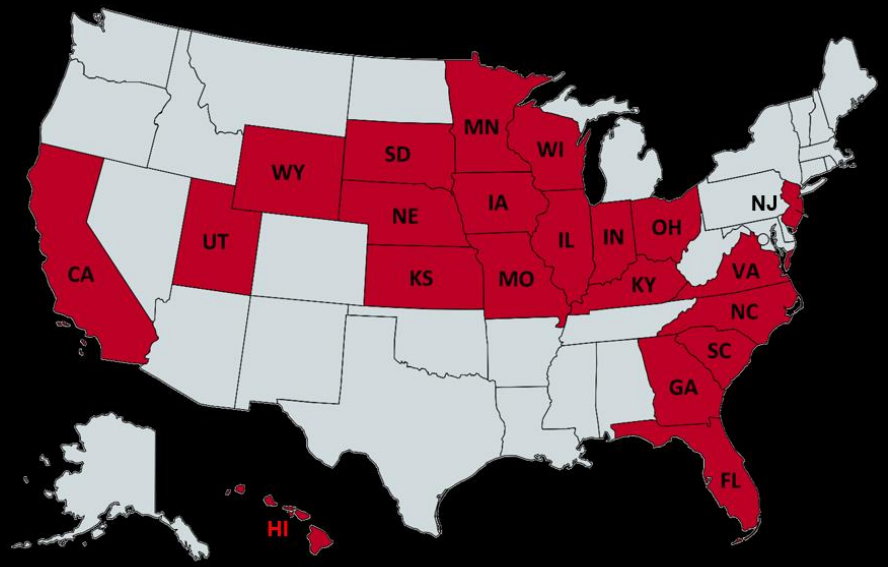
Midwest Pooled Research Progress Update

Midwest Roadside Safety Facility

University of Nebraska-Lincoln



Midwest Pooled Fund Program

- Recently initiated research efforts for FY2022 program in July 2022
- FY2023 program research efforts will initiate in Fall 2022

FY2022

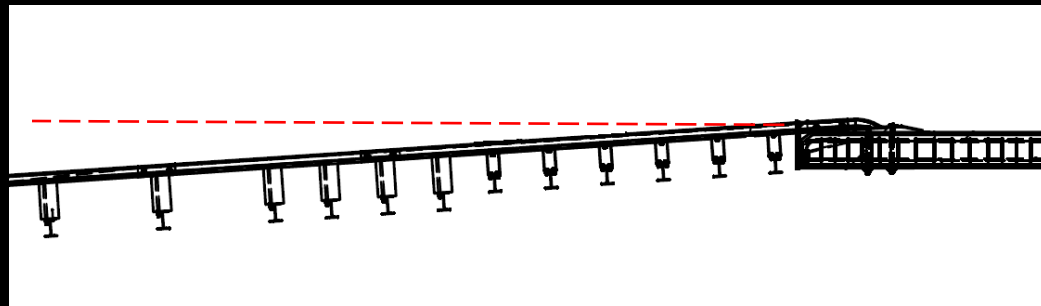
- RPFP-FY2022-MGS-4 - Evaluation of Increased Blockout Depth with the Midwest Guardrail System
- RPFP-FY2022-MGS-5 - Surface Mounted Strong-Post MGS
- RPFP-FY2022-WZ-2 - MASH TL-3 Portable Barrier System – Phase II
- RPFP-FY2022-AGT-3 – Median Approach Guardrail Transition to Concrete Median Barrier
- RPFP-FY2022-WZ-3 - Midwest PCB – Anchored Median Installations
- RPFP-FY2022-MPFW - Midwest Pooled Fund Website
- RPFP-FY2022-CONSULT - Annual Consulting Services Support
- RPFP-FY2022-LS-DYNA - LS-DYNA Modeling Enhancement Support

FY2023

- RPFP-FY2023-MGS-1: Modification and Evaluation of the MGS Long Span with Increased Span Length
- RPFP-FY2023-AGT-1: Guidelines for Flaring Thrie-Beam Approach Guardrail Transitions - Phase IV (Continuation)
- RPFP-FY2023-GET-1: Generic End Terminal – Further Development and Evaluation
- RPFP-FY2023-MWQA-1: Continued Revisions to MwRSF Pooled Fund Q & A Website
- RPFP-FY2023-AUTO-1: Coordination and Collaboration with Vehicle Manufacturers and Automotive Industry
- RPFP-FY2023-MPFW - Midwest Pooled Fund Website
- RPFP-FY2023-CONSULT - Annual Consulting Services Support
- RPFP-FY2023-LS-DYNA - LS-DYNA Modeling Enhancement Support

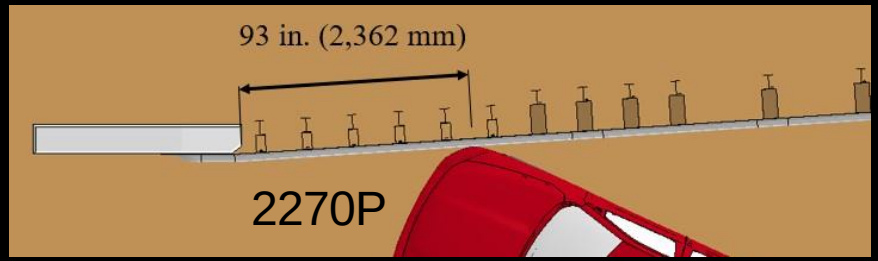
Flared AGT – Phase II

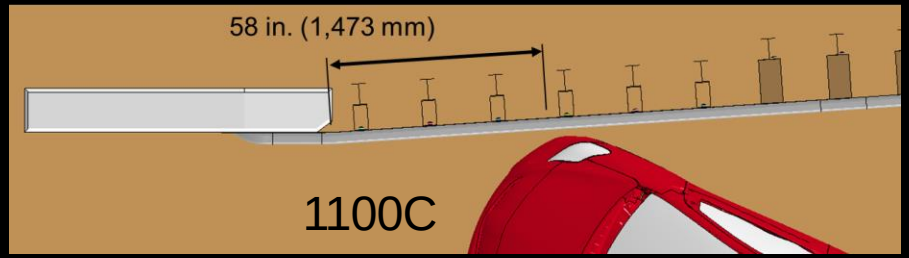
- Objective
  - Develop guidance for flaring AGTs away from the roadway
  - Phase I (YR29): Simulation, selection of flare rate and CIPs
  - Phase II (YR30 & FY 2021): Full-scale crash testing
- Recent Developments
  - Full-scale test no. FLAGT-2 and FLAG-3



Flared AGT

- Phase I Summary
  - LS-DYNA simulation study
  - Identified 15:1 flare as critical flare rate
  - Identified CIPs for 2270P and 1100C vehicles at downstream end of AGT





Flared AGT – Test Article

- W6x9 posts @ 18.75”
- Nested thrie beam
- 15:1 flare @ US end of buttress
- Standardized Transition Buttress

