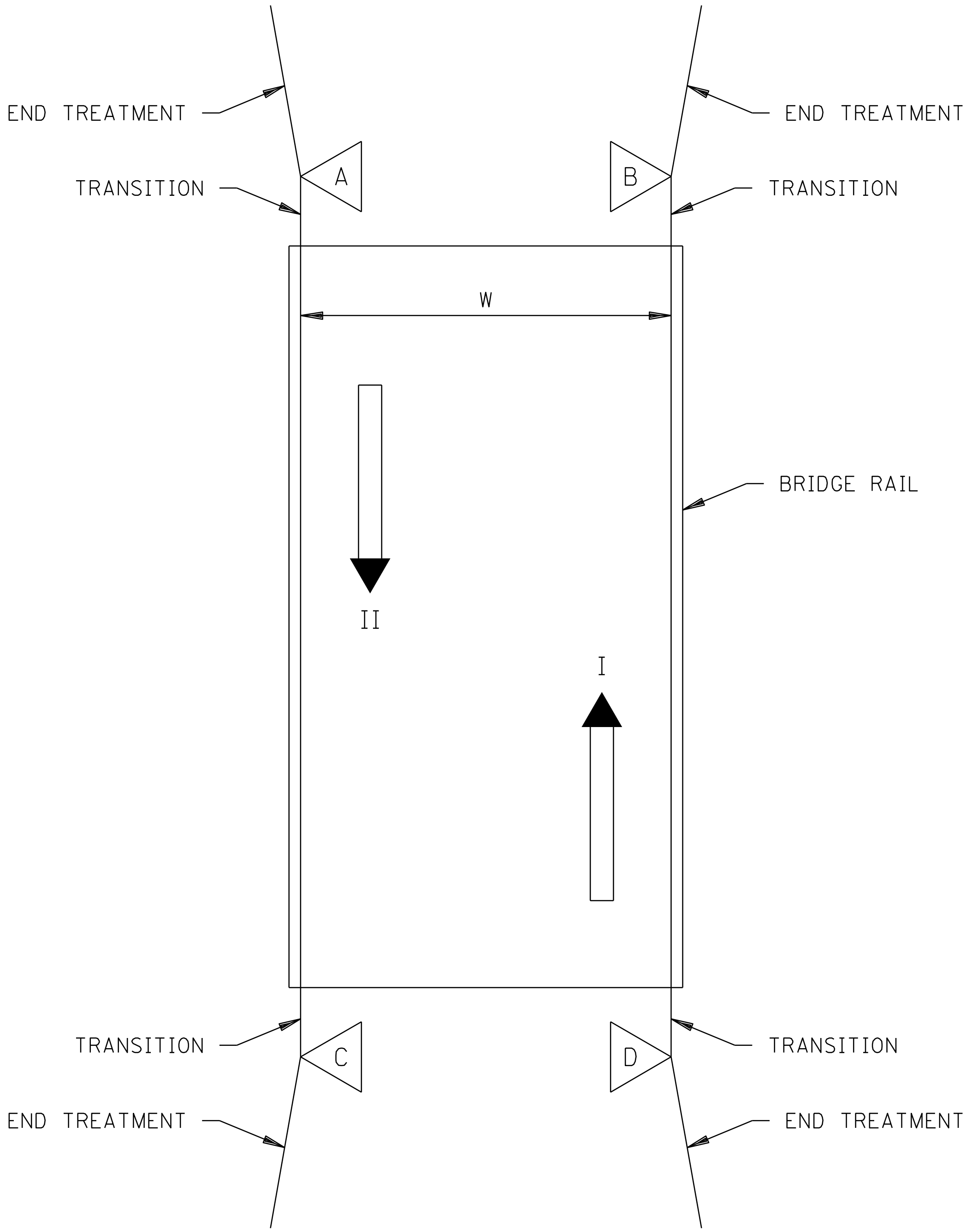
Traffic signals are considered to be fixed objects. However, the potential hazard of fallen traffic signals, cables or mast arms may be as serious a safety problem as non-yielding roadside obstructions. Therefore, supports for overhead signals, either mast arms or span wire, should not be breakaway. Overhead signal supports should be located as far as practicable from the roadway. Signal design criteria established by the *MN MUTCD* must take precedence. Traffic signals are usually not protected by guardrail against collision. The decision to protect must be based on engineering judgment. Remember, the installation of a roadside barrier greatly increases the target area for an errant vehicle, reduces the lateral clearance and poses special problems at its’ terminal ends.

Another fixed object for which it may not be appropriate to provide guardrail protection is a railroad signal installation. It is questionable whether guardrail protection for all railroad signals is in the best safety interest of the traveling public for several reasons; the guardrail itself is an obstacle, it could possibly prevent a driver from taking last second evasive action into the shoulder area to avoid hitting a train, it cannot be placed across the tracks to protect errant vehicles approaching the signal from opposing lanes and it is difficult to provide a crash-worthy end on the track side of the installation (i.e., it can create a blunt-end hazard to traffic from opposing lanes). Therefore, in many cases it may not be appropriate to install signal protection unless guardrail placement is deemed necessary for other hazards such as high embankment, poor alignment, etc. However, on divided highways where there will be more exposure and the need for a crash-worthy end at the tracks does not present a problem, guardrail may be justified on a site-by-site basis.

Table 10-7.01A
GUIDELINES FOR PROTECTION OF FIXED OBJECTS

Fixed Objects Within Clear Zones[1]	**Traffic Barrier Warranted**	
	Yes	**No**
Sign, traffic signal[2] and luminaire supports[3]		
a) Breakaway or yielding design with linear impulse:[3]		
1) less than 1,100 lb-sec		X
2) greater than 1,100 lb-sec	X[4]	
b) Concrete base extending 4 in. or more above ground	X	
Fixed sign bridge supports	X	
Bridge piers and abutments at underpasses Bridge barriers on overpasses	X	
Retaining walls and rock cuts (if wall is not smooth) and culverts	X	
Trees with diameter greater than 6 in. or lines of trees	X[4]	
Wood poles or posts with area of 50 sq. in. or greater	X[4, 5]	

1. Fixed object should be removed or relocated so that a barrier is unnecessary, if practical.
2. See write-up on signals, Section 10-7.01.04.
3. Breakaway or yielding design is desirable regardless of distance from through lane.
4. A judgment decision.
5. In addition, consideration should be given to drilling wood poles to reduce the cross section of the posts with area greater than 30 sq. in. but less than 50 sq. in.



TRAFFIC DIRECTION	DISTANCE BETWEEN BRIDGE RAILS - W (ft)	APPROACH BARRIER REQUIRED AT (1)
I AND II	≤ 2 X CLEAR ZONE WIDTH	A, B, C, D
I AND II	> 2 X CLEAR ZONE WIDTH	A, D
II ONLY	ALL WIDTHS	A, B
I ONLY	ALL WIDTHS	C, D

(1) CHECK ROADSIDE FOR OTHER WARRANTING FEATURES

BRIDGE APPROACH BARRIER CRITERIA
Figure 10-7.01C

10-7.01.05 Clear Zones

The roadside clear zone is the distance from the edge of the traveled way or traveled lane, including the shoulders, a recoverable slope and/or a clear zone runout area, which should be free of any non-traversable hazards or fixed objects. In general, hazards within the clear zone which cannot be removed, relocated or made breakaway will warrant guardrail. A detailed description of clear zones is given in Chapter 4.

