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

U.S. Department of Transportation Federal Highway Administration | Session 4 | 4-1

Session 4 Learning Outcomes

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

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

U.S. Department of Transportation Federal Highway Administration | Session 4 | 4-2

Guardrail Terminals

A barrier terminal must serve two functions:

- Provide the necessary TENSION of the guardrail system for downstream impacts
- Be crashworthy when impacted end-on.

U.S. Department of Transportation Federal Highway Administration | Session 4 | 4-3

End Anchor – MASH

- 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

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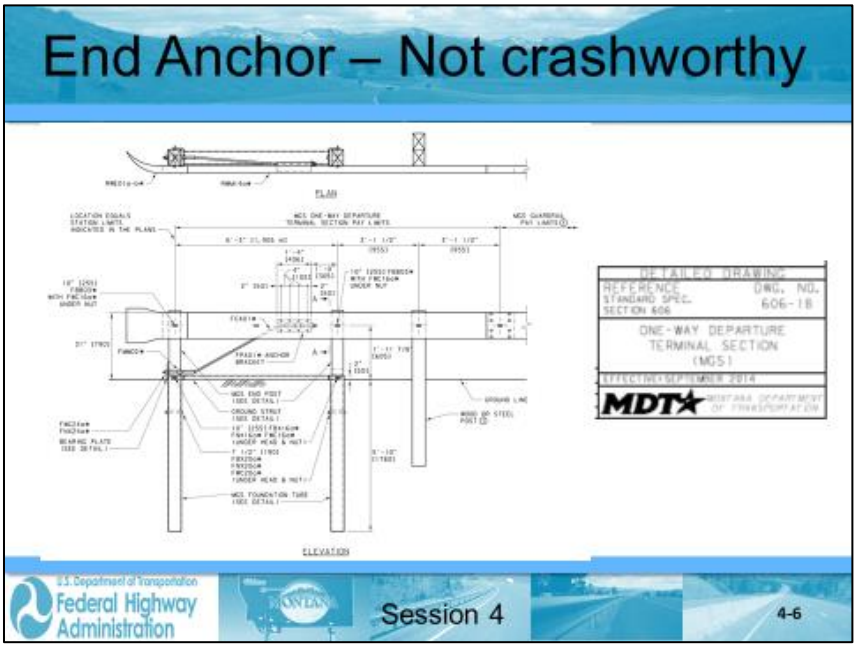
End Anchor – Not crashworthy
PLAN
ELEVATION
DETAILED DRAWING
REFERENCE STANDARD SPEC. SECTION 606
DWG. NO. 606-18
ONE-WAY DEPARTURE TERMINAL SECTION (MOS)
MDT
U.S. Department of Transportation
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MONTANA
Session 4
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U.S. Department of Transportation
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Historic – NOT acceptable
U.S. Department of Transportation
Federal Highway Administration
MONTANA
Session 4
4-8


U.S. Department of Transportation
Federal Highway Administration
MONTANA
Session 4
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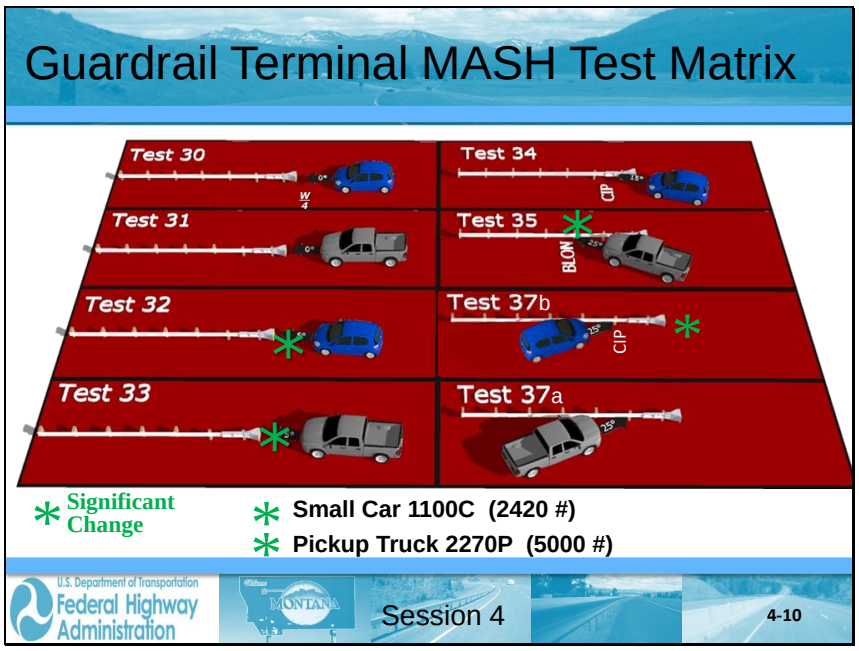
Guardrail Terminal MASH Test Matrix
Test 30
Test 34
Test 31
Test 35
Test 32
Test 37b
Test 33
Test 37a
CIP
BLON
CIP
Significant Change
Small Car 1100C (2420 #)
Pickup Truck 2270P (5000 #)
U.S. Department of Transportation
Federal Highway Administration
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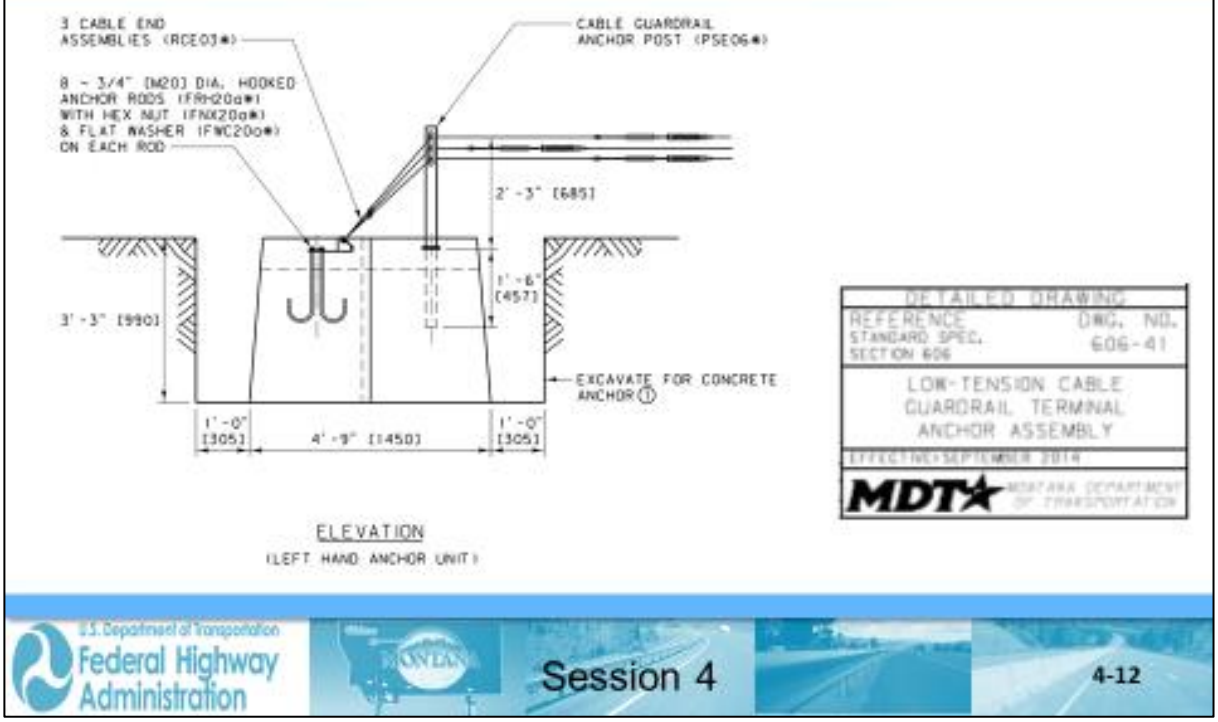
Historic Cable Terminal
NOT Crashworthy
U.S. Department of Transportation
Federal Highway Administration
MONTANA
Session 4
4-11

