Session 2:

Testing Requirements and Performance Characteristics of Common Barrier Systems, Terminals and Crash Cushions

Course Topics

- Session 1 – Introduction
- Session 2 – Testing Requirements and Performance Characteristics of Common Barrier Systems, Terminals, and Crash Cushions

Session 2 Objectives

- Describe the Tests Required for Guardrail Acceptance
- Explain How Common Guardrail Systems Function
- Provide an Overview of Alternative Systems

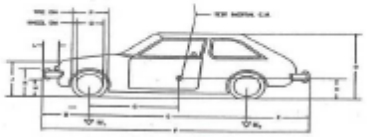
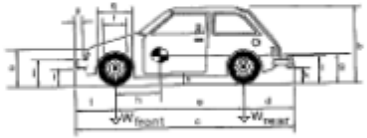
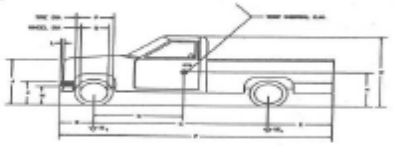
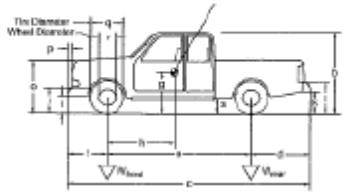
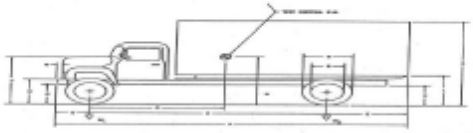
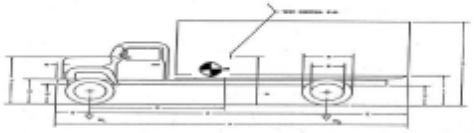
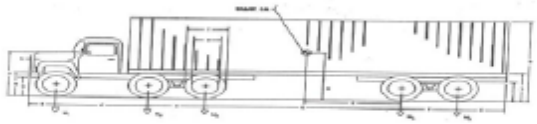
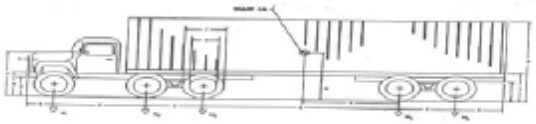
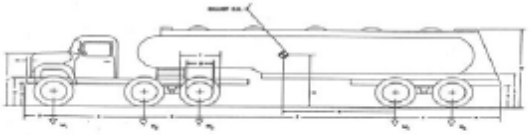
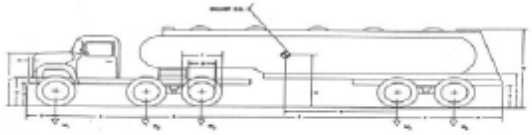
Session 2 Outline

- Crash Testing Guidelines
- Products and Systems
  - Barrier Systems
  - Transition Sections
  - Guardrail Terminals
  - Crash Cushions

Crash Testing Guidelines

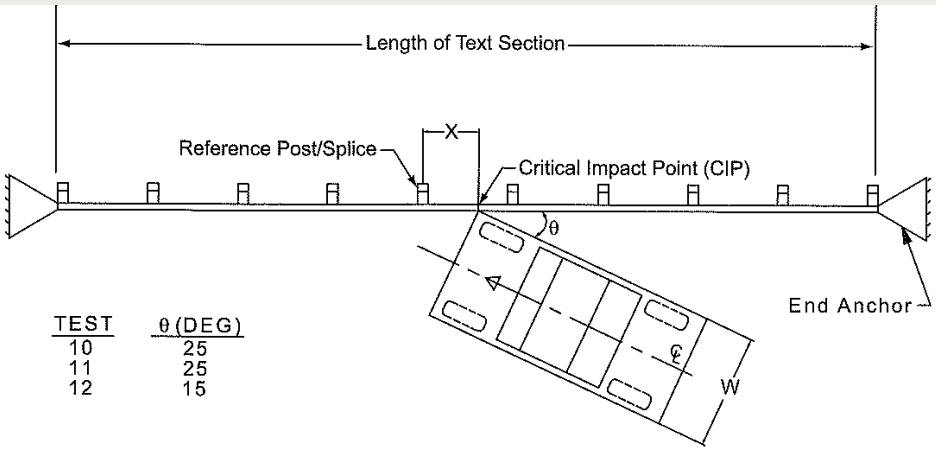
- Prior crash testing and evaluation standards were published in 1993 as NCHRP Report 350, "Recommended Procedures for the Safety Performance Evaluation of Highway Features."
- In 2009, the Manual for Assessing Safety Hardware (MASH) was published by AASHTO and has been adopted as the new testing standard. FHWA now requires new products to be tested to MASH.

MASH vs. NCHRP 350 Design Vehicles

NCHRP 350 Vehicle	MASH Vehicle
	
820 kg (1800 lb) cm = 21.7"	1100 kg (2420 lb) cm = N/A
	
2000 kg (4400 lb) cm = 27.6"	2270 kg (5000 lb) cm = 28"
	
8000 kg (17,650 lb) cm = 66.9"	10000 kg (22000 lb) cm = 63"
	
36000 kg (79,400 lb) cm = 72.8"	36000 kg (79,400 lb) cm = 73"
	
36000 kg (79,400 lb) cm = 80.7"	36000 kg (79,400 lb) cm = 81"

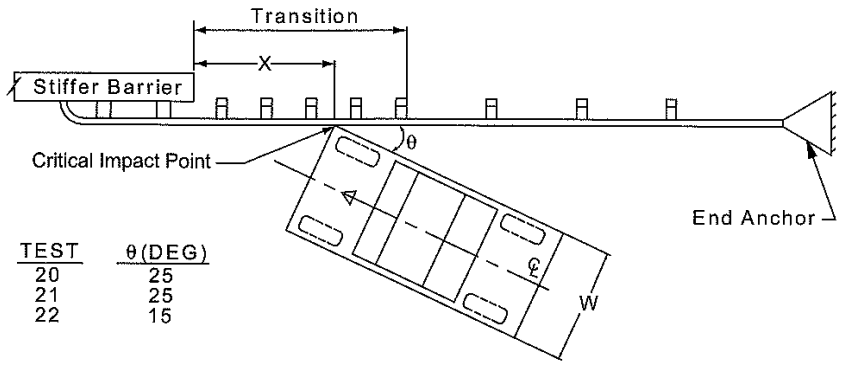
NCHRP 350 comparison with MASH Crew Cab Truck

Impact Conditions for Barrier Tests



TEST	θ (DEG)
10	25
11	25
12	15

TEST 10, 11, and 12



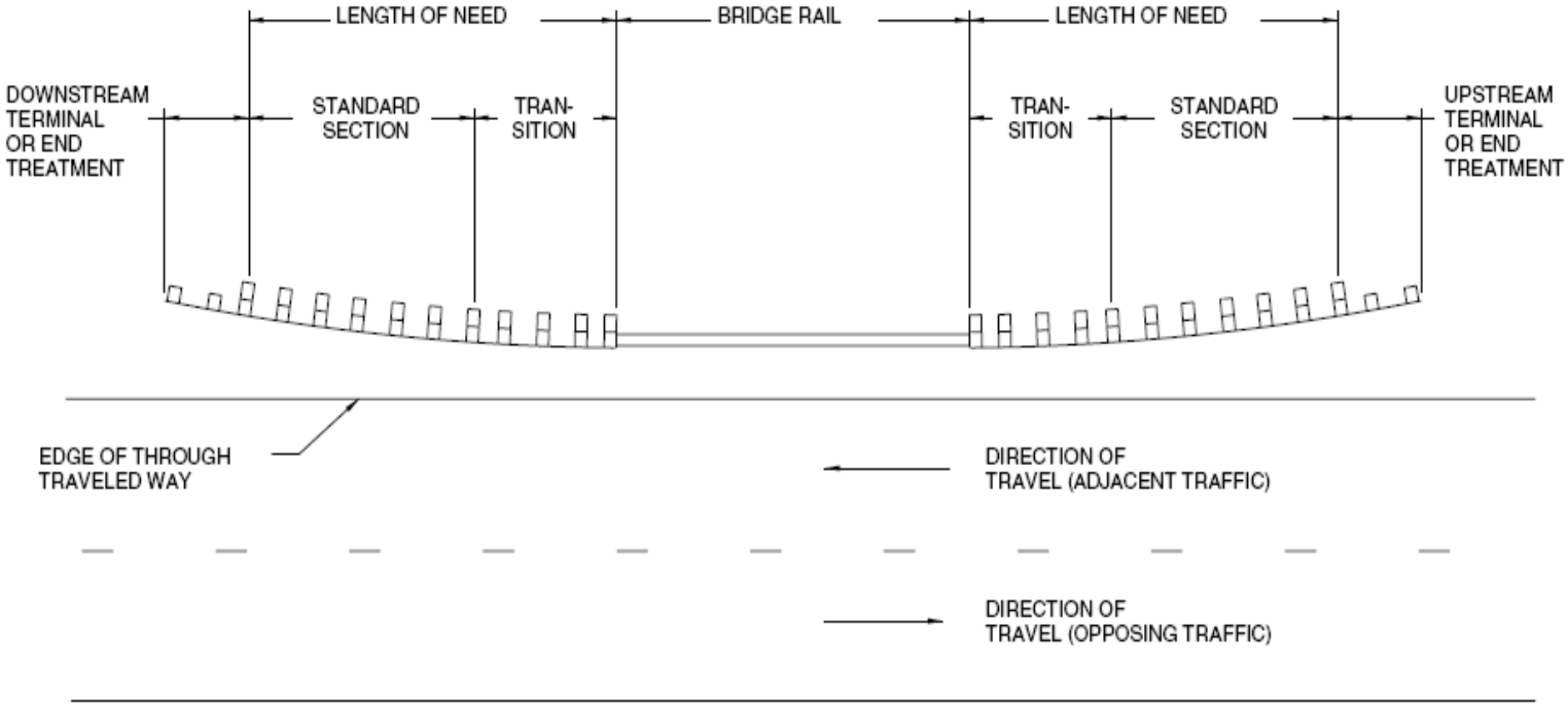
TEST	θ (DEG)
20	25
21	25
22	15

TEST 20, 21, and 22

Products and Systems

- Barrier Systems
- Transition Sections
- Guardrail Terminals
- Crash Cushions

Barrier System Elements



Ref: AASHTO ROADSIDE DESIGN GUIDE, 4rd EDITION – Figure 5.4, Pg. 5-11

Standard Barrier Systems

- Rigid Systems
- Semi-Rigid Systems
- Flexible Systems
- Median Barrier Systems
- Work Zone Barriers

Barrier Systems: Rigid Barriers

- Rigid Barrier Systems typically have little (if any) deflection under most impact conditions.
- Some of these barriers are portable and some are permanent.
- Examples include:
  - New Jersey Safety Shape Concrete Barrier
  - F-shape Concrete Barrier
  - Vertical Concrete Barrier
  - Constant Slope Concrete Barrier

Rigid Barrier Performance

MASH Rigid Barrier Test

Barrier Systems: Semi-Rigid

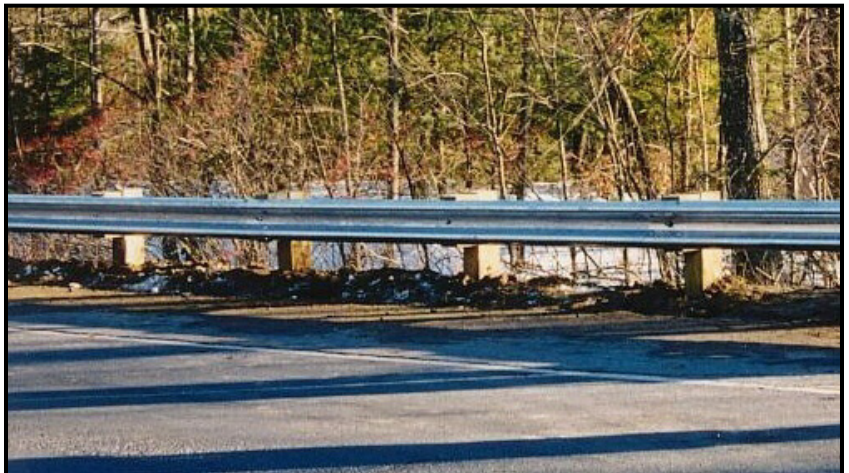
- Semi-Rigid Barrier Systems generally have deflections of a few feet under typical impact conditions, and most consist of beam and post elements. Reducing the post spacing can decrease the deflection.