Test No. FLAGT-1

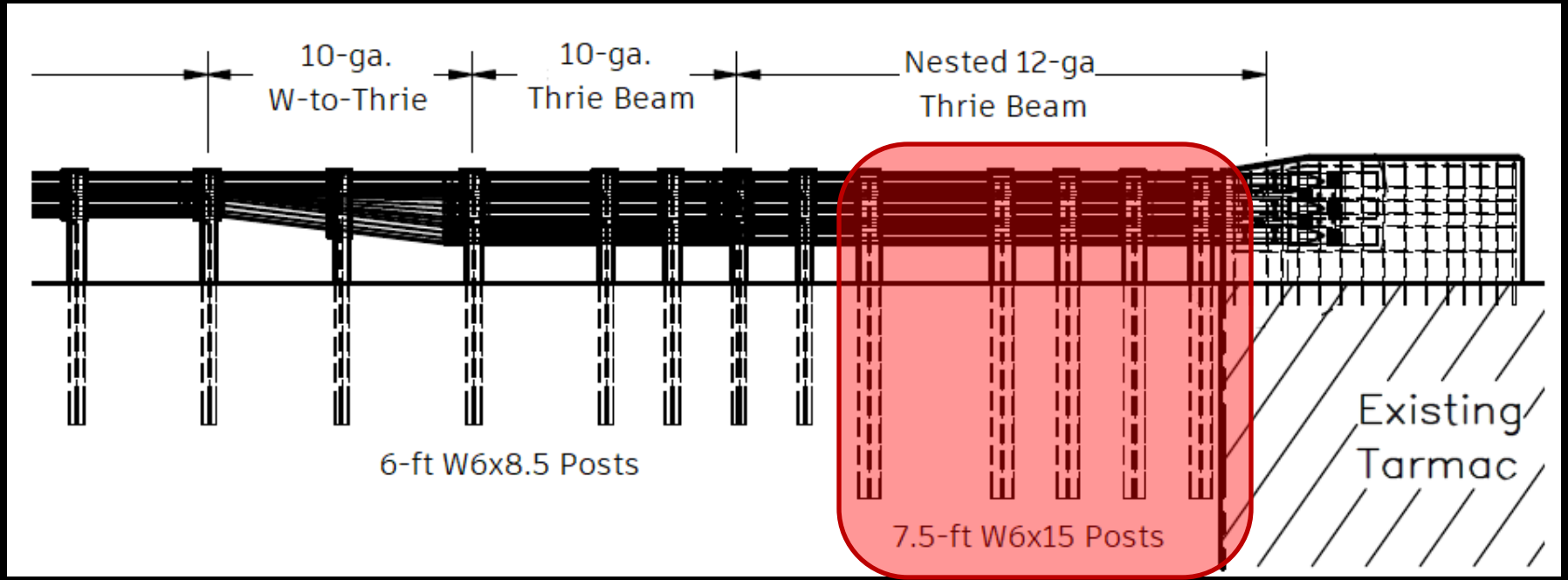
FLAGT-1

Impact Speed	63.3 mph
Impact Angle	25.7° (29.5° effective)
Max. Roll	19°
Max. Pitch	-12°
OIV - Longitudinal - Lateral	-29.1 ft/s -24.1 ft/s
ORA - Longitudinal - Lateral	-24.23 g's -12.46 g's
Dynamic Deflection	16.8 in.
Permanent Set	11.5 in.
Toe Pan Crush	12.0 in. > 9.0

15:1 Flare ➔ 30% increase in I.S.

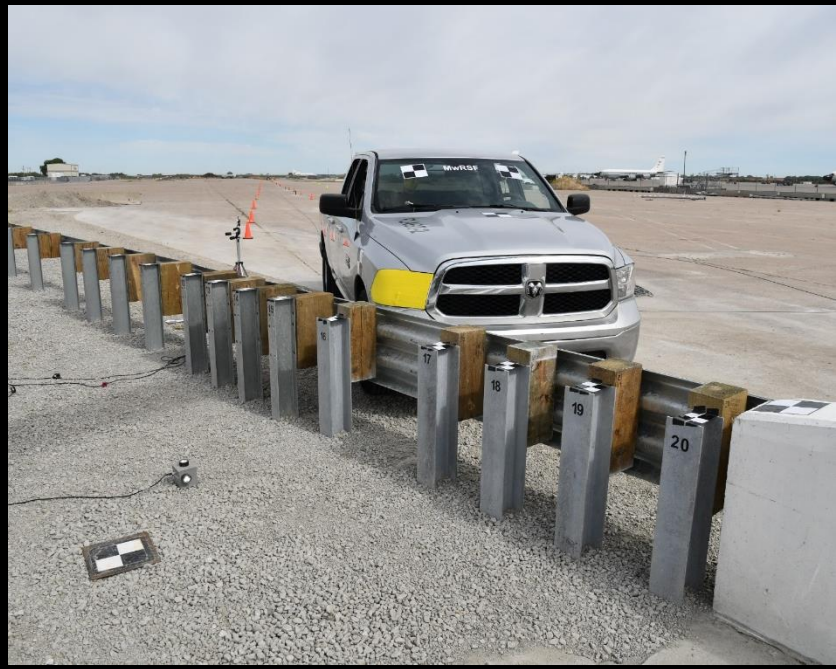
- Higher deflections
- Significant soil movement
- Rail kink/crease at buttress

Flared AGT – System Modifications



- 6.5-ft long W6x9s replaced with 7.5-ft long W6x15s

Test FLAGT-2



Test FLAGT-2

FLAGT-2

Impact Speed	62.6 mph
Impact Angle	25.3° (29.1° effective)
Max. Roll	73°
Max. Pitch	-11°
OIV - Longitudinal - Lateral	-30.4 ft/s -25.6 ft/s
ORA - Longitudinal - Lateral	-11.7 g's -11.5 g's
Dynamic Deflection	8.9 in.
Permanent Set	4.7 in.

FLAGT-2 Occupant Compartment

- Toe pan deformation exceeded MASH limits

Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)
Roof	-1.0	≤ 4
Windshield[D]	2.5	≤ 3
A-Pillar Maximum	0.1	≤ 5
A-Pillar Lateral	-0.8	≤ 3
B-Pillar Maximum	0.0	≤ 5
B-Pillar Lateral	-0.1	≤ 3
Toe Pan - Wheel Well	9.9	≤ 9
Side Front Panel	8.1	≤ 12
Side Door (above seat)	-5.0	≤ 9
Side Door (below seat)	1.2	≤ 12
Floor Pan	6.5	≤ 12
Dash - no MASH requirement	4.3	NA

FLAGT-2, Wheel-Rail Interaction

- Wheel snagged, disengaged early
- Lead to floor pan deformation and vehicle roll

FLAGT-2 Summary

- Modified system (posts) reduced deformations by 40%-50%, similar to previous systems
- Wheel gouging/snag on rail lead to failure
- Need to modify system to prevent wheel gouging and excessive floor pan deformations

Sponsor Survey

Modification Option	Votes
1: 10-ga. Rail	0
2: Reduce flare to 20:1	8
3: 10-ga. Rail and 20:1 Flare	2
4: Develop New Rail Configuration	1

- 2 DOTs indicated a willingness to go with 25:1 (if necessary)
- 2 DOTs expressed desires to avoid 10-ga. rail segments