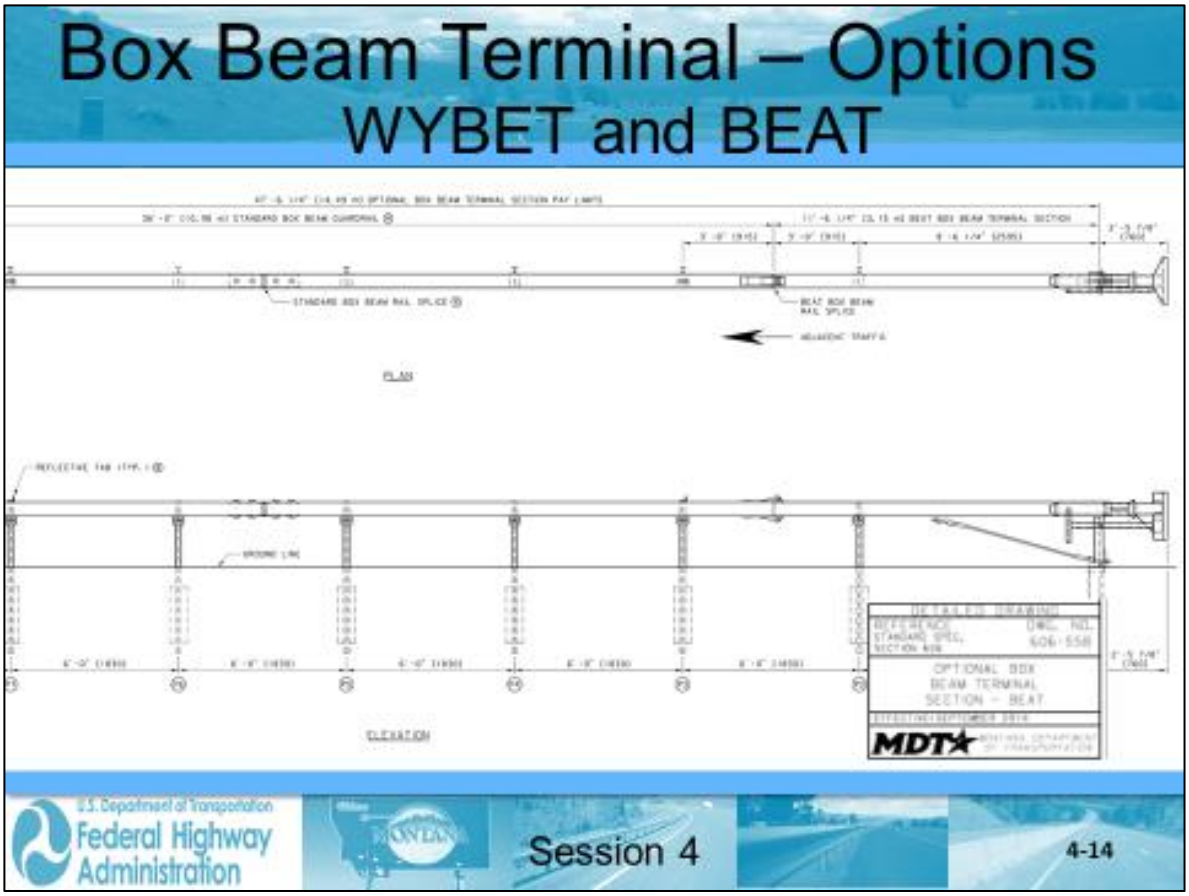
LTC Cable Terminal (generic)



Guardrail Terminals

Types of Approved Terminals available in MDT

- W-beam *energy absorbing* terminals – terminal is parallel to the roadway or has a straight flare with a "slight" offset
- Box beam *energy absorbing* terminals – terminal is parallel to the roadway or has a straight flare with a "slight" offset


Box Beam Terminal – Options
WYBET and BEAT
PLAN
ELEVATION
OPTIONAL BOX BEAM TERMINAL SECTION – BEAT
MDT
U.S. Department of Transportation
Federal Highway Administration
Session 4
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Box Beam – BEAT
U.S. Department of Transportation
Federal Highway Administration
Session 4
4-15