A bridge barrier is one object that cannot be removed or relocated outside of the clear zone. A bridge barrier normally warrants guardrail. The standard plate-beam guardrail approach treatment used at bridges is detailed in the Standard Plans Manual, series 600. These designs should normally be used for approach ends of bridges on divided highways and both ends of bridges on two-way highways, see Figure 10-7.01C, unless the bridge is located at a site that meets all the following criteria:

1. The bridge is located within the limits of a municipality.
2. The bridge site is located where design speeds are less than 40 mph.
3. The roadway is either an urban section with curbs and sidewalk berm or a rural section in which the bridge width equals or exceeds the width of the roadway inclusive of shoulders.

Wherever semi-rigid barrier joins a rigid bridge barrier, a crash worthy transition is needed. This produces a gradual stiffening of the approach to the bridge barrier to protect against vehicle pocketing, snagging or penetration of the system and is accomplished by double-nesting of the guardrail and gradually reducing the post spacing.

Crash-worthy transitions are required at all new bridges, as well as at bridges on which the bridge barriers are reconstructed, when the design speed is 40 mph or greater. For preservation projects, consult TM 17-07-TS-02 "W-Beam Guardrail Upgrade Considerations for Preservation Projects" for guidance on evaluating the existing transition. Approved transitions are shown in the Standard Plans Manual, series 600.

Bridges in high-speed locations with pedestrian traffic require special consideration. If possible, where positive separation of pedestrians and vehicles is provided, the pedestrian traffic should be routed away from the guardrail terminal. If rerouting pedestrian traffic is not possible, a non-extruding end treatment should be considered.

Guardrails should also be provided at approaches to barrier walls that are within the clear zone. The criteria used for design is the same as that used in providing guardrails at bridge approaches.

10-7.01.06 Roadside Hazards

Roadside hazards are non-traversable features usually flanking the roadway for some distance and are potentially damaging for out-of-control vehicles. Examples are rough rock cuts, large boulders, permanent water of 2 ft or more in depth. Guardrail should be provided along the shoulder or off the shoulder and closer to the hazard whenever such hazards are located within the clear zone. Where such parallel hazards exist in the proximity of the roadway but outside of the clear zone, guardrail may be warranted if the relative risk is high, such as being a hazard located on the outside of a curve.

10-7.02 Selection of Barrier Type

Certain types of barrier are selected for specific purposes. The standard types in use by MnDOT and their general areas of application are discussed below.

10-7.02.01 Structural Plate-Beam Guardrail

The W-beam is the most commonly used plate-beam guardrail or barrier in Minnesota and the rest of the nation. It derives its name from the shape of the plate beam. W-beam guardrail is a semi-rigid system on steel posts. In this type of system, impact is resisted by a combination of bending and tension of the rail acting with the posts and limiting lateral deflections. Reduced deflections can be achieved by methods such as nesting of the rail, which consists of two stacked pieces of plate beam, and/or reduced post spacing. (See Table 10-7.02A).

The Type 31 Guardrail System (MGS) is a non-proprietary steel post, W-beam guardrail system that has been successfully crash tested per MASH TL-3 criteria. The Type 31 Guardrail System uses a typical W-beam guardrail with:

- 31 in. top of rail mounting height with a 2 in. up tolerance and a 1 in. down tolerance.
- 6 ft long W6 × 9 steel posts.
- 6 in. × 12 in. routed or non-routed wood blockouts or composite blockouts.
- 12-gauge rail with rail splices at the center of the span location.

**Table 10-7.02A ESTIMATED WORKING WIDTH *
FOR
TYPE 31 W-BEAM GUARDRAIL**

Type 31 with 6 ft-3in. post spacing	5 ft.
Modified 3 ft-1½ in. post spacing	3 ft-7 in.
Modified 1 ft-6¾ in. post spacing	3 ft.
Type 31 with 6 ft-3 in. post spacing at the break point of the 1V:2H slope and 9 ft long posts.	5 ft-3 in.

*Working width is defined in MASH as the distance between the traffic side of the guardrail before the impact and the maximum lateral position of any major part of the guardrail system or vehicle after impact.

Thrie beam is another type of structural plate beam that has one corrugation in addition to those of the W-beam. It is currently only used in bullnose crash cushion and transition design in Minnesota. For further details about the thrie beam guardrail, check the *Roadside Design Guide*.

10-7.02.02 3-Cable Guardrail (Low Tension)

This is a flexible system with either weak wood posts or steel posts. With this system, impact is resisted by cable tension and end anchorage. The posts and cable hook bolts are designed to give way under impact conditions and not interfere with the redirection of the colliding vehicle. Deflections of 10 ft or greater can be expected within the contact area; for design purposes, use 11 ft. This type of guardrail may be used for installations where the design deflection is not a constraint. Cable guardrail should not be installed along embankments steeper than 1:2, around the inside of a curve greater than 4 degrees, or any place where the installation does not develop tension in the cable upon impact.

10-7.02.03 High-Tension Cable Guardrail

This is a flexible system with steel posts. These systems are generally used in median applications, but can also be used as roadside barriers. High-tension cable guardrail is installed with significantly more tension than a low-tension system, thus the deflection of this system is reduced to 6 to 10 ft, dependent on post spacing. All available systems are proprietary. Technical Memorandum 15-08-TS-04 includes design guidance for the systems currently available.

10-7.02.04 Box Beam Guardrail

Box beam guardrail is a semi-rigid system consisting of a rectangular box beam mounted on steel posts. The typical installation consists of a 6 in. x 6 in. steel tube mounted on S3 x 5.7 steel posts on 6 ft centers.

Deflection distance for box beam guardrails fall between the W-beam and the cable systems and can be expected to be up to 5 ft.

The box beam system has only been used in select applications in Minnesota. It offers less of a cross section to windblown snow and may reduce the formation of snow drifting when used. However, the cost is as much or more than the strong post W-beam system, and, although the box beam system provides good impact performance, a strong post system with less dynamic deflection can be more cost effective.

For further details about the box beam guardrail check the *Roadside Design Guide*.

10-7.02.05 Concrete Barrier

Concrete barriers are rigid barriers with minimal deflection. In addition to being used as a median barrier, it may be used along the roadside to protect vehicles from hazards such as rough rock cuts, noise barriers, etc. Several barrier designs are available for consideration.

10-7.02.06 Transitions between Barrier Types

1. Cable to Plate-Beam - The change from cable to plate-beam should be accomplished by overlapping the cable in front of the plate-beam. There should be no direct connection of the two, and each should be anchored independently. An appropriate end treatment is still required for the plate-beam.

   On one-way roadways when changing from plate-beam to cable at the downstream end of the plate-beam, the plate-beam should overlap the cable. There should be no direct connection of the two, and each should be anchored independently. The cable terminal post should be located behind the plate-beam and approximately in-line with the anchor post of the plate-beam terminal end (left end of the plate-beam on Standard Plate 8307).