FLAGT-3 – 20:1 Flare

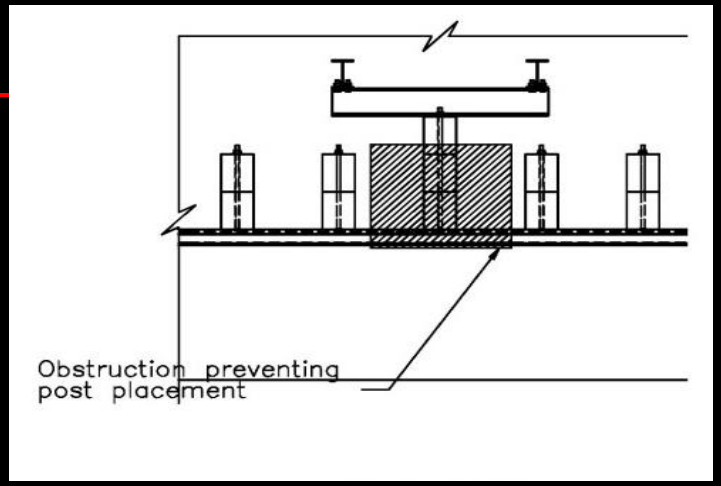
FLAGT-3 – 20:1 Flare

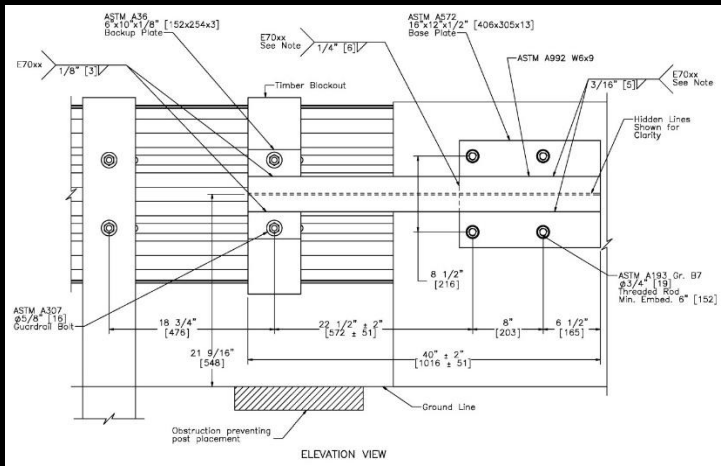
Flared AGT

- MwRSF investigating failure and design options moving forward

AGT Retrofit Options

- Objective:
  - Develop retrofit options for AGTs where obstructions prevent proper post installation
  - Expand on surrogate post options developed previously – Report TRP-03-266-12
- Recent Developments:
  - Concept Development
  - LS-DYNA Simulation
  - Test Plan / CAD





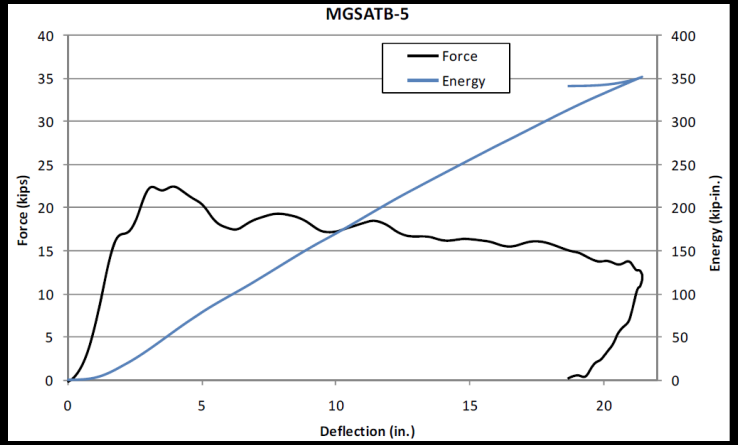
DOT Survey

- Most common site constraints preventing proper post installation
  - Obstructions (drainage structures, utilities, wingwalls
  - Sloped Terrain
  - Pavements

Selected Post Retrofit

- Top-mounted post
  - Addresses ground obstructions, posts in pavements, and possibly slopes
  - Focus on W6x15 post – worst case
  - FY 2022 Project for top mounted MGS with W6x9

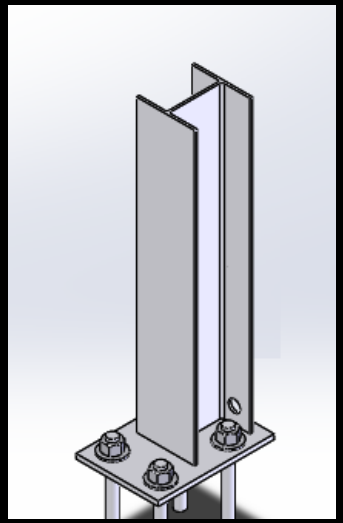
Previous Component Testing

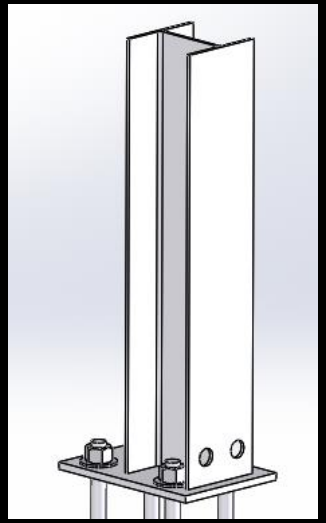


- F_{ave} = 16 -17 kips
- Top Mounted Post: F = 23 kips
  - Z_x = 10.8 $in.^3$
  - Load height = 24 in.
- Need to weaken section
  - Snag and/or pocketing hazard
  - W6x9 to W6x15 transition region
- Weakening also reduces anchor loads
  - Anchorage hardware
  - Slab / footing size

Conceptual Design

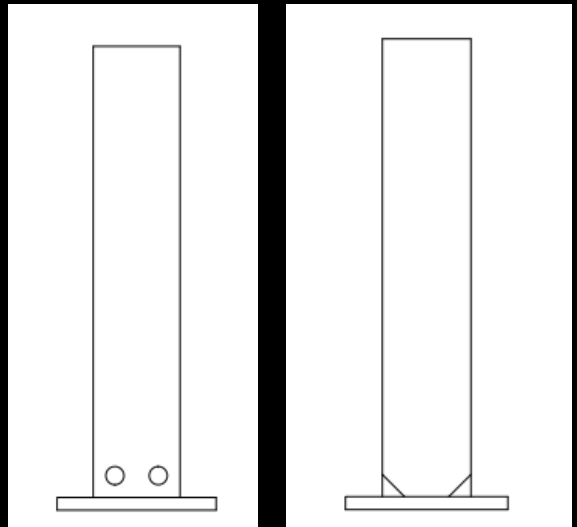
- Weaken compression flange
  - Induce buckling
- Plate bending
  - Maintain resistance force





Component Testing

- Iterative approach
  - Weld specification
  - Compression flange welding
  - Base plate thickness
  - Base plate length
  - Compression flange weakening
    - Holes
    - Chamfers



AGT Post Retrofit Options

- Remaining Tasks
  - Fabricate components
  - Dynamic component testing (6)
  - Slab and footing requirements
  - LS-DYNA analysis of new posts within full AGT

Anchoring Temporary Barrier to Asphalt Pavement Phase II

- Objective
  - Review and evaluate modifications to F-shape PCB with steel pin tie-down anchorages for asphalt road surfaces, adjacent to vertical drop-offs
  - Full-scale crash test modified barrier system to MASH TL-3
- Recent Developments
  - Design concept meeting with States in October
  - Survey and results
  - FE Modeling