Buried in Backslope

- Key design considerations:
  - For slopes steeper than 10:1, keep the height of the w-beam rail constant relative to the roadway grade until the barrier crosses the ditch flow line,
  - Use a flare rate appropriate for the design speed,
  - Add a w-beam rubrail when the distance between the bottom of the w-beam rail and the ground exceeds ~19”,
  - Use an anchor (concrete block or steel posts) capable of developing the full tensile strength of the w-beam rail buried 1’ below ground

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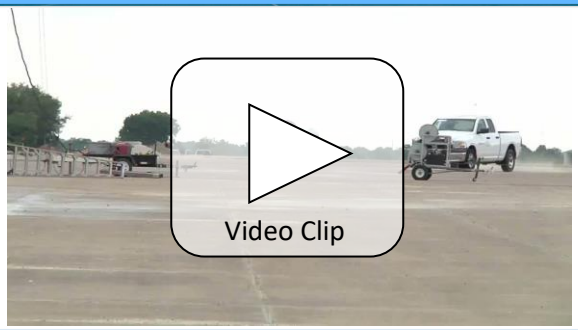
MASH
Buried in Backslope End Terminal



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Session 4

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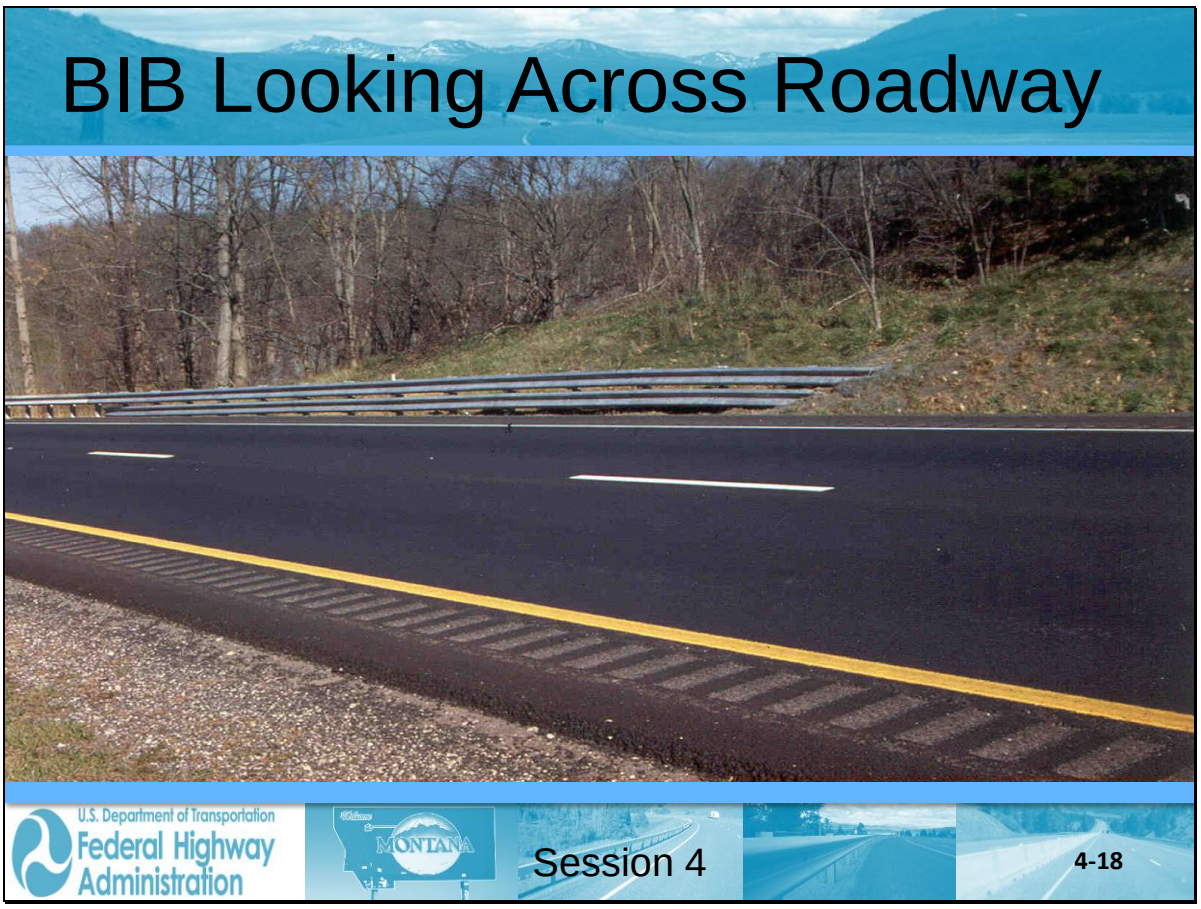
BIB Looking Across Roadway
U.S. Department of Transportation
Federal Highway Administration
MONTANA
Session 4
4-18


Buried Post End Anchor Considerations
Video Clip
U.S. Department of Transportation
Federal Highway Administration
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BIB Considerations
Any concerns with this installation?
U.S. Department of Transportation
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U.S. Department of Transportation
Federal Highway Administration
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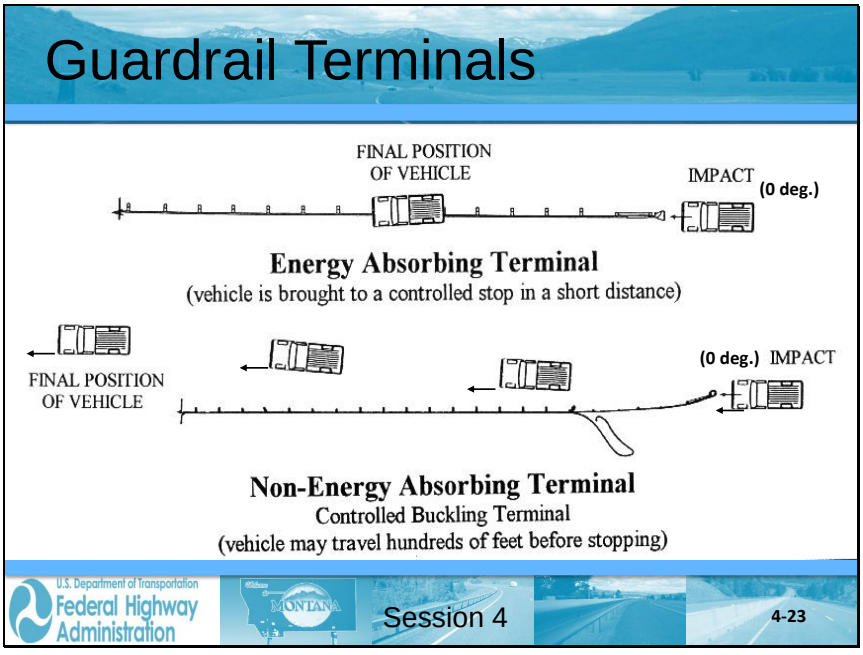
Guardrail Terminals
FINAL POSITION OF VEHICLE
IMPACT
(0 deg.)
Energy Absorbing Terminal
(vehicle is brought to a controlled stop in a short distance)
FINAL POSITION OF VEHICLE
(0 deg.) IMPACT
Non-Energy Absorbing Terminal
Controlled Buckling Terminal
(vehicle may travel hundreds of feet before stopping)
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Federal Highway Administration
MONTANA
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MDT Qualified Product List – MASH Optional Terminal Sections