2. Plate-Beam to Bridge Abutment or Bridge Barrier - To prevent pocketing, the post spacing for the plate- beam is reduced for the 25 ft just prior to the bridge end. These transitions also require the use of two nested, steel plate-beam sections for the first 12 ft-6 in. adjacent to the abutment or bridge barrier that are anchored directly to the abutment or bridge barrier. Curb transitions and rub rail may also be required dependent on the transition design and shape of bridge barrier or end post. Available transitions are shown in the Standard Plans Manual, Sheets series 600.

10-7.02.07 End Treatments for Roadside Barriers

Exposed approach ends of plate-beam guardrail installations are a hazard in themselves and must have end treatments that meet the crash-worthiness criteria of MASH. End treatments that meet the criteria of NCHRP 350 may be used on preservation projects in accordance with TM 17-07-TS-02 "W-Beam Guardrail Upgrade Considerations for Preservation Projects". Approved end treatments are listed in the Approved Products List.

End terminals have not been tested in conjunction with curb. If an existing curb cannot be removed, it can be replaced with 4 in. curb as described in 10-7.01.02. On overlay projects, no correction of the curb is necessary if the thickness of the overlay at the curb face is such that no more than 4 in. of curb remains exposed. The curb may also be ground down to a height of 3 in. beginning at a point 20 ft in advance of the terminal nose and continuing to Post No. 8, a total distance of 58 ft.

At locations where curb height is reduced (by grinding or replacement), the area between the curb and the guardrail shall be made as smooth and level as possible; a 1:10 transverse slope is required.

Regardless of which end treatment is used, it is important that the system be properly installed and that proper grading be provided in order for a terminal to function as intended. Placement and grading standards for tangent and flared end treatments are shown on Standard Plan Sheet 5-297.601.

10-7.03 Length-of- Need

The designer determines the desirable placement of the roadside barrier before making a final selection of the barrier type. The placement determines the installation length upstream and downstream of the hazard, sometimes called the "length-of-need". The length-of-need of the guardrail should extend far enough upstream from the hazard to prevent an errant vehicle from getting behind the guardrail and striking the hazard. On two-way roadways, the length-of-need should prevent an errant vehicle from the opposing traffic from getting behind the barrier and striking the hazard.

The location where the barrier is placed in relation to the hazard is determined by using the following four variables; L_R, L_H, L_2 and L_S. Using the first three variables in the following formula, the designer can compute the length-of-need, *X*, necessary to shield an errant vehicle from the roadside hazard.

$$X = \frac{L_H - L_2}{\left(\frac{L_H}{L_R}\right)}$$

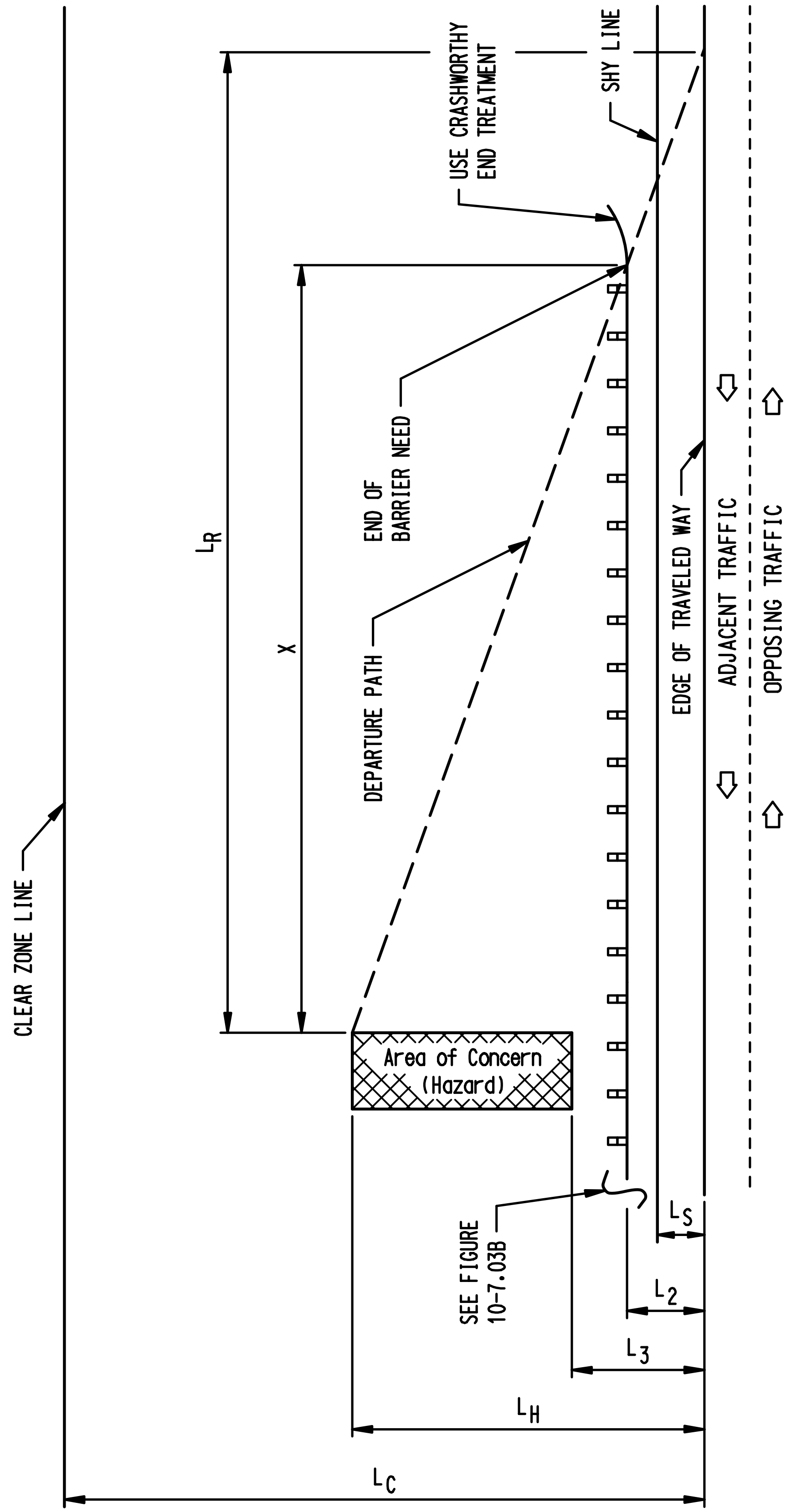
Figures 10-7.03A and B indicate the variables involved in the determination of the layout of a required guardrail installation. Table 10-7.03A gives the design parameters for roadside barrier layout based upon design speed. The variables are explained below:

L_C = Clear zone width (see Figure 4-6.04A)
L_H = Distance from edge of the through lane to the far side of the hazard or the outside edge of the clear zone. This is a critical element of the design and requires some judgment on the part of the designer.
L_2 = Distance from the edge of the through lane to the barrier.
L_3 = Distance from the edge of the through lane to the near edge of the hazard.
L_R = Run-out length or theoretical distance needed for a vehicle that has left the roadway to come to a stop before hitting the hazard (see Table 10-7.03A).
X = Distance from the hazard to the end of the barrier (length-of-need).
L_S = Shy line offset (distance beyond which a roadside object will not be perceived by the driver as a threat, guardrail should be placed outside shy line offset) (see Table10-7.03A).

