

HIGHWAY BARRIER POCKET GUIDE



GUIDELINES FOR
INSTALLATION,
INSPECTION AND
MAINTENANCE
OF COMMONLY
USED SAFETY
BARRIER
SYSTEMS IN
NORTH DAKOTA

NDDOT
North Dakota
Department of Transportation

MAY 2019

GENERAL

BARRIERS

DESIGN

TERMINALS &
CRASH CUSHIONS

TRANSITIONS

SPECIAL DESIGN

MAINTENANCE

Disclaimer

This manual provides a written account of how certain activities are performed and is designed to guide and assist staff in performing their functions. When appropriate, there may be deviations from these written procedures due to changes in personnel, policies, interpretation, law, experimentation with different systems, or simply evolution of the process itself. This manual may be changed at any time. Staff are encouraged to review this manual periodically and suggest changes in the manual to keep the manual current and to minimize differences between the manual and actual practices.

This guide is based upon work supported by the Federal Highway Administration under Grant Agreement No. 693JJ317500085. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the Federal Highway Administration. This document does not constitute a national standard, specification, or regulation.

The purpose of this pocket guide is to present basic guidelines for guardrail installers, inspectors, and maintenance personnel.

The guide presents information contained in the AASHTO Roadside Design Guide, 4th Edition and the NDDOT Standard Drawings and NDDOT Design Manual. Barrier installations are to be built and maintained to current NDDOT standard drawings and manufacturers' recommendations.



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Contents

Introduction _____	1
Clear Zone _____	2
Roadside Obstacles _____	6
Roadside Slopes/Embankments _____	6
Barriers _____	9
Rigid Systems _____	10
Semi-Rigid System _____	12
Flexible Systems _____	16
Barrier Design Principles _____	21
Deflection _____	21
Slope in front of Barrier _____	23
Guardrail in Combination with Curb _____	24
Post Support at Embankment _____	24
Flare Rate _____	25
Length of Need _____	26
Length of Need Procedure _____	29
LON Field Check _____	32
Gaps _____	35
Terminals and Crash Cushions _____	37
Terminals _____	37

Terminal Grading Details	51
Terminal Installation	54
Crash Cushions	55
Transitions	67
W-beam to Rigid Barrier/Bridge Rail	67
Transitions—Cable to W-beam	70
Transitions —G4 (28 in.) to MGS	71
Special Designs	73
Omitted Post	73
Long-span Guardrail System	73
Leaveouts for Posts in Structural Pavement	74
Extra Blockouts	75
Turnout Conflicts (in runs of guardrail)	75
Guardrail Posts in Rock	78
Maintenance	81
General Guidelines	81
NDDOT General Guidelines	82
National Guidelines for W-beam	84
Acronyms	103
Glossary	104
Resources	110

Frequently Asked Questions

When reviewing proposed and existing barrier installations in the field, consider the following questions:

1. Is the obstacle being shielded significantly more severe than the barrier itself; and secondly, what is the likelihood of the obstacle being struck? (page 6, **Roadside Obstacle**)
2. Are there any vertical rigid objects within the guardrail system's design **deflection**? (page 21, **Deflection**)
3. For existing installations, does the guardrail **height** meet criteria? (page 23, **Slope in Front of Barrier—Height**)
4. Is the **slope in front** of the barrier appropriate (page 23, **Slope in Front of Barrier**)
5. If a high-speed facility, are there **curbs** in combination with guardrail? (page 24, **Guardrail in Combination with Curbs**)
6. Is there adequate soil support behind the guardrail shielding a non-recoverable fill slope or has the design been appropriately modified? (page 24, **Post Support at Embankment**)
7. Is the guardrail installation long enough to shield the obstacle? (page 26, **Length of Need**)

8. Should the guardrail be extended upstream to shield other warranting obstacle(s)? (page 32, **LON Field Check**)
9. Is an appropriate terminal being used? (page 40, **Terminal Selection Flow Chart**)
10. Is the **grading** around the terminal (approach, adjacent, and runout distance) appropriate? (page 51, **Terminal Grading Details**)
11. Does the guardrail end within 200 ft. of the start of another guardrail run that could be connected? (page 35, **Gaps**)

This guide, when used in conjunction with field reviews and appropriate NDDOT manuals, practices, and policies and procedures, provides the information needed to answer these questions and ensure that personnel install and maintain appropriately performing barriers.

Introduction

Barrier systems are designed and installed for one primary reason — to reduce the severity of a crash by preventing a motorist from reaching an area of concern, which is either an obstacle or non-traversable terrain feature. Barriers are considered when the consequences of striking the barrier are less severe than that of reaching the obstacle or area of concern.

The first priority should be to remove the obstacle (or redesign it so it is no longer an area of concern). When the obstacle cannot be acceptably mitigated, then a decision is made as to whether installing a barrier is the most appropriate treatment for the situation. The following itemizes this approach:

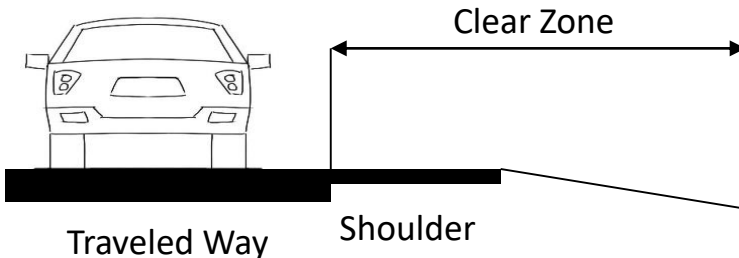
Order of Preference

1. Remove the obstruction.
2. Make the obstruction traversable.
3. Relocate obstruction beyond the clear zone.
4. Reduce impact severity by using an appropriate breakaway system
5. SHIELD the obstruction with a longitudinal barrier or crash cushion (only if obstruction cannot be removed, relocated, or redesigned)
6. Delineate obstruction (only if all above options are not appropriate).

(NDDOT *Design Manual*, Appendix III, 14-B, January 26, 2016)

Clear Zone

The clear zone is defined as the unobstructed, traversable area provided beyond the edge of the through traveled way for the recovery of errant vehicles. The clear zone includes shoulders, bike lanes, and auxiliary lanes, except those auxiliary lanes that function as through lanes. The figure below illustrates this.



There is a distinction between available clear zone and design clear zone. *Available Clear Zone* is the **existing** area for recovery. *Design Clear Zone* is a selected value used for design to provide recovery area for the majority of errant drivers.



The available clear zone should not be compromised.

Make the amount of clear zone as wide as practical.

(AASHTO *Roadside Design Guide*, 4th Edition, 2011, 3.1 The Clear-Zone Concept)

NDDOT Clear Zone Guidance Based on Investment Strategies

- Preventive Maintenance—Existing clear distance
- Minor Rehabilitation—Existing clear distance
- Structural Improvement—20 ft. design clear zone
- Major Rehabilitation—20 ft. design clear zone, except when ADT >2,000, then use AASHTO Design Clear Zone
- New/Reconstruction—Use AASHTO Design Clear Zone

(NDDOT Design Manual, I-06.03)

NDDOT Design Clear Distances based on AASHTO Design Clear Zones

(NDDOT Design Manual, Appendix III-14B)

The AASHTO clear zone values are based on the concept of addressing 80 percent of the vehicle departures from the edge of the traveled way. Some errant vehicles will exceed these distances and the consequences based on the type of obstacles should also be central in the decision-making process to create a forgiving roadside environment.

NDDOT Design Clear Distances (for foreslope)

Design Speed (mph)	Design ADT***	Foreslope				
		FLAT	1V:6H	1V:5H	1V:4H	1V:3H
≤40	UNDER 750	7-10	7-10	7-10	7-10	**
	750–1500	10	12	12	14	**
	1500–6000	12	14	14	16	**
	OVER 6000	14	16	16	18	**
45-50	UNDER 750	10	12	12	14	**
	750–1500	14	16	16	20	**
	1500–6000	16	18	20	26	**
	OVER 6000	20	22	24	28	**
55	UNDER 750	12	14	14	18	**
	750–1500	16	18	20	24	**
	1500–6000	20	22	24	30	**
	OVER 6000	22	24	26	32*	**
60	UNDER 750	16	18	20	24	**
	750–1500	20	24	26	32*	**
	1500–6000	26	30	32*	40*	**
	OVER 6000	30	32*	36*	44*	**
65-75	UNDER 750	18	20	20	26	**
	750–1500	24	26	28	36*	**
	1500–6000	28	32*	34*	42*	**
	OVER 6000	30	34*	38*	46*	**

NDDOT Design Clear Distances (for backslope)

Design Speed (mph)	Design ADT***	Backslopes				
		1V:3H	1V:4H	1V:5H	1V:6H	FLAT
≤40	UNDER 750	7-10	7-10	7-10	7-10	7-10
	750-1500	12-14	12-14	12-14	12-14	12-14
	1500-6000	14-16	14-16	14-16	14-16	14-16
	OVER 6000	16-18	16-18	16-18	16-18	16-18
45-50	UNDER 750	8-10	8	10	10	12
	750-1500	10-12	12	14	14	15
	1500-6000	12-14	14	16	16	18
	OVER 6000	14-16	18	20	20	22
55	UNDER 750	8-10	10-12	10-12	10-12	10-12
	750-1500	10-12	14	16	16	18
	1500-6000	14-16	16	18	20	22
	OVER 6000	16-18	20	22	22	24
60	UNDER 750	10-12	12	14	14	16
	750-1500	12-14	16	18	20	22
	1500-6000	14-18	18	22	24	26
	OVER 6000	20-22	24	26	26	28
65-75	UNDER 750	10-12	14-16	14-16	14-16	14-16
	750-1500	12-16	18	20	20	22
	1500-6000	16-20	22	24	26	28
	OVER 6000	22-24	26	30	28	30

Roadside Obstacles

The following obstacles may warrant guardrail, as defined in NDDOT *Design Manual*, III-13:

- Bridge rail ends,
- Non-breakaway light standards,
- Utility poles, bridge piers,
- Non-breakaway sign supports,
- Large culverts,
- Water (2 ft. or deeper), and
- Rock or rip rap, steep slopes.

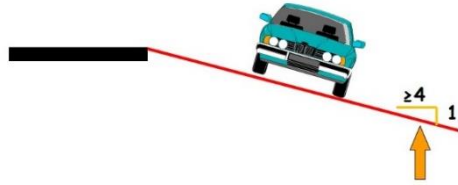
The NDDOT *Design Manual*, III-13.05 addresses the treatments of these obstacles.

Roadside Slopes/Embankments

In general, parallel slopes should be as flat as practical. According to the NDDOT *Design Manual*, Section I-06.03, where grading or roadway widening is required, design guidance is a 4:1 minimum, except on Interregional system >2,000 ADT and Interstate a 6:1 in slope is desirable. Study steep slopes during the safety review to determine if guardrail or flattening the slopes is cost effective.

The AASHTO *Roadside Design Guide* (RDG) classifies slopes as:

Recoverable:
4H:1V and
flatter.

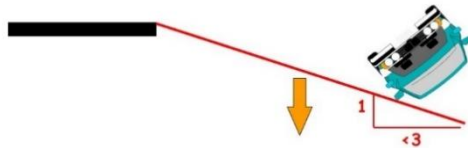


Traversable:
Steeper than
4H:1V but
3H:1V or
flatter.



Although considered traversable slopes, they are not considered recoverable; thus, a vehicle most likely will continue to the bottom of the embankment. A minimum 10 ft. clear recovery area at the bottom of these embankments is recommended.

Critical:
Steeper than
3:1.



ND: Foreslopes 3:1 or steeper require guardrail. (Depending on height)

NDDOT design guidance is consistent with these classifications; however, Section III-13.05.07 provides that foreslopes 3:1 or steeper require guardrail. Steep foreslopes warranting guardrail will normally require using cable guardrail except where an obstacle is within the deflection distance of cable or the slope is steeper than 2:1, in which case shielding with W-beam guardrail is required.

BARRIERS

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.



GENERAL

BARRIERS

DESIGN

TERMINALS &
CRASH CUSHIONS

TRANSITIONS

SPECIAL DESIGN

MAINTENANCE

Barriers

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. Barriers are usually categorized as rigid, semi-rigid, or flexible, depending on their deflection characteristics when struck under NCHRP 350 or MASH TL-3 impact: pickup truck strike at 62 mph and 25 degrees impact angle.

MASH Test Levels

- **TL-1:** 25 deg. impact angle at 31 mph, with small car (2,420 lb.) and pickup truck (5,000 lb.).
- **TL-2:** 25 deg. impact angle at 44 mph, with small car (2,420 lb.) and pickup truck (5,000 lb.).
- **TL-3:** 25 deg. impact angle at 62 mph, with small car (2,420 lb.) and pickup truck (5,000 lb.).
- **TL-4:** TL-3 + 15 deg. impact angle, 56 mph Single-Unit Truck (22,000 lb.)
- **TL-5:** TL-3 + 15 deg. impact angle, 50 mph Tractor-Van Trailer (80,000 lb.)
- **TL-6:** TL-3 + 15 deg. impact angle, 50 mph Tractor-Tank Trailer

(AASHTO *Roadway Design Guide*, Chapter 5, Roadside Barriers)

For more information, see FHWA Resource Charts at

http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/resource_charts/

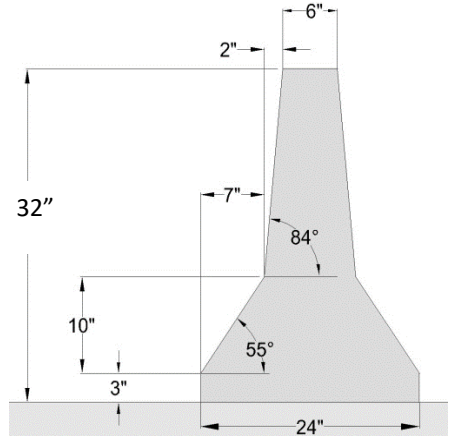
Rigid Systems

Rigid Barrier Systems have little (between 0 to 1 ft.) deflection under the TL-3 conditions described above. Anchor the rigid barrier system by some acceptable means. The original test approved concrete barrier was the New Jersey Safety Shape.

