

Session 4: Testing Requirements and Performance Characteristics of Terminals and Crash Cushions

FAST Act Guardrail Training
Highway Barrier Design Training

**Session 4:
Testing Requirements and
Performance Characteristics of
Terminals and Crash Cushions**

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Session 4

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Session 4 Learning Outcomes

At the end of this session, you will be able to:

- Understand how terminals and crash cushions are tested for crashworthiness
- Identify common terminals and crash cushions
- Understand how these systems function
- Choose the appropriate system for a specific site

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Guardrail Terminals

A barrier terminal must serve two functions:

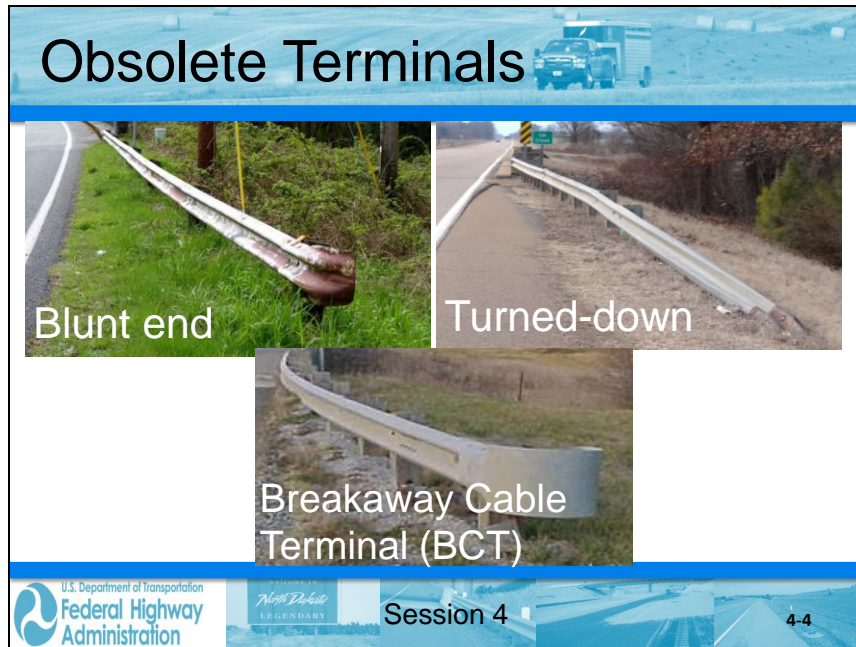
- Provide the necessary TENSION of the downstream guardrail system.
- Be crashworthy when impacted with no spearing, vaulting or rolling

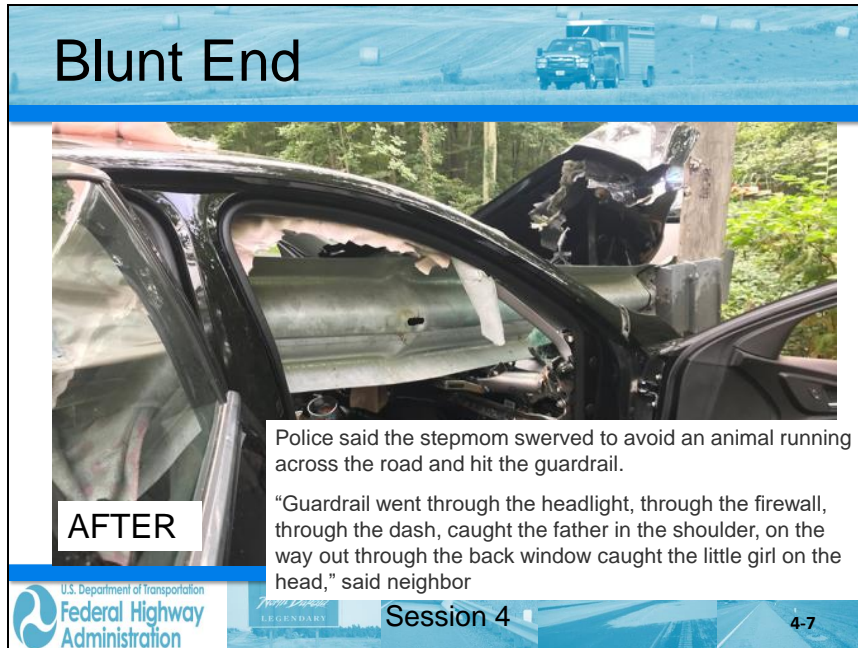
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Guardrail Terminals: Obsolete Turned-down Terminal



Video Clip

Failed Test! Causes vaulting

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Guardrail Terminals: Obsolete BCT Terminal

- Breakaway Cable Terminal (BCT) NCHRP 230
 - W-Beam rail which should have a parabolic curve and 4-ft offset.
 - No impact head or ground strut between the two end posts.
 - 2nd post is a CRT.
 - Rail bolted to all posts and should have no washers on posts 2 thru 8.