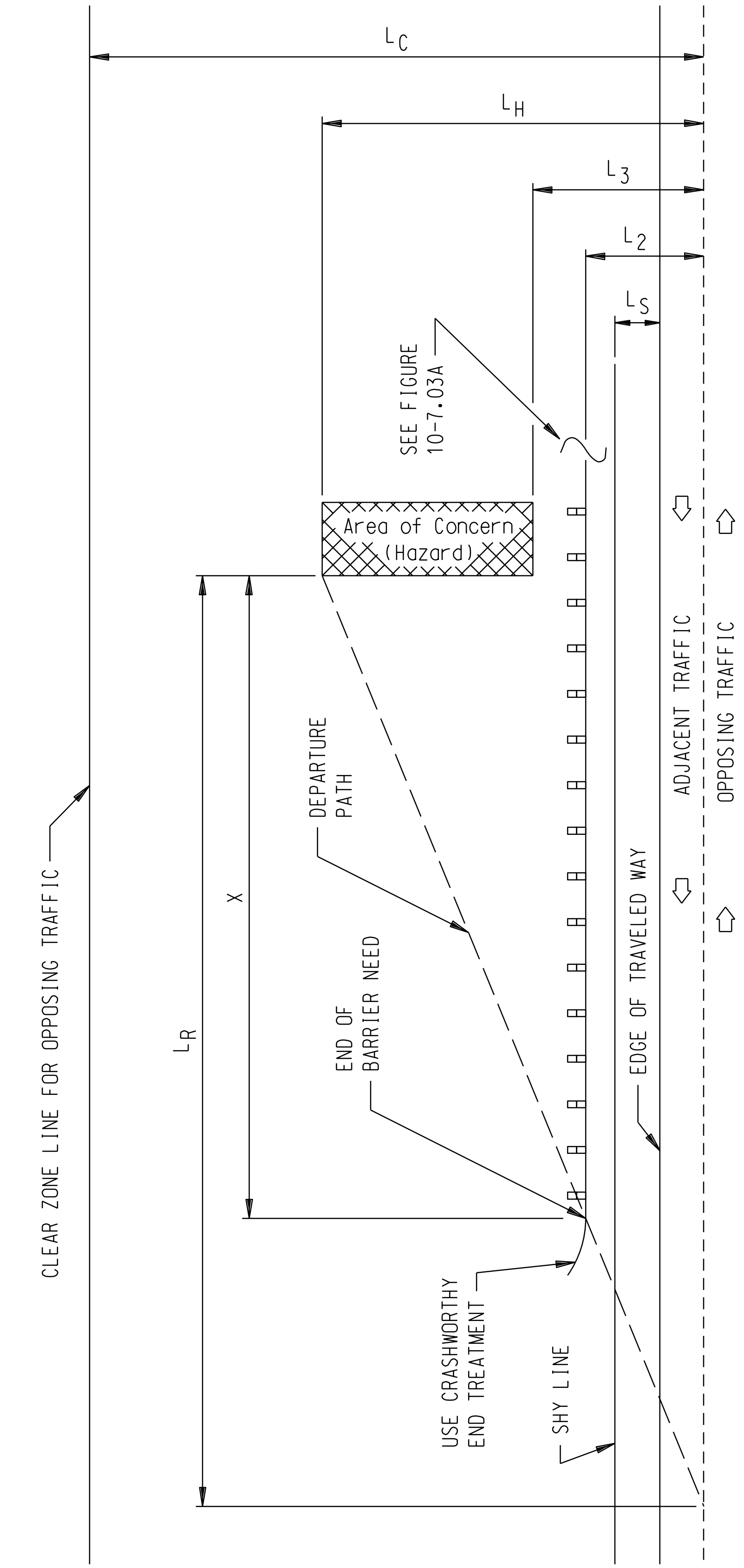
Normally, the barrier is placed as far from the edge of the traveled lane as possible, L_2, while maintaining the required deflection distance between the barrier and the hazard, L_3-L_2. The deflection distance between the barrier and the hazard influences the designer's selection of barrier type. On roadways with side slopes steeper than 1:10, this lateral placement may need to be adjusted to prevent a vehicle from striking the face of the barrier at a point too high or too low, which can cause vaulting or snagging. See Figure 10-7.01B for proper placement.

Table 10-7.03A
DESIGN PARAMETERS FOR ROADSIDE BARRIER LAYOUT

Design Speed mph (km/h)	Runout Length (L_R) Given Traffic Volume (ADT) ft (m)				Shy Line Offset L_S ft (m)
	Over 10,000 vehicles/day	5,000 to 10,000 vehicles/day	1,000 to 5,000 vehicles/day	Under 1,000 vehicles/day	
80 (130)	470 (143)	430 (131)	380 (116)	330 (101)	12 (3.7)
75 (120)	420 (127)	380 (116)	340 (102)	290 (89)	10 (3.2)
70 (110)	360 (110)	330 (101)	290 (88)	250 (76)	9 (2.8)
65 (105)	330 (101)	290 (89)	250 (76)	230 (69)	8.5 (2.6)
60 (100)	300 (91)	250 (76)	210 (64)	200 (61)	8 (2.4)
55 (90)	270 (81)	220 (67)	190 (57)	180 (54)	7 (2.2)
50 (80)	230 (70)	190 (58)	160 (49)	150 (46)	6.5 (2.0)
45 (70)	200 (60)	160 (49)	140 (42)	130 (38)	6 (1.7)
40 (60)	160 (49)	130 (40)	110 (34)	100 (30)	5 (1.4)
35 (55)	140 (42)	110 (34)	100 (29)	90 (26)	4.5 (1.3)
30 (50)	110 (34)	90 (27)	80 (24)	70 (21)	4 (1.1)



BARRIER LAYOUT FOR ADJACENT TRAFFIC
Figure 10-7.03A



BARRIER LAYOUT FOR OPPOSING TRAFFIC
Figure 10-7.03B

Example for adjacent traffic:

Assume a fixed object 20 ft long, measured parallel to the roadway, and 3 ft wide, measured perpendicular to the roadway, located 15 ft from the edge of the 12 ft through lane on a 60 mph road with over 5,000 ADT and a 10 ft bituminous shoulder then;

L_2 = 10 ft (bituminous shoulder)
L_3 = 15 ft
L_H = 18 ft (L_3 + 3 ft object width)
L_R = 250 ft (from Table 10-7.03A)

$$X = \frac{18-10}{\left(\frac{18}{250}\right)} = \frac{8}{0.072} = \quad 111.1\text{ft}$$

For a two-way roadway the hazard must also be checked for opposing traffic. Figure 10-7.03B presents this case.

Example for opposing traffic:

Assume the same conditions used before:

L_2 = 22 ft (previous 10 ft plus 12 ft lane)
L_3 = 27 ft
L_H = 30 ft (L_3 + 3 ft width)
L_R = 250 ft (from Table 10-7.03A)

$$X = \frac{30-22}{\left(\frac{30}{250}\right)} = \frac{8}{0.12} = \quad 66.7\text{ ft}$$

Thus the total length-of-installation required for the two-way condition is 111.1ft upstream of the barrier to shield traffic adjacent to the barrier, 66.7 ft downstream of the hazard to shield traffic in the opposing lane, a 20 ft length of barrier to equal the dimension of the hazard parallel to the roadway for a total of 197.8 ft, minimum, plus two crash worthy terminal sections.