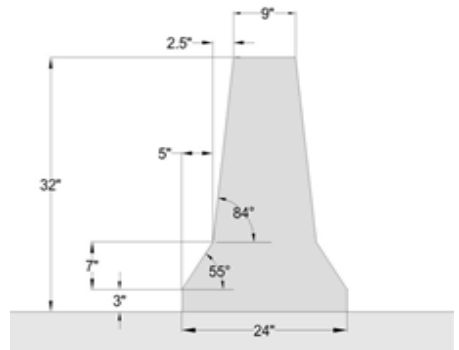
The flatter lower slope is intended to redirect vehicles striking at shallow angles with little vehicle damage, but it can cause instability to vehicles striking at high speeds and angles.

Under MASH, the 32 in. high barrier is now TL-3 and not TL-4. To meet TL-4, the barrier must be 36 in. high and 42 in. high for TL-5.

Additional testing was performed because of concern with the lift and potential instability with the small car. This led to developing the F-shape, which is similar in shape to the New Jersey barrier, but it has a lower height of the breakpoint.

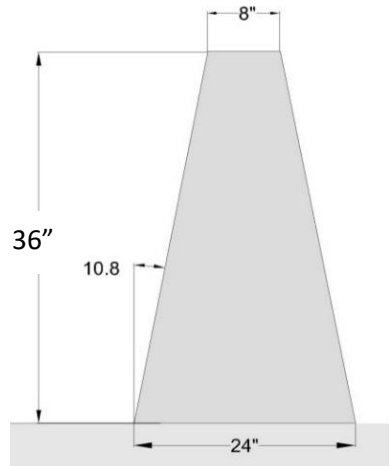


New Jersey Safety Shape



F Shape

A single slope shape was also tested and found acceptable. NDDOT have been using 36" high Texas single slope design as a TL-4 barrier.



Texas Single slope TL-4

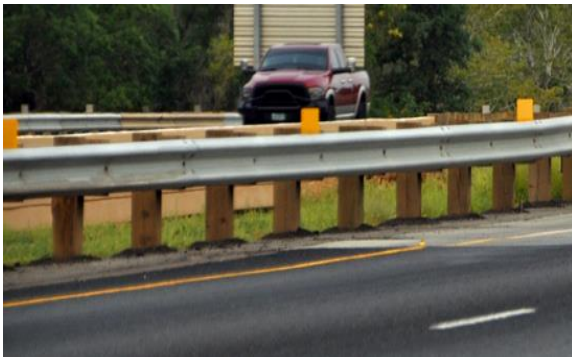
The Zone of Intrusion is the concern of a large vehicle leaning over the barrier following impact and possibly striking a vertical obstacle. Bridge engineers have a particular concern for the bridge piers and have recommended that any barrier within 10 ft. be 54 in. tall and 42 in. beyond 10 ft. The *Roadside Design Guide* suggests the taller barrier begin 10 ft. in advance of the obstacle preceded by a 10:1 slope to the normal barrier height.

Semi-Rigid System

Semi-Rigid Barrier Systems have deflections of a few feet (between 2 ft. and 5 ft.) under the TL-3 pickup impact conditions. Most semi-rigid systems consist of post and beam. Terminate these systems with an anchor on both ends to maintain the tension in the rail. The majority of the current in-place semi-rigid barrier in North Dakota is the 28 in. Guardrail System (G4).

28 in. Guardrail System (G4)

Test Level: NCHRP 350 (MASH TL-3 steel post only)



Rail Splice on Posts

Height: 28 in. (Installation tolerance $-\frac{1}{4}$ in.; +1 in.).

Post: wood 6 in. by 8 in. by 6 ft.

Post Spacing: 6 ft., 3 in.

Block-outs: 6 in. by 8 in. timber.

As of 2018, NDDOT has adopted the use of Midwest Guardrail System (MGS) for its standard guardrail on new construction.

The major differences between the 28 in. Guardrail System (G4) and the MGS are shifting the W-beam rail splices from the posts to mid-span between posts, and raising the rail height to 31 in. These two changes provided a stronger system and a better performance for higher center-of-gravity/bumper height pickup vehicles. The MGS guardrail system uses the same rail element as the G4 (with holes punched every 3 ft. –1½ in.). The NDDOT standard block is 8 in. deep and the post length remains 6 ft. long. The post and the blockout are wood.

Midwest Guardrail System (MGS)

Test Level: MASH TL-3



Rail Splice between posts

Height: 31 in. (Installation tolerance ± 1 in.).

Post: 6 in. by 8 in. by 6 ft. wood posts.

Post Spacing: 6 ft., 3 in.

Block-outs: 6 in. by 8 in. timber block.

Height requirement for 28 in. (G4) system

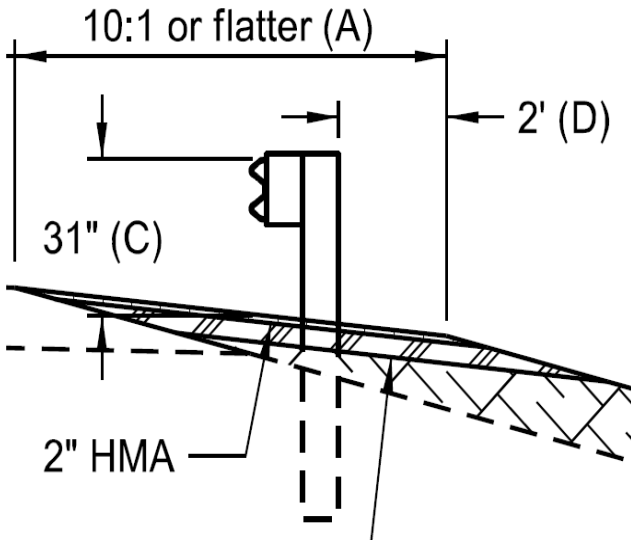
After an overlay, raise, reset, or reconstruct W-beam guardrail less than 26½ in. high.

Height requirement for MGS

The MGS installed at 31 in. can accommodate future overlays with a 3 in. down tolerance.

Height Measurement

(C) Measured from top of guardrail to top of surfacing at front face of guardrail.



Rail Lapping (G4 and MGS).

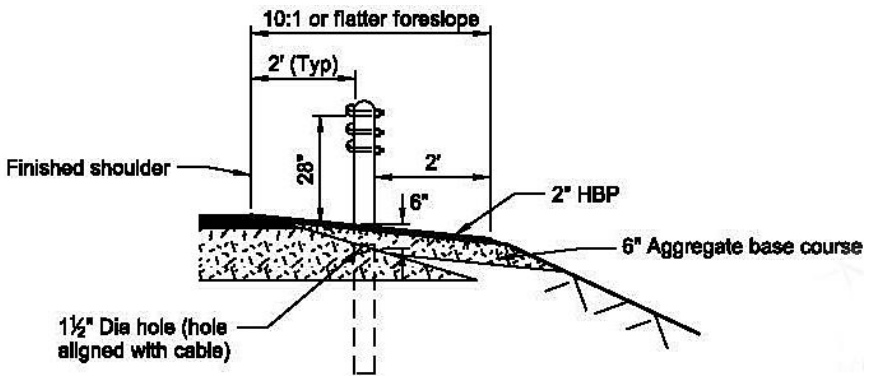
Lap guardrail is in the direction of travel of the adjacent traffic. Although the chance of snagging on the end of a rail panel during impact is unlikely, reverse lapping has been problematic for some maintenance activities (e.g., plowing snow). Rail lapping is also an important indicator of the quality of the installer's workmanship.



Flexible Systems

Flexible barrier systems typically have relatively large deflections. Examples of Flexible Barriers include: Weak-post W-beam, Low-tension cable and High-tension cable. Flexible systems are generally more forgiving because much of the impact energy is dissipated by the deflection of the barrier and lower impact forces are imposed upon the vehicle.

NDDOT has been using a 3-cable low-tension system and providing for 11 ft. deflection. The following shows the NDDOT Standard Drawing D-764-32 for details.



TYPICAL SECTION

For new installations, NDDOT will use High-Tension Cable Guardrail. These are installed with the cables placed under significant tension (>5,000 lbs., depending on manufacturer and temperature). A major advantage of the High-Tension Cable Guardrail systems is that the cables remain near the proper height after most normal strikes (with damage limited to a few

posts) so that the barrier is still effective. High-Tension Cable Guardrail undergo rather large deflections (around 8 ft.) when compared to rigid and semi-rigid barriers. Post spacing and type, and cable heights and attachment vary with the manufacturer.

There are five High-Tension Cable Guardrail, and all are proprietary. Install these systems in accordance with the manufacturer's recommendations and the NDDOT plan requirements. *NDDOT will be using these systems as they become MASH approved.*

Brifen Wire Rope Safety Fence (WRSF) 3 and 4 wire by Brifen USA

<http://www.brifenus.com/>

Post: Z-shaped post can be driven or socketed.

Cable: Top cable is placed in a center slot at top of the post and 2 or 3 cables are weaved around posts and supported by post pegs.



CASS 3-wire system by Trinity

<http://www.highwayguardrail.com/products/cb.html>

Post: C-shaped post can be driven or socketed.

Cable: 3 cables placed in a wave-shaped slot at the center of the post are separated by plastic spacers.



Safence by Gregory Highway Products

http://www.gregorycorp.com/highway_safence.cfm

Post: C-shaped post can be driven or socketed.

Cable: Insert 3 or 4 cables in a slot at the center of the post and separate by plastic spacers.



Gibraltar

<http://gibraltarus.com/en/highway-cable-barrier>

Post: C-channel post can be driven or socketed.

Cable: Cables are attached using a single hair pin and are placed on alternate sides of adjacent posts.



Nu-Cable by Nucor Marion Steel

<http://nucorhighway.com/nu-cable.html>

Post: U-Channel Post, can be driven or socketed.

Cable: 4 cable combination. Cables are attached using locking hook bolts or hook bolts and a strap. Cables are alternately placed on the sides of the post.



DESIGN

Understand the five design principles that are applied for an optimal barrier design and apply a field procedure to check Length of Need.



GENERAL

BARRIERS

DESIGN

TERMINALS &
CRASH CUSHIONS

TRANSITIONS

SPECIAL DESIGN

MAINTENANCE

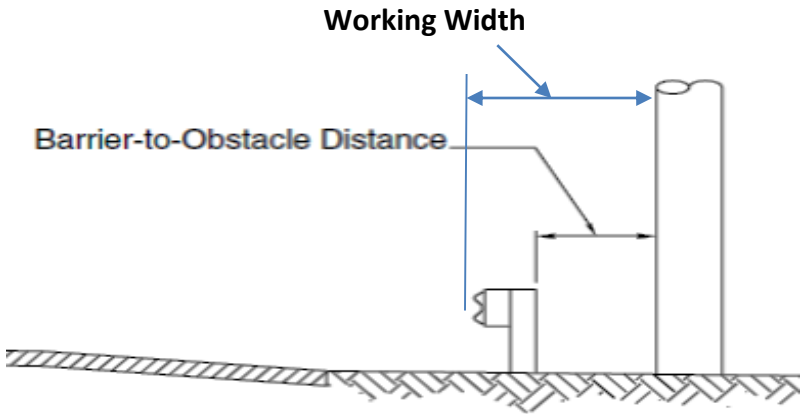
Barrier Design Principles

There are five principles of barrier design that should be addressed for a barrier installation to perform as designed. Some of these principles differ between the MGS and 28 in. (G4) and these differences are noted in the following guidance. Note that the G4 was tested to NCHRP 350 criteria (and successfully to MASH, as a steel post system only); the MGS was tested to MASH with steel and wood posts.

Deflection

The needed deflection distance is based on the results of 62 mph strikes into the guardrail at a 25 deg. impact angle by a pickup truck. The minimum deflection distance, which was used in the past, was 2.5 ft. to 3 ft. from the back of the post for strong-post G4 W-beam.

A better term, which is currently used, is the **Working Width** (shown in figure below). Measure the working width from the face of the barrier to the maximum extent of either the barrier or the vehicle during impact.



MASH testing of the deflections was inconsistent and varied by post type. The working width for the wood post was 59 in.

When these deflection criteria cannot be provided, use additional posts at half or quarter post spacing and nesting to stiffen the rail elements. Add the stiffening gradually so as not to create a hard point. Table 5-4 of the RDG provides some guidance in this regard; however, additional testing under MASH is anticipated.

As noted above, the deflection distance for the HTCB systems are significantly larger, around 8 ft. with 10 ft. post spacing; closer post spacing may reduce the deflection. See Manufacturer's Instruction.

Slope in front of Barrier

Barrier, regardless of type, performs best when a striking vehicle is stable as contact is first made. A vehicle running off the road at high speed and crossing a slope hinge point may become airborne and strike the barrier too high, resulting in override.

High-tension cable guardrail can be placed on a 6:1 slope, but its location on the slope is critical when near a swale. Avoid the area from 1 ft. to 8 ft. from the ditch. It has also been tested on 4:1 slopes within restricted locations (typically, within 4 ft. of the hinge point). Check with the manufacturer's guidelines and NCHRP Report 711 for all options. It is important to follow the manufacturer's guidelines.

It is also important NOT to place rigid barriers where the slope leading to the barrier face exceeds 10:1.

The MGS system can be placed anywhere on a slope (relative to the slope only) as long as the slope in front of the barrier is flat (10:1 or flatter); measure the height from the ground directly beneath the face of the rail.