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Guardrail Terminals: Obsolete BCT Terminal



Video Clip

Failed Test! Causes spearing

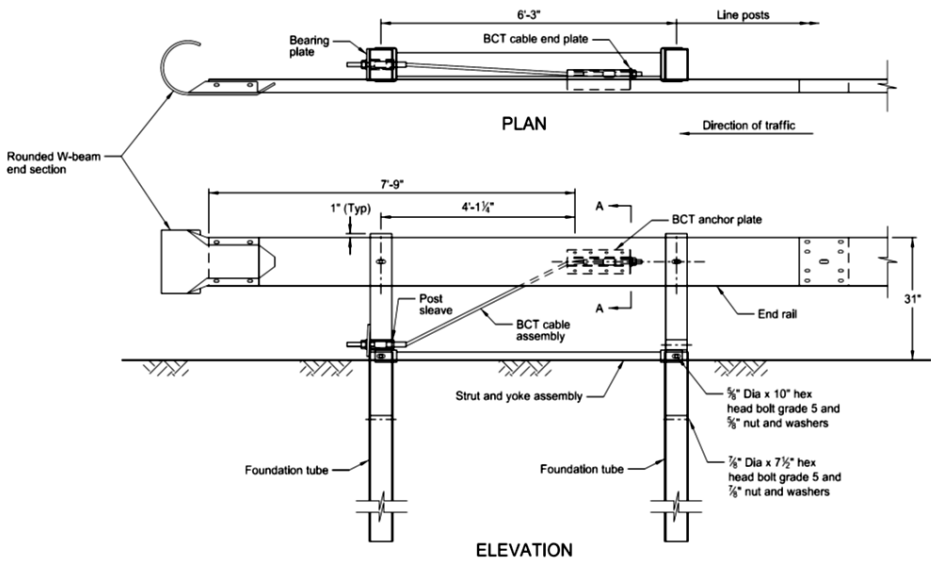
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NDDOT End Anchor



PLAN

6'-3" BCT cable end plate Line posts

Bearing plate

Direction of traffic

ELEVATION

7'-9" 4'-1 1/4" 1" (Typ) A A

Rounded W-beam end section

Post sleeve BCT cable assembly

Strut and yoke assembly

Foundation tube

End rail

BCT anchor plate

31"

5/8" Dia x 10" hex head bolt grade 5 and 5/8" nut and washers

7/8" Dia x 7 1/2" hex head bolt grade 5 and 7/8" nut and washers

Ref: NDDOT Standard Drawing, D764-41, July 2017

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End Anchor – MASH (Not crashworthy for end on impact)