Normally plate beam should be installed in multiples of 12 ft-6 in. or 25 ft (typical rail lengths). Thus, in the above example, the length to install would be 200 ft.

Portions of end treatments can be included in the length-of-need. Since the length of end treatments varies, this must be determined for each end treatment that will be used.

On one-way facilities, the guardrail should extend downstream past the hazard a sufficient length to provide a terminal section for anchorage. When determining the location of the terminal section in relation to the hazard, assume that the last 4 posts have no retaining or redirective capabilities. Thus, the next-to-last post should be located beyond the area of guardrail need. This may require the installation of one extra section of guardrail to ensure that the motorist is fully protected from a collision with the hazard.

This mathematical determination of the installation length of traffic barrier is applicable to a straight section of highway alignment. A vehicle that leaves the road on the outside of a curve will tend to follow a tangential run-out path. Therefore, instead of using the theoretical distance, L_R, to determine the length of need of barrier, a tangent line from the curve to the outside edge of the hazard or to the clear zone should be used to determine the length of barrier needed. In this way, the barrier length becomes a function of the distance that it is located away from the edge of the driving lane. This can be readily obtained by scaling it graphically, see Figure 10-7.03C. A graphical approach to the determination of the installation length can also be applied to tangent sections of roadway by assuming an appropriate departure angle, normally 15 degrees, from the edge of the traveled way. This departure path would be similar to the dashed line in Figures 10-7.03A and B. This can be done on a plan sheet. Examples are given in the *Roadside Design Guide*.

The lateral placement of the approach rail should also satisfy the criteria on embankment slopes in Section 10-7.01.03. If the existing slope is steeper than 1:10, fill should be provided to flatten the slope to 1:10, as illustrated in Figure 10-7.03D.

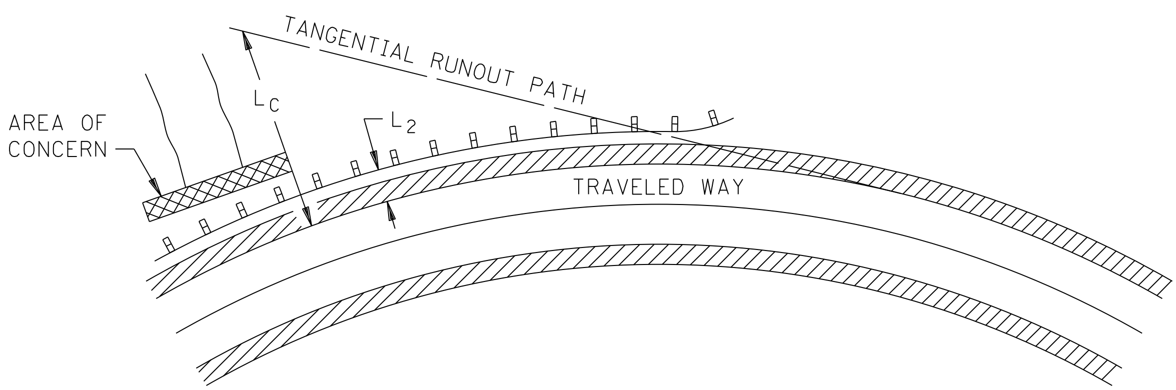
The placement of guardrail at bridge ends will vary depending upon the potential hazards that may exist at individual sites and where the guardrail is located. These hazards may be fixed objects such as trees or culverts; non-traversable features such as slopes at the bridge approach or extending a distance from the bridge; or other features such as rivers, railroads and crossing roadways. On undivided highways, the opposite roadside will require consideration of the length-of-need and location of the bridge approach rail.

The length-of-need for guardrail at bridge ends normally includes the 25-ft transition to the bridge barrier as well as the standard line rail "L" (See Figure 10-7.03E). Also the standard line rail may include any portion of the end treatment that has redirective capabilities, as explained earlier.

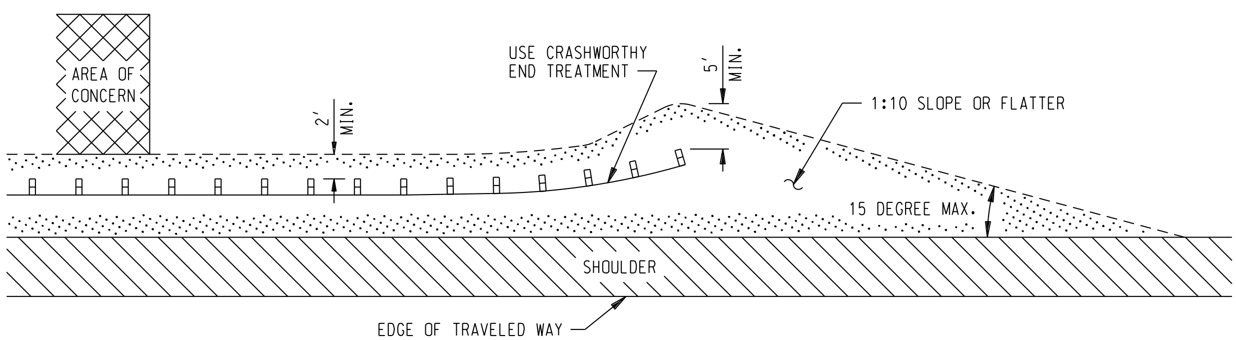
In general, short intermittent sections of any roadside barrier are undesirable. Gaps of less than 200 ft are to be avoided, unless roadside topography will permit very desirable terminal layouts, in which case safety and economics might justify shorter gaps.

10-7.04 Vertical Adjustment

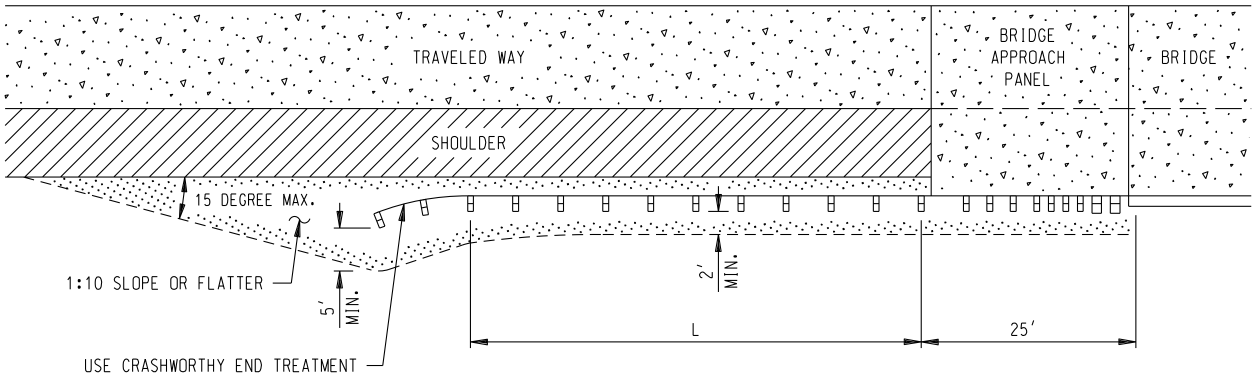
Guardrail should be built according to specifications and the appropriate Standard Plates and Plans. Existing guardrail to be left in place after pavement improvements, should be evaluated as to its effectiveness if the pavement elevation has been changed. Distance from the edge of pavement, shoulder type, shoulder cross slope and characteristics of the existing guardrail must be considered carefully before calling for vertical adjustment on the plans. Generally, a variation of -1 in. or +2 in. from the nominal height is acceptable.