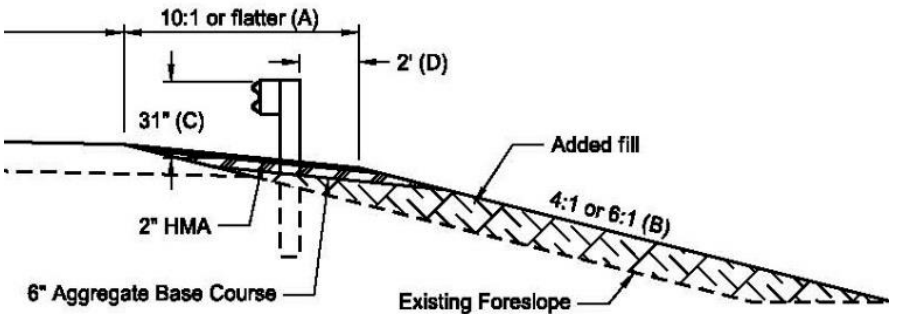
The G4 system can also be placed anywhere on a 10:1 slope.

Guardrail in Combination with Curb

Using the curb in combination with guardrail on high-speed facilities is generally not recommended. When necessary at high-speed locations (45 mph or greater), use a 4 in. or shorter sloping-face curb with the curb face flush with face of rail. Placement of MGS in conjunction with curb—up to 6 in. high and up to 6 in. behind the face of curb—was recently successfully crash tested to MASH TL-3. However, the test was not successful when a post was omitted. It was also successfully tested at lower speed (MASH TL-2) in combination with a 6 in. curb when the face of barrier was 6 ft. behind the curb.

Post Support at Embankment

If guardrail is shielding a steep embankment, there should be sufficient soil support behind the post to provide for the post's strength. NDDOT standard drawing D-764-49 shows grading at a slope of 10:1 or flatter extending 2 ft. behind the post.



The MGS was successfully tested to MASH at the hinge point of a 2:1 slope. It was also successfully tested with an 8 ft. long steel post located 1 ft. down the 2:1 slope. These would be considered as special treatments.

For the G4 system with the post placed at the slope break point of a 2:1 slope, 7 ft. long posts at half post spacing tested successfully to NCHRP 350 TL-3.

Flare Rate

NDDOT encourages the use of flared guardrail wherever possible.

A barrier placed on a flare moves the barrier and terminal farther away from the edge of traffic and reduces the amount of barrier needed. If the barrier is flared, then consider two features:

- Slope in front of the barrier must be 10:1 or flatter; and
- Flare rate must satisfy the allowable values given in the NDDOT Guidance below. As the flare rate increases the angle at which the barrier can be impacted also increases.

NDDOT standard flare rates which are maximum taper rates:

- 10:1 for 30 mph to 45 mph,
- 11:1 for 50 mph,
- 12:1 for 55 mph,
- 14:1 for 60 mph,
- 15:1 for 65 mph and 70 mph, and
- 16:1 for 75 mph)

(Ref: NDDOT *Design Manual*, Appendix III-13B)

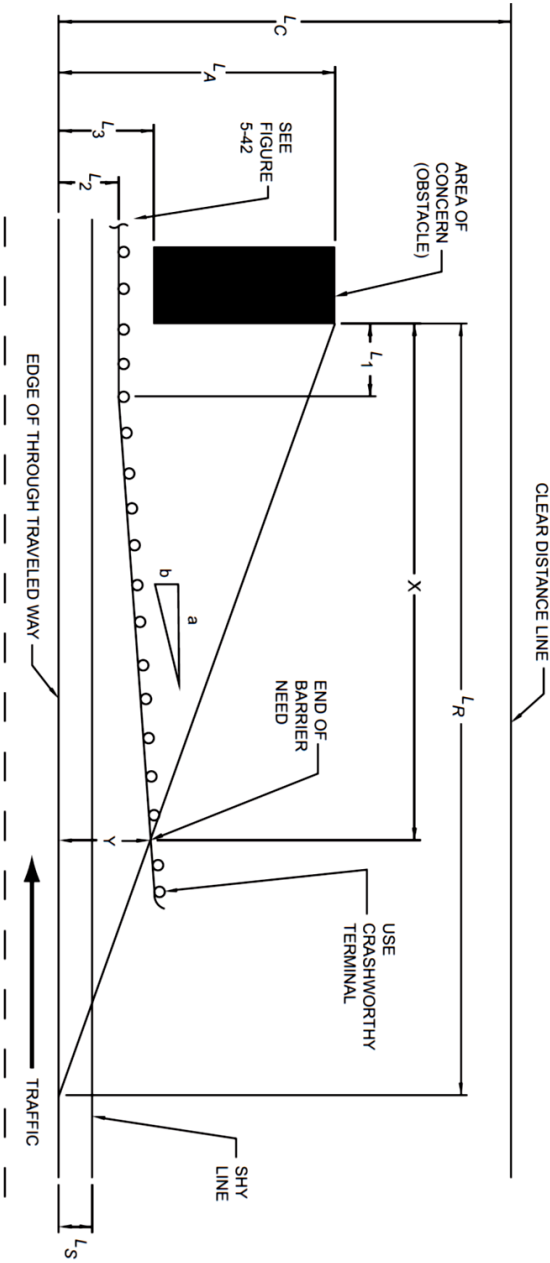
Where necessary, a barrier may be flared at a rate flatter than the standard taper rates.

Install a minimum length of 25 ft. of tangent railing in advance of an obstruction and in all cases, a curved section will transition the straight section to the flared section.

(NDDOT *Design Manual*, III-13.06, Guardrail Location)

Length of Need

Length of need (X) is defined as the length of fully effective barrier needed in ADVANCE (upstream) of the obstacle to prevent a vehicle that has left the roadway from reaching the shielded obstacle. It is determined by the designer selecting the appropriate variables, as shown below and calculating the LON (the X value).



Approach Barrier Layout (LON)

X = Distance from the obstruction to end of barrier need.

Y = Distance from edge of through traveled way to end of barrier need.

L_A = Distance from edge of through traveled way to lateral extent of obstruction.

L_1 = Tangent length of barrier upstream from obstruction.

L_2 = Distance from edge of through traveled way to barrier.

L_3 = Distance from edge of through traveled way to obstruction.

L_C = Distance from edge of through traveled way to outside edge of the clear zone.

L_R = The theoretical Runout Length needed for a vehicle leaving the roadway to stop.

$a : b$ = Flare Rate.

(AASHTO *Roadside Design Guide*, 2011, Figure 5-39, pages 5-49)

Length of Need Procedure

1. Choose an appropriate LA, as it is a critical part of the design process. This distance should include all features or obstacles to be shielded. (If the obstacle extends a significant distance away from the travel way, such as a river, or cannot be defined, then the Clear zone, LC, can be used for LA.)
2. Select a runout length (L_R) from the table below.
3. If the barrier is flared, then the designer selects the tangent length, (L_1). If the installation is parallel to the roadway, $L_1 = 0$. If a semi-rigid barrier is connected to a rigid barrier, then the tangent length should be at least as long as the transition section. Also, NDDOT requires a 25 ft. tangent section in advance of the obstruction.
4. If the barrier is flared away from the roadway, then do not exceed the maximum recommended flare rates shown above.
5. Calculate the Length of Need (X) from the following equation

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

For parallel installations, i.e., no flare rate, the previous equation becomes:

$$X = \frac{L_A - L_2}{L_A / L_R}$$

The table below shows the values for L_R —the Runout Length. (These are the current values NDDOT uses and differ from those used in the current AASHTO RDG).

Design Speed (mph)	Runout Length (L_R) Given Traffic Volume (ADT) (ft.)			
	Over 6,000	2,000 to 6,000	800 to 2,000	Under 800
75	520	485	430	395
70	475	445	395	360
65	450	425	370	345
60	425	400	345	330
55	360	345	315	280
50	330	300	260	245
45	260	245	215	200
40	230	200	180	165
30	165	165	150	140

(NDDOT *Design Manual*, Section III-13.07, October 2007)

These values for L_R can also be used in the field for a quick check to verify if the length of barrier is adequate as described below.

For two-way roadways, an identified obstacle must sometimes be shielded for opposite-direction traffic. The LON formula is exactly the same; except all lateral measurements are now from the roadway centerline.

In accordance with NDDOT guidelines, when guardrail is to be installed on the outside of curves sharper than 1 Degree 15 minutes ($R < 4583.66$ ft.); the LON will require a graphical design procedure.

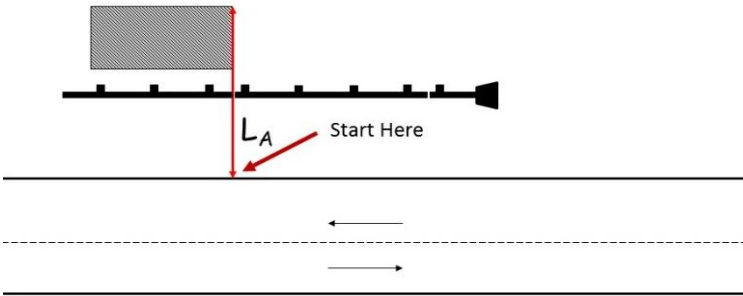
(Ref: NDDOT *Design Manual*, III-13.10)

After determining the total amount of barrier needed for the obstacle (in advance of obstacle—length of obstacle—downstream of obstacle), and after considering other barrier contributing to the amount of barrier needed that is paid for under another bid item (such as effective portion of end terminal, bridge rail, transition, etc.), use 12.5 ft. or 25 ft. panel lengths and convert to *LF* for bid purposes.

LON Field Check

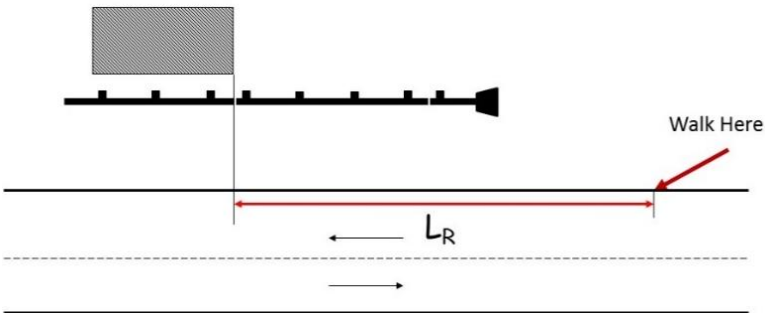
The following is a guide for performing a check in the field to verify that adequate length of barrier is provided:

Stand on the edgeline directly opposite the upstream end of the obstacle.

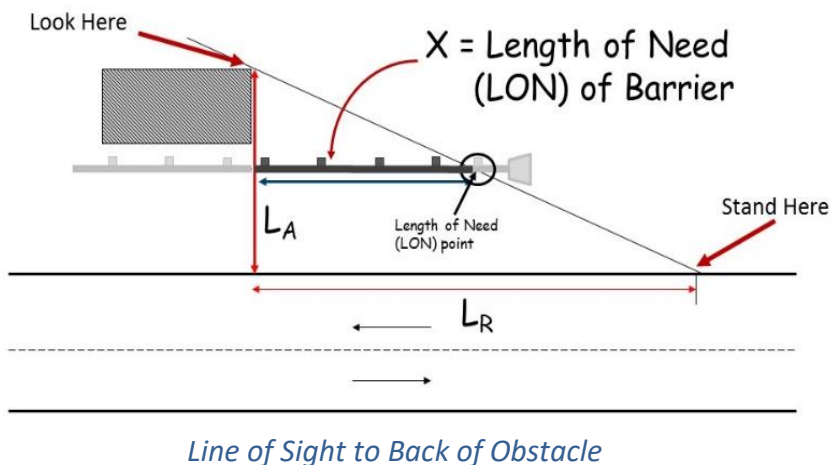


Stand at Upstream End of Obstacle

Pace off upstream the appropriate runout length from table.



Pace the Runout Length

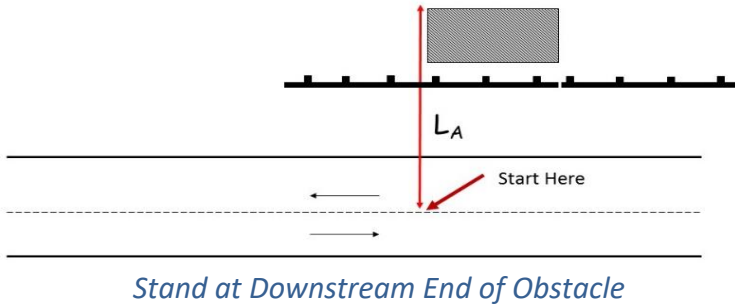


From that point, turn and look at the back of the obstacle. (If the obstacle has no clear far side, such as a river or embankment, this distance may be limited to the design clear zone.)

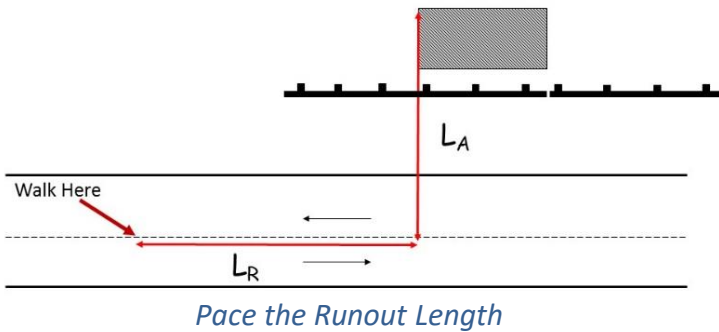
If the proposed (or actual) guardrail installation crosses (or is close to) that line of sight, then the area is adequately covered.

Need to check LON for the opposing direction of traffic. This time the pacing would be from the downstream end of the obstacle and would be along the centerline.

Stand on the centerline directly opposite the downstream end of the obstacle.

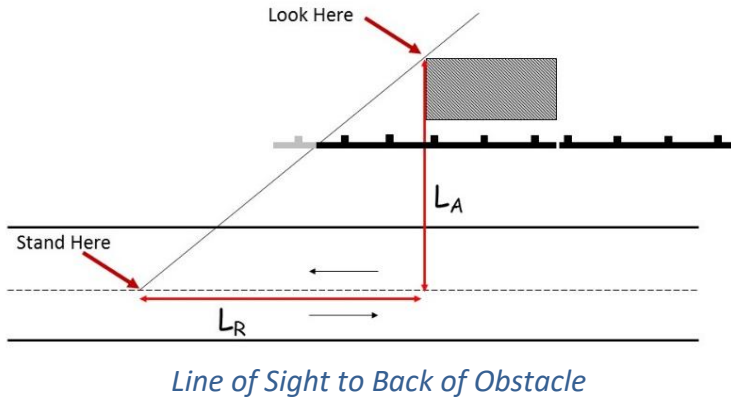


Pace off downstream the appropriate runout length from table.