Previous Testing

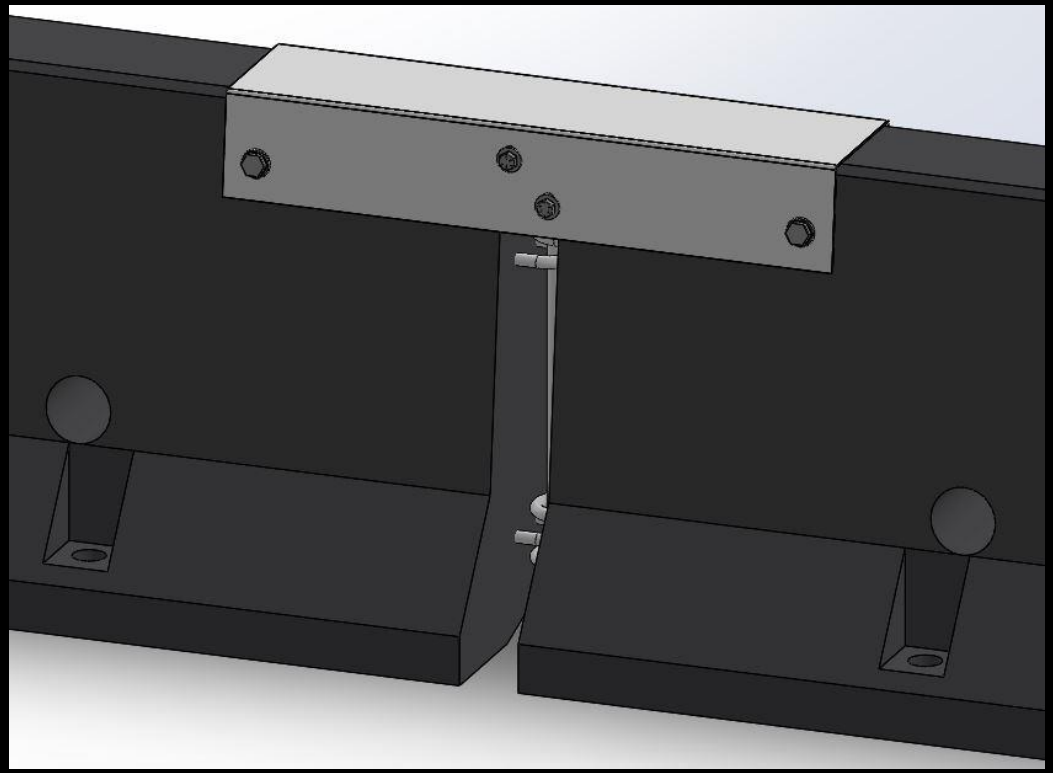
- WITD-2
  - NCHRP Report 350 system
  - Wheel well and toe pan deformation = 13.5 in. (MASH < 9 in.)
- WITD-3
  - Increased barrier offset to 18 in.
  - Wheel well and toe pan deformation = 10.4 in. (MASH < 9 in.)

Retrofit Concepts

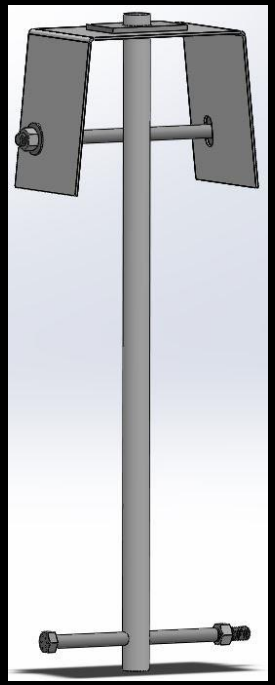
1. Saddle caps with concrete anchors
2. Saddle caps without concrete anchors
3. Front side plate
4. Back side attachments

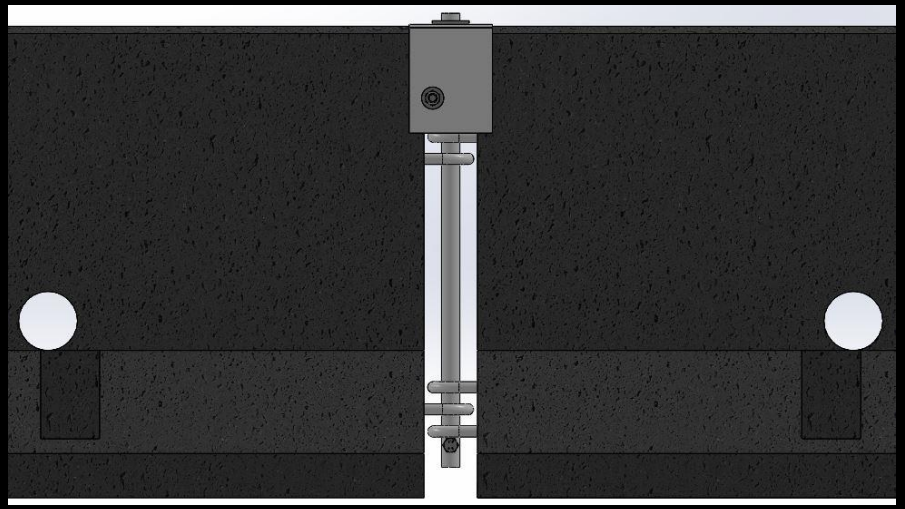
Attempt to provide shear transfer and joint shielding