QPL List

Reset | Excel

ID #	Producer/Supplier	Qualified Product Name	Eff Dt	Expiration	Category	Mtrl #	Material Na...
99-ROADSYS-SUPP	ROAD SYSTEMS INC	MSKT	20170208	20200208	GRD	606.02.00.01	MASH W-b...
88-TRNHWPR-FAB	TRINITY HIGHWAY PRODUC...	SoftStop End Terminal	20161019	20201019	GRD	606.02.00.01	MASH W-b...

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Guardrail Terminals: Energy Absorbing

- Depending on Qualified Product List, it is the contractor's option as to which manufacturer's system they wish to provide.
  - All are energy-absorbing.
  - Some systems may have different configurations, such as post type.
- What is **important** is to understand how the system works

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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 47’ long; attachment to 31” MGS Barrier
  - Cable-anchored system, Compression system

Needs a full panel of MGS beyond end of Terminal

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MASH
MSKT

U.S. Department of Transportation Federal Highway Administration | Session 4 | 4-27

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MSKT
SKT
U.S. Department of Transportation
Federal Highway Administration
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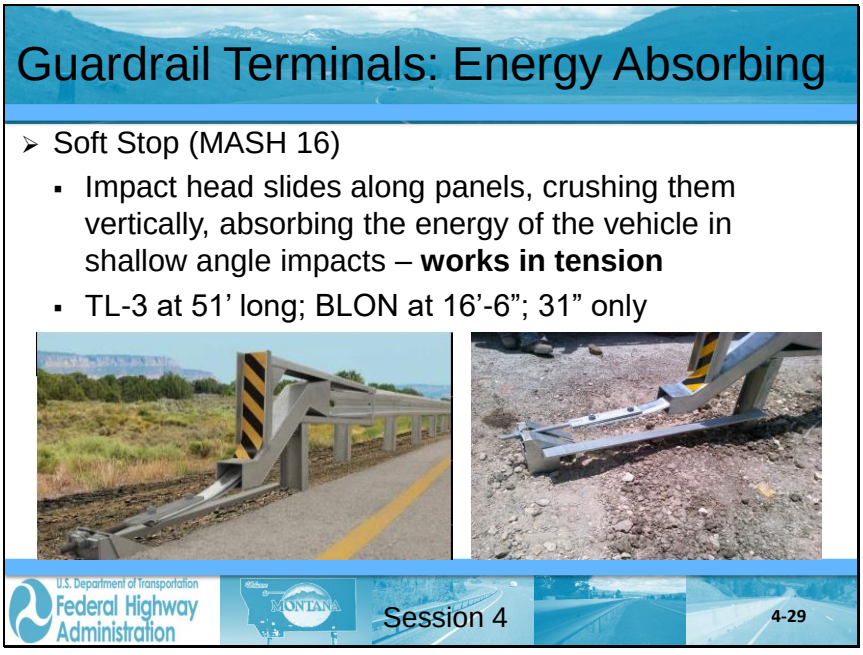
Guardrail Terminals: Energy Absorbing
Soft Stop (MASH 16)
Impact head slides along panels, crushing them vertically, absorbing the energy of the vehicle in shallow angle impacts – works in tension
TL-3 at 51' long; BLON at 16'-6"; 31" only
U.S. Department of Transportation
Federal Highway Administration
MONTANA
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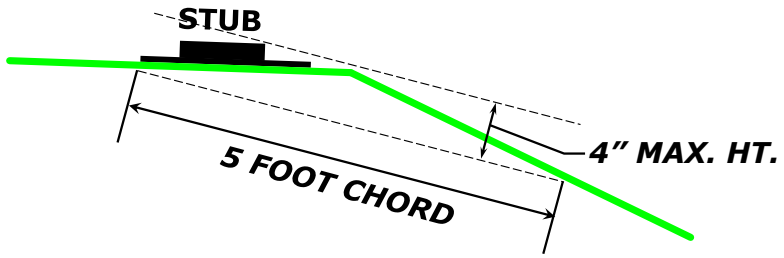
Terminal Grading

- 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*** stub height criteria is satisfied