Semi-Rigid Barrier Performance

MASH Strong Post W-Beam Test

Barrier Systems: Semi-Rigid

- W-Beam Guardrail
  - 12” wide W-beam rail section (12-gauge thickness).
  - Posts are spaced at 6’-3” centers, and the nominal rail height is 27 ¾”
  - Two post options:
    - Steel posts, W6 x 8.5/9.0 x 6’-0” long.
    - Wood posts, 6” x 8” x 6’-0” long.
  - Block-outs: 6” x 8” wood or plastic.



Extra Block-outs (Strong-post W-beam)

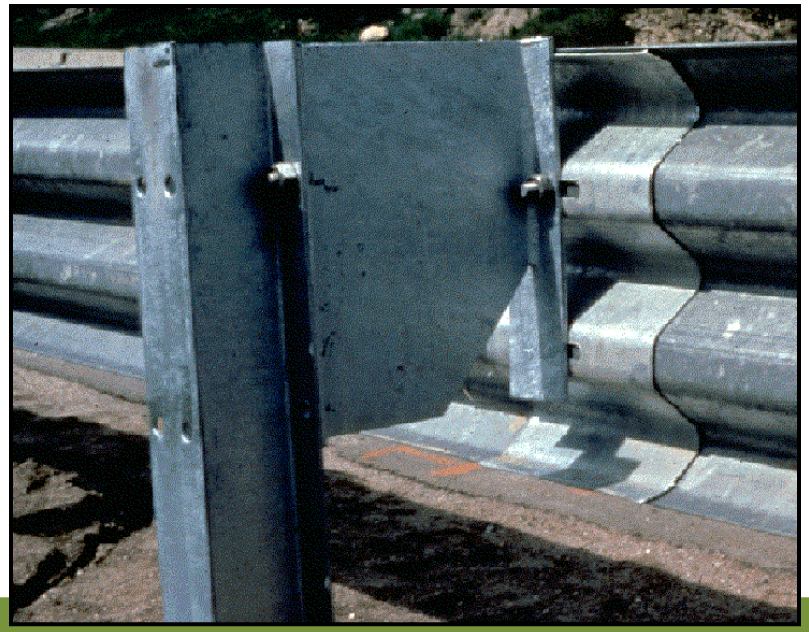
- Two block-outs may be used at any time, for any number of posts.
- Three block-outs may be used at one post only.

Barrier Systems: Semi-Rigid

- Thrie-Beam Guardrail
  - 20” wide Thrie-beam rail section (12-gauge thickness)
  - Posts are spaced at 6’-3” centers, and the rail height is 32”.
  - Two post options:
    - Steel posts, W6 x 8.5/9.0 x 6’-6” lg.
    - Wood posts, 6” x 8” x 6’-6” lg.
  - Block-out: 6” x 8” wood or plastic

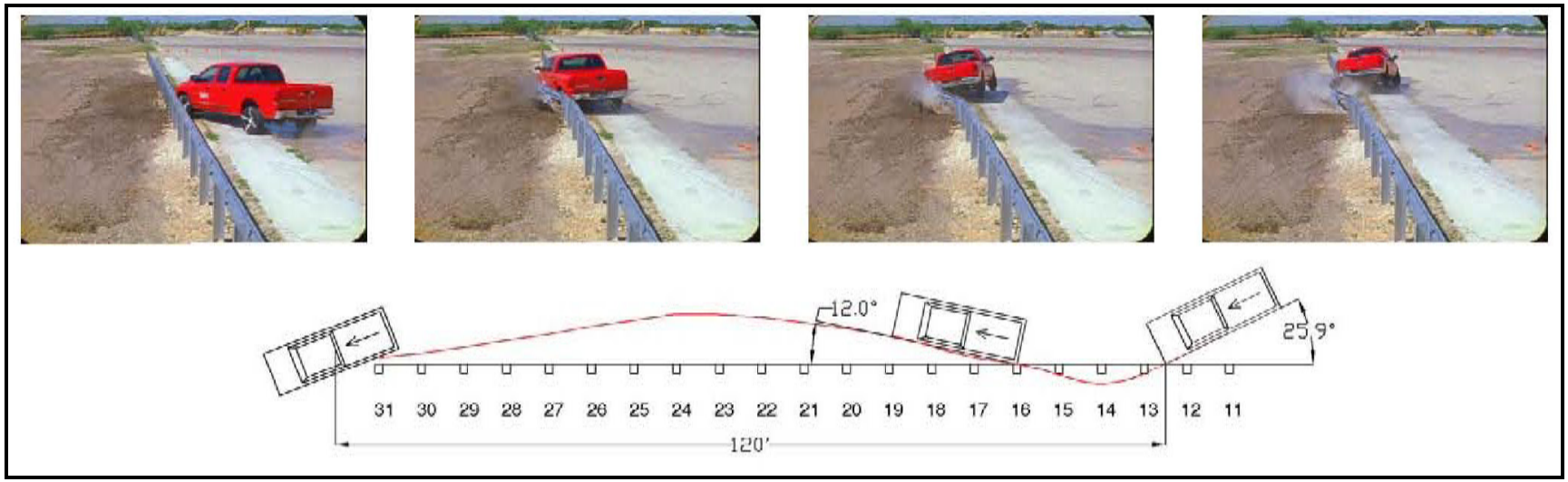
Barrier Systems: Semi-Rigid

- Modified Thrie-Beam Guardrail
  - Modified Thrie-Beam Guardrail uses W6 x 8.5/9.0 x 6’-9” long steel posts, a W14 x 22.1# modified notched steel block-out, and a rail height of 34”.



Next Generation Testing

- Many manufacturers and agencies are modifying their designs to incorporate the new MASH testing requirements.



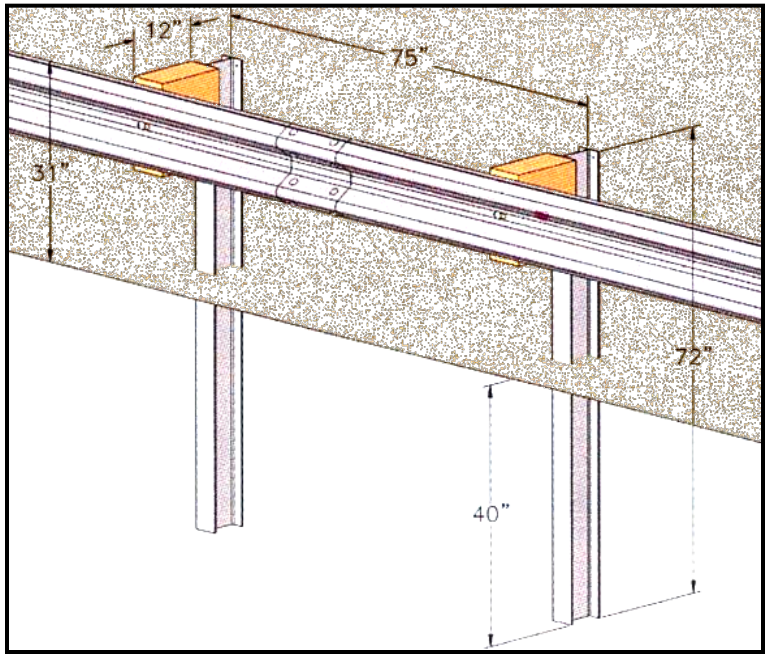
Next Generation Systems

An overview of the latest Guardrail technology.

Midwest Roadside Safety Facility
under the
Midwest Pooled Fund Project

"MGS" System

- 31" Height
- Mid-Span Splices
- Standard I-Beam Posts
- 12" Deep Block-out



Effective 2010 added to Standard Construction Details

MGS MASH Test 3-10

Next Generation Systems

An overview of the latest Guardrail technology.

Gregory Highway Products

www.gregorycorp.com

"GMS" System

- 31" Height, No Block-out
- Mid-Span Splices **or** At Post
- Standard I-Beam Post
- Uses a "Mini" Spacer Bolt component
- W-Beam or Thrie Beam Approval

Next Generation Systems

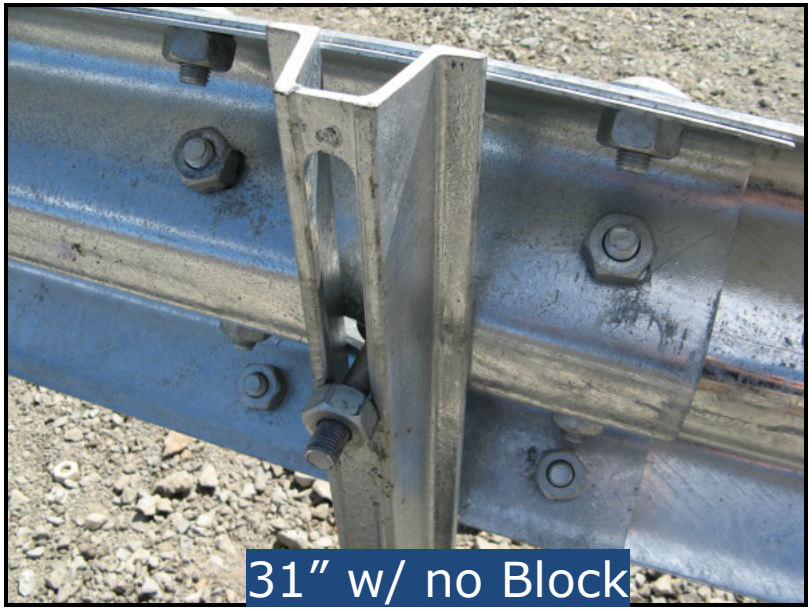
An overview of the latest Guardrail technology.

Nucor Steel Marion Inc.

www.nucorhighway.com

“NU-GUARD” System

- 31” w/ No Block-out
- 27” w/ Block-out
- Splices At Post
- 5 lb/ft U-Channel Post



Next Generation Systems

An overview of the latest Guardrail technology.

Trinity Industries

www.highwayguardrail.com

"T-31" System

- 31" w/No Block-out
- Mid-Span Splices
- "Steel Yielding" Posts
- T-39 for Thrie Beam Use

Barrier Systems: Flexible Barriers

- Flexible Barrier Systems typically have relatively *large deflections* meaning significant barrier damage when impacted. Reducing the post spacing can decrease the deflection.