EXAMPLE OF BARRIER DESIGN FOR FIXED OBJECT ON HORIZONTAL CURVE
Figure 10-7.03C



SUGGESTED ROADSIDE SLOPES FOR APPROACH BARRIERS
Figure 10-7.03D



BRIDGE APPROACH RAILINGS
(WITH AND WITHOUT SHOULDERS)
Figure 10-7.03E

10-7.05 Median Barriers

10-7.05.01 Service Requirements and Performance Criteria

A median barrier is a longitudinal traffic barrier primarily used in "narrow" medians to prevent across-the-median, head-on collisions between vehicles in opposing traffic. The barrier shall be designed, using established criteria, to perform several functions:

Restrain the design vehicle and not allow the vehicle to climb over or wedge under the installation.
Stop or redirect the vehicle in such a manner that passengers restrained by seat belts can survive, preferably uninjured.
Redirect or stop the vehicle in such a manner to minimize the hazard to following or adjacent traffic. Ideally, the vehicle should remain close to the barrier and not be directed back into the traffic stream.
Function so that barrier fragments do not endanger vehicle occupants or other traffic.

Generally, while crash severity and fatalities decrease after a traffic barrier has been installed in a median, the crash frequency increases. This increase is attributed to the decrease in maneuvering space for run-off-the-road vehicles. Thus, the barrier must not only be structurally adequate to prevent penetration through the barrier, it must also provide for the safety of the occupants of impacting vehicles. These two interdependent factors, structural strength and occupant safety, must be considered simultaneously in order to achieve optimum barrier performance. The safety of the maintenance crews that must repair damaged barriers must also be considered. The design should not inhibit general maintenance of the barrier, particularly in narrow medians where high-speed traffic would be impeded and traffic would endanger the repair crew.

Median barriers may be divided into three major types according to lateral stiffness. These are rigid, semi-rigid and flexible barriers. The rigid barrier is used where no lateral deflection is acceptable. Rigid barriers are typically made of concrete with a shape that meets safety criteria. The most common shapes are the F-shape, single slope, and the vertical wall barrier. The most common semi-rigid barrier is the strong-post/strong-beam system (the W-beam guardrail system). This type is used where small lateral deflections are allowable. The flexible barrier, represented by the cable barrier, is used where large lateral deflections can be tolerated. Median barriers must meet the same performance criteria applied to other roadside barriers. Rigid barriers are discussed in Section 10-7.05.03. The semi-rigid and flexible barriers are discussed in Section 10-7.02.

10-7.05.02 Project Considerations for Median Barriers

As a general rule, a median barrier should be installed only when it has a potential of significantly reducing the occurrence of cross-median crashes and the overall severity of median related crashes. It should be kept in mind that the barrier is a hazard itself and should be used only where a collision with the barrier is of less consequence than the collision potential beyond the barrier.

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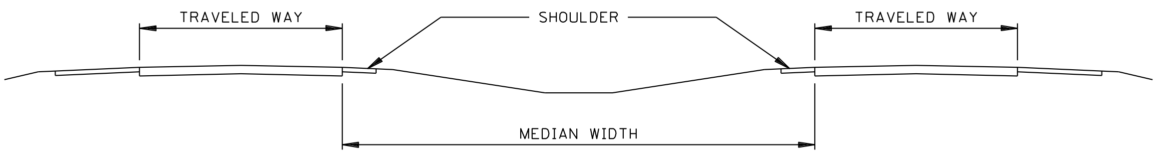
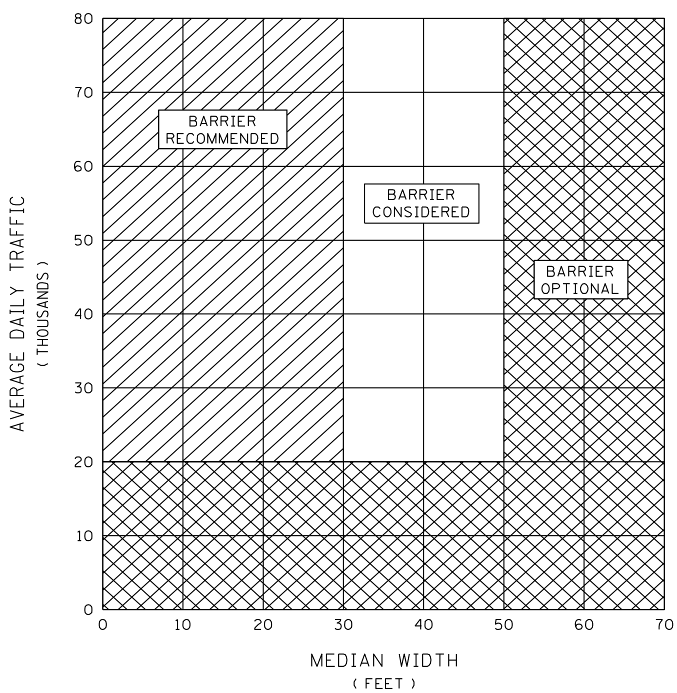
The terminal points in barrier systems are generally critical elements in the performance of the system. An unprotected median barrier terminal is essentially a fixed-object hazard to a motorist. For this reason the use of median barriers are generally restricted to full access-controlled facilities where there are no median crossings requiring discontinuities in the barrier. Special designs may be required where at-grade crossings are permitted and median barrier is used. Crash cushions or energy-absorbing end terminals are typically used to shield median barrier ends.

The main considerations for median barriers are median width and traffic volume. An additional consideration is the design speed of the highway. On existing roads, crash history may also be a factor. Figure 10-7.05A presents the need for a median barrier based on median width and traffic volume for high-speed roadways.

Figure 10-7.05A indicates that median barrier:

1. Is Recommended - when Average Daily Traffic (ADT) is 20,000 or greater for medians 30 ft. or narrower.
2. Is Considered - when ADT is 20,000 or greater and median widths are greater than 30 ft. and less than or equal to 50 ft. wide.
3. Is Optional - when ADT is below 20,000 or when median widths are greater than 50 ft.wide.





MEDIAN BARRIER CRITERIA
FOR HIGH SPEED FULLY CONTROLLED ACCESS ROADWAYS
Figure 10-7.05A

When considering the placement of barrier, a cost/benefit analysis or an engineering study evaluating such factors as traffic volumes, vehicle classifications, median crossover history, crash incidents, vertical and horizontal alignment relationship, and median/terrain configurations may be conducted to determine the appropriate application for

For any divided highway, the median roadside must also be examined for other barrier-warranting factors such as hazards and lateral drop-offs.