From that point, turn and look at the back of the obstacle. (If the obstacle has no clear far side, such as a river or embankment, then this distance may be limited to the design clear zone—measured from the centerline.)

If the proposed (or actual) guardrail installation crosses (or is close to) that line of sight, then the area is adequately covered.



Pay special attention so as to appropriately address all obstacles in the immediate vicinity that would warrant shielding. There may be other warranting obstacles near an obvious obstacle (i.e., the bridge pier), such as a steep transverse embankment within the clear zone that should be considered when determining adequate length of barrier.

Gaps

Avoid short gaps between runs of barrier. In general, connect gaps of less than 200 ft. between barrier termini into a single run. Short gaps are acceptable when the barrier is terminated in a cut slope. Consider maintenance access issues when determining whether or not to connect barriers.

TERMINALS AND CRASH CUSHIONS

Systems used in North Dakota. System Description, Characteristics, Requirements and Links to Manufacturers Website.



GENERAL

BARRIERS

DESIGN

TERMINALS &
CRASH CUSHIONS

TRANSITIONS

SPECIAL DESIGN

MAINTENANCE

Terminals and Crash Cushions

Terminals

A guardrail anchor is required at the end of a run of guardrail to develop tensile strength throughout its length. In addition, when the end of the guardrail is subject to head-on strikes, a crash-tested guardrail terminal is required.

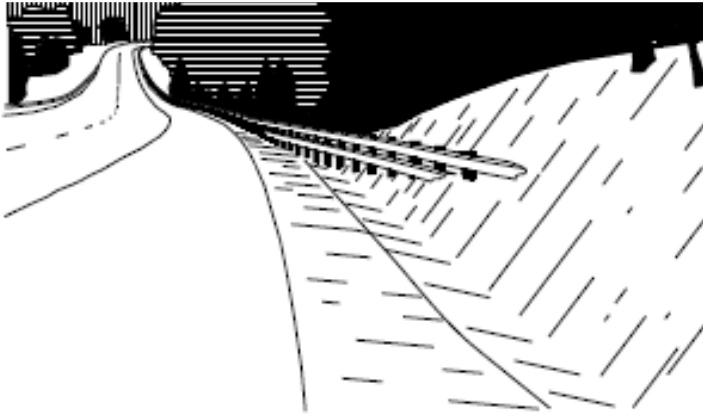
The three types of crashworthy terminals are: Buried in Backslope, non-energy-absorbing, and energy-absorbing systems.

Terminal Types and Selection

(As of 2018, NDDOT requires that all crashworthy terminals meet MASH.)

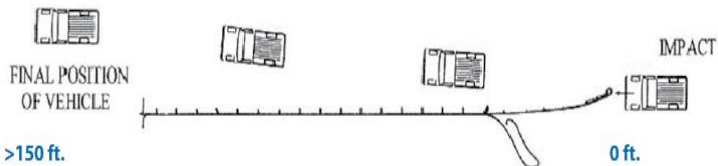
Buried in Backslope is the preferred treatment when a cut slope is present (or close by) according to the AASHTO Roadside Design Guide. When properly designed and installed, it adequately shields the obstacle(s) and eliminates the possibility of any end-on strikes.

Although tested with foreslopes as steep as 4:1, the rail height must be relatively constant in relation to the shoulder. If the distance from the ground to the bottom of the rail exceeds 19 in., then add a rubrail to prevent vehicle snagging on the exposed posts.



The ideal backslope is 2:1. If the slope is not particularly steep (flatter than 3:1) this design can be overridden by an errant vehicle; therefore, provide the full LON, with a minimum longitudinal 75 ft. clear area behind the rail.

Non-Energy-absorbing Terminals serve both functions: develop anchorage and reduce the possibility of spearing by the rail element. (The SRT is the typical non-energy-absorbing terminal.) However, because they do not absorb significant energy for end-on strikes, they do not significantly reduce vehicle speed, regardless of angle. Use these only when the Length of Need, discussed earlier, for the shielded obstacle(s) has been met. Crash testing has shown that the pickup truck traveling at 62 mph and striking the terminal head-on can travel 150 ft. or more behind the guardrail system, as illustrated below.



28
Non-Energy-absorbing Terminal

Therefore, where a non-energy-absorbing terminal is used, it is important to verify that the grading is completed, as shown on the NDDOT Standard Drawings and that the LON has been provided; the LON should be at least 150 ft.

Energy-absorbing Terminals. Crash testing has shown that an energy-absorbing terminal can stop a striking pickup truck, travelling at 62 mph, in about 50 ft. when struck head-on (as shown below), and thus may be used at locations where the LON or the 150 ft. minimum cannot be achieved (contact the District Traffic Safety Engineer). Recognize, however, that a vehicle at a higher angle impact on the end will pass through the terminal and end up in essentially the same location as if it had been a non-energy-absorbing terminal.

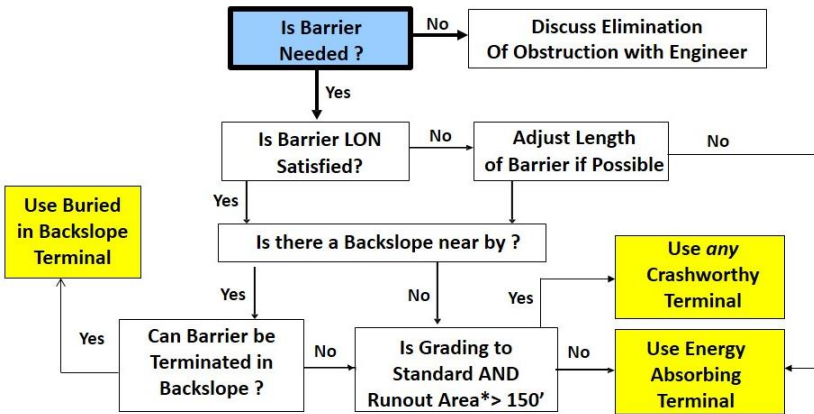


Energy-absorbing Terminals

Because non-energy-absorbing and energy-absorbing terminals function differently by design, it is critically important to use the correct type of terminal for the particular site conditions as it relates to adequate LON and availability of proper grading.

The flow chart below taken from the FHWA Technical brief titled “Selection, Installation, and Maintenance of W-Beam Guardrail End Terminals” provides guidance in selecting the appropriate terminal type.

Type of Terminal Selection



For additional commonly used terminals throughout the U.S., visit the FHWA website at http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/barriers/index.cfm

Energy-Absorbing Terminal Systems

MASH Sequential Kinking Terminal (MSKT)

NDDOT Standard Drawing D764-51

For current details of this system, see Manufacturer's Installation/Assembly Manual at:

<http://www.roadsystems.com/mash-mskt/>



Test Level: MASH: TL-2 and TL-3

Distinguishing Characteristics:

- Square impact head.
- Enclosed feeder chute (SKT engraved).
- Post 1 Tube top section, W 6 by 15 bottom section.
- Post 2 steel-hinged post.
- Posts 3–8 standard 6 ft. long posts.
- Other features same as the previously approved SKT 350, see below.

How it works: The energy of a vehicle in a head-on strike is absorbed by the impact head being forced down the rail elements deforming them in short kinks. For higher angle hits on the nose, the vehicle breaks away the end and passes through and behind the guardrail. For side impacts beyond the LON point (post 3), redirect the vehicle in front of the rail.

SoftStop

NDDOT Standard Drawing D764-51

For current details of this system, visit Manufacturer's Installation/Assembly Manual at website:

<http://www.highwayguardrail.com/products/SoftStop.html>



Test Level: MASH: TL-1, TL-2 and TL-3

Distinguishing Characteristics:

- Narrow, rectangular impact head and chute.
- Anchor post in front of the impact head (post 0).
- Post 1–4 ft., 9½ in. SYTP (Steel Yielding Terminal Post).
- Posts 2–6 ft. SYTP.
- Posts 3–8 standard 6 ft. long posts.
- TL-3 at 50 ft., 9½ in. long
- BLON at 16 ft. 6 in.
- 31 in. only, adaption needed for Type 28 in. connection.
- End-rail element is split, passes through the impact head, and is connected (with two bolts) to post 0 (the foundation post).

How it works: Using a proprietary head design, the system flattens and extrudes the W-beam guardrail upon end-on strikes, dissipating energy while guiding the flattened rail

through the mouth at the bottom of the unit. The front anchorage is designed to allow the rail panels to remain anchored during end-on impacts. For higher angle hits on the nose, the vehicle pushes over the guardrail and passes through and behind the guardrail.

MAX-Tension (Roadside and Median)

For current details of this system, visit Manufacturer’s Installation/Assembly Manual at website:

<http://www.barriersystemsinc.com/maxtension-mash-end-treatment>



Test Level: MASH: TL-2 and TL-3

Distinguishing Characteristics

- Rectangular Impact Face does NOT work on rail.
- All steel driven posts.
- Uses a slider mechanism at post 3 that gathers and retains the rails when hit head-on.
- Anchor consists of posts 1 and 2 connected by tension struts and a soil plate below grade on post 2.

How it works: The MAX system uses tensioned cables, telescoping panels, and a cutting tooth to absorb the kinetic energy and safely contain or redirect the striking vehicle.

MASH Flared Energy-Absorbing Terminal (MFLEAT)

For current details of this system, see Manufacturer's Installation/Assembly Manual at:

<http://www.roadsystems.com/mash-mfleat/>



Test Level: MASH: TL-3

Distinguishing Characteristics:

- Square impact head.
- Enclosed feeder chute.
- 39 ft.-7 in. straight flared length.
- 3 ft. offset.
- Posts 1-3 are steel-hinged post.
- BLON at post 4.
- Other features similar to the previously approved FLEAT 350, see below.

How it works: This is an energy-absorbing terminal, which is also a flared terminal. The energy of a vehicle in a head-on impact is absorbed by the impact head being forced down the rails sequentially kinking them and exiting on the traffic side of the guardrail.

Existing Guardrail Terminal Systems

The following terminals have met NCHRP 350 testing and are presented here for identification. (Under NDDOT MASH Implementation Plan, for Major Rehabilitation and New/Reconstruction, the minimum was changed from NCHRP Report 350 to MASH.)

ET Plus (Guardrail Extruder Terminal) (NCHRP 350 TL-3)

- Flattens the rail element as it passes thru head when hit head-on or at a shallow angle.
- Weakened wood or steel posts options.
- 50 ft. long, straight.
- Cable and strut-anchored system.
- BLON at post 3.



*Flanges only
on the sides
— unique to
ET-Plus*

For current details of these systems, visit Manufacturer's Installation/Assembly Manual at website:

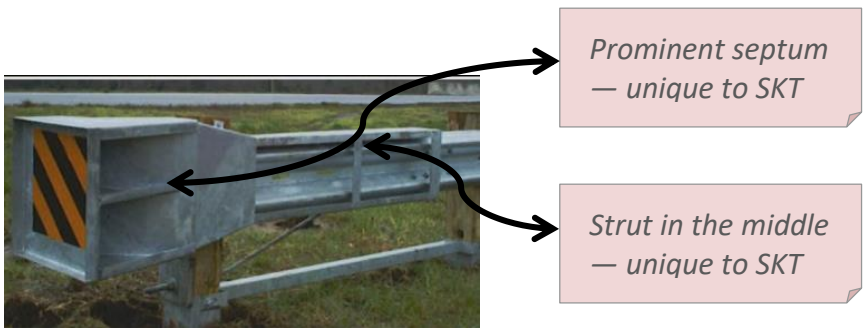
<http://www.highwayguardrail.com/products/etplus.html>

The ET Plus has a rectangular impact head. Its predecessor, ET2000, had a square impact head.

SKT 350 (Sequential Kinking Terminal) (NCHRP 350 TL-3)

NDDOT Standard Drawing D764-05

- Head kinks panels when hit head-on or at a shallow angle.
- Wood or steel post options, posts 1 and 2 breakaway.
- TL-3 at 50 ft. long—straight—BLON at post 3.
- Cable-anchored or cable and strut (wood) anchor system.



For current details of this system, view Manufacturer's Installation/Assembly Manual at website:

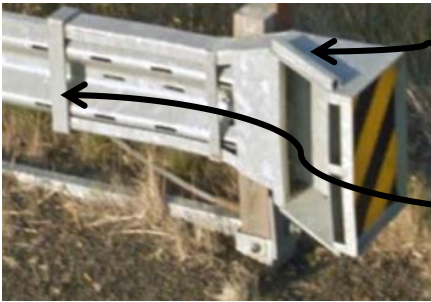
<http://roadsystems.com/skt.html>

FLEAT 350 (Flared Energy-Absorbing Terminal) (NCHRP 350 TL-3)

NDDOT Standard Drawing D764-06

NDDOT Standard Drawing D764-38 MGS

- Straight flare (not parabolic).
- Curls the rail tightly toward the roadway.
- Wood or steel post options, posts 1 and 2 breakaway.
- TL-3 at 37 ft., 6 in. long.
- BLON at post 3.
- Cable and strut-anchored system.



*Square bar is
unique to FLEAT*

*A strut at each
end*

For current details of this system, visit Manufacturer's
Installation/Assembly Manual at website:

<http://roadsystems.com/fleat.html>

SRT (Slotted Rail Terminal) (350) (NCHRP 350 TL-3)

NDDOT Standard Drawing D764-07

NDDOT Standard Drawing D764-39 MGS

- Flared terminal, 4 ft. offset steel–3 ft. or 4 ft. offset option wood.
- W-beam panels with horizontal slots.
- Steel and wood options, all breakaway or yielding.
- TL-3 at 37 ft., 6 in. long.
- BLON at post 3.
- Cable and strut-anchored system.