Flexible Barrier Performance

Barrier Systems: Flexible Barriers

- Weak Post W-Beam Rail
  - 12” wide W-beam rail section (12-gauge thickness)
  - S3 x 5.7 posts
  - No block-out
  - Posts are spaced at 12’-6” centers, and the rail height is 32”.
  - In order to meet NCHRP 350 TL-3, panel splices were placed mid-span.

NCHRP Report 350 TL-3 Design

Report 350 Weak Post W-Beam TL-3 Test

MASH Weak Post W-Beam TL-3 Test

Barrier Systems: Flexible Barriers

- High Tensioned Cable Barrier
  - Five different designs available
  - All designs are proprietary
  - Reduced deflections
  - Reduced maintenance
  - Requires unique terminal system

Socketed Posts often used.

Barrier Systems:
High Tensioned Barrier Suppliers

- Brifen
- Gibraltar
- Nucor Marion Steel
- Safence – Gregory Industries
- Trinity (Cable Safety System-CASS)

NOTE: All of the High tensioned Cable Barrier Systems tested to TL-3 & TL-4. Anchor Terminal Systems have been developed for each product. Some systems have been successfully tested on 4H:1V slopes.

Brifen USA

http://www.brifenusa.com

- Interweaving cables creates a “mini-anchor” at each post due to friction as the tensioned cables weave past each post.
- 4 or 3 cable design available.

Gibraltar

http://www.gibraltartx.com

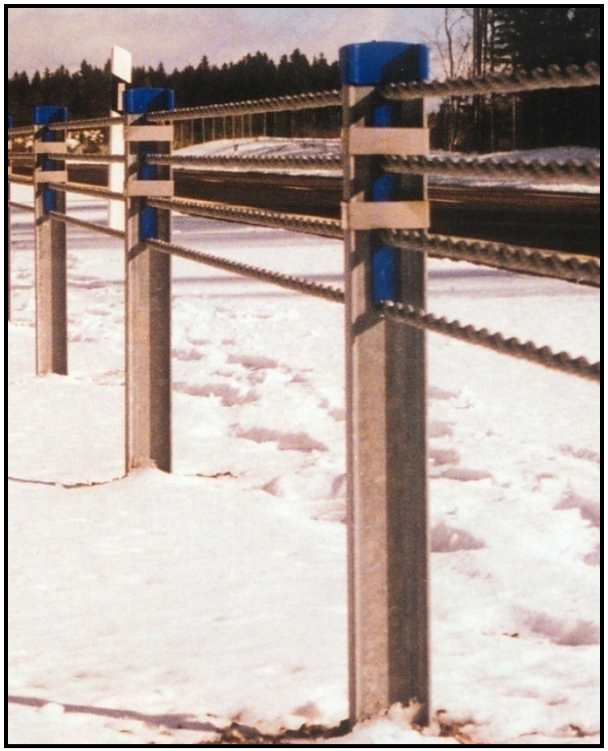
- Has hairpin type connection to post.
- Posts to cable connection is alternate side-to-side
- Also has a 4-cable version

Nucor Steel Marion

- Uses U-Post design.

http://www.nucorhighway.com

Safence – Gregory Industries



http://www.safence.com

- Post has slot located in the upper section of the web.
- Has a 3 or 4 cable design.

Trinity Industries

(Cable Safety System-CASS)

http://www.highwayguardrail.com

- Post has waved-shape slot located in the web of the upper portion of the post.
- Offers a couple different post designs.

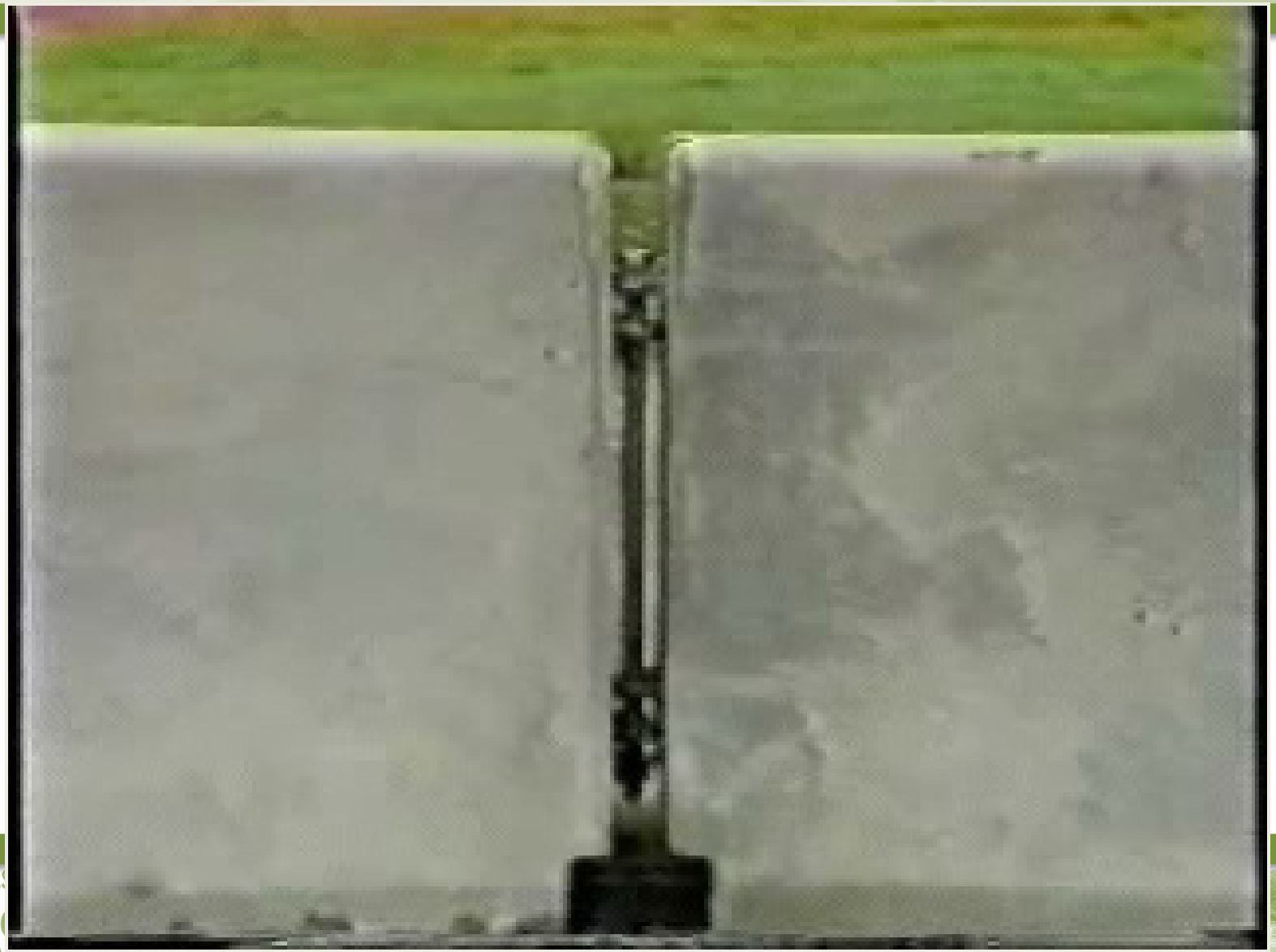
Barrier Systems: Median Barriers

- Used to separate opposing traffic on a divided highway or to separate through traffic from local traffic.
- Many barriers approved for roadside applications are also acceptable for medians as long as the barrier is symmetrical.
- Width of the median is an important consideration.
- Also must consider the dynamic deflection of the barrier to avoid intrusion into opposing traffic.
- There are terminals designed specifically to shield the ends of median barriers.

Barrier Systems: Work Zone Barriers

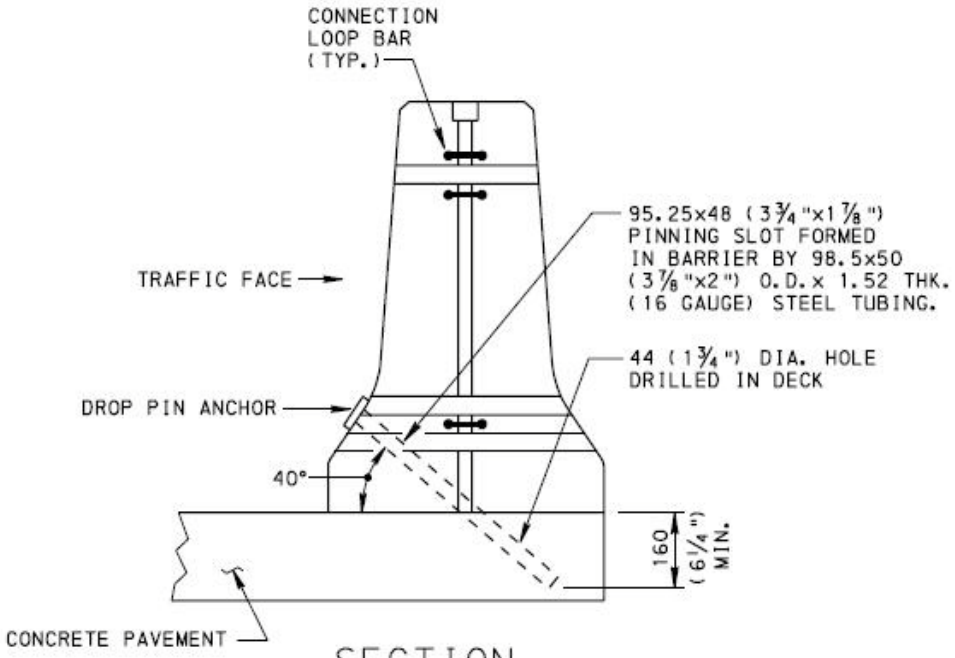
- Types of work zone barriers include:
  - Concrete safety shape barrier
  - Quick-change movable concrete / portable steel barriers
  - Plastic, water-filled barriers
- Dynamic deflection of the barrier is an important consideration in choosing a work zone barrier.