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

Stub Height Criteria



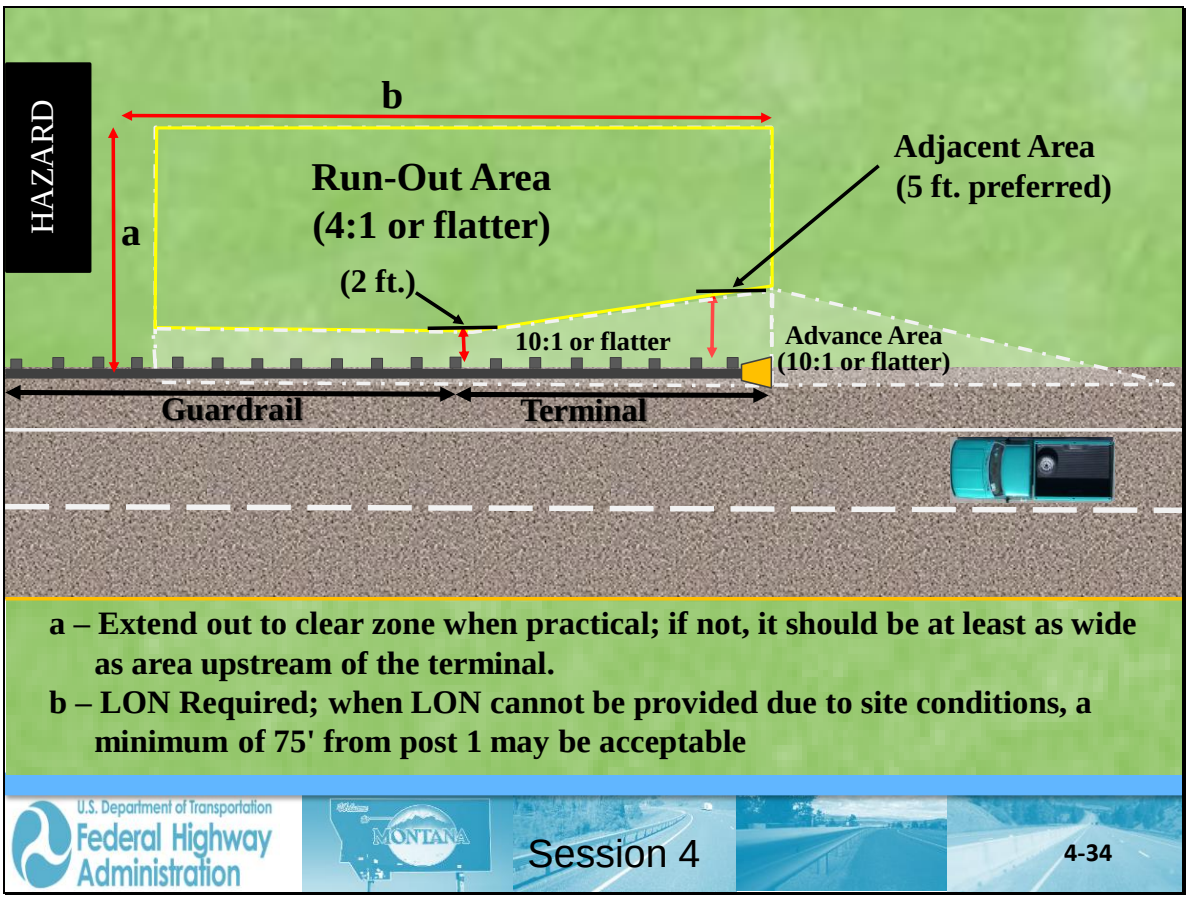
RDG Figure 4.1

Ref: AASHTO Roadside Design Guide, 4th Edition – Figure 4.1

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.


HAZARD
b
a
Run-Out Area
(4:1 or flatter)
Adjacent Area
(5 ft. preferred)
(2 ft.)
10:1 or flatter
Advance Area
(10:1 or flatter)
Guardrail
Terminal
a – Extend out to clear zone when practical; if not, it should be at least as wide as area upstream of the terminal.
b – LON Required; when LON cannot be provided due to site conditions, a minimum of 75' from post 1 may be acceptable
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Federal Highway Administration
MONTANA
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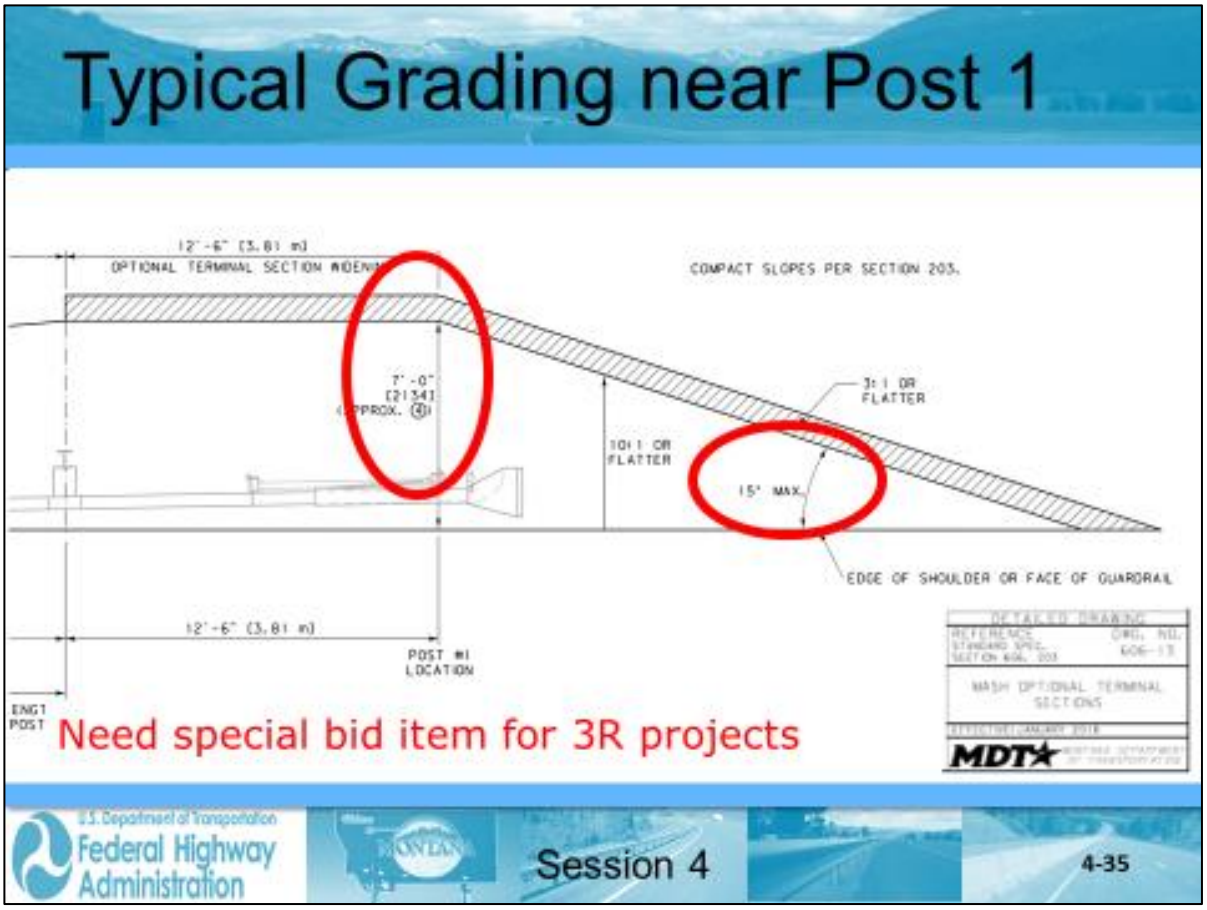
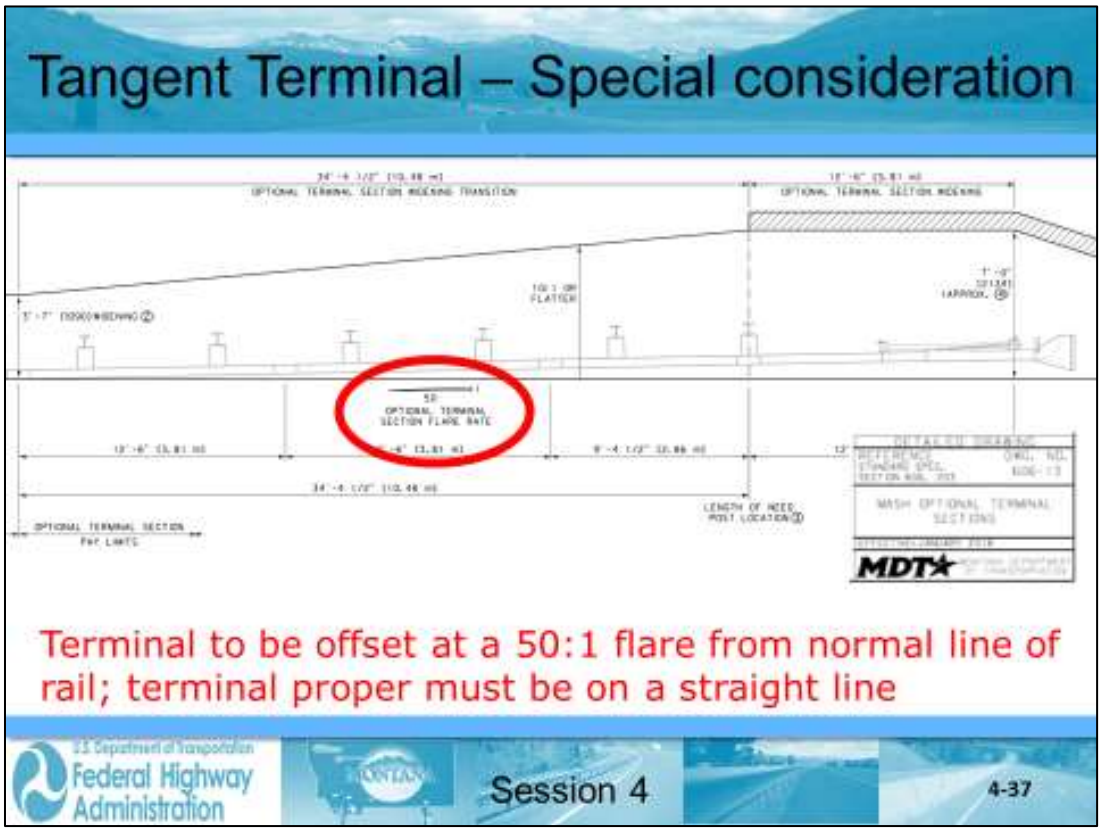