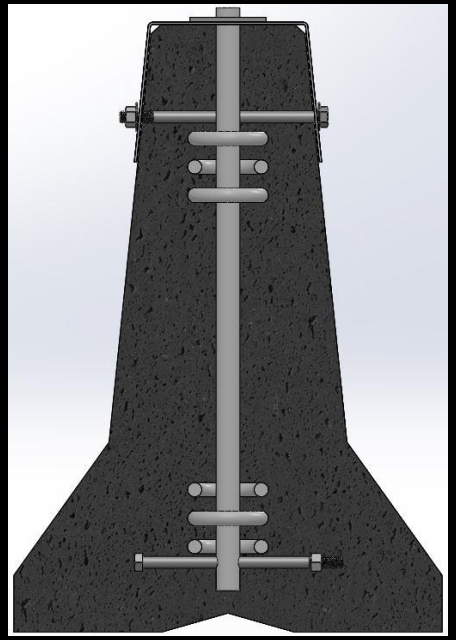
1. Saddle Cap with Concrete Anchors



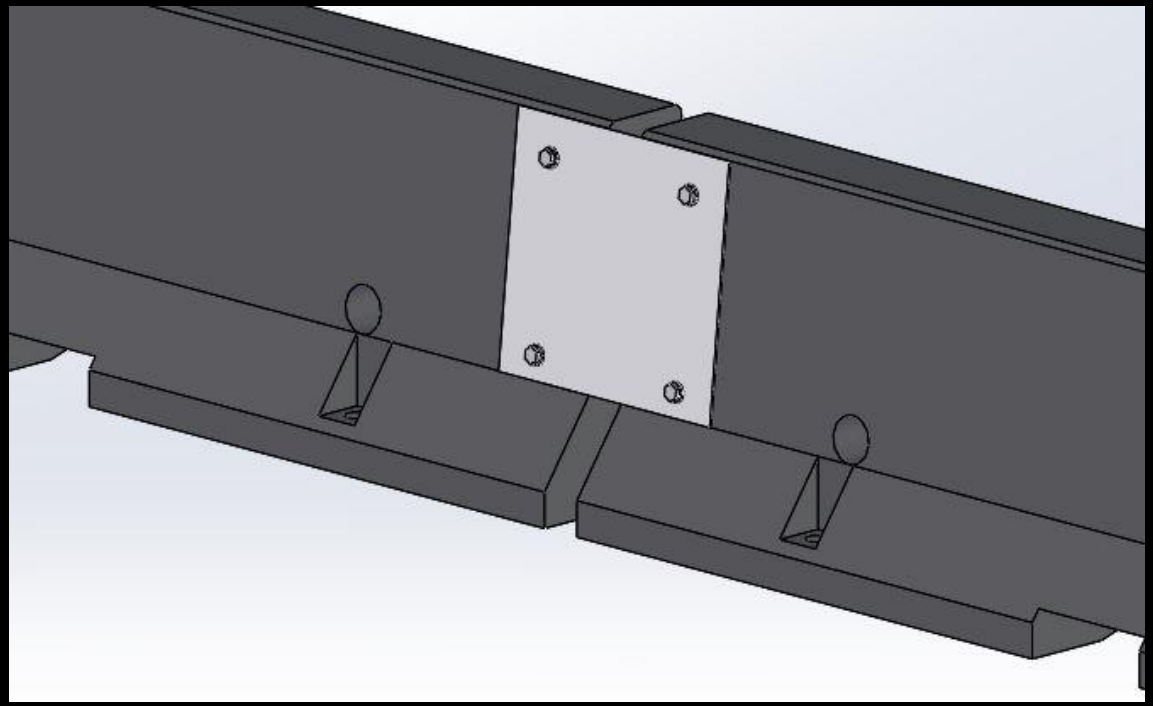
2. Saddle Cap without Concrete Anchors



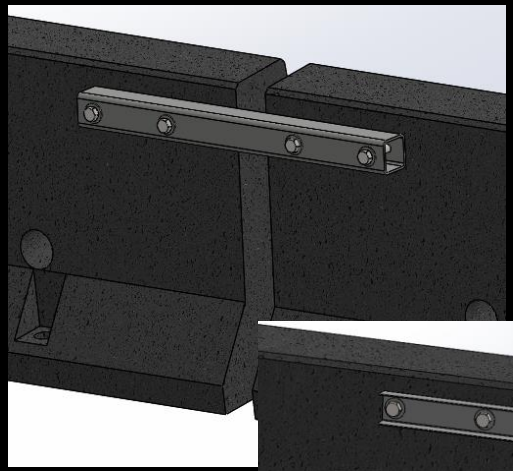


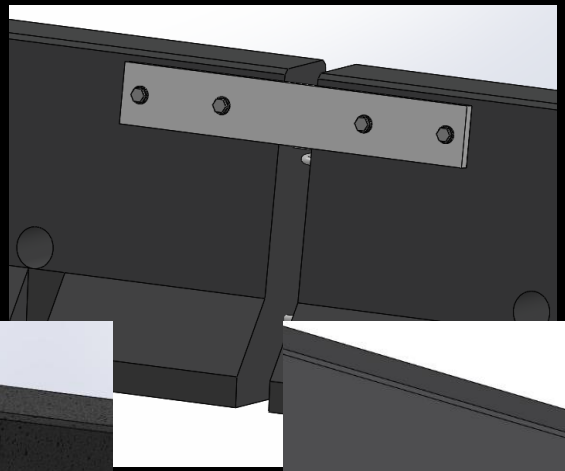


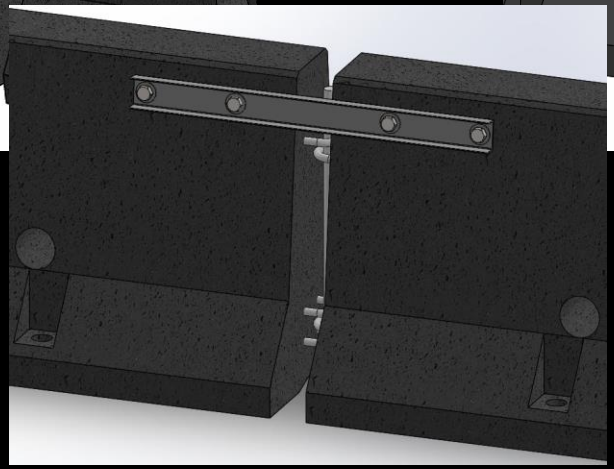
3. Front Side Plate

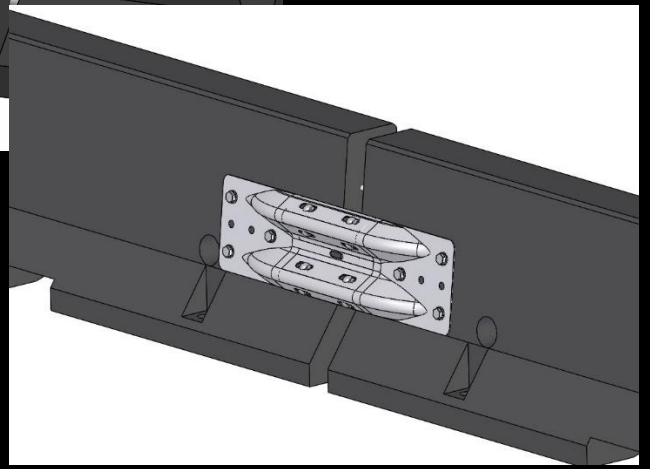


4. Back Side Attachments









MwRSF Rankings

Ranking Category	1. Saddle Cap w/ Concrete Anchors	2. Saddle Cap w/o Concrete Anchors	3. Front Side Plate	4. Back Side Attachments
Crashworthiness Potential	1	3	1	2
Installation	5	1	3	4
Cost	4	1	3	5
Total	10	5	7	11

- Ranking: 1 is best, 5 is worst, categories weighted equally
- Survey - 8 responses

Survey Results

- Preferred Concept

Item	Overall Rank	Rank Distribution	Score	No. of Rankings
Concept 2: Saddle Cap without Concrete Anchors	1		31	8
Concept 4: Back Side Attachments	2		19	8
Concept 1: Saddle Cap with Concrete Anchors	3		15	8
Concept 3: Front Side Plate	4		15	8

Future Work

- LS-DYNA analysis
  - Saddle cap without concrete anchors
  - Refine design
- Recommendation of design for full-scale testing
- Full-scale crash test – 3-11
- Summary report and recommendations

End Terminals Adjacent to Curbs

- Objective
  - Determine effect of curb adjacent to tangent, energy-absorbing guardrail end terminal
  - Full-scale crash test nos. 3-30 and 3-32
- Recent Developments
  - Development of test setup and ordering of materials

