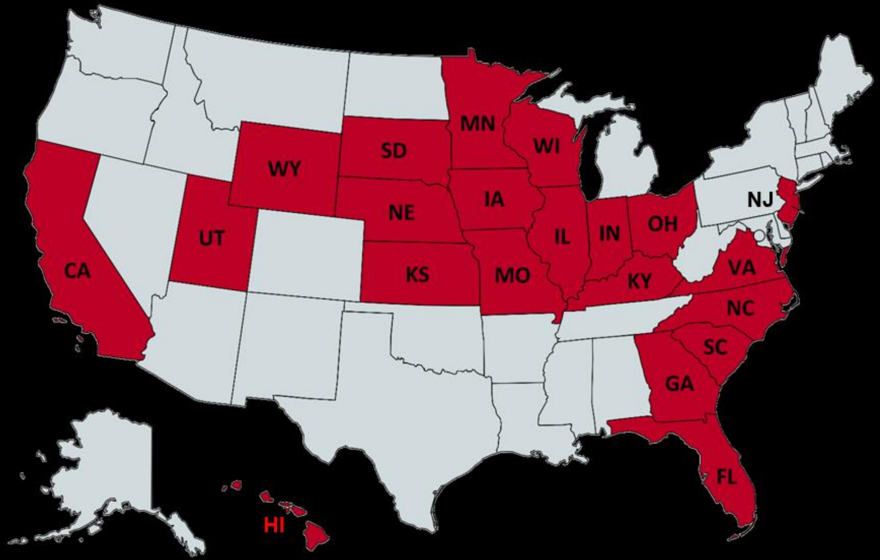
Midwest Pooled Fund Research Progress Update

Midwest Roadside Safety Facility

University of Nebraska-Lincoln



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
  - Completed full-scale crash testing
- Lead Engineer: Bob Bielenberg

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 – 2’ lateral offset
- Backfilled Curb
  - MSKT has 3” height adjustment for 31” and 28” guardrail systems

Test Configuration

Test CET-1 (MASH 3-30)

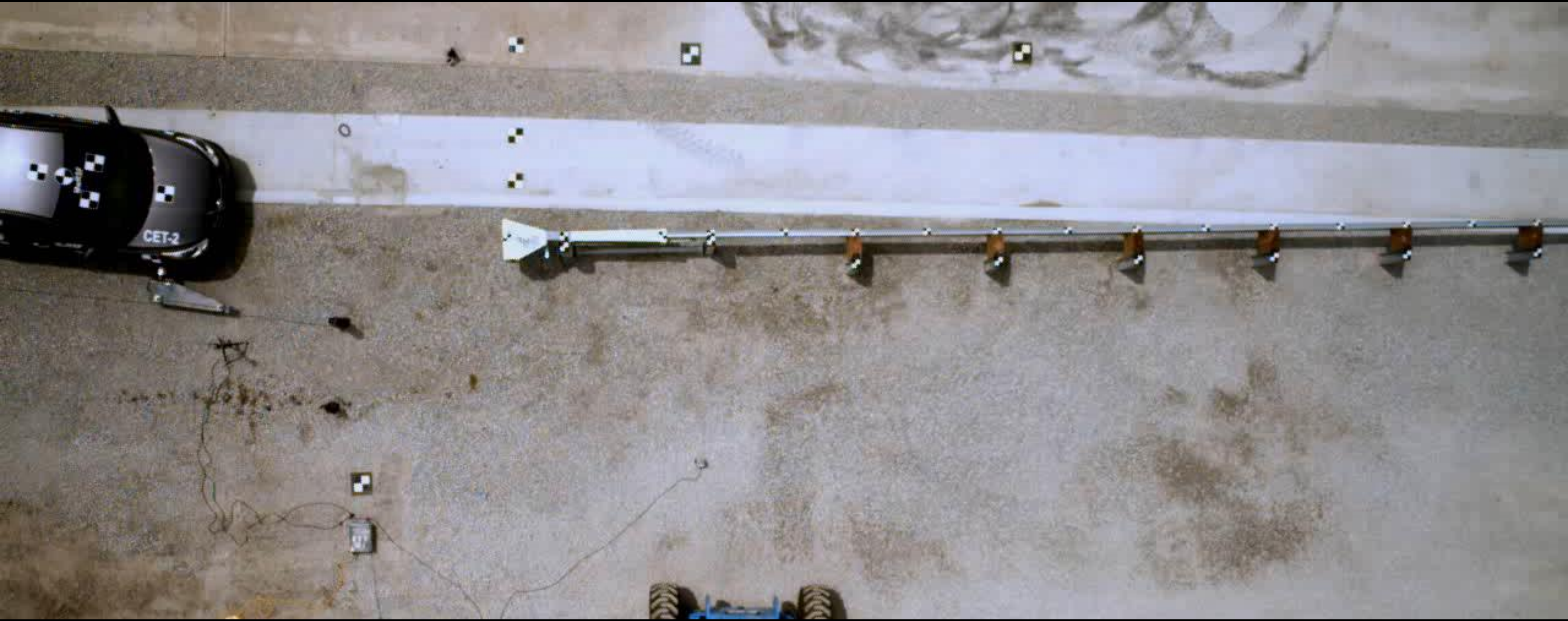
Test CET-1 (MASH 3-30)