*Slots —
unique to SRT*

For current details of this system, visit Manufacturer's
Installation/Assembly Manual at website:

<http://www.highwayguardrail.com/products/et-srt350.html>

Modified Eccentric Loader Terminal (MELT) (NCHRP 350 TL-2), Generic



- No impact head.
- Rail installed on parabolic curve.
- Strut between the steel tube foundations for the two end posts act together to resist the cable loads.
- All-wood posts.

CAT (Crash Cushion Attenuating Terminal) (NCHRP 350 TL-3) Median Terminal



- Special HS bolts tear tabs between multiple slots in rail upon head-on impact.

- Typically used to terminate a double-faced strong-post median W-beam barrier.
- Can be attached directly to a double-sided concrete median barrier with appropriate transition section.
- Cable-anchored, compression system.
- BLON at Post #5.

For current details of this system, visit Manufacturer's Installation/Assembly Manual at website:

www.highwayguardrail.com/products/cat350.html

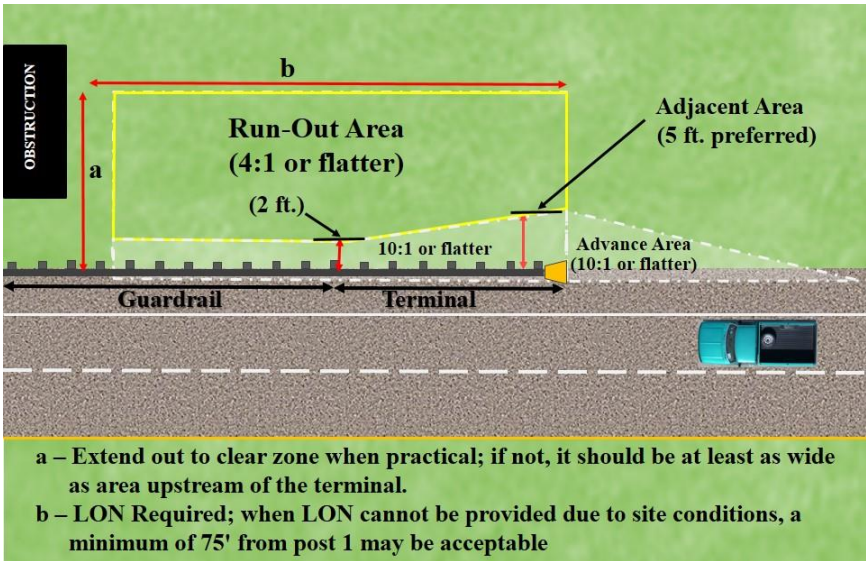
Special W-beam Energy Guardrail Anchor

NDDOT Standard Drawing D-764-41 provides an MGS end anchor (D764-14 for the 28 in. guardrail) to be used where the only concern is to develop the tension in the guardrail for strikes along the face of the barrier. Avoid using where approach traffic can strike the end and a crashworthy terminal would be appropriate. Example usage: trailing end on one-way roadway.

Generally, no rail is needed on the departure ends of bridges on divided roadways unless site-specific circumstances require additional barrier.

Terminal Grading Details

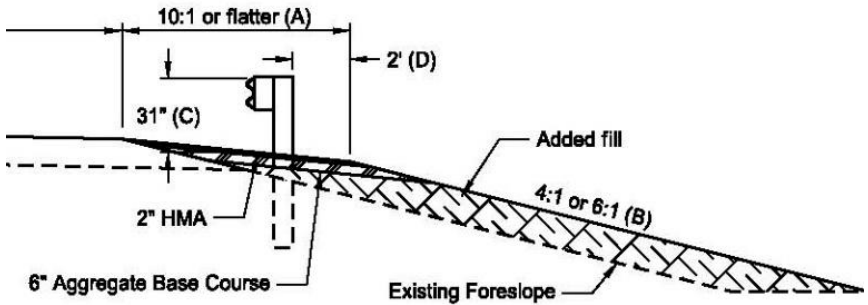
A terminal is most likely to perform best when a vehicle is stable at the moment of impact. There are three grading areas around guardrail terminals to help achieve the desired performance: advance, adjacent, and run-out distance; these are highlighted on figure below.



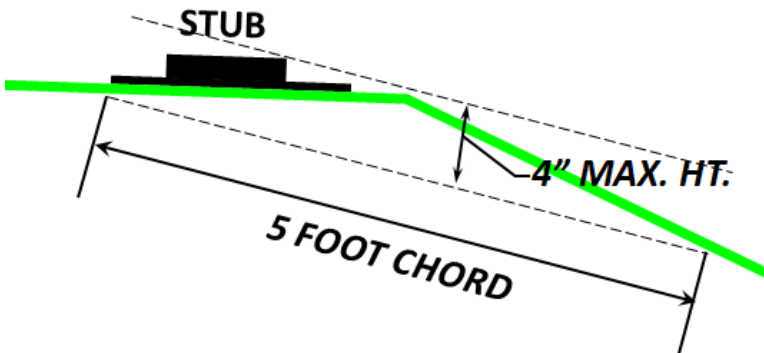
Terminal Grading Areas

When building a grading platform, design and construct it as shown on NDDOT Standard Drawing D764-49. Note that the areas approaching and immediately adjacent to the terminal should be 10:1 or flatter.

Important: Provide quantity for grading material in contract.



A second consideration for terminal grading is the stub height criteria, shown in figure below. Any hardware remaining after the vehicle impact should not exceed this stub height criteria.

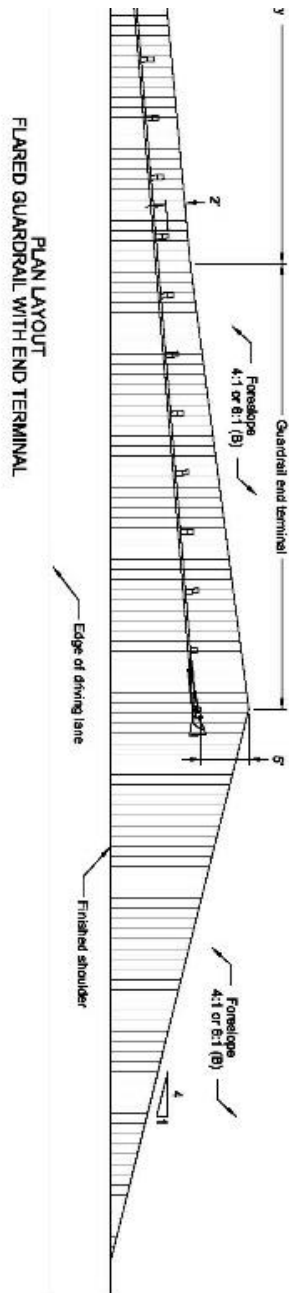


Stub Height Criteria

NOTES:

- (A) Slope flatter than 10:1 may be required to provide proper guardrail height.
- (B) Where normal foreslope is 4:1 the added fill shall be 4:1. Where normal foreslope is 6:1 the added fill shall be 6:1.
- (C) Measured from top of guardrail to top of surfacing at front face of guardrail.
- (D) Dimension at end terminals may vary per Plan Layouts shown on this sheet.

(NDDOT Standard Drawing D 764-49)



Terminal Installation

Review the following items for a proper installation:

- Grading should be appropriate.
- Stub height should satisfy criteria.
- All parts should be for the specific model being installed.
- For breakaway cable anchorages:
 - Top of post 1 should be able to separate from its base for end-on strikes—to release the cable.
 - Properly orient and restrain the bearing plate on the cable at post 1 so that it remains in that position. The bearing plate should not be buried.
- For energy-absorbing, compression-based systems with impact heads:
 - Firmly seat rail panel into the head.
 - System should be on a straight line for its full length.
 - Proper cable anchor bracket attachment to the rail must allow for the release of the anchor bracket when hit by the impact head.
 - No bolt through the rail at post 1.
 - Use rail to post bolts only when called for and attach on the correct side of the post.
 - Securely attach impact head to post 1 (again, no post to rail connection).
 - Ensure top of impact head is parallel with the top of the rail.

- Tighten anchor cable appropriately.

It is a challenge to remember all the intricacies of properly installing the multitude of systems and models within each system. It is impossible to overemphasize the importance of having and following the **MANUFACTURER'S INSTALLATION MANUAL AND SHOP DRAWINGS** onsite for every installation.

Crash Cushions

Crash cushions are generally used to shield a point obstacle or where space is limited.

There are many approved crash cushions for permanent installations. MASH standards took effect January 1, 2019.

Crash cushions can be classified by the following:

- **Sacrificial.** Designed for a single impact.
- **Reusable.** Some components need to be replaced, but some major components are salvageable.
- **Low-maintenance and/or self-restoring crash cushions.** Suffer very little and are readily restored or self-restoring.

For additional commonly used crash cushions throughout the U.S., visit the FHWA website:

http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/barriers/index.cfm

Sand Barrels—Sacrificial

Sand barrels are relatively inexpensive. They are sacrificial and provide no redirection. For these reasons, they are most effective in shielding fixed object obstacles where likelihood of impacts is low, such as in the photo below.



Four types of sand barrels:

Fitch/ CrashGard / Energite / Big Sandy



Energite



Fitch



TraFFix Big Sandy



CrashGard

Individual barrel designs vary in shape by manufacturer, but they all function in the same manner: Sand-filled plastic barrels

decelerate a striking vehicle by transferring the vehicle's momentum to the variable masses of sand in the barrels it hits.

Arrays of sand barrels may be designed to shield any shape obstruction and obstacles of varying widths.

Striking vehicles will not be redirected. With no redirective capability, the corner of the obstruction must be reasonably shielded. The rear corner barrel should offset the shielded object by at least 30 in.

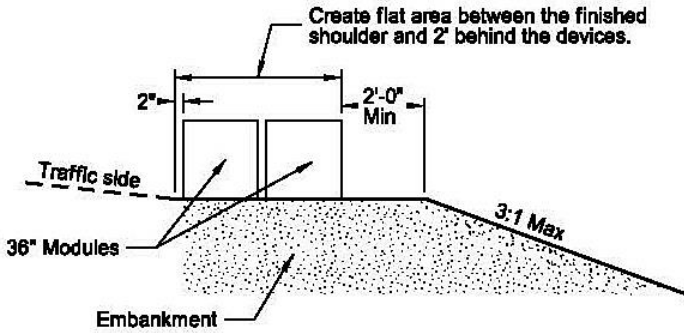
It is acceptable to mix barrel types as long as they are in the correct location.

The sand barrels are arranged by weight (200, 400, 700, 1,400, and 2,100 lbs.) in accordance with NDDOT *Standard Drawing and Design Manual*, which also specifies the orientation of the layout (expected angle of impact, 10 degrees desirable) along with a 30 in. offset of the last barrel to the obstacle to reduce the potential *coffin corner* strikes.

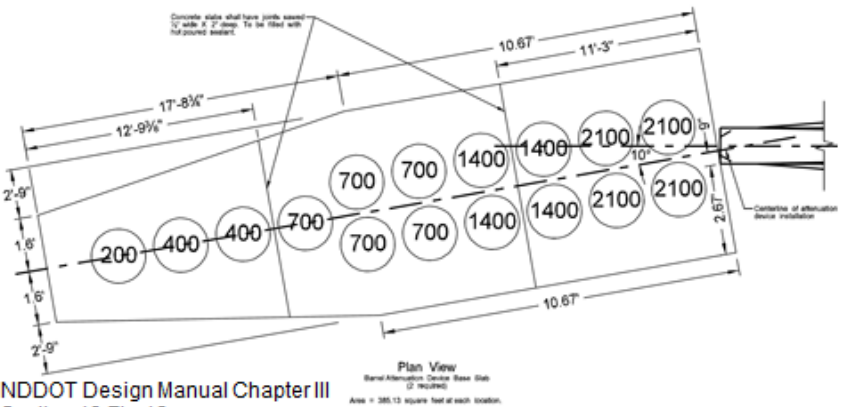
If the system is to function properly in all anticipated climate conditions, it is important that the moisture content and any anti-freezing treatment follow the specification.

A pad, with marked barrel locations, is desirable.

(NDDOT Standard Dwg. D704-1)



**Section A-A
(Type B Layout)**



NDDOT Design Manual Chapter III
Section 13 Fig.12



Sacrificial Bullnose



- Ensure a minimum 62 ft. of clear area from the nose to the obstacle.
- Slopes into the face of barrier and in front should be 10:1 or flatter.
- Transition to bridge rail should begin no sooner than post 9 from the nose.

Water-filled Barriers—Sacrificial

Absorb 350/Sled(MASH)/ACZ 350 (TL-2 and TL-3)



Absorb 350 (TL-3)



Sled (MASH)



ACZ-350

- Individual crash cushion designs vary in shape by manufacturer, but they all function in a similar manner.
- Typically used in work zones to shield temporary concrete barrier.
- Vehicles striking the nose at an angle will not be redirected.
- No appreciable redirective capability under most impact conditions.

QuadGuard (NCHRP 350), QuadGuard M10 (MASH) (TL-2 and TL- 3) Reusable



- Can be attached directly to a W-beam or Thrie-beam median barrier, as well as to a concrete safety shape.
- Slides back on a single track when struck head-on and uses specially fabricated side panels having four corrugations that redirect the vehicle in side impacts.
- Hex-foam cartridges crush upon impact, absorbing the energy of the striking vehicle for end-on hits and need to be replaced if damaged.
- Pad requirement—see manufacture’s installation manual.
- Available in widths from 24–36 in. with parallel sides and 69 or 96 in. with flared sides. (M10 currently only available at 24 in.)

For current details of this system, visit Manufacturer’s Installation/Assembly Manual at website:

http://www.energyabsorption.com/products/products_quadguard2_crash.asp

TRACC (TRinity Attenuating Crash Cushion) (NCHRP 350) (TL-2 and TL-3) Reusable



- Permanent or construction zone.
- TL-3 TRACC / TL-2 Short TRACC / FASTRACC / WIDETRACC.
- Designed to attach to W-beam or concrete median barrier.
- Has double tiered 10-gauge W-beam side panels; shipped to the field assembled.
- Absorbs energy by cutting internal metal plates on the top sides of the guidance tracks when forced backward in an end-on impact.
- Pad required—see manufacture’s installation manual requirements.