10-7.05.03 Rigid Median Barriers

The preferred rigid barrier for median installations is the Single Slope barrier. Three height options for single slope barriers are detailed in the Standard Plans Manual, series 600. In general, the middle height option of 42” will allow more flexibility for future preservation projects. The 54” option should be used when glare screen is desired. Additional placement criteria, for special conditions, are discussed in the AASHTO *Roadside Design Guide*, Chapter 6.

10-7.05.04 Sloped Medians

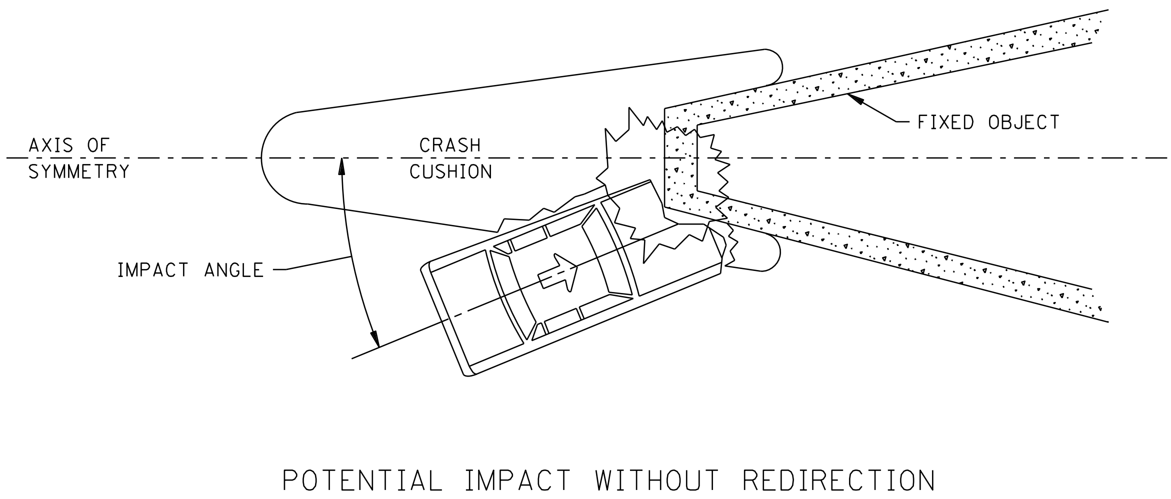
As mentioned previously, a level median is necessary for optimum barrier performance. A rigid or semi-rigid barrier must have an adjacent graded median with slopes of 1V:10H or flatter, to facilitate vehicle stability prior to impact. Where these conditions do not exist, special placement is necessary as discussed in the AASHTO *Roadside Design Guide*, Chapter 6. Some flexible barrier systems can be installed on steeper slopes. Refer to the specific flexible barrier type to determine slope design guidance.

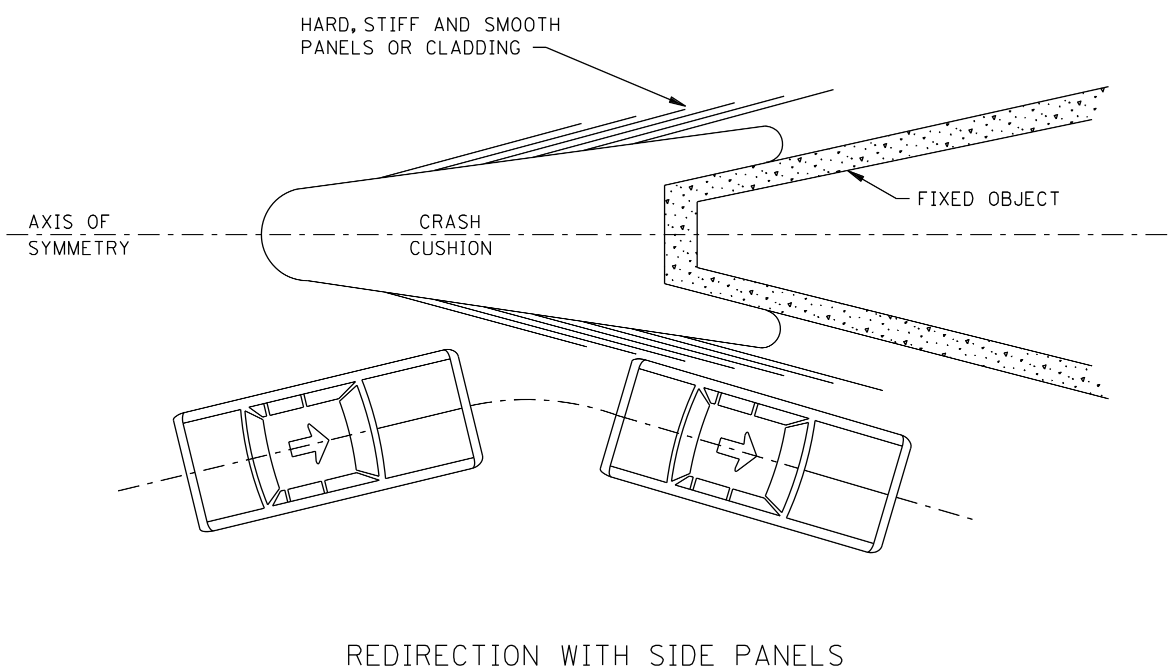
10-8.0 CRASH CUSHIONS

10-8.01 General

Crash cushions are protective systems that prevent errant vehicles from impacting hazards by either smoothly decelerating the vehicle to a stop after a frontal impact, or by redirecting it away from the hazard after a side impact. Crash cushions are adaptable to many roadside hazard locations where longitudinal barriers cannot practically be used. In addition, crash cushions may prove to be more cost effective at many fixed-point hazards than barriers because of their smaller target area. Many studies have documented the effectiveness of crash cushions, generally concluding that their benefits far exceed their costs.

Side impacts on the crash cushion can result in a severe collision if the vehicle is not protected from contacting the corner of the obstacle the cushion is shielding. Sufficient distance and energy-absorbing material usually cannot be provided to stop the vehicle before it impacts the obstacle in this manner. On many crash cushions, fender panels (hard, stiff, smooth panels) are provided along the sides to re-direct the vehicle; see Figure 10-8.01A. For non-redirective crash cushions, the designer must give careful consideration to the cushion's placement and design in the transition zone between the cushion and the fixed object.