Test CET-1 (MASH 3-30)

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-1 (MASH 3-30)

Test CET-2 (MASH 3-32)



Test CET-2 (MASH 3-32)

Test CET-2 (MASH 3-32)

Impact Speed	61.2 mph
Impact Angle	5.3°
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

Test CET-2 (MASH 3-32)

Conclusions

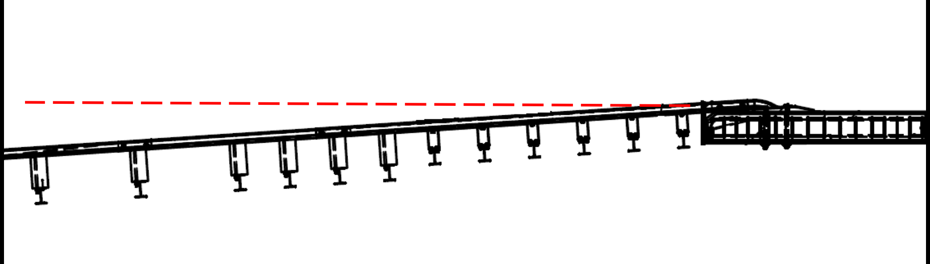
- End terminal met MASH TL-3 for test nos. 3-30 and 3-32
- 4" curb did not adversely affect end terminal performance
  - Similar end terminal head engagement, stability, and feed/stroke
- LS-DYNA comparison
  - Testing had higher feed lengths and vehicle roll and pitch values
  - Limited concern for other simulated tests deemed less critical
- MSKT testing comparison
  - Minor differences in occupant risk and stability observed
  - Feed length reduced slightly in curb testing
- Potential for 4" curbs in combination with existing end terminals

Limitations

- Unknown performance of other terminal designs
  - Other end terminals may have different behaviors
  - Other end terminal performance at 1:25 flare unknown
  - MSKT had existing design for modifying rail height relative to curb
- Only two of eight full-scale tests conducted
- Limited to 4” tall, sloped curbs
  - Taller and/or more vertical curbs may adversely affect performance

Flared AGT – Phase II

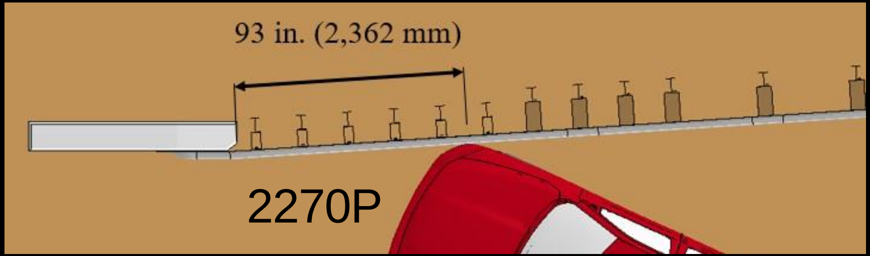
- Objective
  - Develop guidance for flaring AGTs away from the roadway
  - Phase I (YR29): Simulation, selection of flare rate and CIPs
  - Phase II (YR30, FY 2021, FY2023): Full-scale crash testing
- Recent Developments
  - Full-scale test no. FLAGT-3