- 2 Design Tested
- Both have a strut between last 2 posts



TxDOT Design
9'- 4 ½ " rail element
Rail ends at last post



Eligibility Letter B-256

MwRSF Design
12'- 6" rail
Rail extends past last post



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End Anchor – MASH

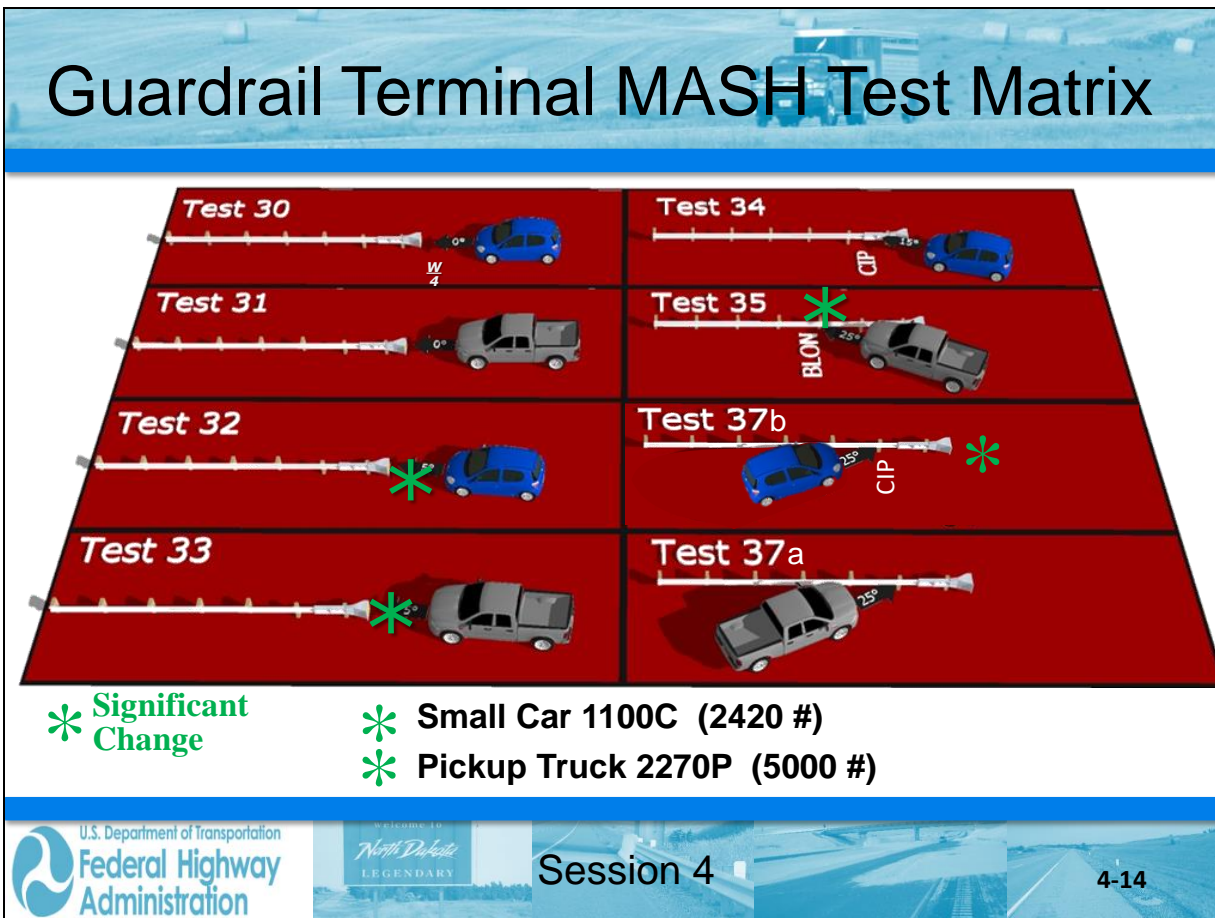


Video Clip

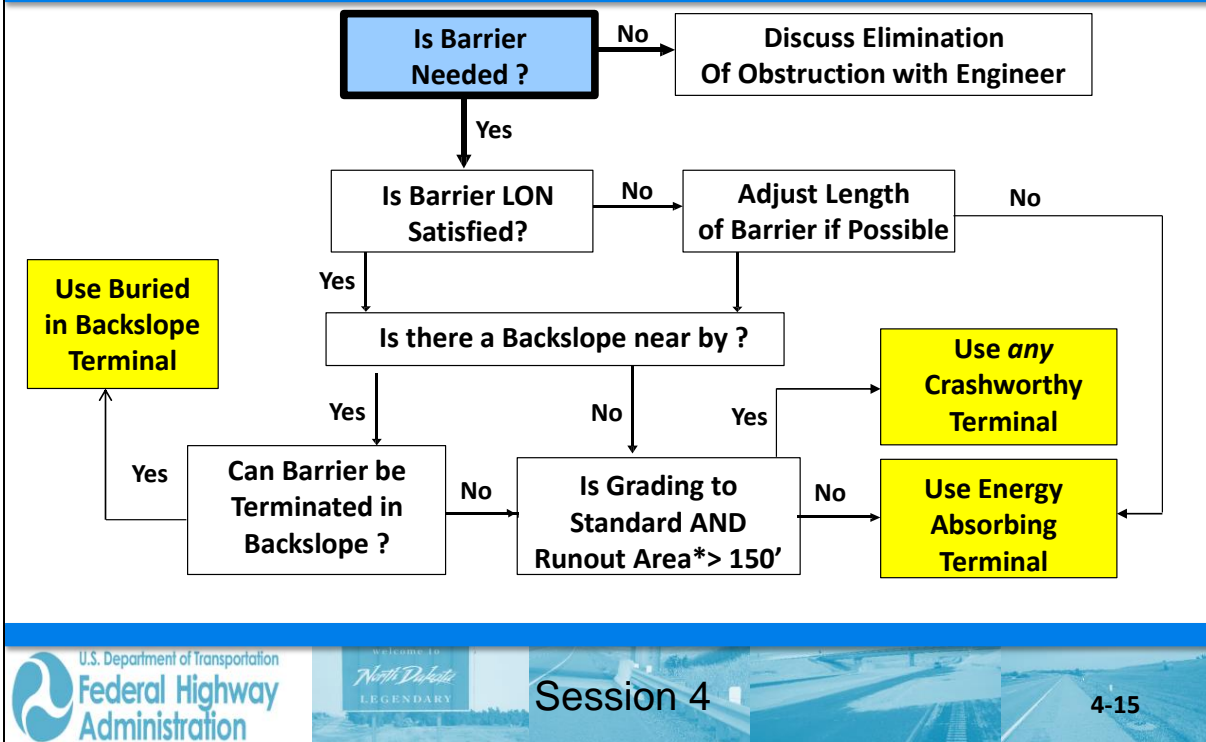


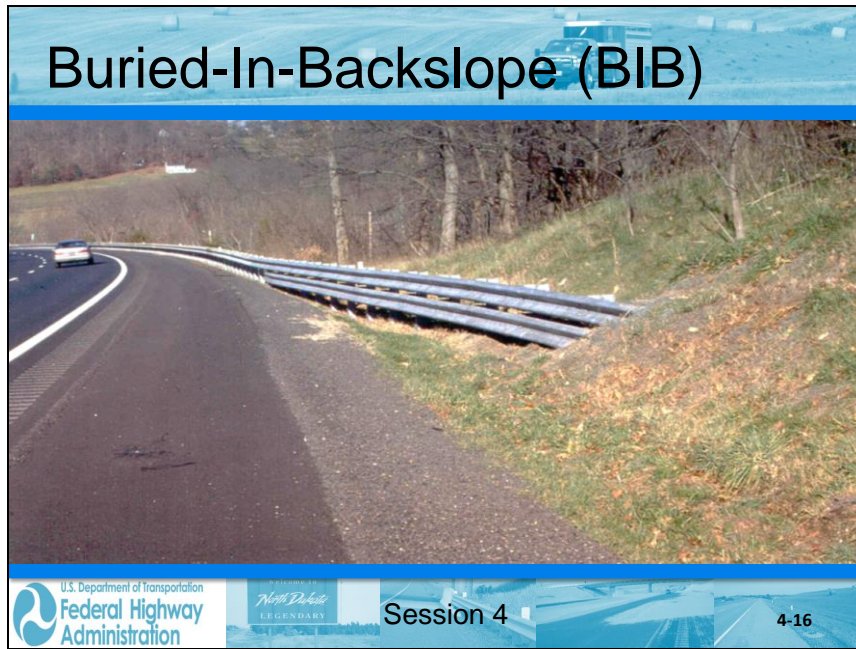
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Suggested FHWA Terminal Selection Flow Chart





MASH Test for Buried in Backslope End Terminal



Video Clip

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Guardrail Terminals

- **Flared terminal.** Either *non-energy-absorbing* or *energy-absorbing* terminals – up to a 4' offset at post 1 (ND offset depends on terminal type and taper rate of guardrail leading up to terminal)
- **Tangent terminal.** Parallel to the roadway or has a straight flare with a moderate (2 ft. max) offset – all are *energy-absorbing* terminals