For current details of this system, visit Manufacturer’s Installation/Assembly Manual at website:

<http://www.highwayguardrail.com/products/tracc.html>

TAU II and TAU IIR Systems (NCHRP 350) (TL-2 and TL-3) Reusable



- Designed to attach to a median barrier.
- Common set of parts for 36 in.–102 in. widths in 6 in. increments.
- Energy-absorbing elliptical cartridges crush (and are reusable for the II-R) upon impact. Three-beam panels slide back when struck end-on and along with two cables at the bottom, redirect vehicles when struck on the side.
- Anchored at front and rear only.
- Pad requirement—see manufacturer’s installation manual.

For current details of this system, visit Manufacturer’s Installation/Assembly Manual at website:

<http://www.barriersystemsinc.com/tau-ii-crash-cushion>

QuadGuard Elite (NCHRP 350/MASH) (TL-2 and TL-3) Low Maintenance and Self-Restoring



- Similar operation to QuadGuard (NCHRP 350), except that QuadGuard M10 (MASH) uses high-density polyethylene plastic (HDPE) cylinders that self-restore to absorb energy.
- Essentially for use in locations where a high number of hits is anticipated.
- Pad requirement—see manufacturer’s installation manual.

For current details of this system, visit Manufacturer’s Installation/Assembly Manual at website:

http://www.energyabsorption.com/products/products_quadguard2_crash.asp

SCI Smart Cushion

(NCHRP 350/MASH)(TL-2 and TL-3) Low Maintenance



- Variable Reaction Force.
- Internal cables and a hydraulic cylinder provide resistance to stop a vehicle.
- Steel panels redirect side impacts.
- Minimal component replacement. General repair parts consist of replacing shear pins.
- Needs repair before next hit.
- Pad requirement—see manufacturer’s installation manual.

For current details of this system, visit Manufacturer’s Installation/Assembly Manual at website:

<http://workareaprotection.com/attenuators/>

TRANSITIONS

When two systems are connected with different deflection properties a gradual stiffening transition typically occurs between the two systems.



GENERAL

BARRIERS

DESIGN

TERMINALS &
CRASH CUSHIONS

TRANSITIONS

SPECIAL DESIGN

MAINTENANCE

Transitions

W-beam to Rigid Barrier/Bridge Rail

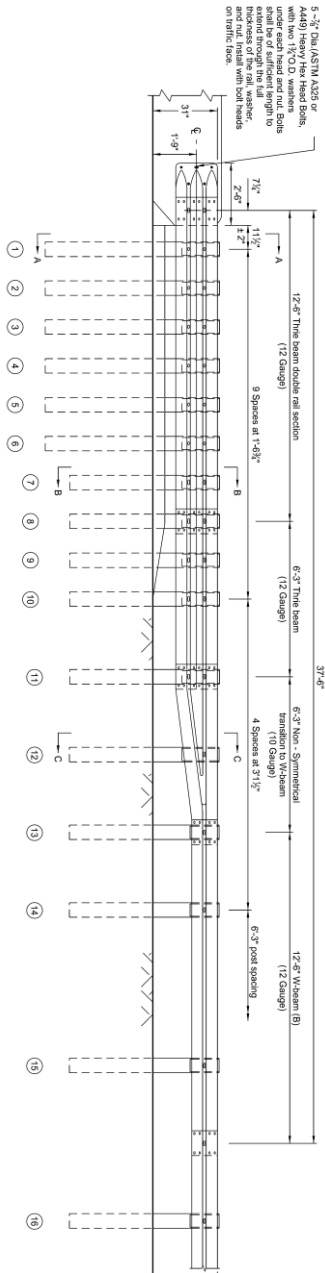
When a semi-rigid barrier precedes a rigid barrier, a gradual stiffening transition typically occurs between the two systems. Details for the transition are shown on NDDOT Standard Drawing D764-60 for MGS W-beam transition with approach curb to concrete Single Slope or Jersey Barrier. D764-63 is for MGS W-beam transition to concrete Safety Shape transition; D764 is for MGS W-beam transition with approach curb to in-place concrete New Jersey-shaped barrier. Standard Drawings D764-09 and D764-11 address transitions for the G4 (28 in.) system and D-764-10 uses Thrie-beam to provide for a transition to a Double Box Beam Retrofit.

Regardless of the system (G4 or MGS), transition details include the following four essential elements and which the figure illustrates:

1. Strong structural connection of steel beam to the concrete (to provide for tension continuity).
2. Additional, and typically, larger posts.
3. Nested W-beam or Thrie-beam.
4. Some design to reduce snagging of the wheel on the rigid barrier (typically a curb or rubrail or flared back bridge parapet). Note that any curb is part of the transition design

(and does not violate any guidance for standard runs of guardrail).

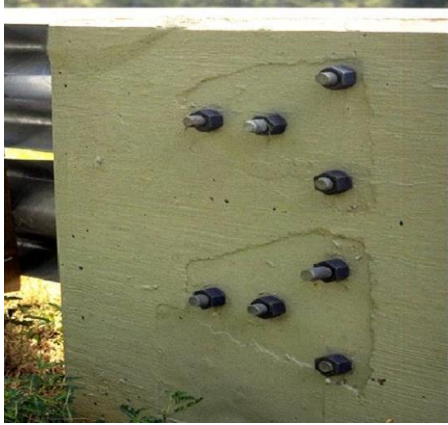
Although the Standard Drawings may not be applicable to all situations encountered in the field, including these four elements might provide an acceptable transition; coordinate with the appropriate design or traffic safety staff.



5 - 3/8" Dia. (ASTM) 120# B
 Add 1/2" Dia. Saw Head Bolts
 under each lead end nut. Bolts
 extend through the full
 length of the rail section
 and are secured with washers
 on traffic face.

(NDDOT Standard Drawing, D764-60)

A strong structural connection employ bolts that extend through the barrier wall, as noted in D764-60.



Transitions—Cable to W-beam

There also needs to be a transition from cable to W-beam. A generic transition is an overlap of the systems with a spatial separation of systems of at least 8 ft. so as not to redirect a striking vehicle into the terminal and sufficient length to prevent passing through the overlap.



Transitions —G4 (28 in.) to MGS

For situations requiring a transition between the two systems, transition from a ± 28 in. tall barrier or terminal to a 31 in. tall barrier over the span of two 12 ft.-6 in. sections of W-beam rail.

SPECIAL DESIGNS

Designs for when certain situations are encountered.



GENERAL

BARRIERS

DESIGN

TERMINALS &
CRASH CUSHIONS

TRANSITIONS

SPECIAL DESIGN

MAINTENANCE

Special Designs

Omitted Post

As with any special design, only omit a post in special circumstances; and only within a standard run of guardrail with the engineer's approval.

The **MGS** has been developed where single posts may be omitted in runs of MGS W-beam guardrail without any modifications to the typical MGS system (i.e., no weakened posts, no nested rail elements, no special posts), but always consider the following:

1. A minimum length of 25 ft. is required between omitted posts, a terminal, or other special design.
2. Omitted posts cannot be used **within transitions**, terminals, or special designs.
3. There are no curbs.
4. Always consider the additional deflection.

Long-span Guardrail System

The long-span guardrail design is an alternate treatment that has been tested to span low-fill culverts (or other impediments to driving posts) in lieu of attaching posts to the top of these structures with a maximum of 3 posts omitted. As with the Omitted Post design, only use the long-span system in a standard run of guardrail (not in the transition section, terminal, etc.). Where using the long-span design, it is

important to verify that no fixed object protrudes more than 4 in. above the ground within the deflection area (8 ft. for the MGS design) behind the system, as well as the 25 ft. minimum spacing requirement, as identified under the omitted post above.

The MGS long-span design uses three CRT posts with 12 in. blockouts on each side of the opening, but NO nesting of rail.

A similar design is available for the G4 system with the addition of 100 ft. of nested rail and double blockouts with the CRT posts.

With any omitted post(s) design, always consider additional deflection.

Leaveouts for Posts in Structural Pavement

In order for a post to move backward before failing (as intended), the support around the post must not be rigid; therefore, provide leaveouts in any structural pavement surrounding a post. The recommended minimum leaveout area in the mow strip or pavement will allow at least 7 in. of post deflection at the ground line. For installations in structures greater than 8 in. thick, use guidance for installation in rock.

Extra Blockouts

It is acceptable to use double blockouts (up to 16 in. deep) to increase post offset and avoid obstacles without any limit to the number of posts. Under special circumstances, use additional blockouts (up to 24 in. depth) at one or two posts.

Turnout Conflicts (in runs of guardrail)



When encountering a side road, the NDDOT preference is, wherever possible, to relocate approaches rather than provide breaks in the guardrail installation. Where this cannot be accomplished, it may be necessary to leave an opening in the run of guardrail.

Leaving an opening in a standard run of guardrail for a turnout conflict like a driveway or access road presents a difficult situation for the designer. One option is to use standard W-beam barrier that curves around the intersection with a separate guardrail run on the upstream side of the access point.

However, a new obstacle is introduced by the standard W-beam installation, which can be struck at a severe angle. To eliminate this non-crashworthy aspect, another option is to use an offset energy-absorbing terminal (if there is room) along the main highway and then continue the guardrail run on the upstream side of the access point. This is similar to guidance in *ND Design Manual*, III–13.09.01. However, there is still some risk of a vehicle gating through or passing behind it to reach the obstacle.

A design developed in the 1980s successfully sustained the direct hit—although only at 50 mph speed. The design, which can go from an 8.5 ft. to a 35 ft. radius, used weakened wood posts (CRT) through the radius and the rail wrapped around the vehicle on impact, safely decelerating it. The design requires a special anchor to develop adequate tension and a large clear area behind the rail (though it could have a 2:1 slope). This design was distributed to highway agencies as FHWA Technical Advisory T5040.32.



NDDOT has a similar curved rail design (Standard Drawing D-764-13) for use on low-volume, low-speed roadways. The speeds on the main roadway should be 55 mph or less and 750 ADT or less. However, this design does not have the special terminal anchor, as in FHWA Technical Advisory T5040.32, to develop adequate tension on a short run of guardrail on the side road.

Analysis of a somewhat similar design with an 8 ft. radius rail was determined acceptable for NCHRP 350 TL-2, though with flat ground behind the rail (FHWA letter B-209).

A design successfully passed MASH TL-3 testing.



MASH TL-3 (no eligibility letter)

However, it is quite extensive and requires some amount of flat area behind the rail to set the sand barrels, as well as an area for the rail to deflect into upon impact. Further testing is being conducted to develop less-involved designs.

Guardrail Posts in Rock

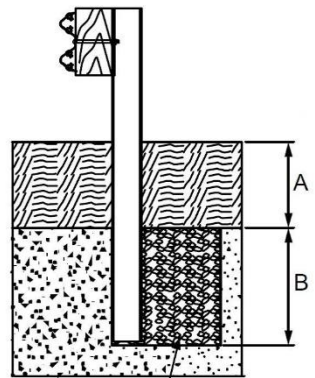
Where encountering rock at a single guardrail post, use the appropriate Omitted Post design for either the MGS or the G4. Where rock is encountered at three or fewer guardrail posts, use the MGS Long-Span design. Where rock is encountered at more than three guardrail posts, place the posts in cored holes, as shown in the AASHTO RDG Figure 5-51(b) – eligibility letter B-64B.

Case 1

Where $A < 18''$

A = Depth of soil over rock formation

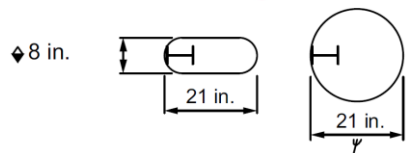
B = Depth of embedment into rock formation



Backfill with coarse aggregate similar to ASTM C 33 Size No. 57.

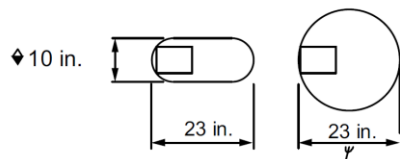
Plan View Steel Posts

Either hole configuration acceptable



Plan View Wood Posts

Either hole configuration acceptable



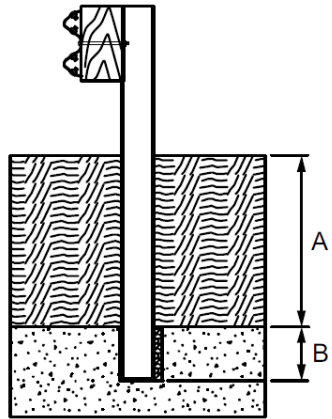
Notes: For overlying soil depths (A) ranging from 0 to 18 in., the depth of required drilling (B) is equal to 24 in.

Case 2

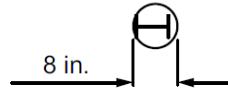
Where $A \geq 18''$

A = Depth of soil over rock formation

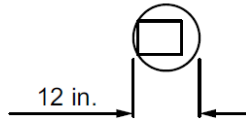
B = Depth of embedment into rock formation



Plan View Steel Posts



Plan View Wood Posts



Notes: For overlying soil depths (A) ranging from 18 in. to full post embedment depth. The required depth into rock (B) is equal to full post embedment depth minus (A). Full post embedment depth for blocked-out W-beam is about 44 in.

MAINTENANCE

Keep guardrail systems in reasonable working condition so they are able to function as designed.



GENERAL

BARRIERS

DESIGN

TERMINALS &
CRASH CUSHIONS

TRANSITIONS

SPECIAL DESIGN

MAINTENANCE

Maintenance

Keep guardrail systems in reasonable working condition so they are able to function as designed. Some deterioration occurs as a result of crash damage and environmental degradation.

Much of this wear can be considered *cosmetic* and may not measurably affect barrier performance. However, some kinds of damage can degrade performance, such as those listed below in the Longitudinal Barrier Damage and Terminal Damage sections. Repair these types of damage in a reasonable time frame. It is important to assess, prioritize, and schedule repairs for identified damaged barrier sites.