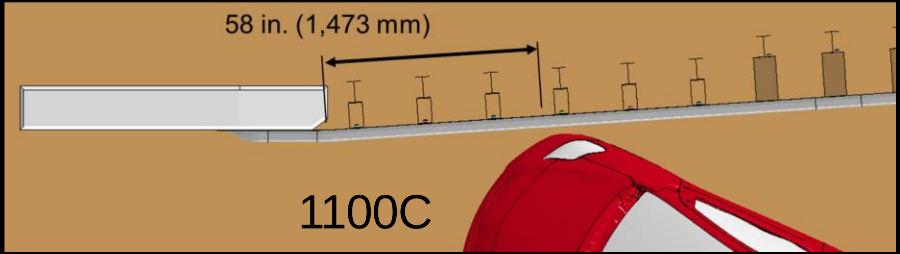


- Lead: Scott Rosenbaugh (srosenbaugh2@unl.edu)

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 12-ga thrie beam
- 15:1 flare @ US end of buttress
- Standardized Transition Buttress

Test No. FLAGT-1

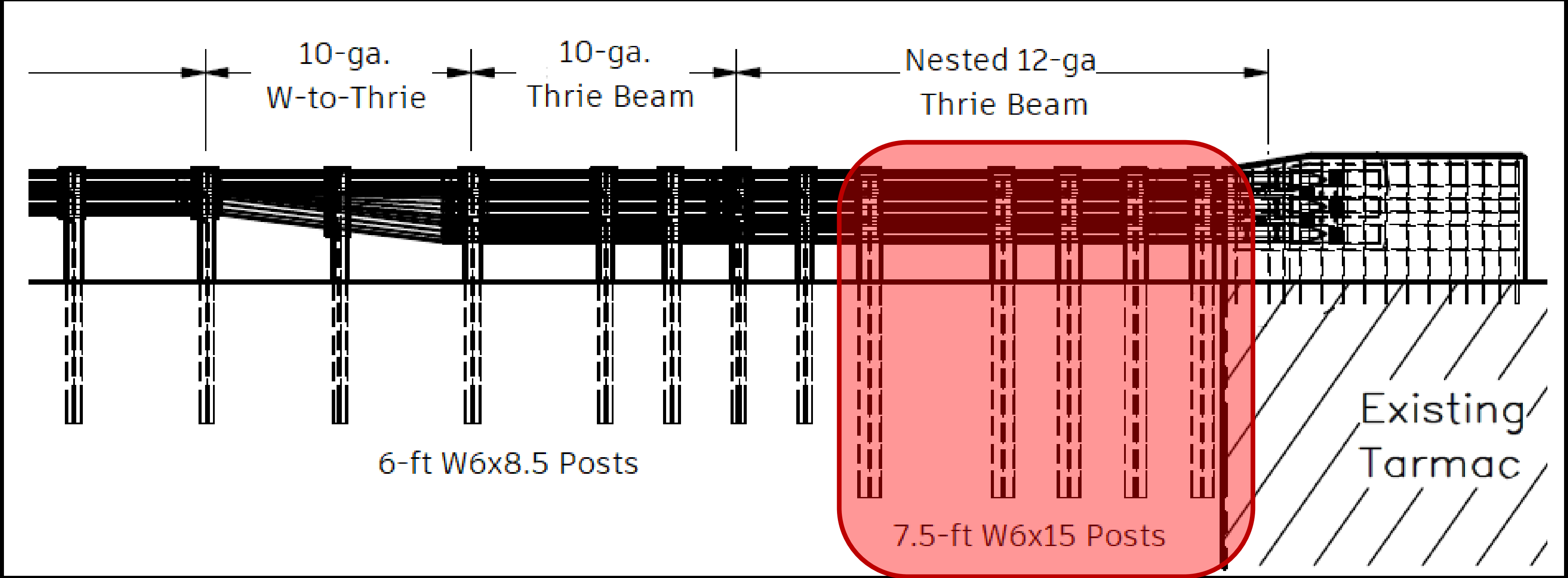
FLAGT-1

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.