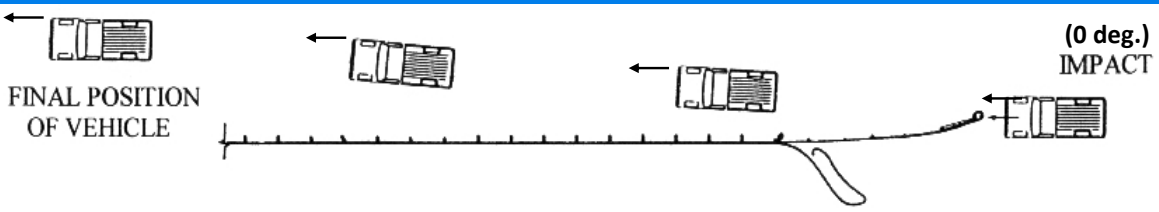
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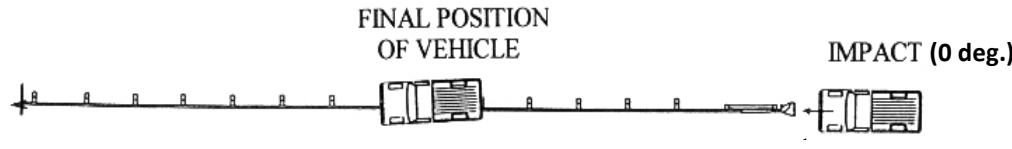
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Guardrail Terminals



Non-Energy Absorbing Terminal
Controlled Buckling Terminal
(vehicle may travel hundreds of feet before stopping)



Energy Absorbing Terminal
(vehicle is brought to a controlled stop in a short distance)

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Guardrail Terminals: Energy Absorbing

➤ **MSKT** MASH Version of SKT (MASH 16)

- Kinks Guardrail when hit head-on or at a shallow angle
- Steel post system; BLON at 3rd Post
- TL-3 at 46' 10½" long; attachment to 31" MGS Barrier
- Cable-anchored system

NDDOT Std. D764.51



Ref: FHWA Eligibility Letter CC-126 dated 12/27/16



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MASH
MSKT



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Guardrail Terminals: Energy Absorbing

- Soft Stop (MASH 16)
 - Using a proprietary head design, the system flattens and extrudes the W-beam guardrail upon end-on impacts, 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 during end-on impacts
 - TL-3 at 50' 9 1/2 " long; BLON at 16'-6"; 31" only

NDDOT Std. D764.50

Ref: FHWA Eligibility Letter CC-115 dated 11/12/15



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MASH Soft Stop



Video Clip



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Guardrail Terminals: Energy Absorbing

- MAX-Tension (MASH 16)
- MAX-Tension Median (MASH 16)
 - The MAX system utilizes cables, telescoping panels, and a cutting tooth to absorb the kinetic energy
 - TL-3 at 50' long; BLON at 9'-4 ½"; 31" only



Ref: FHWA Eligibility Letter CC-133 dated 6/15/17



Ref: FHWA Eligibility Letter CC-141 dated 01/10/2018



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MASH MAX-Tension

MASH Test 3-30



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Flared Guardrail Terminals: Energy Absorbing

- **MFLEAT** *MASH Version of FLEAT (MASH 16)*
 - Curls the rail (by kinking) tightly towards the roadway.
 - Steel post system; BLON at 4th Post
 - TL-3 at 39' 7" straight flared length. 3-ft. offset.
 - Cable-anchored, compression system



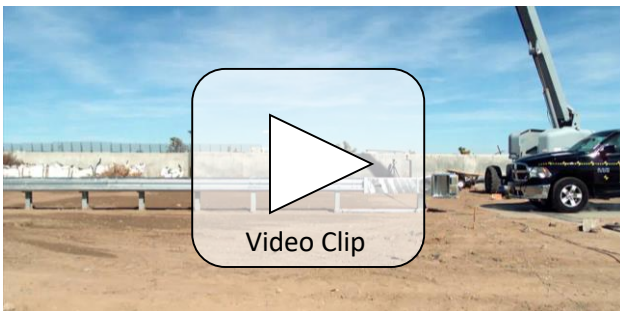
Ref: FHWA Eligibility Letter CC-143 dated 04/10/19



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MASH
MFLEAT



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NCHRP 350 Terminals

The following terminals have met NCHRP 350 testing and can remain in-place. (Under NDDOT MASH Implementation Plan, for Major Rehab & New/Reconstruction the minimum was changed from NCHRP Report 350 to MASH.)

- ET Plus (Guardrail Extruder Terminal)
- SKT 350 (Sequential Kinking Terminal)
- FLEAT 350 (Flared Energy Absorbing Terminal)
- SRT (Slotted Rail Terminal, Non-Energy Absorbing)
- MELT (Modified Eccentric Loader Terminal, Non-Energy Absorbing) TL-2
- CAT (Crash Cushion Attenuating Terminal) W-beam Median



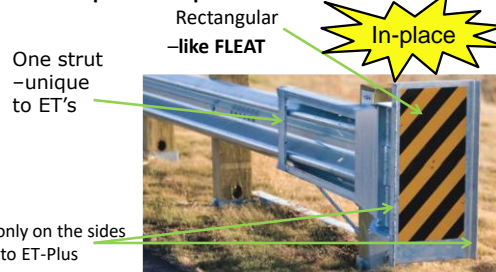
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Guardrail Terminals: Energy Absorbing

➤ ET Plus (Guardrail Extruder Terminal)(NCHRP 350)

- 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' long - *straight*
- Cable and strut anchored system
- BLON at 3rd post



Ref: FHWA Eligibility Letter CC-12Q dated 3/15/10



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Guardrail Terminals: Energy Absorbing