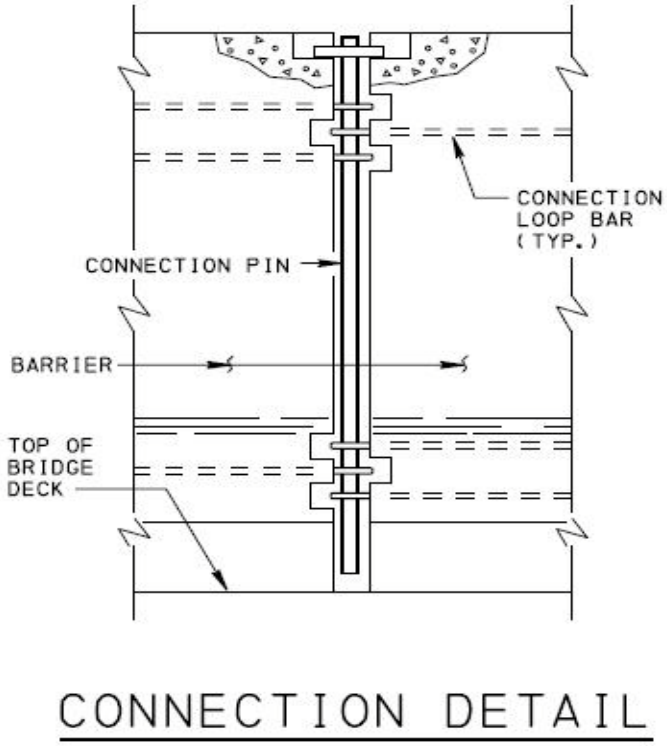
Work Zone Barrier Performance



NCHRP Report 350 TL-3 Test

Drop-Pin Temporary Concrete Barrier





Barrier Systems: Work Zone Barriers

- Concrete Safety Shape Barrier

Barrier Systems: Work Zone Barriers

- Portable Steel Barriers

BarrierGuard 800

ArmorGuard Barrier

ZoneGuard Barrier

Vulcan Barrier

Barrier Systems: Work Zone Barriers

- Quick-Change Movable Barrier

Barrier Systems: Work Zone Barriers

- Plastic, Water-Filled Barriers

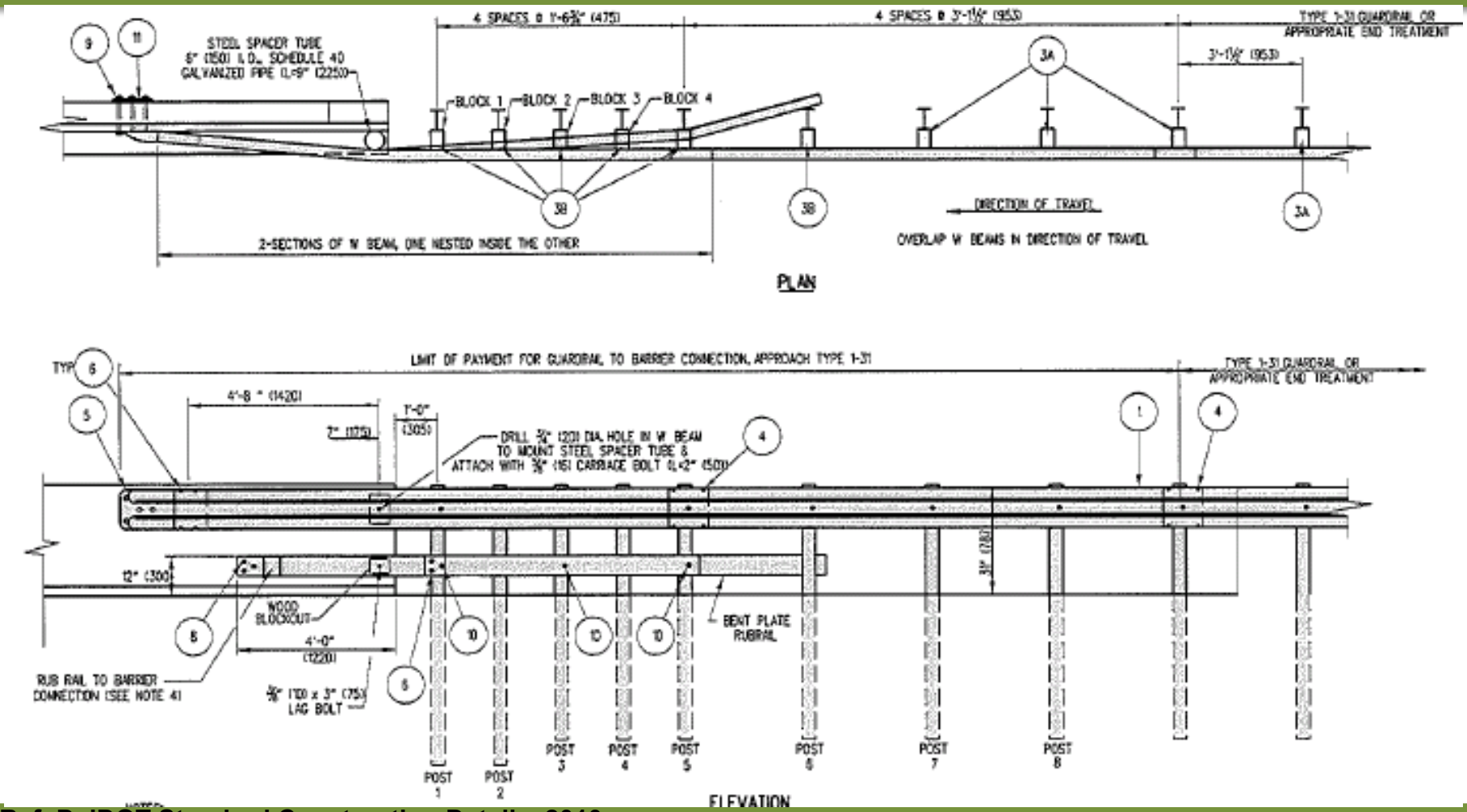
Internal Steel Frame

External Steel Frame

Transition Sections

- Used where barriers with different shapes join together, or where a semi-rigid barrier attaches to a rigid barrier, or where a flexible barrier joins a semi-rigid barrier.
- Prevents pocketing / excessive deflections
- Common features of typical transition systems:
  - Extra posts
  - Double nested rail elements
  - Snag prevention
  - Positive connection

DelDOT Transition



Ref: DelDOT Standard Construction Details, 2010

Inadequate Transition

Transition Sections

- Increased crash severity due to pocketing.

Low Tension Cable to W-Beam Transition

High Tension Cable to W-Beam Transition

Guardrail Terminals

- Types of Terminals:
  - Buried in backslope
  - W-beam *energy absorbing* terminals – terminal is parallel to the road or has slight offset (Type 1)
  - W-beam *non-energy absorbing* terminals – terminal is significantly flared away from the road (Type 2)
  - W-beam *median* terminals – specially designed for ends of median barriers (Type 3)
  - Crash Cushions

Guardrail Terminals: Buried in Backslope

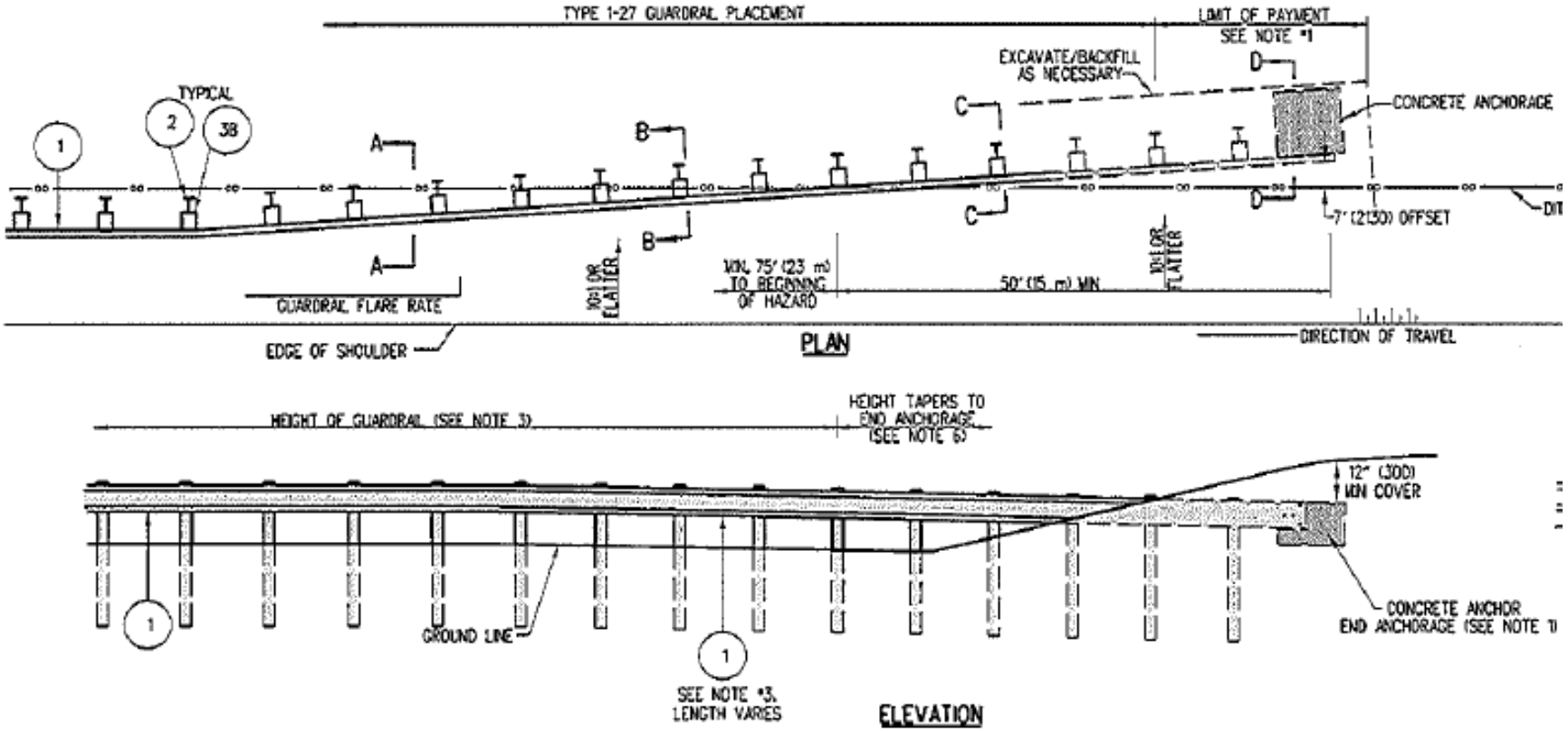
- Buried in Backslope End Terminals
  - Generic designs.
  - The terminal of choice when a natural backslope is reasonably close to the point where the barrier is introduced.
  - When properly designed and located, provides full shielding for the identified hazard, eliminates the possibility of an end-on impact with the barrier terminal and minimizes the likelihood of access behind the rail.