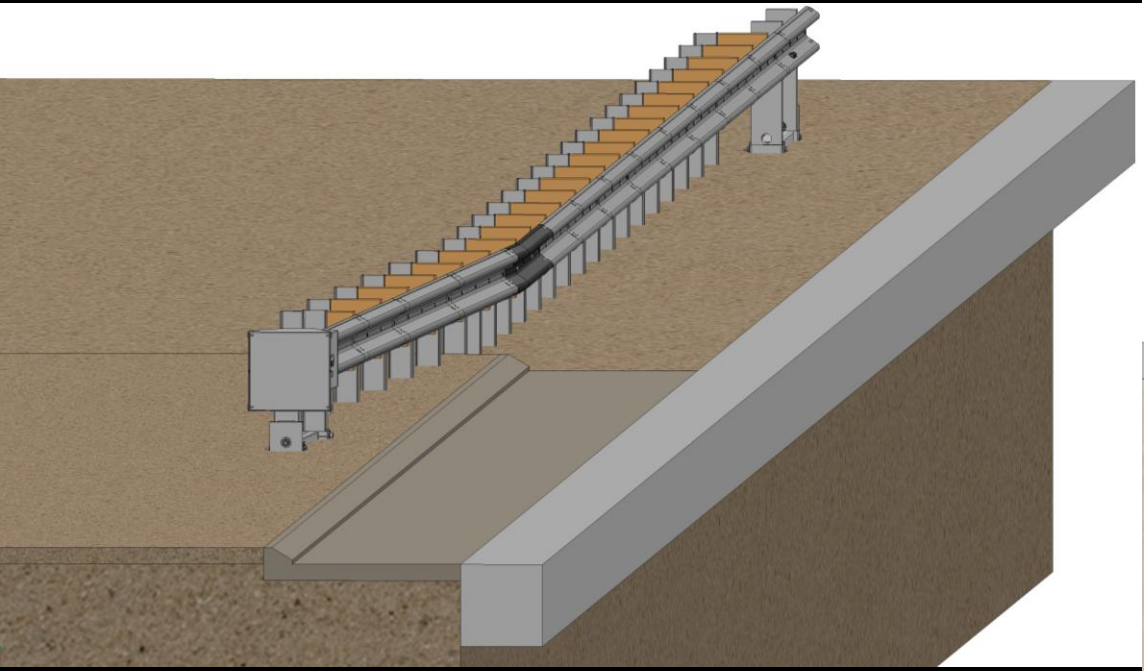
Previous Simulation Analysis

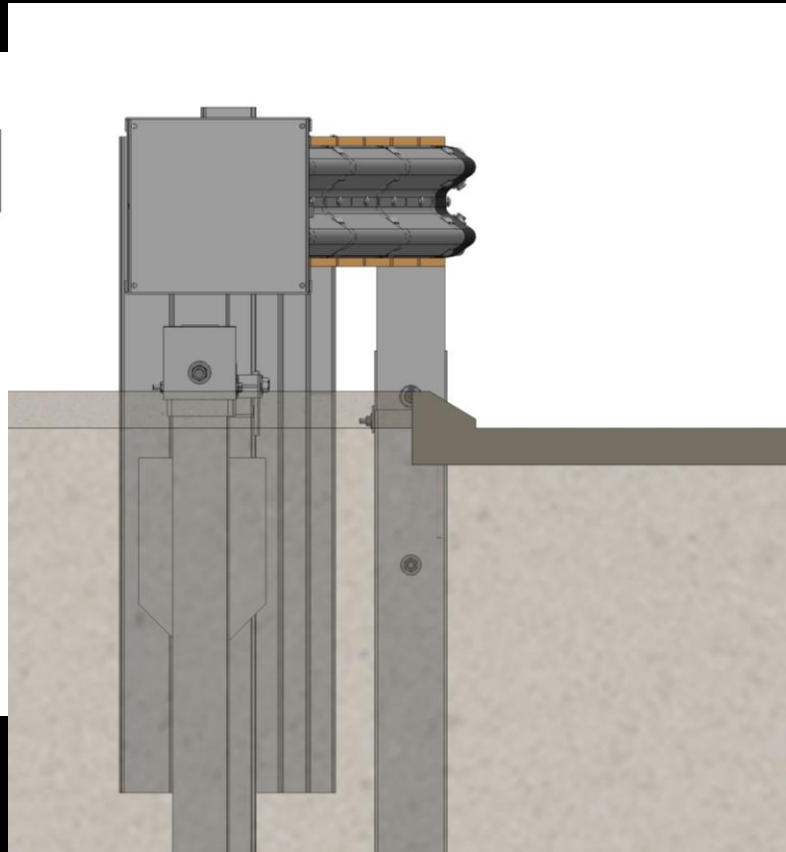
- Simulated compression end terminal with 2,” 4”, and 6” vertical and sloped curbs under various MASH terminal tests
- Results
  - 2” tall curbs had minimal effect on terminal behavior
  - 4”-6” curbs and vertical curbs generated vehicle yaw
- Recommendations
  - Conduct tests 3-30 and 3-32 on 4” tall, Type C curb

Test Configuration

- MSKT End Terminal
- Rail
  - Rail flush with curb
  - Height = 31” from roadway
- 4-in. Type C curb
- 1:25 flare
- Backfilled Curb
  - MSKT has 3” height adjustment for 31” and 28” guardrail systems

Test Configuration





Test CET-1 (MASH 3-30)

Test CET-1

Impact Speed	60.7 mph
Impact Angle	0.6°
Max. Roll	-12°
Max. Pitch	20°
Max. Yaw	250°
OIV - Longitudinal - Lateral	-22.9 ft/s -0.3 ft/s
ORA - Longitudinal - Lateral	-9.8 g's 6.8 g's
Occupant Compartment Deformation	<1/2"
Stroke Length	~17 ft

Test CET-2 (MASH 3-32, 5° angle)

Test CET-2

Impact Speed	61.2 mph
Impact Angle	~5°
Max. Roll	24°
Max. Pitch	23°
Max. Yaw	-108°
OIV - Longitudinal - Lateral	-23 ft/s 1.0 ft/s
ORA - Longitudinal - Lateral	-10.1 g's 6.8 g's
Occupant Compartment Deformation	<1/2"
Stroke Length	~18 ft

End Terminals Adjacent to Curbs

- MASH 3-30: Passed
- MASH 3-32: Passed
- Future Work
  - Analysis and comparisons to simulations and level terrain crash tests
  - No further testing currently in project
  - Summary report and recommendations

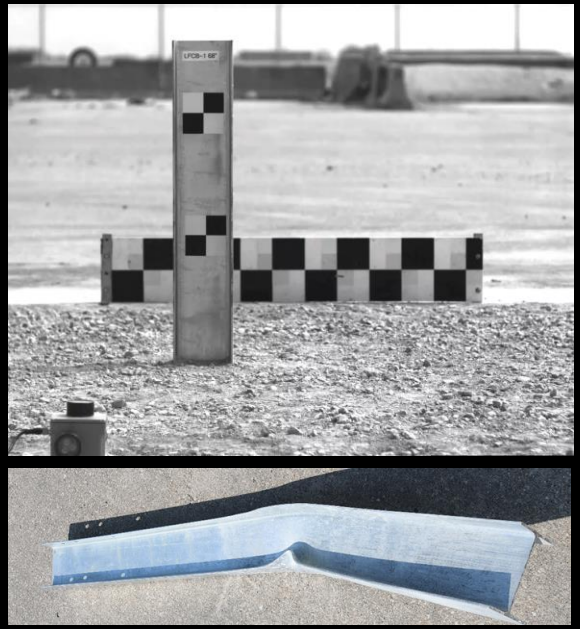
End Terminals Adjacent to Curbs

- Future Work
  - Full-scale crash testing
    - Test nos. 3-30 and 3-32
    - Anticipated May 2022
  - Analysis
    - Comparison of full-scale crash tests with previous LS-DYNA results
    - Limited LS-DYNA evaluation if discrepancies exist
    - Preliminary curb/terminal guidance based on results
    - Recommendations for further research
  - Summary report and recommendations

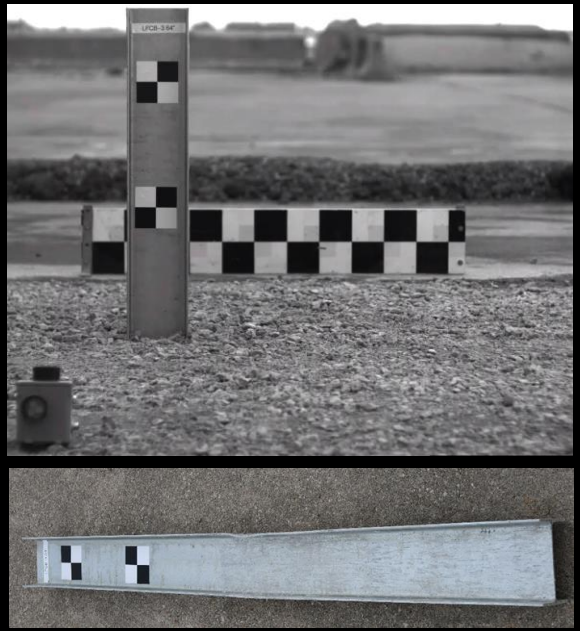
MGS over Low-Fill Culverts (Indiana)