➤ SKT 350 (Sequential Kinking Terminal)(NCHRP 350)

- Head kinks panels when hit head-on or at a shallow angle
- Wood or Steel post options, post 1 & 2 breakaway
- TL-3 at 50' long – *straight* - BLON at 3rd Post
- Cable-anchored or cable& strut (wood) anchor system



Ref: FHWA Eligibility Letter CC-88 dated 3/8/05



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Guardrail Terminals: Energy Absorbing

➤ **FLEAT 350 (Flared Energy Absorbing Terminal)(NCHRP 350)**

- Straight flare (not parabolic)
- Curls the rail tightly toward the roadway
- Wood or Steel post options, post 1 & 2 breakaway
- TL-3 at 37'-6" long;
- BLON at 3rd Post
- Cable and strut anchored system

Up to 4' flare

This square bar is unique to FLEAT

A strut at each end –unique to FLEAT

Extruder discharge is towards the roadway –unique to FLEAT

Somewhat Rectangular

Ref: FHWA Eligibility Letter CC-88 dated 3/8/05

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In-place

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Guardrail Terminal: Non- Energy Absorbing

➤ **SRT (Slotted Rail Terminal) (350)**

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

Slots –unique to SRT

Ref: FHWA Eligibility Letter CC-124 dated 12/23/15

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In-place

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NCHRP 350 TL-2

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

In-place

NCHRP 350 TL-2

MELT Modified Eccentric Loader Terminal (Nonproprietary)

FLARED

Diaphragm insert
— unique to MELT

Block-out 2nd post

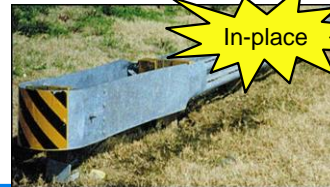
Diaphragm bolts
— unique to MELT



Same design as the ELT except for the nose design. Prior to implementation of NCHRP 350, this was a commonly used end treatment. It was only approved under 350 for TL-2 (speeds 45 mph or less) applications.

Guardrail Terminals: W-Beam Median

- CAT (Crash Cushion Attenuating Terminal) (NCHRP 350)
 - 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.



Ref: FHWA Eligibility Letter CC-14 dated 6/4/90



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Terminal Grading

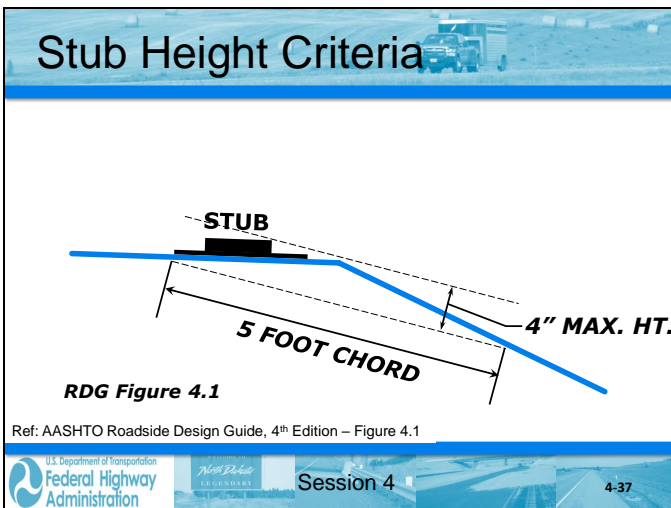
- Special grading requirements for guardrail terminals:
 - Flat terrain (10:1 or flatter) is required *in ADVANCE* of all terminals so that vehicles are relatively stable on approach
 - Flat grading must extend *behind* post 1 (**ADJACENT**) so vehicle is stable at impact **and** no stub height criteria is violated

Ref: FHWA Memorandum, Roadside Safety Hardware, May 26, 2015 with attachment and
Ref: AASHTO Roadside Design Guide, 4th Edition, Section 8.3.3.