Guardrail Terminals: Buried in Backslope

Guardrail Terminals: Buried in Backslope

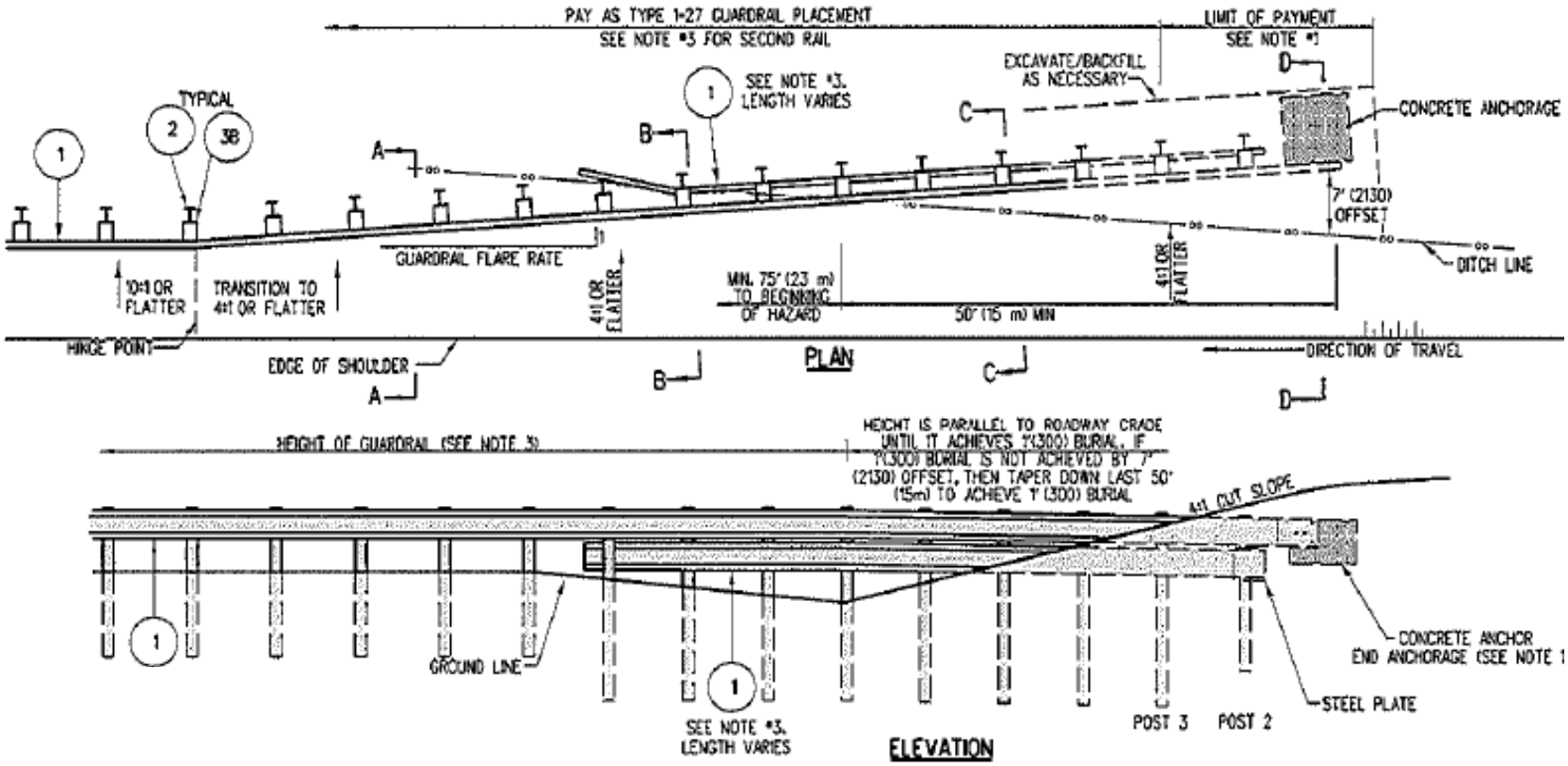
- Key design considerations:
  - Keep the height of the W-Beam rail constant relative to the roadway grade until the barrier crosses the ditch flow line,
  - Use a flare rate appropriate for the design speed,
  - Add a W-beam rubrail where needed, and
  - Use an anchor (concrete block or steel post) capable of developing the full tensile strength of the W-Beam rail.

Guardrail Terminals: Buried in Backslope



Ref: DelDOT Standard Construction Details, 2010, B20 1 of 3

Guardrail Terminals: Buried in Backslope



Ref: DelDOT Standard Construction Details, 2010, B20 2 of 3

Guardrail Terminals: Free-Standing

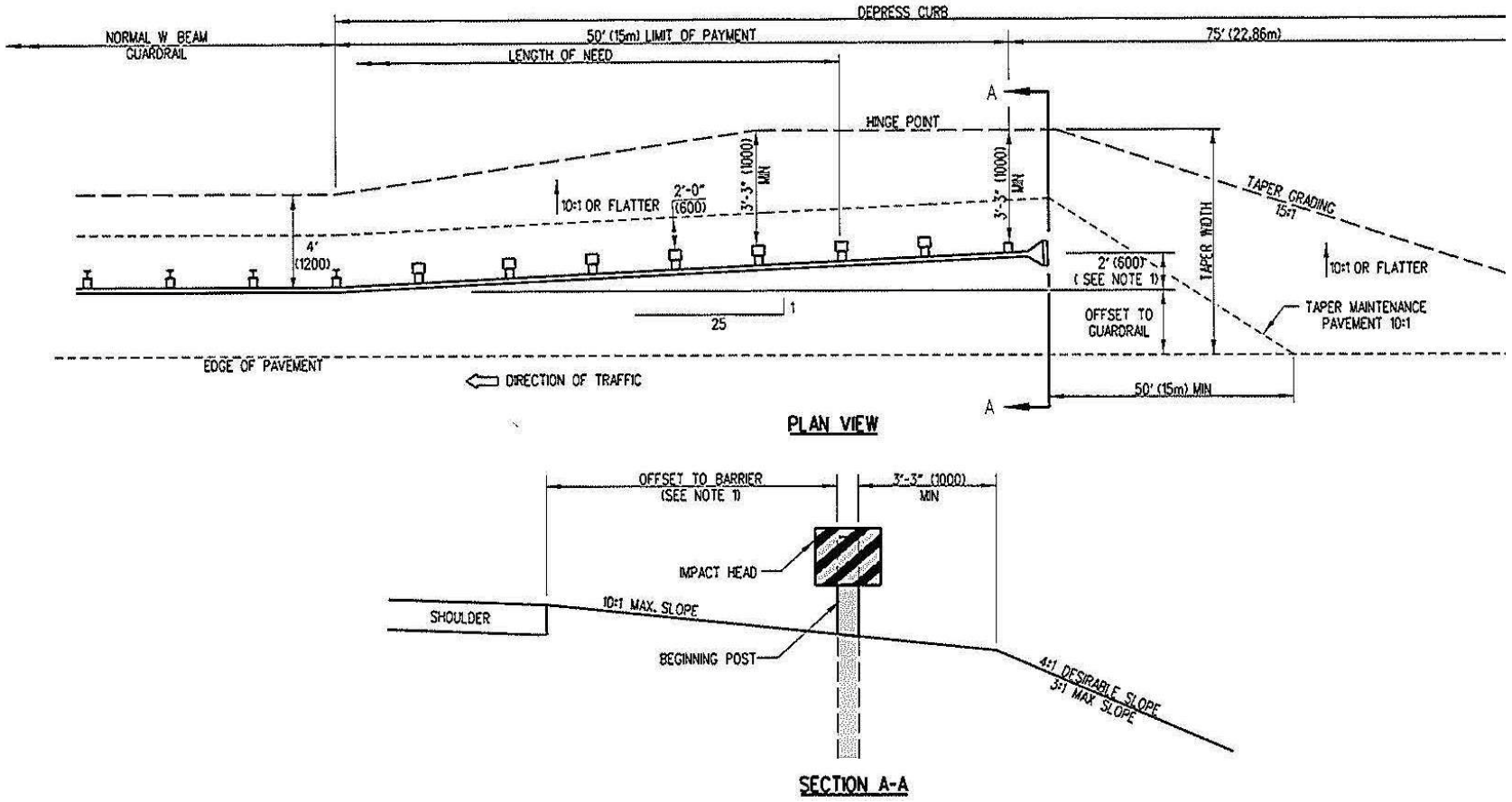
A free-standing terminal must serve two functions:

- Be crashworthy when impacted end-on.
- Provide anchorage for downstream hits.

Guardrail Terminals

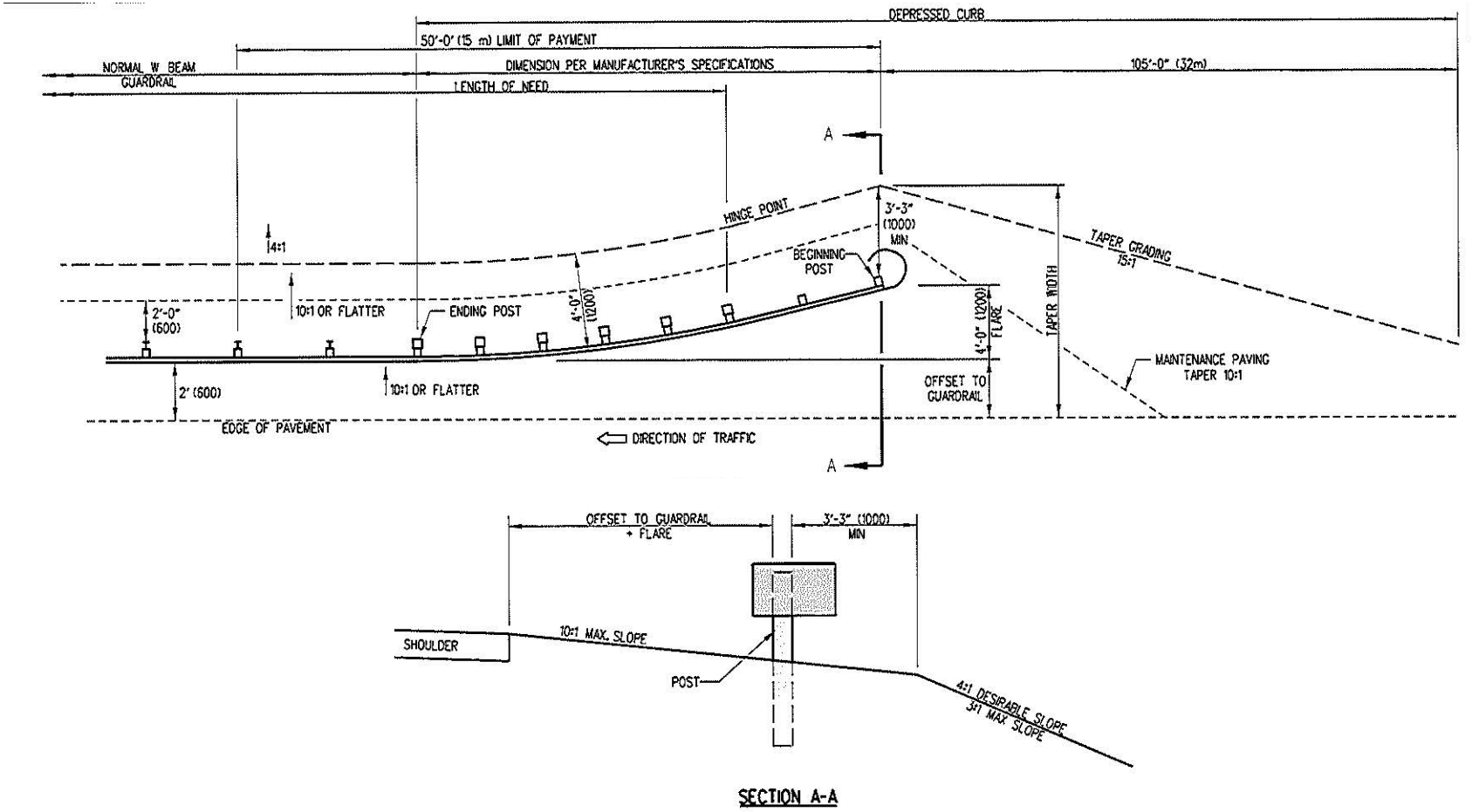
- Special grading requirements for Guardrail terminals:
  - Avoid installing terminals on or too near steep slopes.
  - Relatively flat terrain is required *in front of terminals* so that vehicles do not vault into the air or dive into the ground.
  - Modest slopes are used *behind terminals* to allow sufficient recovery areas for vehicles gating through the end treatment.
  - FHWA and AASHTO has guideline requirements for both tangent and flared terminals.