SIDE IMPACTS
Figure 10-8.01A

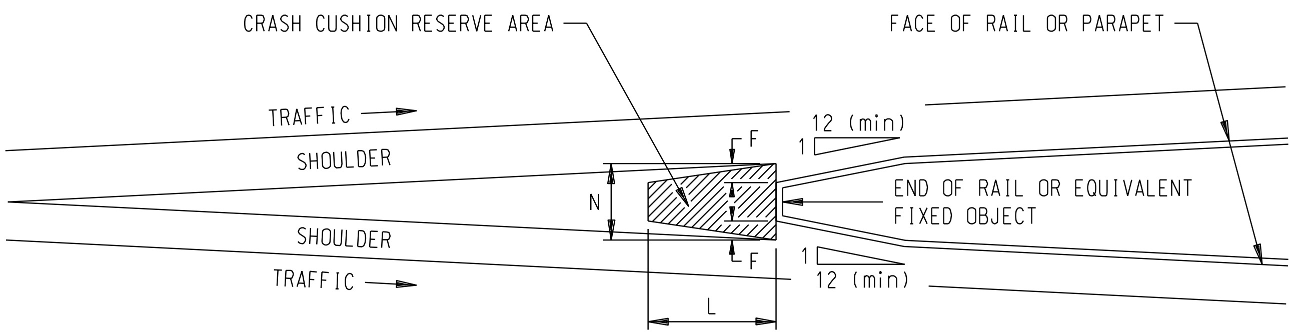
10-8.02 Project Considerations for Crash Cushions

On new highway designs every effort should be made to eliminate the need for attenuation devices. Where a crash cushion must be provided, the installation location should be designed to be level and free of curbs. In off-ramp gore areas on new highway designs, the design should provide a crash cushion reserve area as presented in Figure 10-8.02A and Table 10-8.02A. This design usually applies to elevated structures. It will allow sufficient space to install a crash cushion should it become warranted for unforeseen reasons in the future.

Table 10-8.02A suggests the area that should be made available for the installation of a crash cushion. Although a gore location is depicted, the recommendations in the table can be applied to other fixed objects that require shielding. The preferred conditions should be considered to be the optimum for any location. The unrestricted conditions represent the minimum requirements for all locations with the exception of sites where it can be demonstrated that these dimensions, as opposed to the dimensions of the restricted condition, are unattainable. The information in the table is generic. It may not apply to some proprietary systems. It is recommended that the designer investigate the systems available that will adequately protect the hazard and then determine the requirements from the manufacturers' specifications.

Crash cushions are most often warranted at fixed-point locations. Typical highway features that may warrant an installation are:

1. Exit gore areas, particularly on structures;
2. Area between twin bridges where guardrail cannot be adapted;
3. Bridge barrier ends, piers or abutments;
4. Non-breakaway sign and signal supports;
5. Retaining wall ends or culvert head walls; and
6. Median barrier exposed ends.



NOTE:
NO CURBS OR RAISED PAVEMENT TO BE BUILT IN THE AREA SURROUNDING OR OCCUPIED BY THE CRASH CUSHION.

RESERVE AREAS FOR GORES
Figure 10-8.02A

Table 10-8.02A
RESERVE AREAS FOR GORES

Design Speed on Mainline (mph)	Dimensions for Crash Cushions (ft)						Reserve Area (ft)		
	Minimum						Preferred		
	Restricted Conditions			Unrestricted Conditions					
	N	**L**	**F**	**N**	**L**	**F**	**N**	**L**	**F**
30	6	8	2	8	11	3	12	17	4
40	6	11	2	8	16	3	12	23	4
45	6	14	2	8	21	3	12	28	4
50	6	17	2	8	25	3	12	33	4
55	6	20	2	8	31	3	12	29	4
60	6	24	2	8	37	3	12	46	4
70	6	28	2	8	45	3	12	55	4
80	6	31	2	8	49	3	12	61	4

Note: This table should be used only for preliminary design purposes. For final design, contact the manufacturer.

10-8.03 Types

Many types of crash cushions have been developed and tested. Approved proprietary crash cushions for permanent applications are listed on the Roadside Barriers Approved Products List. The Bullnose crash cushion is a non-proprietary option for certain situations, detailed in the Standard Plans Manual, series 600. Approved temporary crash cushions are listed on the Temporary Traffic Control Approved Products List.

10-8.04 Selection

10-8.04.01 Site Considerations

In selecting the proper crash cushion, the following site characteristics must be considered:

1. The width of the obstacle.
2. The available space. For a given design speed and acceptable vehicle deceleration, each crash cushion type will require a specific length. The site under consideration may be restricted in what is available without unduly interfering with traffic or other obstructions in the vicinity.
3. The nature of the obstacle. This may make it highly desirable or necessary to provide a redirective crash cushion. Also, the highway geometry approaching the site may increase the likelihood of a side impact, further enhancing the desirability of a redirective type.

10-8.04.02 Placement

Several factors should be considered in the placement of a crash cushion:

1. Level terrain:
   All crash cushions have been designed and tested for level conditions. Vehicle impacts on devices placed on a non-level site could result in an impact at the improper height and/or undesirable vehicle behavior. Therefore, the cushion should be placed on a level surface or on a cross slope not to exceed 5 percent.
2. Curbs:
   Curbs in front of or along the side of a crash cushion can induce vehicle vaulting. This may result in impact at the improper height and/or other undesirable vehicle behavior. Therefore, no curbs should be present on new projects at proposed crash cushion installations. On existing highways, all curbs should be removed at proposed installations.
3. Surface:
   A concrete pad must be provided under the crash cushion.

4. Elevated structures:
   There is some concern that the unanchored inertial systems may "walk" or crack due to the vibration of an elevated structure. This could adversely affect its performance. The manufacturer's installation instructions should be followed carefully, and the manufacturer should be consulted if questions arise.
5. Orientation:
   The crash cushion should be oriented to accommodate the probable impact angle of an encroaching vehicle. This will maximize the likelihood of a head-on impact. This angle will depend upon the design speed, roadway alignment and lateral offset distance to the cushion. For most roadside conditions, an angle of approximately 10 degrees as measured between the highway and crash cushion longitudinal centerline is considered appropriate.

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10-9.0 TRAFFIC CONTROL IN WORK ZONES

Standards for traffic control in work zones are contained in the *Minnesota Manual on Uniform Traffic Control Devices*, Part VI and in the Field Manual section of part VI, which has been printed as a separate document.

10-10.0 REFERENCES

1. ***Traffic Engineering Manual*** - The *Traffic Engineering Manual* issued by the Office of Traffic Engineering is the Department reference for policy and procedures

2. ***Minnesota Manual on Uniform Traffic Control Devices*** - The *MN MUTCD* sets forth the basic principles that govern the design and usage of traffic control devices. These principles appear throughout the manual, and it is important that they be given primary consideration in the selection and application of each device.

   The manual presents traffic control device standards for all streets and highways open to public travel regardless of type or class or the governmental agency having jurisdiction. Where a device is intended for only limited application or for a specific system, the text specifies the restrictions on its use.

3. ***Work Zone Traffic Control*** - The *MN MUTCD*, Part VI sets uniform standards for traffic control during construction and maintenance operations. Part VI contains the principles and procedures for providing safety for motorists and workers in the vicinity of traffic control zones. Sample layouts for both long term and short term temporary traffic control zones are illustrated.

   The Field Manual is a section of Part VI of the *MN MUTCD* and has been reprinted as a separate document for use in field operations of temporary traffic control zones for periods of up to three days. For longer periods of time, a traffic control plan should be developed.

4. ***Minnesota Statute*** - Minnesota Statutes, Chapters 160-173, include most of the State laws affecting roads and highways in Minnesota. Chapter 169, Highway Traffic Regulation, is most important to traffic engineers.

5. ***Roadside Design Guide*** - The *Roadside Design Guide* is a document developed by AASHTO that presents information and operating practices related to roadside safety.