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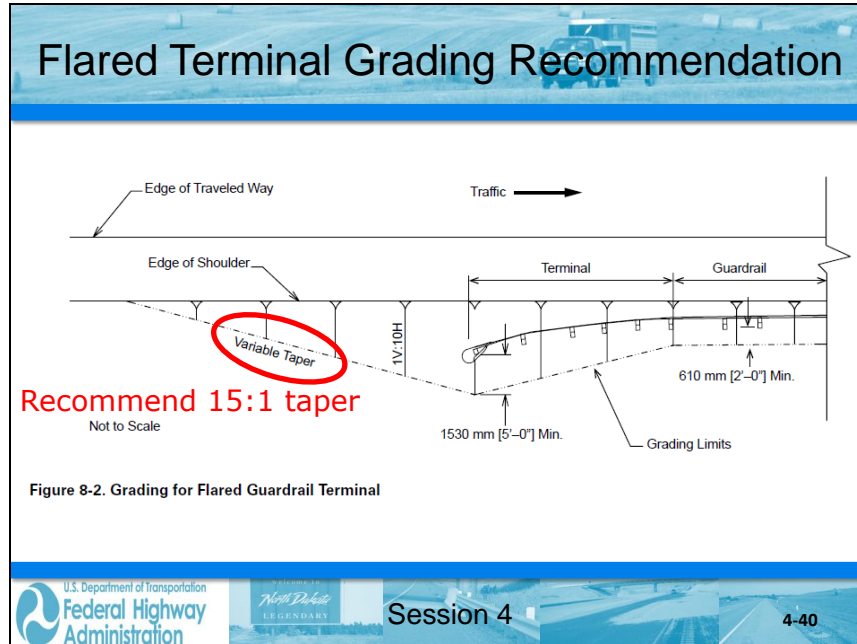
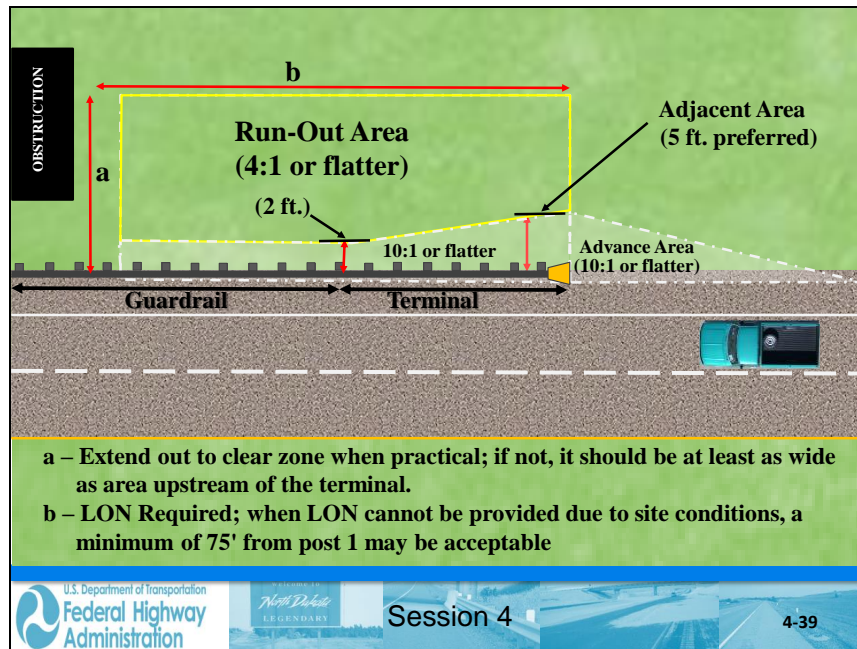


Terminal Grading Requirements

- **Runout Distance Grading** - refers to the area into which a vehicle may travel after impacting a terminal ahead of its length-of-need point.
 - The lateral runout distance directly behind a terminal ideally should be at least as wide as the roadside clear distance immediately upstream of terminal.
 - The minimum recovery obstacle-free area behind and beyond a terminal should be approximately 75 ft. long.

Ref: AASHTO Roadside Design Guide, 4th Edition, Section 8.3.3.







ND Grading Detail

(Similar for Non- flared guardrail with flared terminal)

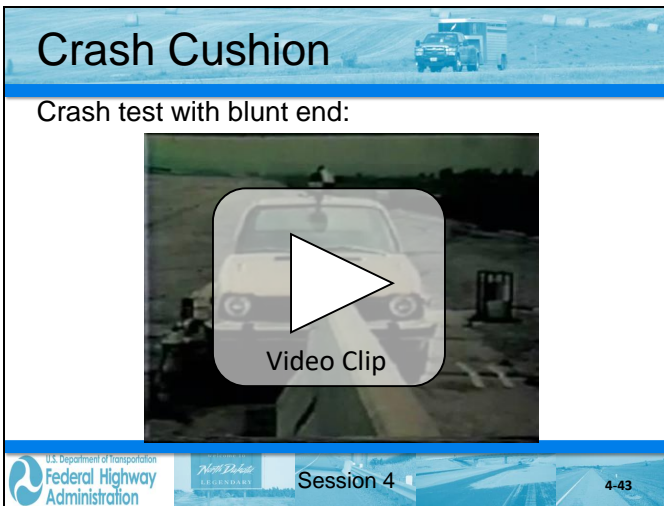
Ref: NDDOT Standard Drawing, D764-49, July 2017





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Crash Cushion

Crash test with ramped end:

Video Clip

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Crash Cushions

- Crash Cushions are generally used to shield a point obstacle or as a terminal for a rigid barrier
- Safely decelerate vehicle head-on impact
- Redirect or capture vehicle in side impact

As of Jan. 2019, New installations of crash cushions on NHS must meet MASH. Existing 350 devices may remain in place.



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Principles of Crash Cushion Design

- Absorption of Kinetic Energy
- Transfer of Momentum (Sand Barrels)



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Crash Cushion Theory

The diagram illustrates the theory of crash cushions for two vehicle types: a small car and a pick-up truck. It shows the sequence of events from impact to the final position of the vehicle.

Small Car Scenario:

- A small car (blue) moves from the right towards a crash cushion.
- Impact:** The car strikes the **SOFT NOSE** section of the cushion.
- The car travels through the **SOFT NOSE** section and then the **HARD SECTION** (represented by vertical posts).
- The car comes to a stop against a **RIGID OBJECT** at the end of the cushion.
- FINAL POSITION OF VEHICLE:** The car is stopped against the rigid object.

Pick-up Truck Scenario:

- A pick-up truck (blue) moves from the right towards a crash cushion.
- Impact:** The truck strikes the **SOFT NOSE** section of the cushion.
- The truck travels through the **SOFT NOSE** section and then the **HARD SECTION** (represented by vertical posts).
- The truck comes to a stop against a **RIGID OBJECT** at the end of the cushion.
- FINAL POSITION OF VEHICLE:** The truck is stopped against the rigid object.

Textual Explanations:

- Soft nose to bring a small car to a controlled stop**
- Harder back section to bring a pick-up truck to a controlled stop**

Footer:

- U.S. Department of Transportation Federal Highway Administration
- WELCOME TO North Dakota LEGENDARY
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Crash Cushion Classifications

- **Sacrificial**
 - Designed for a single impact
- **Reusable**
 - some components need replacement but some major components are salvageable.
- **Low-Maintenance and/or Self-Restoring Crash Cushions**
 - suffer very little, and readily restored or self restoring.