Guardrail Terminals: Energy Absorbing (Type 1)



Ref: DelDOT Standard Construction Details, 2010

Guardrail Terminals: Non-Energy Absorbing (Type 2)



Ref: DelDOT Standard Construction Details, 2010

Guardrail Terminals: W-Beam Energy Absorbing

- For W-beam tangent terminals, various foundation tube and post combination options are available - follow State standards and specifications.
  - 6’-0” long steel foundation tubes without soil plates may only be used at posts #1 and #2.
  - If foundation tubes and soil plates are used at posts #3 and #4 or at #3 through #8, the tubes must be either 4’-6” or 5’-0” long.
  - Soil plates for the tubes at posts #3-#8 are now optional.
  - 4’-6” or 5’-0” long foundation tubes with soil plates may also be used at post #1 and #2 if desired.

Guardrail Terminals: W-Beam Energy Absorbing

- ET-2000 & ET Plus (Guardrail Extruder Terminal)
  - Flattens guardrail when hit
  - Breakaway wood or steel posts (several options available)
  - 25’ long (TL-2)
  - 50’ long (TL-3)
  - Recommended 1-2 ft. offset to reduce nuisance hits
  - Cable-anchored system

ET Plus Extruder Terminal

SKT-SP & FLEAT-SP Steel Post Terminals

Guardrail Terminals: W-Beam Energy Absorbing

- SKT 350 (Sequential Kinking Terminal)
  - Kinks Guardrail when hit
  - Breakaway wood or steel posts – several options available
  - TL-2 is 25’ long; TL-3 is 50’ long
  - Recommended 1-2 ft. offset to reduce nuisance hits
  - Cable-anchored system

Guardrail Terminals: W-Beam Energy Absorbing

- FLEAT 350 (FLared Energy Absorbing Terminal)

  Straight flared (not parabolic),

  - Breakaway posts (wood or steel)
  - Energy Absorbing Variable offset 25’-0” long (TL-2) or 37’-6” long (TL-3)
  - Cable-anchored system

Guardrail Terminals: W-Beam Energy Absorbing

- X-Tension
  - Only Terminal that is Non-Gating
  - Redirective along the entire length
  - Resistance is at the impact head – works in tension
  - Cables in the W-Beam are pulled thru friction plate
  - Median, Tangent, Flared from same hardware kit

Guardrail Terminals: W-Beam Non-Energy Absorbing

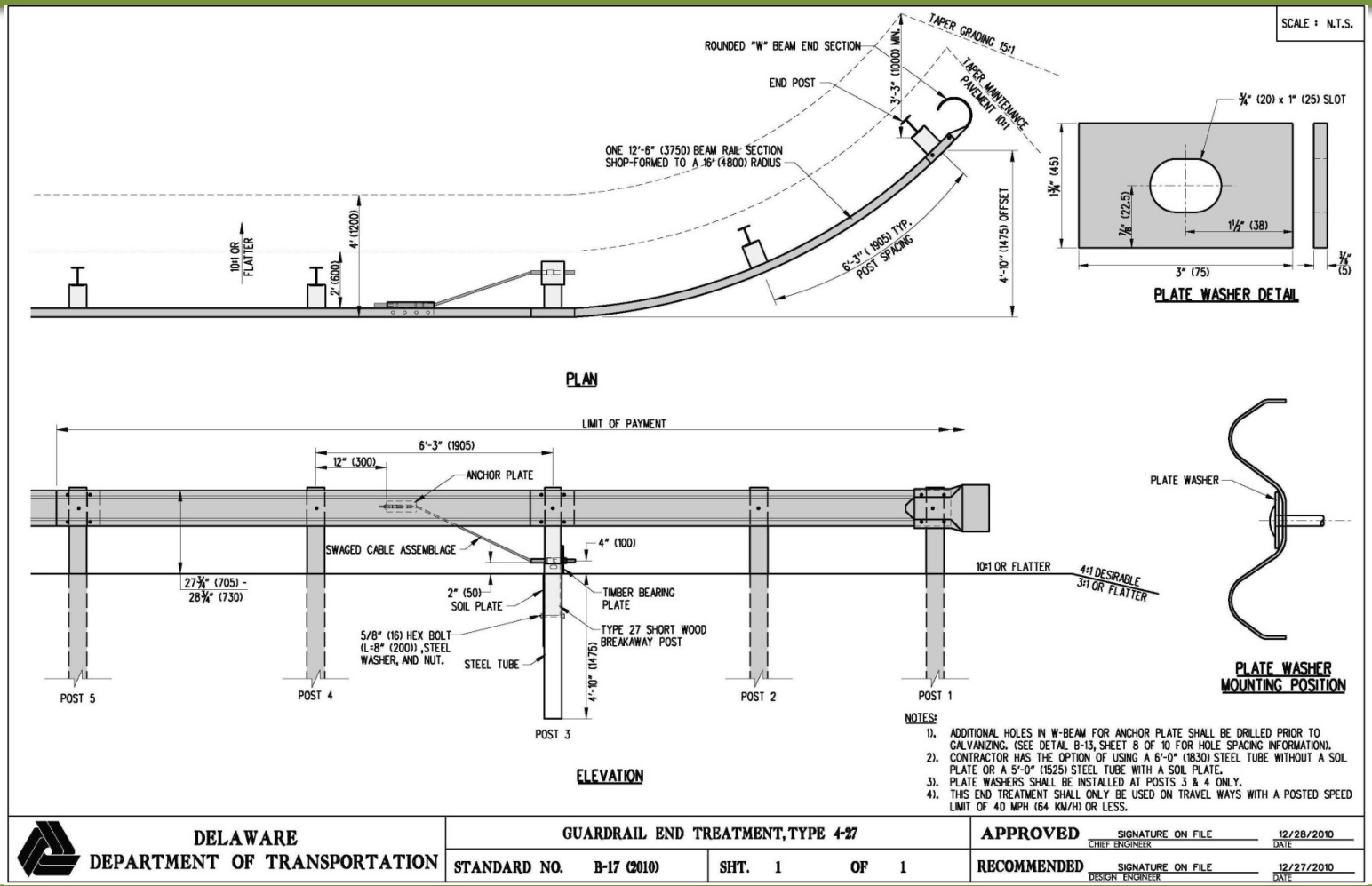
- SRT 350 (Slotted Rail Terminal)
  - W-Beam rails with a parabolic curve and oversized slots
  - Variable parabolic offset 3’-4’
  - 37’-6” long with 8 posts
  - Cable-anchored system

Slot Guard Detail

Guardrail Terminals: W-Beam Non Energy Absorbing

- SRT-HBA (Hinged Break Away) Straight Flared SRT
  - Another version of the SRT that uses 2 steel HBA breakaway steel posts and 5 breakaway wood posts.
  - 37’-6” long
  - Fixed 4’-0” offset

Guardrail Terminals: DelDOT Type 4 (TL-2 Design)



Non-Conforming Existing W-Beam Terminal Designs

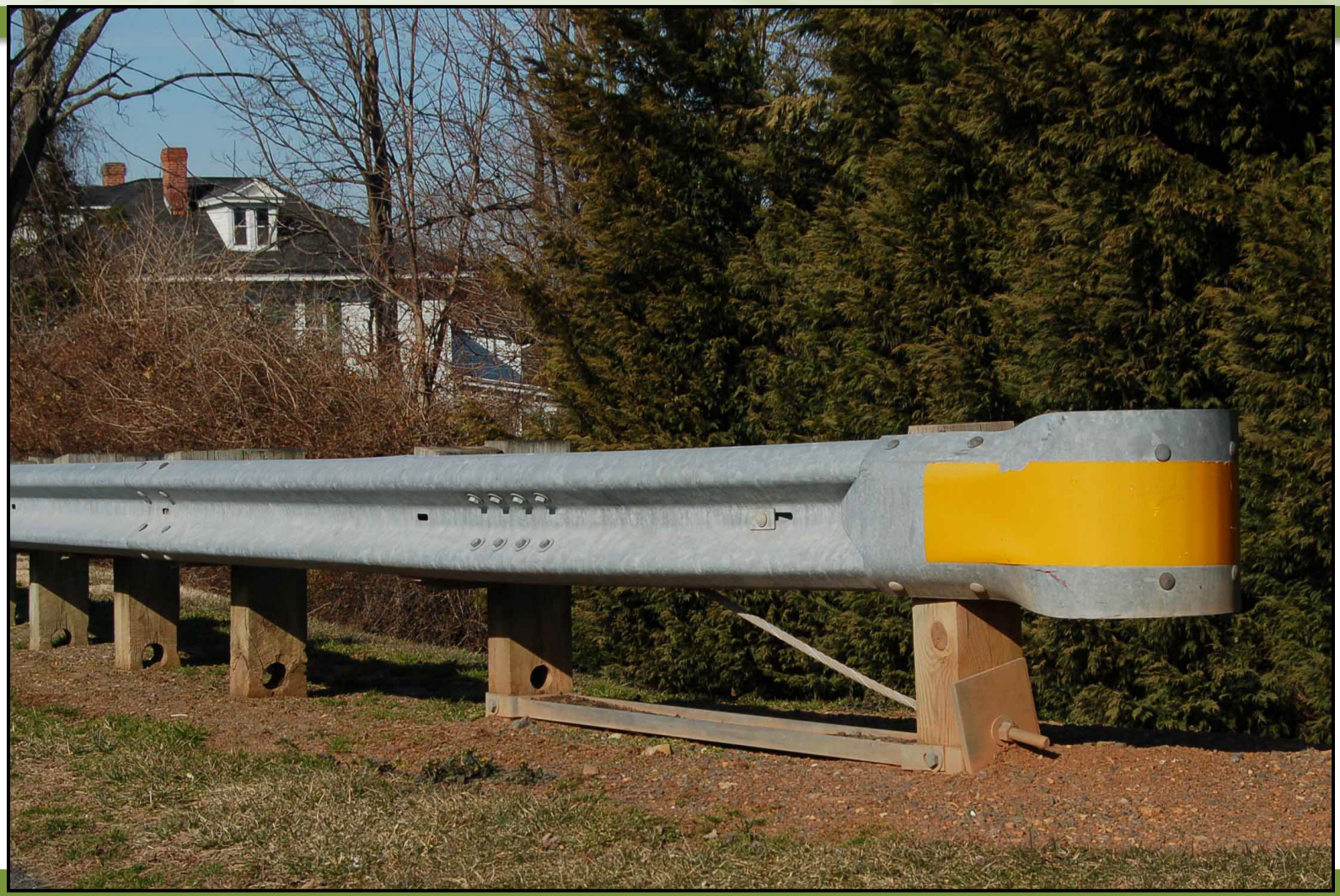
- Twisted-end Terminal
- Breakaway Cable Terminal (BCT)
- Modified Eccentric Loader Terminal (MELT)