Typical Grading near Post 1
12'-6" (3.81 m)
OPTIONAL TERMINAL SECTION WIDENING
COMPACT SLOPES PER SECTION 203.
7'-0"
(2134)
APPROX. (4)
10:1 OR
FLATTER
3:1 OR
FLATTER
15° MAX.
EDGE OF SHOULDER OR FACE OF GUARDRAIL
12'-6" (3.81 m)
POST #1
LOCATION
ENGT
POST
Need special bid item for 3R projects
WASH OPTIONAL TERMINAL SECTIONS
MDT
U.S. Department of Transportation
Federal Highway Administration
Session 4
4-35


Good thought, but not adequate
U.S. Department of Transportation
Federal Highway Administration
Session 4
4-36


Tangent Terminal – Special consideration
Terminal to be offset at a 50:1 flare from normal line of rail; terminal proper must be on a straight line
U.S. Department of Transportation
Federal Highway Administration
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U.S. Department of Transportation
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PRE-ASSESSMENT PHOTO
U.S. Department of Transportation
Federal Highway Administration
Session 4
4-39

EXISTING TERMINALS

Guardrail Terminals
Tangent, Energy-Absorbing

- SKT 350 (Sequential Kinking Terminal)(NCHRP 350)
  - Kinks panels when hit head-on or at a shallow angle
  - Wood or Steel post system (many options)
  - TL-3 at 50' long; BLON at 3rd Post
  - Cable-anchored, Compression system

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

Guardrail Terminals
Tangent, Energy-Absorbing

- ET Plus (Guardrail Extruder Terminal)(NCHRP 350)
  - Flattens the rail element when hit head-on
  - Weakened wood or steel posts (several options available)
  - 50' long; attaches to either height w-beam system
  - BLON at 3rd Post
  - Cable-anchored, compression system

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

Non-crashworthy Terminal
BCT Terminal

- Breakaway Cable Terminal (BCT) NCHRP 230
  - W-Beam rail with a parabolic curve and 4-ft offset.
  - No impact head or ground strut between the two end posts.
  - Only two breakaway posts.
  - Rail bolted to all posts.