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Crash Cushions - Sacrificial

➤ Sand Barrels (NCHRP 350)

Four types of sand barrels:

Fitch/ CrashGard / Energite / Big Sandy.

- Individual barrel designs vary in shape by manufacturer, but they all function the same
- Arrays of sand barrels may be designed to shield any shape obstruction
- Impacting vehicles will not be redirected.
- Since no re-directive capability, the corner of the obstruction must be reasonably shielded. The rear corner barrel should offset the shielded object by at least 30”.



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Inertial Barriers

➤ Sand Barrels:



Energite



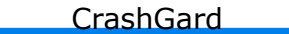
Not being produced



MASH CC 139



TraFFix Big Sandy



CrashGard



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Sand Barrel Application



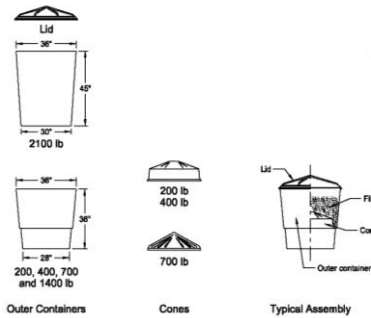


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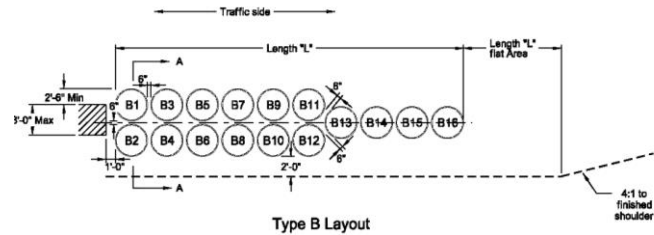
NDDOT Attenuator Device



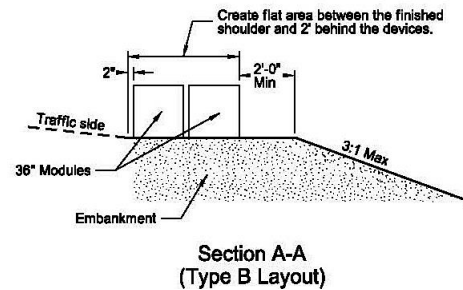
Typical Module Construction Detail

Distance from top edge	Module Weights (LBS)				
	200	400	700	1400	2100
8 1/2"					
5"					
4"					
3"					
0"					

Module Number	Type B Attenuator Device									
	Dash Number									
	75	70	65	60	55	50	45	40	35	30
Module Weights (LBS)										
B1	2100									
B2	2100									
B3	2100	2100	2100	2100	2100	2100	2100	2100	2100	
B4	2100	2100	2100	2100	2100	2100	2100	2100	2100	
B5	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
B6	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
B7	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400



Note:
Angle attenuation devices 10 degrees towards traffic when placed at piers offset from roadway