Twisted-end Terminal

BCT


SBCT
4

MELT

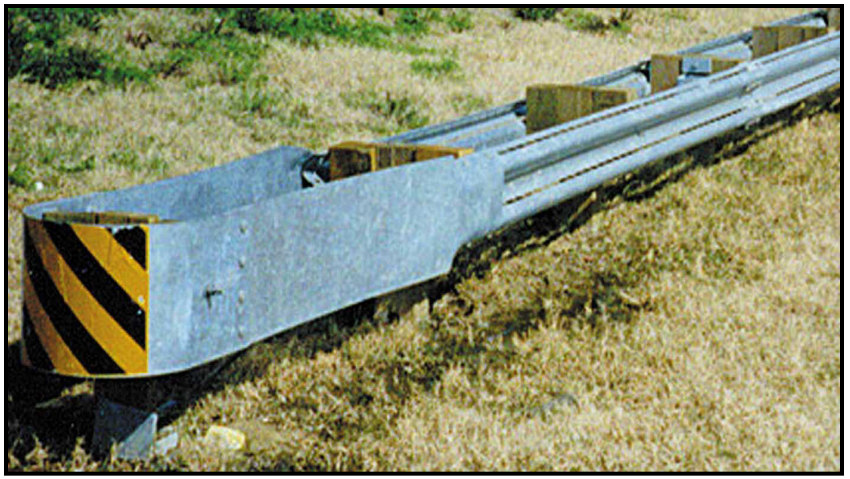


Guardrail Terminals: W-Beam Median (Type 3)

- Brakemaster 350
  - Spring-loaded braking mechanism absorbs energy.
  - Can be attached directly to a W-Beam median barrier, or to a Thrie-Beam median barrier using the standard W-Beam to Thrie-Beam transition section.
  - Short W-Beam fender panel sections 31’-6” long Cable-anchored system

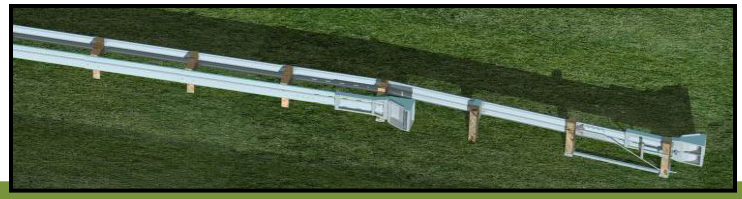
Guardrail Terminals: W-Beam Median

- CAT (Crash Cushion Attenuating Terminal)
  - Slotted rail tears tabs between slots
  - Best suited to terminate a double-faced strong-post median W-Beam barrier
  - Can be attached directly to a W-Beam median barrier, or to a Thrie-Beam median barrier using the standard W-Beam to Thrie-Beam transition section
  - Cable-anchored system



Guardrail Terminals: W-Beam Median

- FLEAT-MT (FLared Energy Absorbing Terminal-Median Terminal)
  - Intended for use in medians over 6 feet wide.
  - Attaches directly to a W-Beam median barrier, or to a Thrie-Beam median barrier using the standard W-Beam to Thrie beam transition piece.
  - During an impact, the vehicle pushes the leading impact head down the rail section while sequentially kinking the rail element.
  - Most components interchangeable with the Tangent SKT and Flared FLEAT roadside terminals.



Guardrail Terminals: W-Beam Median

- X-Tension
  - Only Terminal that is Non-Gating
  - Redirective along the entire length
  - Resistance is at the impact head – works in tension
  - Cables in the W-Beam are pulled thru friction plate
  - Median, Tangent, Flared from same hardware kit

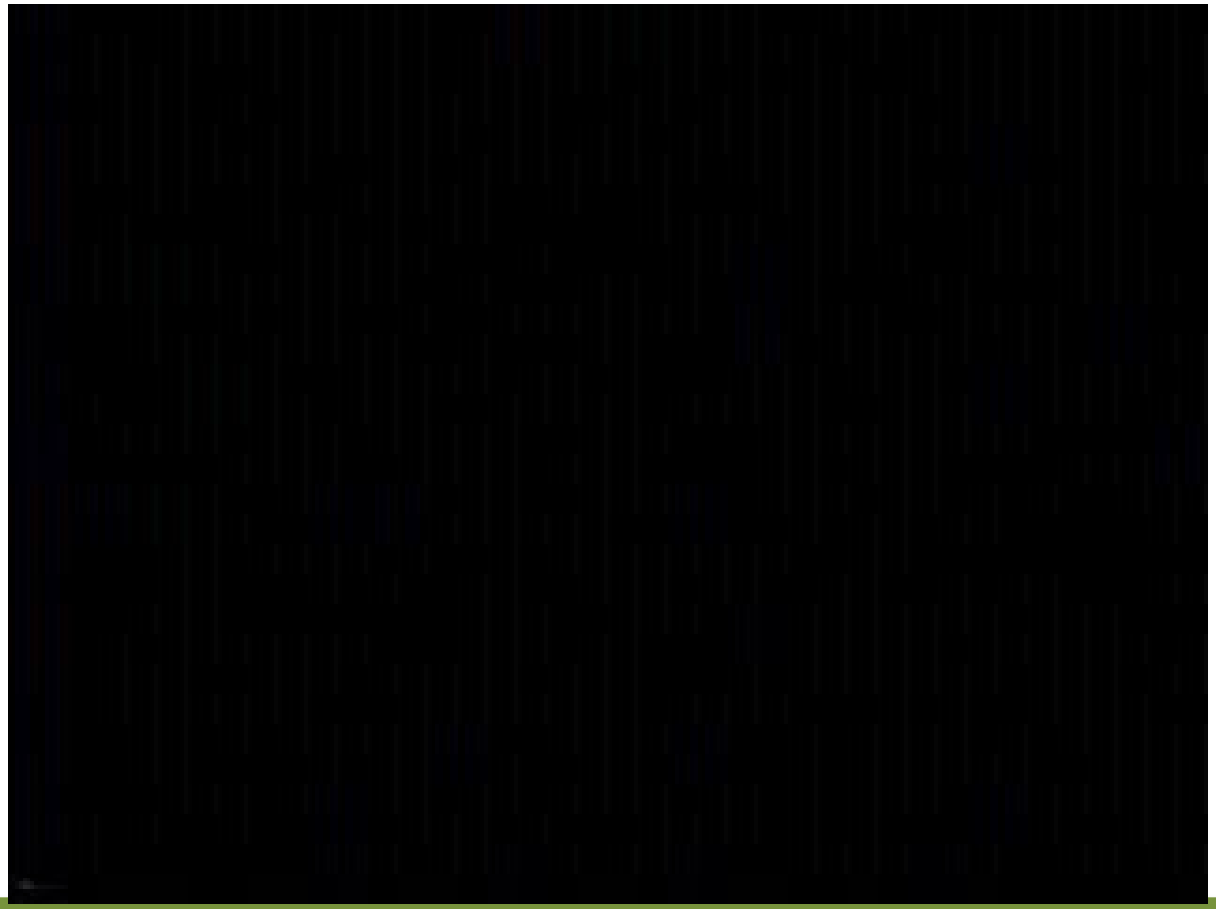
Crash Cushions

Crash cushions or attenuators are placed in front of fixed objects (to soften or “cushion” or “attenuate” impacts) that can not be treated otherwise.

- Types of crash cushions
  - Non-redirective and gating (Sacrificial)
  - Non-gating (Reusable/Low Maintenance)
- Applications of Crash Cushions
  - Permanent
  - Temporary
  - Truck Mounted
  - Special applications

Crash Cushions

Crash test with blunt end:



Crash Cushions

Crash test with ramped end:

Crash Cushions: Non-Gating

- QuadGuard
  - 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 after a crash.
  - Available in widths from 2 to 3 feet.
  - Adjustable in length from 1 to 12 bays for various speeds including 70 mph.

Crash Cushions: Non-Gating

- QuadGuard Variations:
  - **QuadGuard Wide** – wide tapered version of the Quadguard (widths from 5’-9” to 7’-6”)
  - **QuadGuard Elite** – uses High Density Polyethylene cylinders; essentially self- restoring after most impacts and best suited for use in locations where a high number of hits is anticipated.

Crash Cushions: Non-Gating

- QuadGuard Variations:
  - **QuadGuard LMC** (Low Maintenance) – narrow parallel sided version that uses elastomeric cylinders; essentially self-restoring after most impacts and best suited for use in locations where a high number of hits are anticipated.
  - **QuadGuard 69/90 LMC** – wide tapered version of the QuadGuard LMC (widths from 5’-9” to 7’-6”).

Crash Cushions: Non-Gating

- TRACC (TRinity Attenuating Crash Cushion)
  - Permanent or Construction Zone
  - TL-3 TRACC / TL-2 Short TRACC / FASTRACC / WIDETRACC
  - Designed to attach to a concrete median barrier.
  - Consists of an impact “sled,” energy absorbing tracks, intermediate steel frames, and double tiered 10 gauge W-Beam side panels; shipped to the field assembled.

Crash Cushions: Non-Gating

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

Crash Cushions: Non-Gating

- Quest

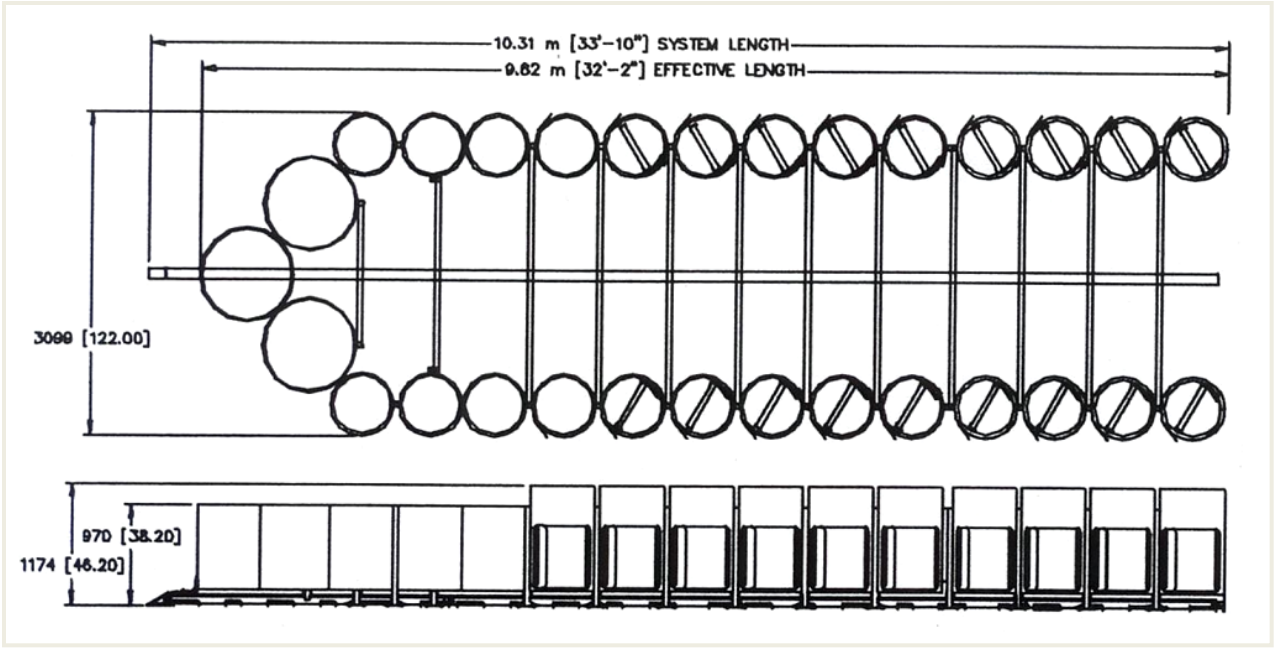
Crash Cushions: Non-Gating

- REACT 350 (Reusable Energy Absorbing Crash Terminal)
  - Permanent or Construction Zone attenuator adjustable for various speeds.
  - Intended primarily to shield the end of concrete median barrier and best used in locations where frequent hits are expected.
  - Consists of 9, 6 or 4 cylinders (3’ in diameter, 4’ tall) with varying wall thickness, re-directive side cables, and front and back anchorage.
  - Cylinders are made of High Density Polyethylene; essentially self-restoring and requires little maintenance.