- Objective
  - Evaluate use of MGS w/ reduced post embedment & potentially w/ reduced post spacing to satisfy MASH TL-2 & TL-3 criteria when installed over low-fill culverts
- Recent developments
  - Developed improved lumped parameter/spring models for simulating shallow embedments
  - Calibrated models using six bogie tests

Dynamic Bogie Testing – LFCB-1 ~ 6



Test Nos. LFCB-1 and LFCB-2
[W6x8.5 with 36 in. Embedment]



Test Nos. LFCB-3 and LFCB-4
[W6x8.5 with 32 in. Embedment]

Test Nos. LFCB-5 and LFCB-6
[W6x8.5 with 28 in. Embedment]

Dynamic Bogie Testing – LFCB-7 ~ 9

- W6x16 post at 40 in., 34 in., and 28 in. embedments, no post bending

Test No. LFCB-9

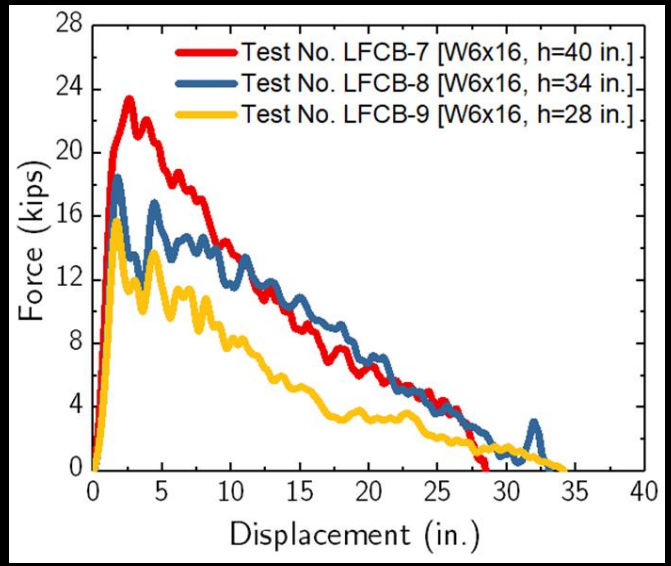
Test No. LFCB-7
[40 in. Embed.]

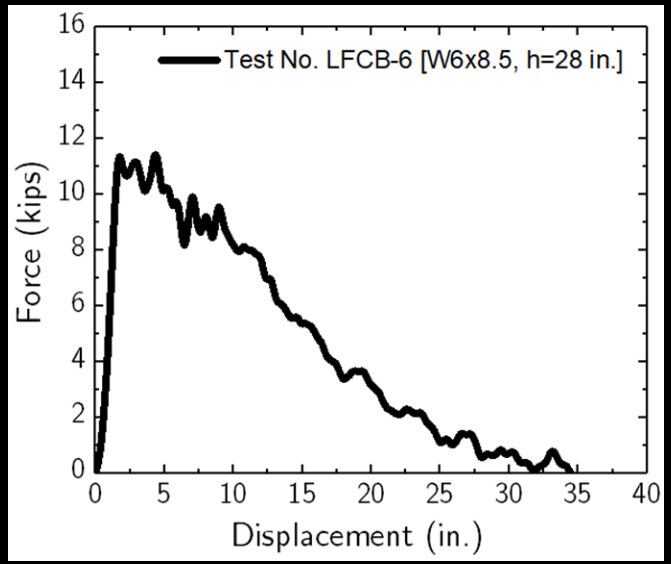
Test No. LFCB-8
[34 in. Embed.]

Test No. LFCB-9
[28 in. Embed.]

Bogie Testing Results

- Results from bogie tests LFCB-7 thru LFCB-9 & LFCB-6 used to develop spring model input for computer simulation
  - In LFCB-6, W6x8.5 post did not bend





MGS over Low-Fill Culverts (Indiana)

- Remaining Tasks
  - Incorporate calibrated reduced embedment post and soil models in full- and half-post spacing MGS
    - Simulate MASH TL-2 & TL-3 impacts
  - Recommend TL-3 and TL-2 configurations
  - Analyze need for transition to standard MGS
  - Summary report

High-Tension, Four-Cable Median Barrier System

- Objective
  - Develop MASH TL-3 high-tension, four-cable, median barrier system for placement anywhere within 6H:1V V-ditch
- Recent Developments
  - Draft report - MASH 3-11 (level terrain), MASH 3-17 (6:1 V-ditch)

Testing Completed

- Test 3-11 w/ 8 ft post spacing (MTP-1)

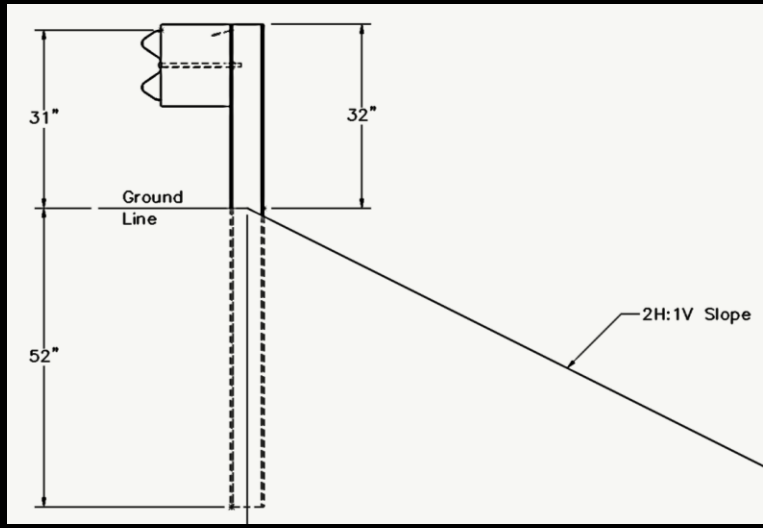
- Test 3-17 w/ 16 ft post spacing (MTP-2)

Future Work

- Publish summary report - tests MTP-1 & MTP-2
- Initiate FY2021 project remaining level terrain tests
  - Test designation no. 3-10 – narrowest post spacing
  - Test designation no. 3-11 – widest post spacing
  - Scheduled for late summer 2022
- Needed crash tests – V-ditch testing
    - Test designation no. 3-13 – narrowest post spacing
    - Test designation no. 3-14 – narrowest post spacing
    - Test designation no. 3-15 – widest post spacing
    - Test designation no. 3-16 – narrowest post spacing
    - Test designation no. 3-18 – widest post spacing

Modified MGS on 2:1 Slope

- Objective
  - MASH TL-3 evaluation of MGS w/ ½-post spacing and 7-ft long W-6x9 posts adjacent to 2H:1V slope
  - Two full-scale crash tests (MASH 3-10 and 3-11)
- Recent Developments
  - System fabrication
  - MGS7S-1 – Test no. 3-10 conducted
  - MGS7S-2 – Test no. 3-11 conducted



Test No. MGS7S-1

Test No. MGS7S-1

Test No. MGS7S-1

Impact Speed	62.8 mph
Impact Angle	25.3°
Max. Roll	-5.9°
Max. Pitch	-2.6°
OIV - Longitudinal - Lateral	-20.8 ft/s -19.6 ft/s
ORA - Longitudinal - Lateral	-14.6 g's -10.2 g's
Dynamic Deflection	≈ 18-20 in.
Working Width	TBD