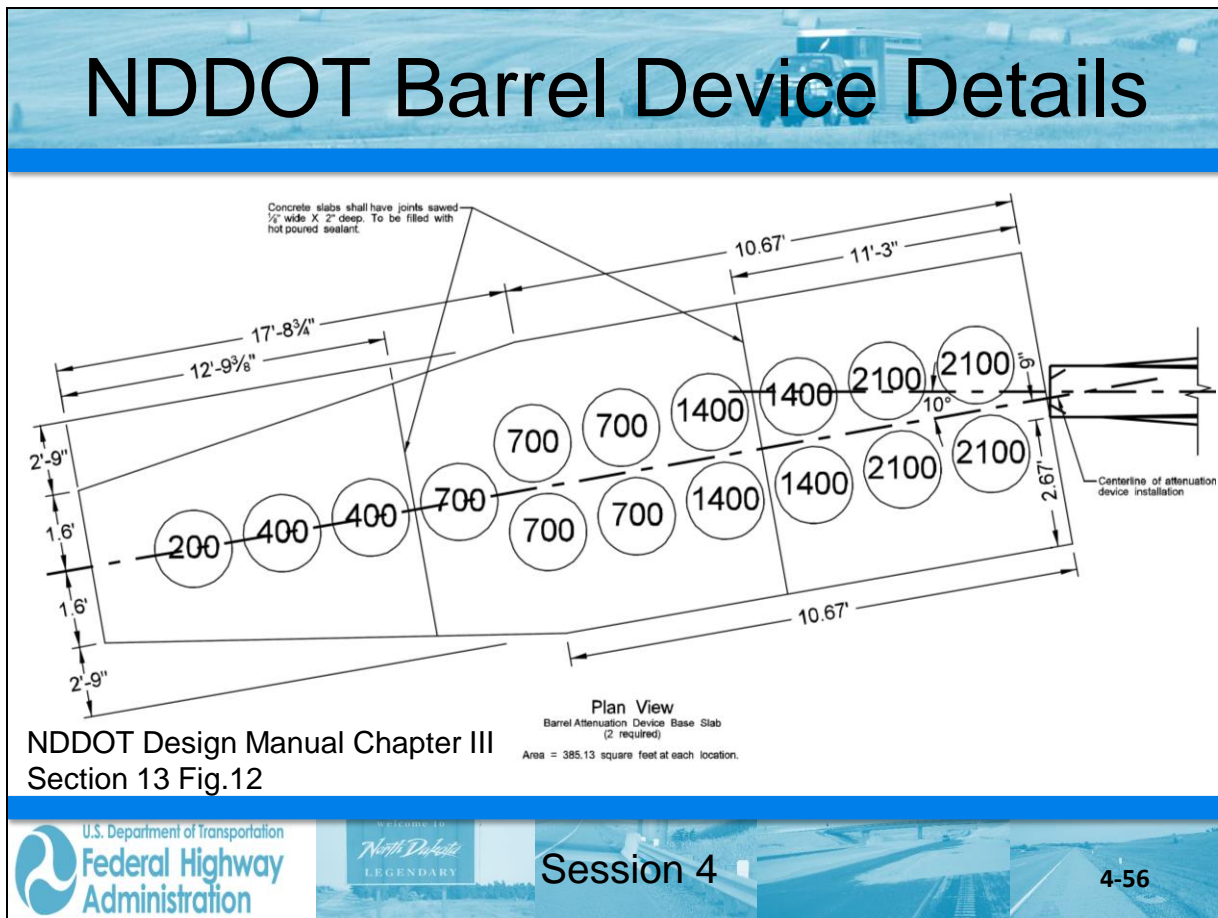


Ref: NDDOT Std. D704-1



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Crash Cushion Sacrificial Bullnose

There needs to be 62 ft. of clear area from the nose to the obstacle

Slopes into the face of barrier and in front of should be 10:1 or flatter



A transition to bridgerail should begin no sooner than the 9th post from the nose



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Crash Cushions - Sacrificial

➤ Water-filled Barriers

Absorb 350/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 impacting the nose at an angle will not be redirected.
- No appreciable re-directive capability under most impact conditions.



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Crash Cushions: Water Filled

➤ Non-Redirective and Gating



Absorb 350 (TL-3)



Sled (MASH)



ACZ-350



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Water Filled



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Crash Cushions – Reusable

➤ QuadGuard (NCHRP 350), GuardGuard M10 (MASH)

- 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.
- Energy-absorbing cartridges in each bay need to be replaced if damaged
- Available in widths from 24 to 36 inches with parallel sides and 69 or 96 inches with flared sides (M10 only available at 24")



REF: FHWA Eligibility Letters CC-35M dated 3/29/16 350 CC-121 dated 7/30/12 MASH

Crash Cushions – Reusable

- TRACC (TRinity Attenuating Crash Cushion) (NCHRP 350)
 - 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.



REF: FHWA Eligibility Letter CC-54G dated 3/9/05



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Crash Cushions – Reusable

- TAU II and TAU IIR Systems (NCHRP 350)
 - Approved for TL-2 & TL-3 systems.
 - Designed to attach to a median barrier.
 - Common set of parts for 36" to 102" widths in 6" increments.
 - Consists of Thrie-beam panels, energy absorbing cartridges, steel diaphragms and two cables at the bottom to provide redirection. Anchored at front and rear only.



REF: FHWA Eligibility Letter CC-75 dated 9/14/01



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Crash Cushions – Low Maintenance/Self Restoring

➤ QuadGuard Elite (NCHRP 350/MASH)

- Uses High Density Polyethylene cylinders to absorb energy
- Essentially for use in locations where a high number of hits is anticipated.



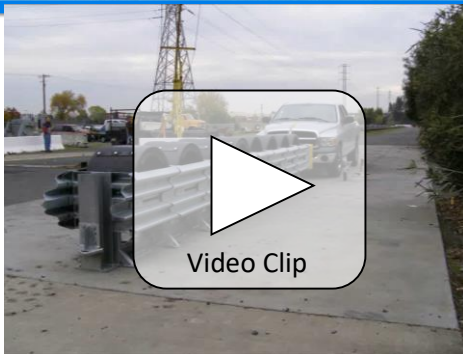
REF: FHWA Eligibility Letter CC-57E dated 12/18/15



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MASH Test – Self Restoring



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Crash Cushion – Low Maintenance

- SCI Smart Cushion (NCHRP 350/MASH)
 - Variable Reaction Force
 - Minimal component replacement
 - Needs repair before next hit
 - Non-gating system



REF: FHWA Eligibility Letter CC-128 dated 8/16/16

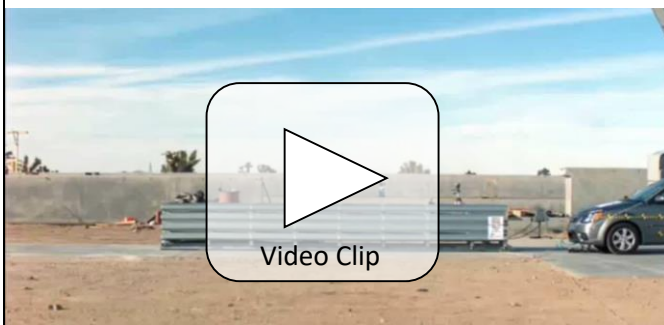


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MASH Test – Low Maintenance



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Grading for Median Pier Protection

- The median should be filled to provide a flat area wide enough to provide a minimum of 5 feet of flat area (measured perpendicularly from the device toward the roadway) adjacent to a Type B attenuation device when this type of end protection is installed. Where a crash cushion will be used to shield the barrier end, provide a minimum width of 5 feet of flat area adjacent to the jersey barrier for the entire length of the median pier protection embankment. From this point the fill should be placed at a 12:1 or flatter slope to the finished edge of the shoulders.

NDDOT Design Manual **III-13.05.02**



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Review Learning Outcomes

- Understand how terminals and crash cushions are tested for crashworthiness
- Identify common barrier terminals and crash cushions
- Understand how these systems work
- Choose the appropriate system for a specific site

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