For Identification Only


Non-crashworthy Terminal
BCT Terminal
Video Clip
Failed Test! Causes spearing
Federal Highway Administration
Session 4
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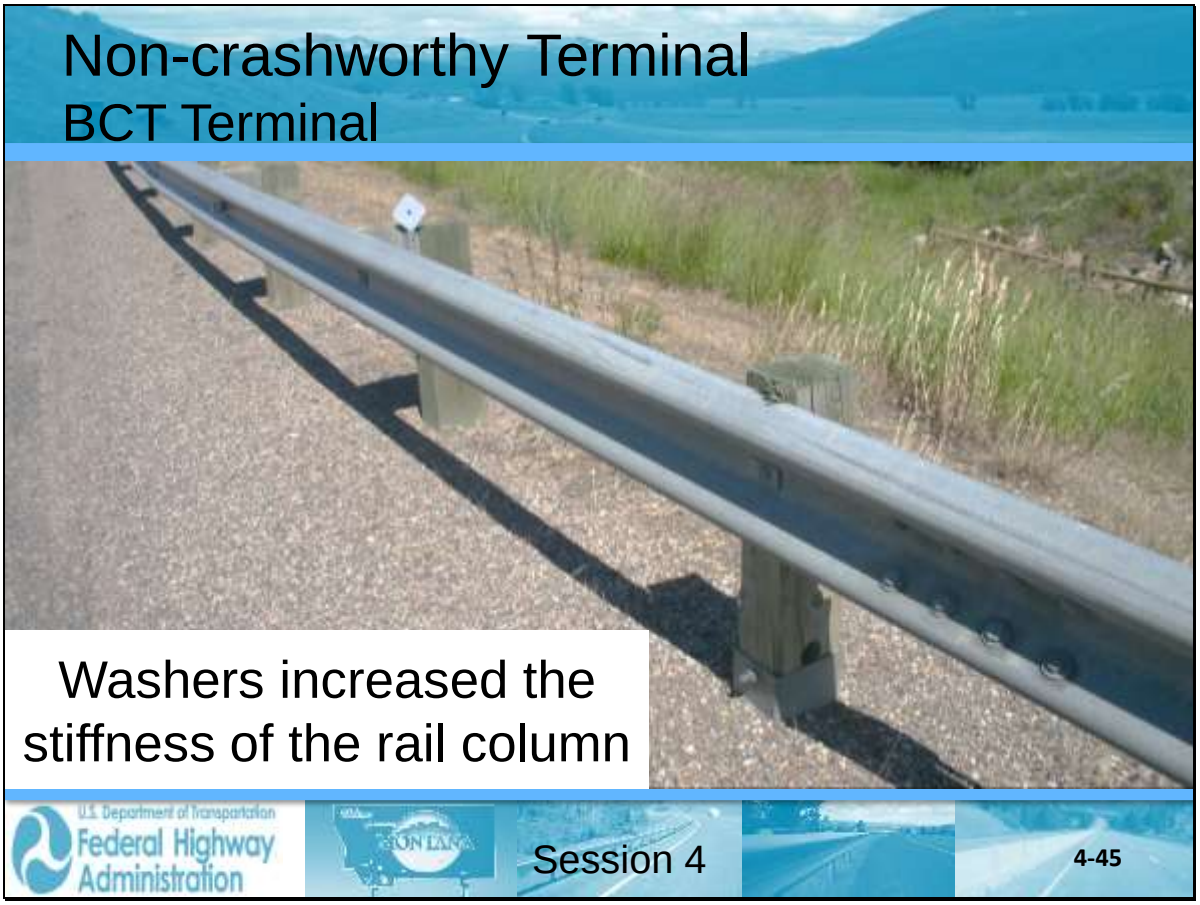
Non-crashworthy Terminal
BCT Terminal
Washers increased the stiffness of the rail column
U.S. Department of Transportation
Federal Highway Administration
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4-45

Guardrail Terminals: Non-energy Absorbing – For Identification Only

- MELT – Modified Eccentric Loader Terminal
  - W-Beam rail with an accentuated parabolic curve and 4-ft offset.
  - Strut between the steel tubes foundation of the two end posts.
  - 37'-6" long with 8 breakaway posts; BLON at Post #3.
  - No rail-to-post bolts except at posts 1 and 8 and beyond.

For Identification Only

(NCHRP 350 TL-2)

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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
  - Length of needs begins at post 4.

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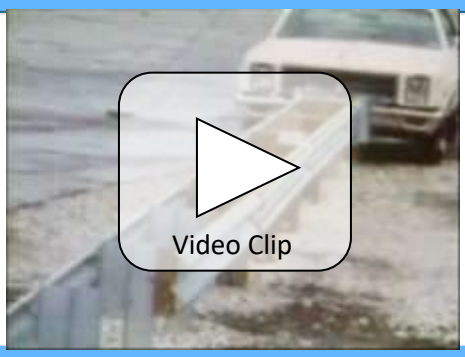
Two-sided Terminal (230 video/350 passed)
CAT Terminal



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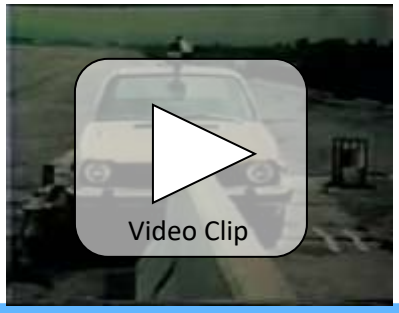
Crash Cushion
Crash test with blunt end:



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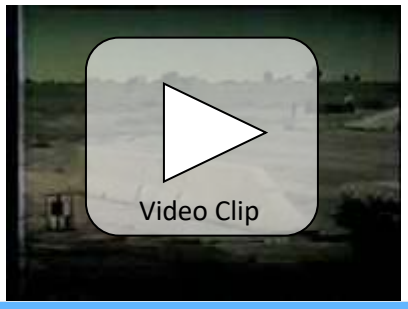
Crash Cushion
Crash test with ramped end:



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4-50

Crash Cushions
Gating Non-Redirective; TEMPORARY

- Water-filled Barriers

  Absorb 350 / <u>Sled(MASH)</u> / 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.

Crash Cushions
Gating Non-Redirective; TEMPORARY

- Water Filled Crash Cushions:

Absorb 350 (TL-3)

WORK ZONE APPLICATION

Sled (MASH)

ACZ-350

MDT Guidance

9.6.2 Warrants

Impact attenuator warrants are the same as barrier warrants. Once an obstacle is identified, the design team should first attempt to remove, relocate, or make the obstacle break away. If the foregoing is impractical, then consider an impact attenuator.