Test No. MGS7S-2

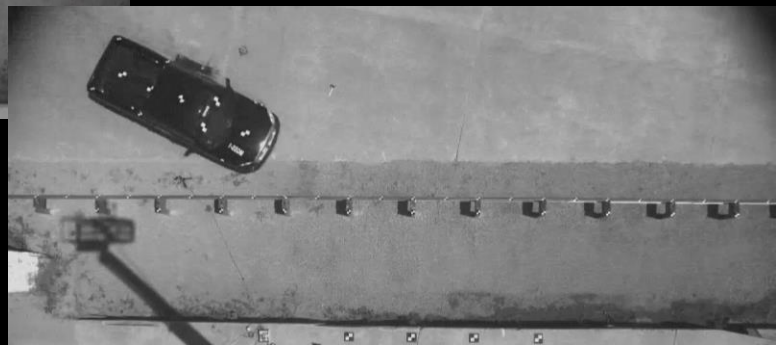
Test No. MGS7S-2

Impact Speed	62.6 mph
Impact Angle	25.4°
Max. Roll	5.7°
Max. Pitch	-3.8°
OIV - Longitudinal - Lateral	-18.5 ft/s -17.3 ft/s
ORA - Longitudinal - Lateral	-10.2 g's -9.5 g's
Dynamic Deflection	≈ 27-30 in.
Working Width	TBD

MGS Adjacent to 2H:1V Slopes

MGS w/ 7’ long posts @ 37.5” spacing
≈ 27-30” dynamic deflection

MGS w/ 9’ long posts @ 75” spacing
44.3” dynamic deflection



MGS w/ 6’ long posts @ 75” spacing
72.9” dynamic deflection

Modified MGS on 2:1 Slope

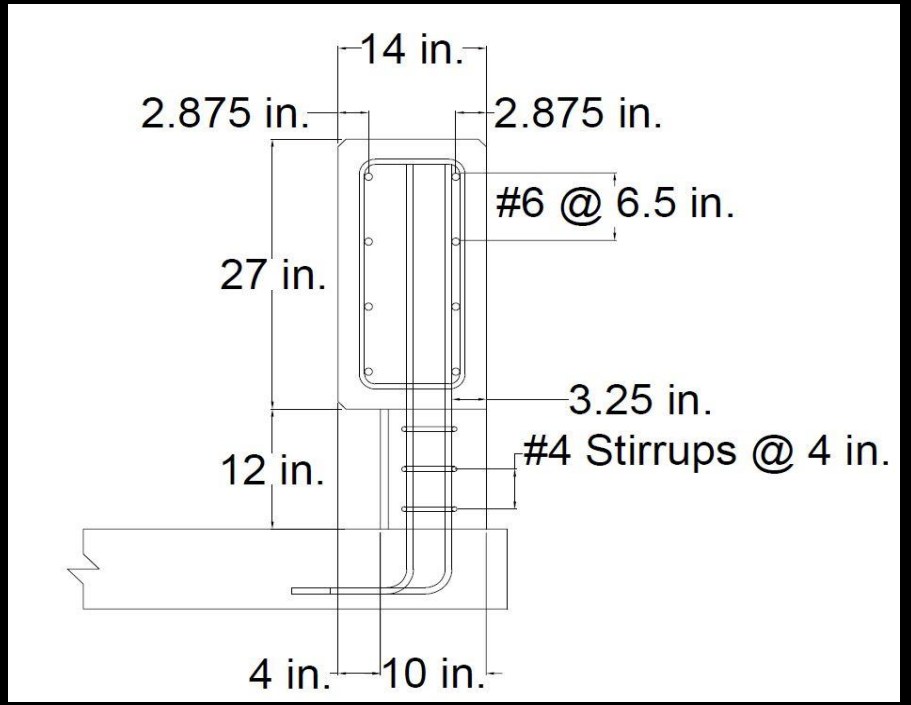
- Remaining Tasks
  - Transition recommendations
    - Review TTI reduced post spacing efforts and MGS strong post on culvert recommendations
  - Summary report
  - FHWA eligibility letter

TL-4 Open Concrete Rail (KS,IA,SD,VA,NE)

- Objective
  - Development of a MASH TL-4 open concrete bridge rail
    - Optimize vertical opening for aesthetics and drainage while mitigating snag potential
    - Limit deck damage
    - Accommodate pavement overlays
- Recent Developments
  - Test OCBR-1 – MASH 4-10
  - Test OCBR-2 – MASH 4-11
  - Test OCBR-3 – MASH 4-12

Design

- 39” height
  - 36” for TL-4 + 3” future overlay
- Beam
  - 14” wide, 27” tall
  - (8) #6 longitudinal bars
  - #4 stirrups @ 12”
- Post
  - 36” long, 10” wide, 12” tall
  - 4” post setback
  - (12) #5 vertical bars
- 9 ft post spacing
  - 6 ft openings



Test Installation

Railing height = 39”
(prior to overlay)

Test No. OCBR-1 (MASH 4-10)

Test No. OCBR-1 (MASH 4-10)

Impact Speed	64.2 mph
Impact Angle	25.3°
Max. Roll	6.3°
Max. Pitch	-6.4°
OIV - Longitudinal - Lateral	-29.2 ft/s -32.5 ft/s
ORA - Longitudinal - Lateral	-7.2 g's -12.7 g's
Dynamic Deflection	0.1"
Working Width	14.1"

Test No. OCBR-1 (4-10)

Test OCBR-2 (MASH 4-11)

Test No. OCBR-2 (MASH 4-11)

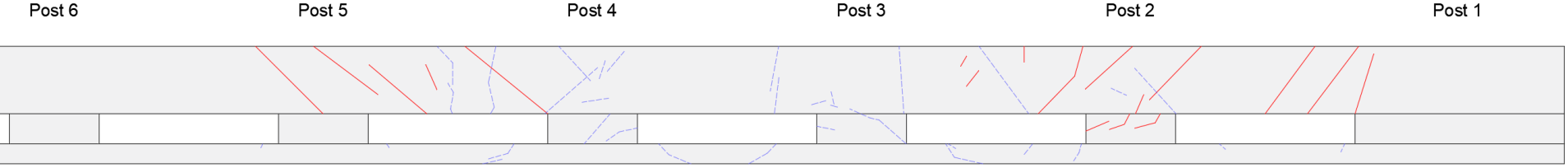
Impact Speed	61.8 mph
Impact Angle	24.7°
Max. Roll	9°
Max. Pitch	-2°
OIV - Longitudinal - Lateral	-18.3 ft/s -28.2 ft/s
ORA - Longitudinal - Lateral	-4.7 g's -10.9 g's
Dynamic Deflection	1"
Working Width	15"

Test OCBR-3 (MASH 4-12)

Test OCBR-3 (MASH 4-12)

Test OCBR-3

Impact Speed	56.6 mph
Impact Angle	15.2°
Max. Roll - Box	15°
Max. Pitch - Box	-2°
Dynamic Deflection	~1”-1.5”
Working Width	~48”



TL-4 Open Concrete Rail (KS,IA,SD,VA,NE)

- Full-scale testing
  - MASH 4-10 – pass
  - MASH 4-11 – pass
  - MASH 4-12 – pass
  - MASH TL-4 compliant
- Future work
  - Implementation guidance
  - Configure AGT attachments
  - Summary Report