General Guidelines

The following are General Guidelines for maintenance:

- Delineate the area of damage to warn the motorists as soon as practical after the discovery/notification of the damage. For some types of damage, such as a ruptured rail or a terminal left in a condition that renders it unable to function and/or is not crashworthy, schedule repair as soon as practical. To mitigate a blunt rail end condition, it is recommended that the rail be unbolted from several posts and the leading end dropped to the ground. This will avoid exposing a blunt end condition until the installation can be repaired.
- Review damaged guardrail as soon as reasonable to determine the scope of repair based on individual site conditions.

- At a minimum, consider upgrading existing or damaged barrier systems not meeting current criteria.

NDDOT General Guidelines

Chapter 4. TRAFFIC OPERATIONS

Desired Service Levels for Safety Appurtenances

	Yearly	Spring	Summer	Fall	Winter
Cable Guardrail		1		1	
W-beam Guardrail	2				
Attenuators		1		1	
Barrels		1	1	1	1

1. Inspect and Adjust
2. Inspect

Cable Guardrail

Inspect and adjust cable guardrail every spring and fall to ensure proper tension of the cables. Refer to Standard Specifications for Road and Bridge Construction for details on cable tension.

Guardrail Maintenance

Maintain guardrail as it was constructed. Refer to the plans, department design standards, and manufacturer’s installation manuals for proper installation of the various guardrails and end treatments. Use SFN 58523 Inspection Checklist—Cable Guardrail End Anchorage to annually inspect

all guardrails for broken, loose, or missing parts and proper operation of the end treatments.

Promptly repair guardrail after it has been damaged. Repair work should start in a few days and work should progress continuously until repairs are completed.

Crash Cushion

Maintain all types of crash cushions as constructed. Use the appropriate crash cushion inspection checklist form to inspect each in spring and fall. (To sort forms by Maintenance Division, click on Division Title at the top of the page and then choose the appropriate crash cushion-inspection checklist form.)

Records

Each district will maintain a file of inspection reports for inspections completed on street light standards, traffic signals, and roadside safety devices. Use inspection checklists for all the various inspections and keep on file in the district office.

In addition, NDDOT provides Inspection checklists for:

- Cable Guardrail
- Attenuation Barrel Inspection
- W-beam Guardrail and End Treatment
- Crash Cushion Inspection
- Box Beam Guardrail

These can be found at

<https://intranetapps.nd.gov/dot/apps/forms/forms.aspx>

National Guidelines for W-beam

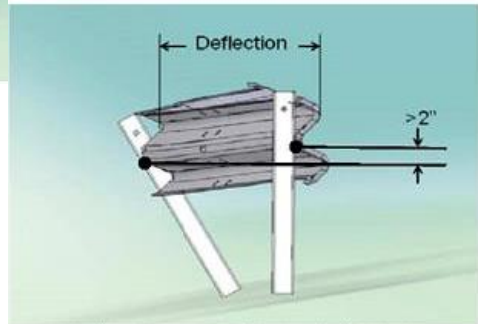
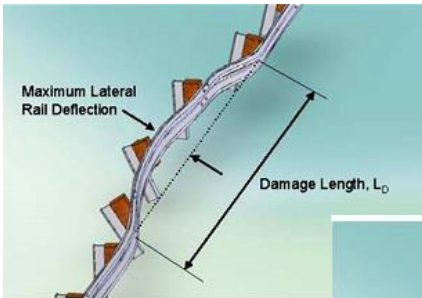
The following pages are excerpts from NCHRP Report 656, *Criteria for the Restoration of Longitudinal Barrier*. Note that the types and degree of damage to the barrier itself and to barrier terminals is prioritized as High, Medium, or Low. Use these rankings, along with the perceived likelihood of a second impact—at the crash-testing criteria of high speed, high angle—in the same location to set repair priorities. **Note: These evaluations were based on analysis of the G4 (28 in.) system, not the MGS. (For MGS, the system is still functional with one post missing.)**

Repair priority scheme

Priority Level	Description
High	A second impact results in unacceptable safety performance, including barrier penetration and/or vehicle rollover.
Medium	A second impact results in degraded but not unacceptable safety performance.
Low	A second impact results in no discernible difference in performance from an undamaged barrier.

W-beam Barrier Repair Threshold

Damage Mode: Post and Rail Deflection



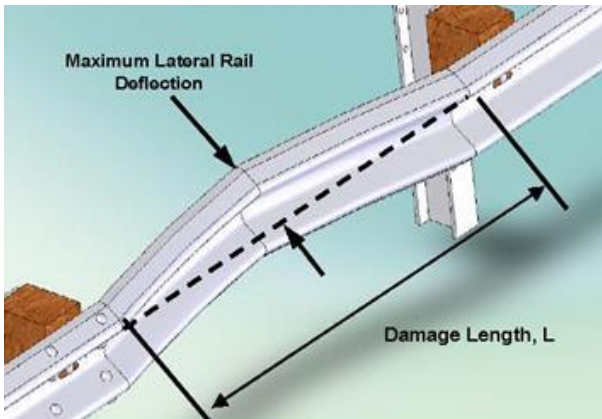
(Weak Post W-Beam Shown Only for Clarity. Each measurement taken at rail middle fold)

Relative Priority	Repair Threshold
High	One or more of the following thresholds: <ul style="list-style-type: none"> • More than 9 in. of lateral deflection anywhere over a 25 ft. length of rail. • Top of rail height 2 or more inches lower than original top of rail height.
Medium	6–9 in. lateral deflection anywhere over a 25 ft. length of rail.

Low	Less than 6 in. of lateral deflection over 25 ft. length of rail.
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W-beam Barrier Repair Threshold

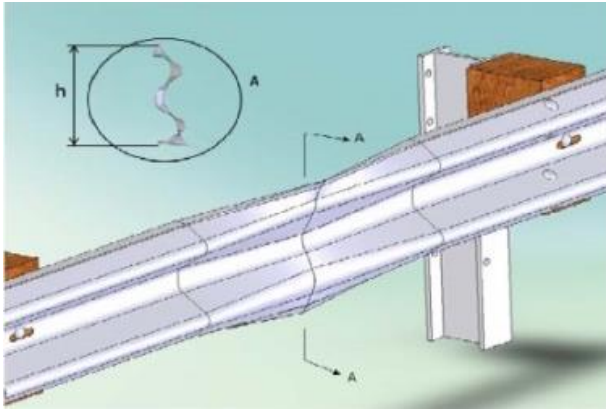
Damage Mode: Rail Deflection Only



Relative Priority	Repair Threshold
Medium	6–9 in. of lateral deflection between any two adjacent posts. Note: Use post/rail deflection guidelines for deflection over 9 in.
Low	Less than 6 in. of lateral deflection between any two adjacent posts.

W-beam Barrier Repair Threshold

Damage Mode: Rail Flattening



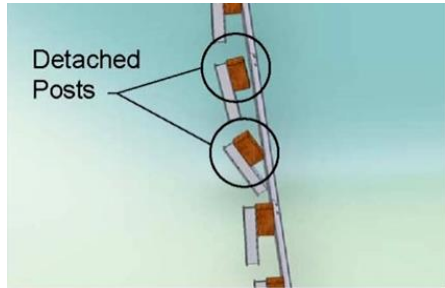
Relative Priority	Repair Threshold
Medium	One or more of the following thresholds: <ul style="list-style-type: none">• Rail cross-section height, h, more than 17 in. (such as may occur if rail is flattened).• Rail cross-section height, h, less than 9 in. (such as a dent to top edge).
Low	Rail cross-section height, h , between 9 and 17 in.

W-beam Barrier Repair Threshold

Damage Mode: Posts Separated from Rail

Note:

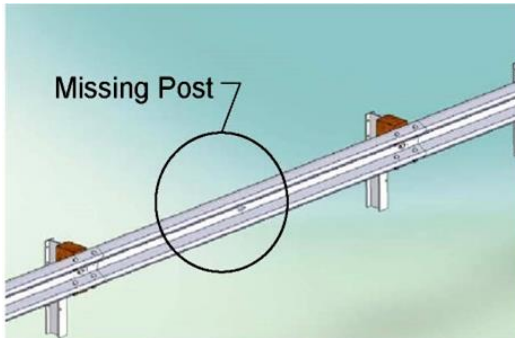
1. If the blockout is not firmly attached to the post, then use the missing blockout guidelines.
2. Evaluate damage against post/rail deflection guidelines.



Relative Priority	Repair Threshold
Medium	One or more of the following thresholds: <ul style="list-style-type: none">• 2 or more posts with blockout attached with post-rail separation less than 3 in.• 1 or more post with post-rail separation exceeding 3 in.
Low	1 post with blockout attached with post-rail separation less than 3 in.

W-beam Barrier Repair Threshold

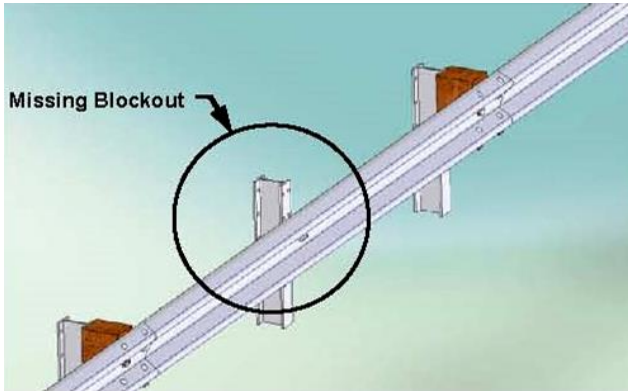
Damage Mode: Missing/Broken Posts



Relative Priority	Repair Threshold
High	1 or more posts: <ul style="list-style-type: none">• Missing,• Cracked across the grain,• Broken,• Rotten, or• With metal tears.

W-beam Barrier Repair Threshold

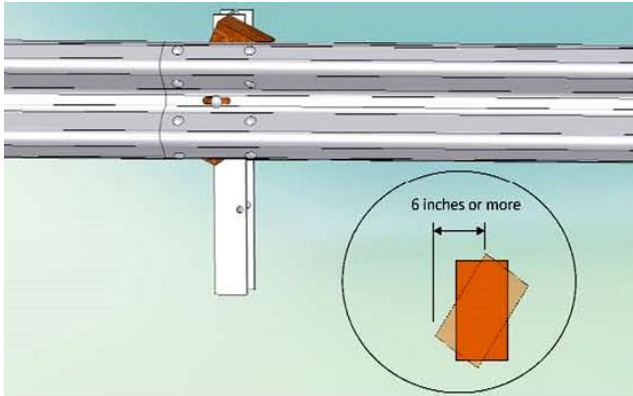
Damage Mode: Missing Blockout



Relative Priority	Repair Threshold
Medium	Any blockouts: <ul style="list-style-type: none">• Missing,• Cracked across the grain,• Cracked from top or bottom blockout through post bolt hole, or• Rotted.

W-beam Barrier Repair Threshold

Damage Mode: Twisted Blockout

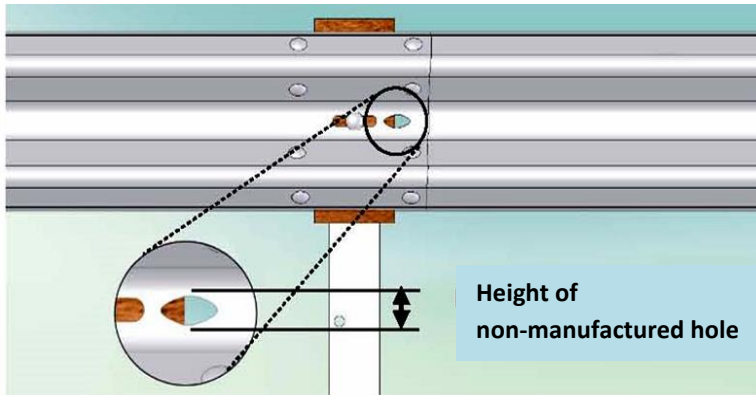


Relative Priority	Repair Threshold
Low	Any misaligned blockouts, top edge of block 6 in. or more from bottom edge. Note: Repairs of twisted blockout are relatively quick and inexpensive.

W-beam Barrier Repair Threshold

Damage Mode: Non-Manufactured Holes

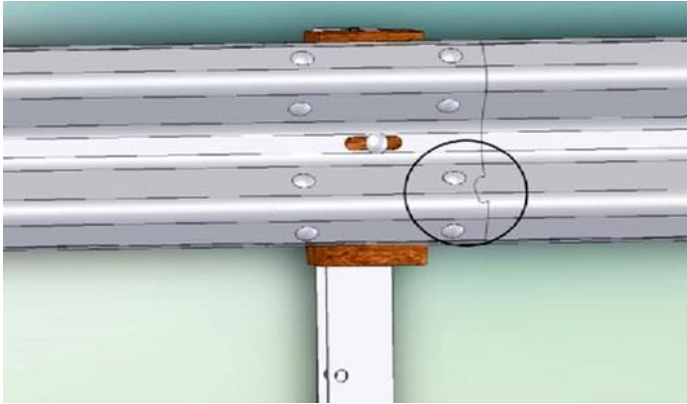
(such as crash-induced holes, lug-nut damage, or holes rusted through the rail).



Relative Priority	Repair Threshold
High	One or more of the following thresholds: <ul style="list-style-type: none">• More than 2 holes less than 1 in. in height in a 12.5 ft. length of rail.• Any holes greater than 1 in. height.• Any hole that intersects either the top or bottom edge of the rail.
Medium	<ul style="list-style-type: none">• 1–2 holes less than 1 in. in height in a 12.5 ft. length of rail.