Crash Cushions: Non-Gating

- REACT 350 (Reusable Energy Absorbing Crash Terminal)

Wide System / Width varies from 8’-0” to 10’-0” / 32’-2” long

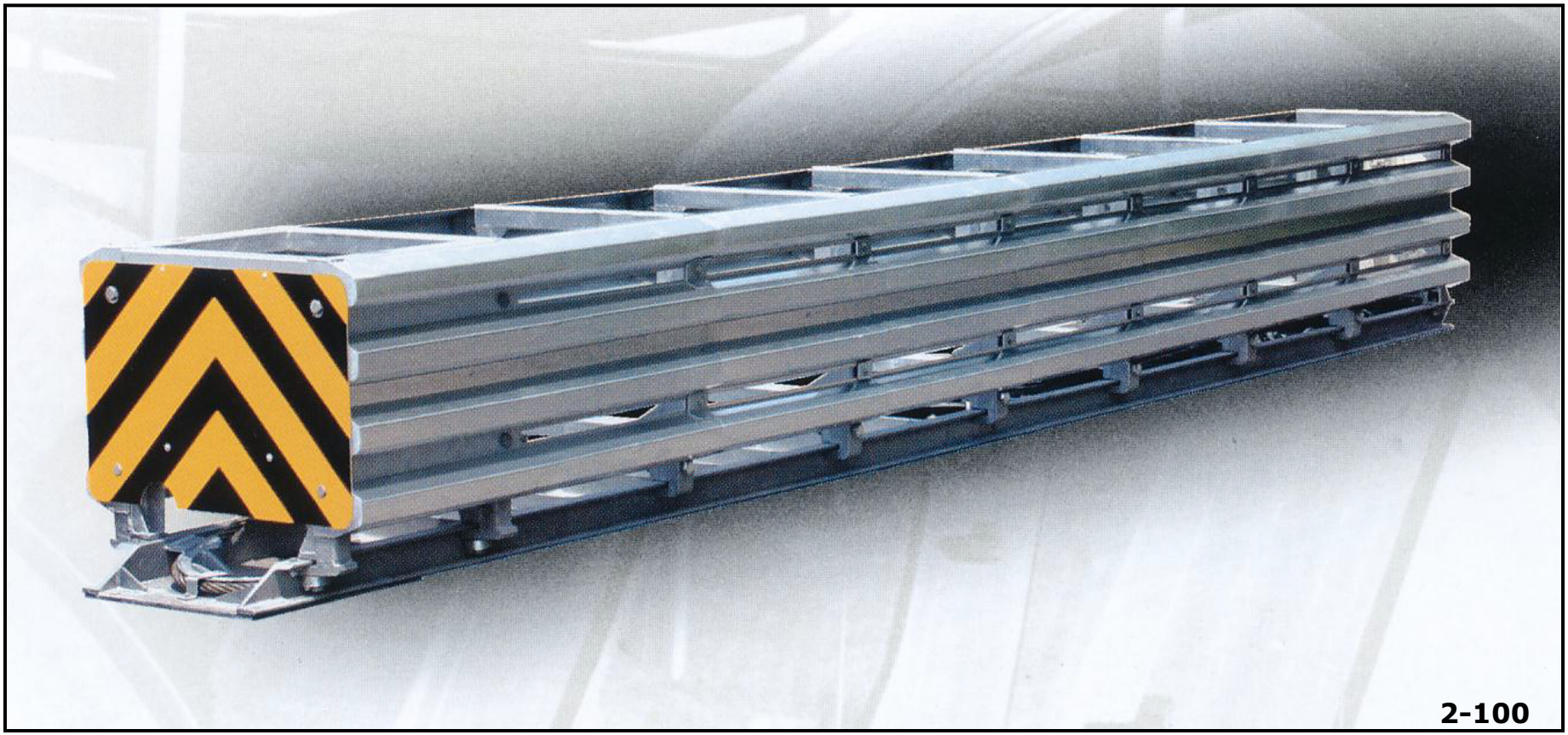


Crash Cushions: Non-Gating

- HEART Hybrid Energy Absorbing Reusable Terminal

Crash Cushions: Non-Gating

- SCI Smart Cushion
  - Variable Reaction Force
  - Re-usable without Component Replacement



Crash Cushions: BEAT

- BEAT-SSCC
  (Single Sided Crash Cushion)

- BEAT-BP
  (Bridge Pier System)

Crash Cushions: Non-Redirective and Gating

- Sand Barrels
  - Four types of sand barrels:

CrashGard /Energite / Fitch / TrafFix Devices.

  - Individual barrel designs vary in shape by manufacturer, but they all function the same. For the same barrel weights, they are interchangeable within a given array.
  - Arrays of sand barrels may be designed to shield any shape hazard.
  - Susceptible to damage from nuisance hits; best used in areas where nuisance hits are infrequent.
  - No appreciable re-directive capability, so the corner of the hazard must be reasonably shielded. The rear corner barrel should overlap the shielded object by at least 30”.

Crash Cushions: Non-Redirective and Gating

- Sand Barrels:

Energite

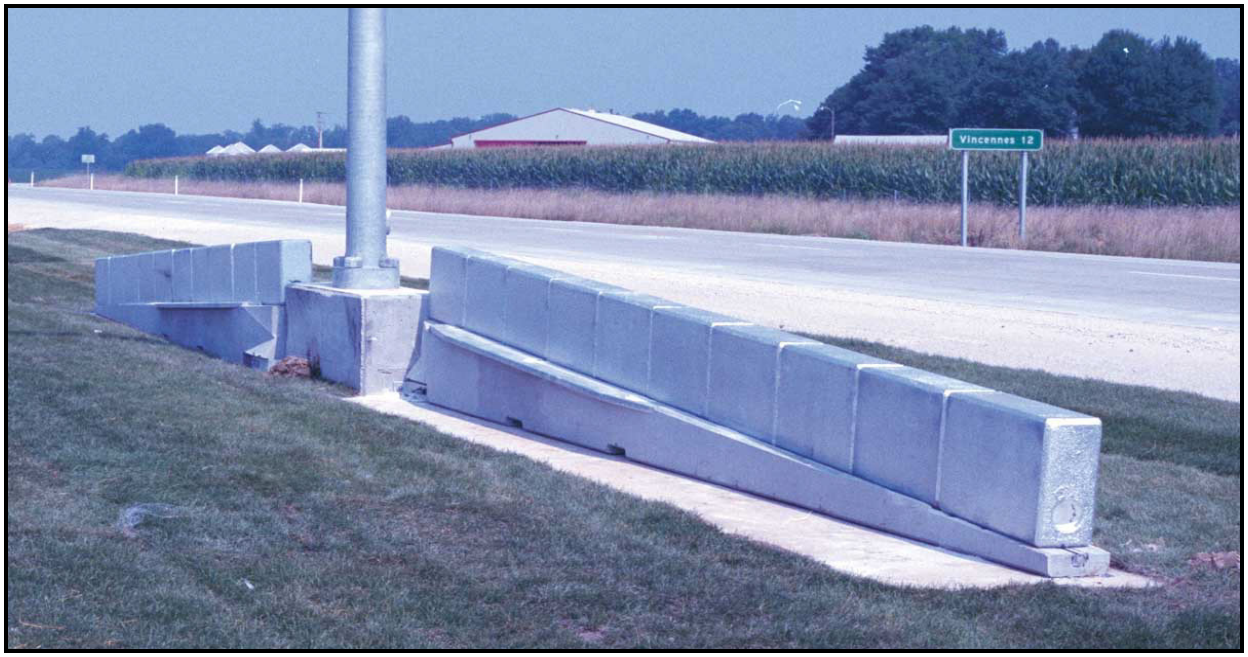
TrafFix Big Sandy

Fitch

CrashGard

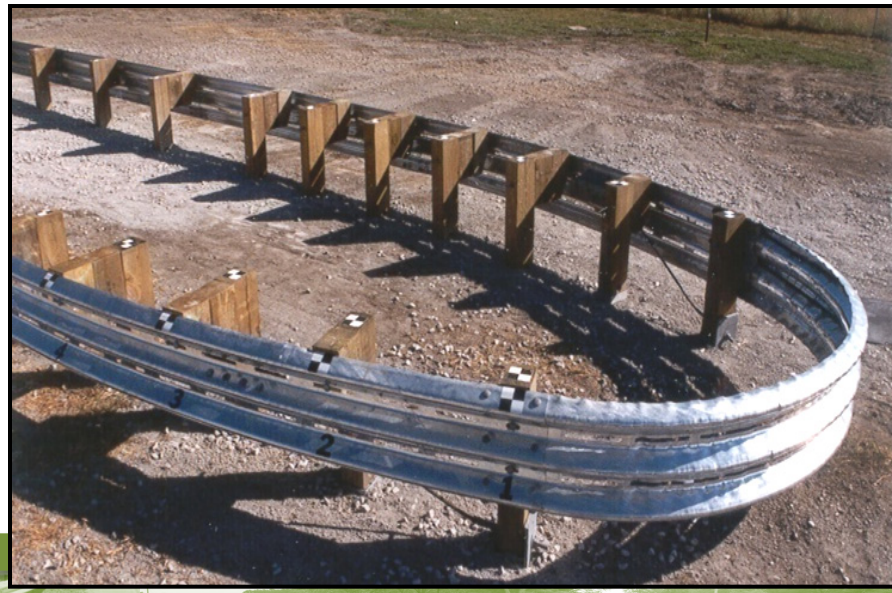
Crash Cushions: Other Products

- ADIEM (Advanced Dynamic Impact Extension Module)
  - Developed to terminate and attach directly to a concrete safety shape median barrier.
  - Consists of a precast concrete base onto which 10 low-strength concrete modules 3’-0” long are placed, making the system 30 feet long. The modules are coated to prevent moisture from deteriorating the low-strength concrete.



Crash Cushions: Other Products

- Thrie Beam Bullnose Attenuator
  - Generic design of a median treatment.
  - Consists of a symmetrical assembly of 5 slotted Thrie-Beam rails: front section with a 5’-2” radius, two with a 34’-1” radius and two straight sections.
  - Two steel cables are set behind the top two corrugations in the curved nose section to help capture the vehicles during end-on impacts.



Crash Cushions: Other Products

- EASI-Cell Crash Cushion
  - Designed for locations such as tollbooths, utility poles and railroad crossing signals.
  - Consists of an array of High Density Polyethylene cylinders in 8 rows of 4 columns each, making the unit 4’-3” wide x 8’-6” deep. Each individual cylinder is 12 ¾” diameter and 3’-3” tall.
  - Designed to be self-restoring after impacts.

Crash Cushions: Other Products

- CushionWall
  - Energy Absorbing wall

Session 2 Outcomes

- Know What Tests are Required for Safety Hardware Acceptance
- Understand How Common Barrier, Terminal, and Crash Cushion Systems Function
- Be Aware of Alternative Systems