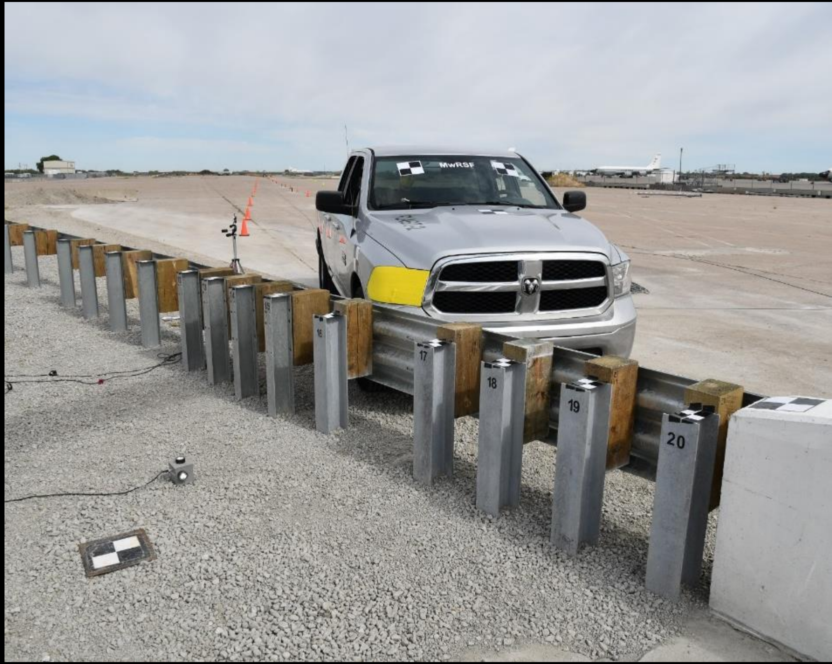
- Higher deflections
- Significant soil movement
- Rail kink/crease at buttress

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.
Toe Pan Crush	9.9 in. > 9.0 in.

FLAGT-2, Wheel-Rail Interaction

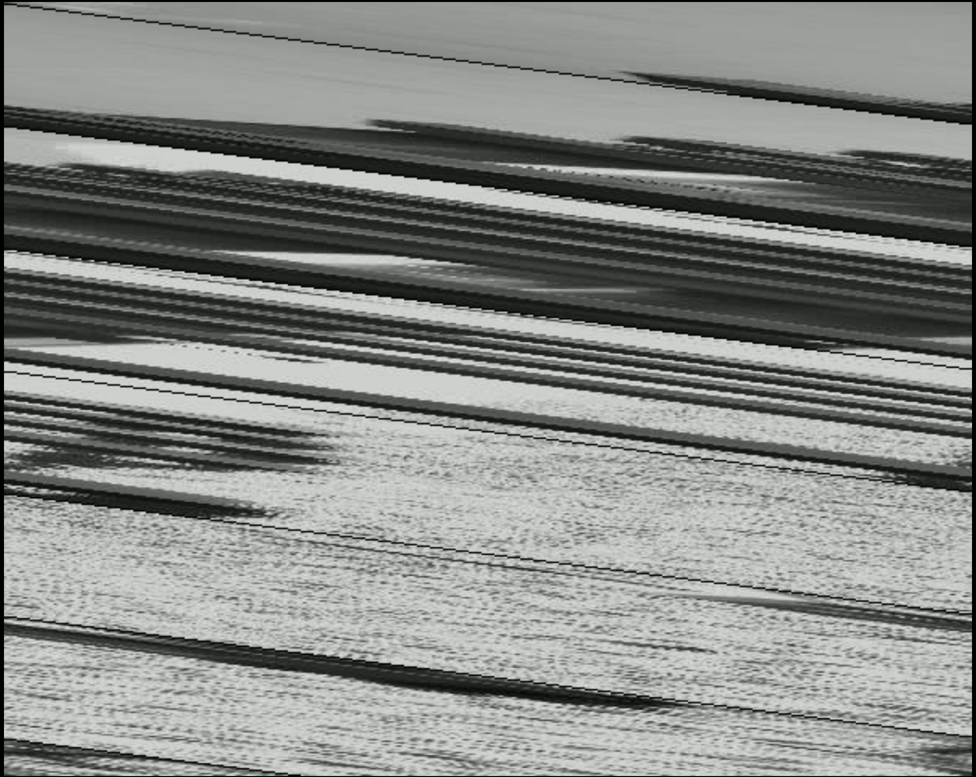
- Wheel snagged, disengaged early
- Lead to floor pan deformation and vehicle roll