Impact attenuators are most often installed to shield fixed-point obstacles which are too close to the traveled way to allow room for other types of barriers and are more likely to sustain a head-on impact. Examples include exit gore areas (particularly on structures), bridge piers, and non-breakaway sign supports. Impact attenuators are often preferable to guardrail to shield these obstacles. Site conditions and costs will determine whether to use a barrier or impact attenuator. Impact attenuators are the only type of terminal section used for CBR requiring an end treatment.

Crash Cushions
Redirective and Non-Gating

Redirective and Non-gating as follows:

- Contains and redirects vehicles impacting along the sides of the device essentially its entire length
- Contains vehicles impacting the nose either head-on or at a 15º angle.
- Approved for TL-2 & TL-3 systems.
- Designed to shield a point hazard; either attached or stand alone.

Crash Cushion:
Redirective and Non-Gating - MDT

IMPACT ATTENUATOR – QUADGUARD	606-30A
IMPACT ATTENUATOR – TRACC	606-30B
IMPACT ATTENUATOR – TRACC (METRIC)	606-30B
IMPACT ATTENUATOR – QUEST	606-30C
IMPACT ATTENUATOR – QUEST (METRIC)	606-30C
IMPACT ATTENUATOR – QUADGUARD II	606-30D

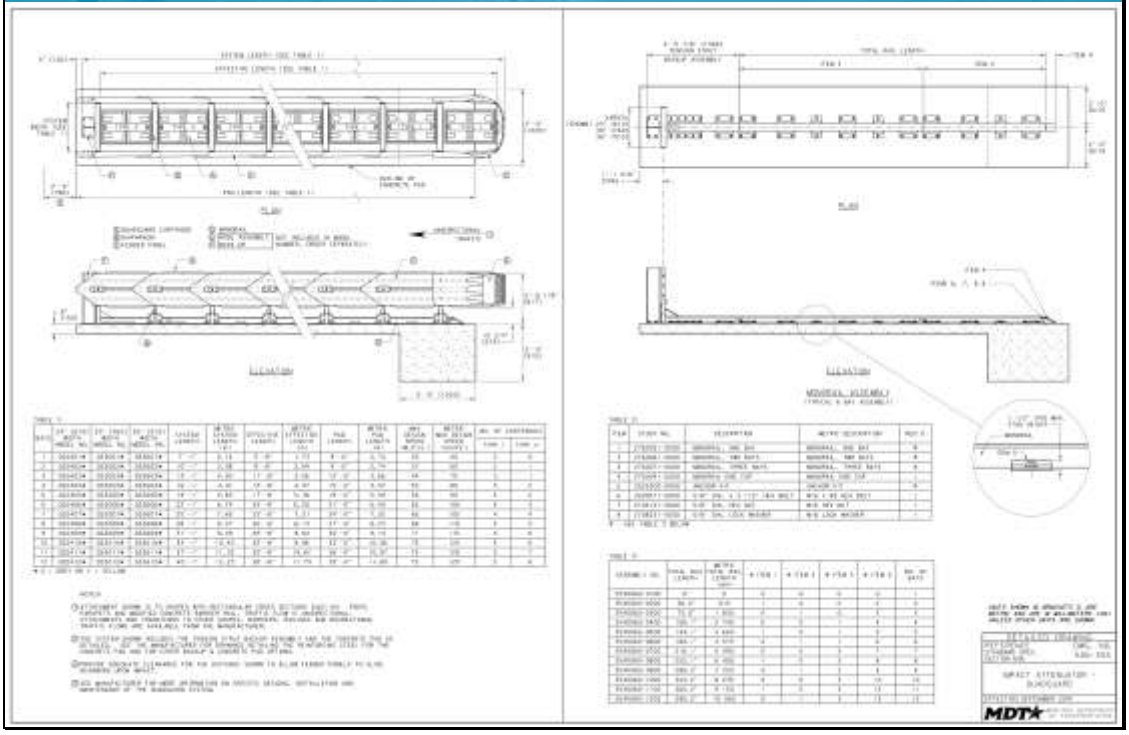
These Detailed Drawings will soon be replaced with a QPL, and refer to manufacturers material

Crash Cushion – QuadGuard's

- QuadGuard & QuadGuard II (350)
- QuadGuard M10 (MASH)
- QuadGuard Elite(350)

- 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; damaged cartridges need to be replaced after a crash.
- Available in widths from 24 to 36 inches with parallel sides and 69 to 90 inches with flared sides. (M10 only available at 24")

Crash Cushion – QuadGuard - MDT



Crash Cushion – TRACC

- TRACC (TRinity Attenuating Crash Cushion) (NCHRP 350)
  - TL-3 TRACC / TL-2 Short TRACC / FASTRACC / WIDETRACC
  - Has double tiered 10 gauge W-Beam side panels; shipped to the field assembled.
  - Absorbs energy by cutting internal metal plates.

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Crash Cushion – QUEST

- Quest (NCHRP 350)
  - Approved for TL-2 & TL-3 systems.
  - Designed to attach to a concrete or metal beam barrier.
  - Consists of a series of W-beam fender panels supported by diaphragms.
  - Absorbs energy by crushing pipes when struck end on.

REF: FHWA Eligibility Letter CC-87D dated 12/18/15

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Crash Cushion – SCI (SMART)

- SCI Smart Cushion (NCHRP 350/MASH)
  - Variable Reaction Force
  - Re-usable with minimal component replacement
  - Needs repair before next hit

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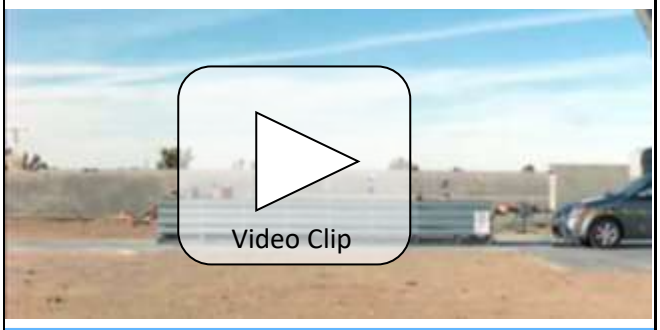
Example Non-gating Crash Cushion



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Very Appropriate Use

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Crash Cushions – Self-Restoring
(one of several)

- 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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Example Self Restoring Crash Cushion

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Session 4
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Review Learning Outcomes

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

Federal Highway Administration
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