W-beam Barrier Repair Threshold

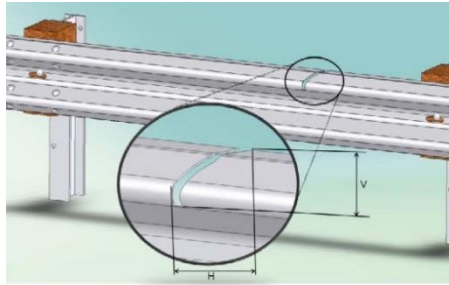
Damage Mode: Damage at Rail Splice



Relative Priority	Repair Threshold
High	More than 1 splice bolt: <ul style="list-style-type: none">• Missing,• Damaged,• Visibly missing any underlying rail, or• Torn through rail.
Medium	1 splice bolt: <ul style="list-style-type: none">• Missing,• Damaged,• Visibly missing any underlying rail, or• Torn through rail.

W-beam Barrier Repair Threshold

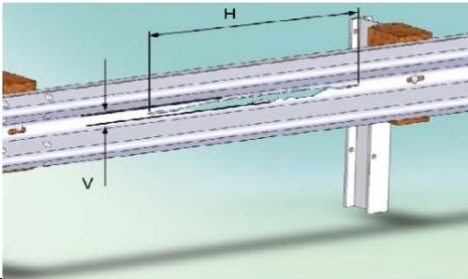
Damage Mode: Vertical Tear



Relative Priority	Repair Threshold
High	Any length vertical (transverse) tear.

W-beam Barrier Repair Threshold

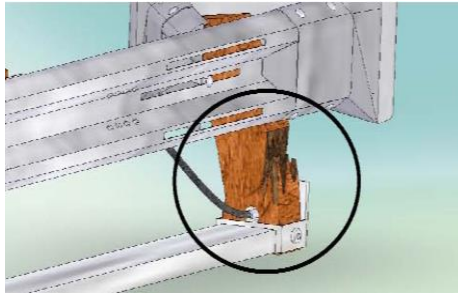
Damage Mode: Horizontal Tear



Relative Priority	Repair Threshold
Medium	Horizontal (longitudinal) tears greater than 12 in. long or greater than 0.5 in. wide.
<p>Note: For horizontal tears less than 12 in. in length or less than 0.5 in. in height, use the non-manufactured holes guidelines.</p>	

Terminal Repair Threshold

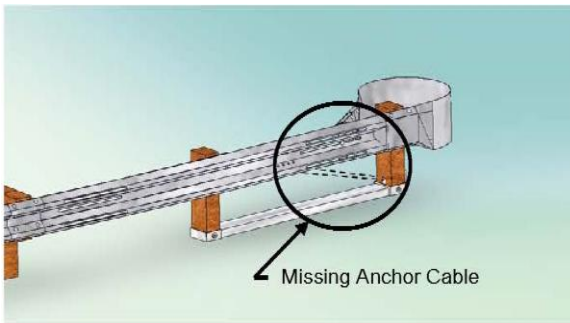
Damage Mode: Damaged End Post



Relative Priority	Repair Threshold
High	Not functional (sheared, rotted, cracked across the grain).

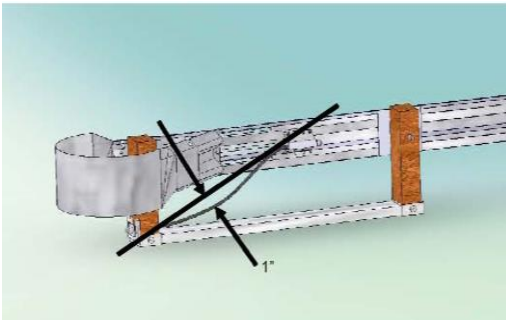
Terminal Repair Threshold

Damage Mode: Anchor Cable



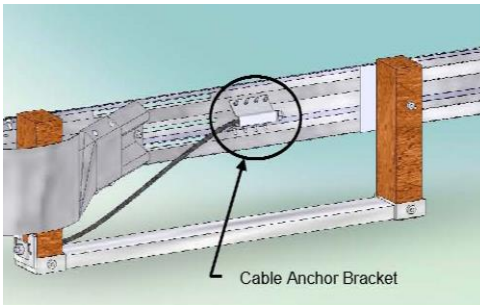
Relative Priority	Repair Threshold
High	Missing.

Terminal Repair Threshold
Damage Mode: Anchor Cable



Relative Priority	Repair Threshold
Medium	More than 1 in. of movement when pushed down by hand.

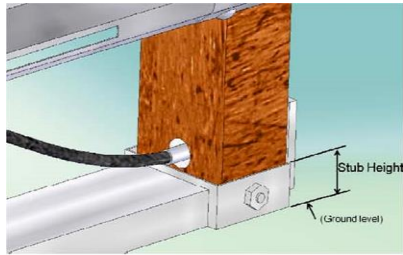
Terminal Repair Threshold
Damage Mode: Cable Anchor Bracket



Relative Priority	Repair Threshold
Medium	Loose or not firmly seated in rail.

Terminal Repair Threshold

Damage Mode: Stub Height

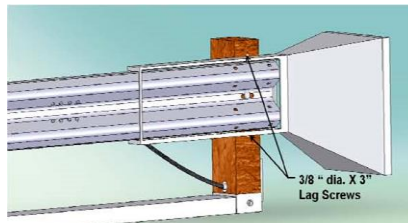


Relative Priority	Repair Threshold
Medium	Height exceeding 4 in.

Note: Although NCHRP 656 Report rates this deficiency as medium priority, if the height is excessive, it could be potentially catastrophic.

Terminal Repair Threshold

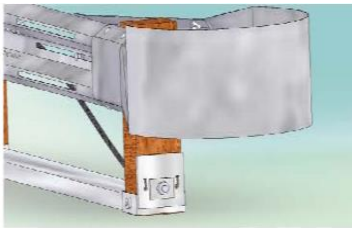
Damage Mode: Lag Screws (Energy-absorbing Terminals Only)



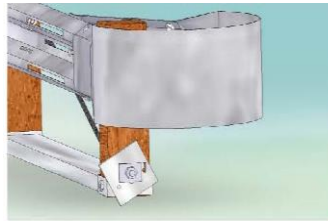
Relative Priority	Repair Threshold
High	Missing or failed lag screws.

Terminal Repair Threshold

Damage Mode: Bearing Plate



(Correct Bearing Plate)



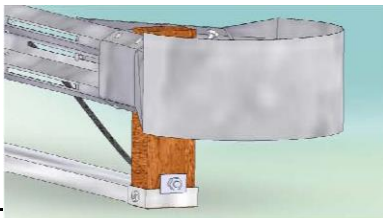
(Misaligned Bearing Plate)

Relative Priority	Repair Threshold
Medium	Loose or misaligned.

Note: Although the NCHRP 656 Report rates this as a medium priority, this can very easily be repaired in the field, thus avoiding a potentially serious crash outcome. Its significance is illustrated by it being listed on the manufacturer’s inspection checklists.

Terminal Repair Threshold

Damage Mode: Bearing Plate



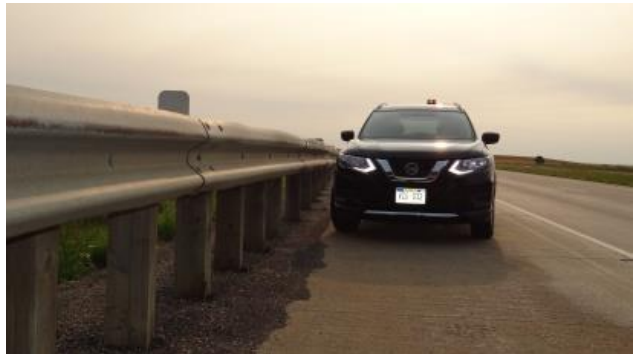
Relative Priority	Repair Threshold
High	Missing bearing plate.

Note: Although not included in the NCHRP 656 Report, improper seating of the rail in an extruder head terminal (as the Figure below shows) will not allow the terminal to function properly in a crash and could penetrate a vehicle during a strike. Once identified, correct this condition at the earliest reasonable opportunity.



Improper Seating of Rail into Head

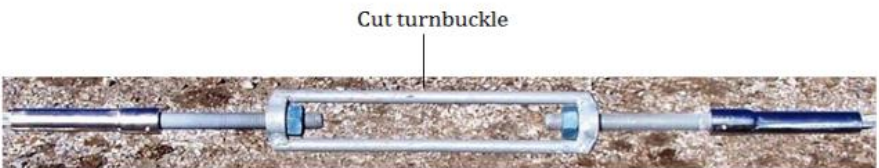
Also, the purpose of guardrail is to contain the vehicle and not allow vaulting or underride. Therefore, consider any reduction in the system height to less than 26½ in. (G4 /28 in. system) a high-priority repair. However, the MGS system, originally installed at 31 in., has a low threshold of less than 28 in. Also evaluate excessively high rail. (Installation tolerance is 30 in. for G/4 and 34 in. for MGS.).



Cable Guardrail Guidelines

Cable guardrail systems are designed to contain and redirect a striking vehicle while minimizing the forces on the vehicle and its occupants. Proper maintenance includes checking that the cables are properly tensioned and at the correct height.

- **Routine tension check.** Perform this check even in the absence of a strike, but it is particularly important during the first few years following installation. (NDDOT Guidance—spring and fall)
- **Keep the cable intact.** In the event of a crash resulting in a vehicle becoming entangled in the cable, keep the cable; only cut the cable when there is a life or death situation. Alternatives to cutting the cable include:
 - Removing the vehicle by towing it in the opposite direction from which it struck the system.
 - Loosening the cables at the turnbuckles.
 - Cutting the turnbuckle is preferable to cutting the cable. Remove the adjacent posts on either side of the turnbuckle. Ensure personnel are clear of the cable; cut the center of the turnbuckle as shown below.



- Check cable height and repair to meet Standard Plan D-764-32 (28 in.) for low-tension cable or manufacturer's specifications for high-tension cable.
- Inspect cable for kinks or broken strands.
- Check for missing or damaged posts (more critical with low tension) and missing hook.

(Note: Damaged posts can also present a spearing concern should a secondary impact occur; crews should remove damaged or bent-over posts to eliminate the spearing potential.)

- Check that cables are attached to the anchors, and that the anchors are flush with the ground surface.

Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
BLON	Beginning Length of Need
CIP	Critical Impact Point
FARS	Fatal Analysis Reporting System
FAST ACT	Fixing America's Surface Transportation Act
FHWA	Federal Highway Administration
HTC	High Tension Cable
LON	Length of Need
MUTCD	Manual on Uniform Traffic Control Devices
MASH	Manual for Assessing Safety Hardware
MGS	Midwest Guardrail System
NCHRP	National Cooperative Highway Research Program
RDG	Roadside Design Guide
ROR	Run-off-Road
ROW	Right-of-Way
SHSP	Strategic Highway Safety Plan
SPWB	Strong Post W-Beam
TL	Test Level
VMT	Vehicle Miles Traveled
WZ	Work Zone

Glossary

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 plane, 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 Zone. The unobstructed, traversable area provided beyond the edge of the through traveled way for the recovery of errant vehicles. The clear zone includes shoulders, bike lanes, and auxiliary lanes, except those auxiliary lanes that function like through lanes.

Cost-effective. An item or action taken that is economical in terms of tangible benefits produced for the money spent.

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

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) occupant 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 selected speed used to determine the various geometric design features of the roadway. The assumed design speed should be a logical one with respect to the topography, anticipated operating speed, the adjacent land use, and the functional classification of the highway.

Drainage Feature. 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 the end of a roadside or median barrier.

Energy-Absorbing Terminals. Terminals that can stop vehicles in relatively short distances in direct end-on impacts (usually 50 ft. or less depending on type of terminal).

Flare. The variable offset distance of a barrier to move it farther from the traveled way, generally, in reference to the upstream end of the barrier.

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 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 vehicles path of impact.

Impact Attenuator. See Crash Cushion.

Length of Need (LON). Length of a longitudinal barrier needed to shield an area of concern.

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

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 median.

Non-Energy-absorbing Systems. Systems that will allow an unbraked vehicle to travel 150 ft. or more behind and parallel to guardrail installations or along the top of the barrier when struck head-on at high speeds.

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

Offset. Lateral distance from the edge of traveled way to a roadside object or feature.

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.

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 4H:1V 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 shield roadside obstacles or no-traversable terrain features. It may occasionally be used to protect pedestrians or “bystanders” from vehicle traffic.

Roadside Signs. Roadside signs can be divided into 3 main categories: overhead signs, large roadside signs, and small roadside signs. Large roadside signs may be defined as those greater than or equal to 50ft² in area. Small roadside signs may be defined as those less than 50ft² in area.

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

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

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

Test Level. A set of conditions, defined in terms of vehicular type and mass, vehicular impact speed, and vehicular impact angle that quantifies the impact severity of a matrix test.

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, the four classes of traffic barriers are roadside barriers, median barriers, bridge railing, and crash cushions.

Transition. A section of barrier between two different barriers, or more commonly, where a roadside barrier connects 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 minimized.

Traveled Way. The portion of the 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 3H:1V and 4H:1V generally fall into this category.

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

Resources

North Dakota Department of Transportation (NDDOT)

- NDDOT Design Manual
<http://www.dot.nd.gov/manuals/design/designmanual/designmanual.htm>
- NDDOT Standard Plan Drawings and notes
<https://www.ugpti.org/dotsc/prepguide/index.php>
- NDDOT Standard Drawings
<http://www.dot.nd.gov/dotnet2/view/std drawings.aspx>

Federal Highway Administration (FHWA)

<https://www.fhwa.dot.gov/>

- FHWA Hardware Policy and Guidance
http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/
- FHWA Longitudinal Barriers
https://safety.fhwa.dot.gov/roadway_dept/countermeasures/reduce_crash_severity/listing.cfm?code=long
- FHWA Resource Charts
http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/resource_charts/

American Association of State Highway and Transportation Officials (AASHTO) <https://www.transportation.org/>

- AASHTO, *Roadside Design Guide*, 2011.
- *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009.
- *Manual for Assessing Safety Hardware*, 2016 (MASH16).

Roadside Safety Pooled Fund sites:

- MwRSF: <http://mwrsf-ga.unl.edu/>
- TTI: <http://www.roadsidepooledfund.org/>

NOTES