Selected Modification

20:1 Flare ➔ 2.9°

FLAGT-3

FLAGT-3



FLAGT-3

Impact Speed	62.6 mph
Impact Angle	24.7° (27.6° effective)
Max. Roll	360°
Max. Pitch	-7.5°
OIV - Longitudinal - Lateral	-23.4 ft/s -27.5 ft/s
ORA - Longitudinal - Lateral	-4.3 g’s -12.6 g’s
Dynamic Deflection	4.6 in.
Toe Pan Crush	6.2 in. < 9 in.
Roof Crush	6.9 in. > 4 in.

FLAGT-3

Flared AGT – Phase II

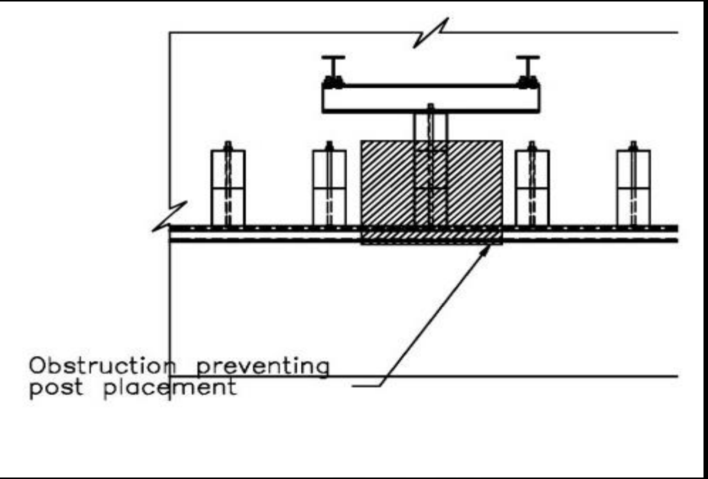
- After reviewing several options, states elected to re-evaluate the flared AGT with a 25:1 flare

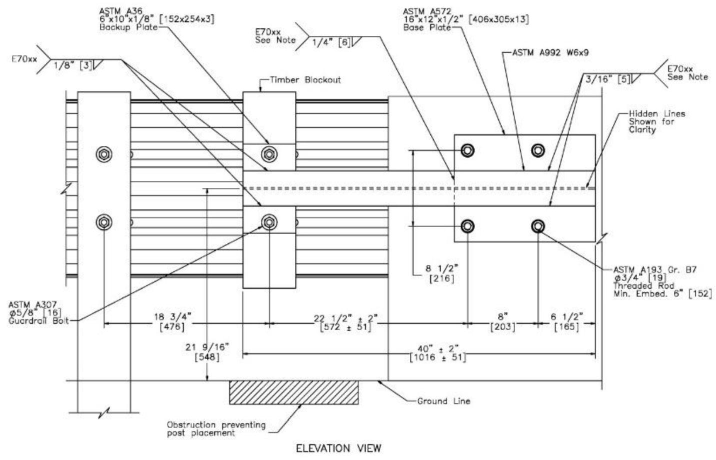
AGT Retrofit Options

- 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:
  - Dynamic Component Testing

- Lead Engineer: Scott Rosenbaugh





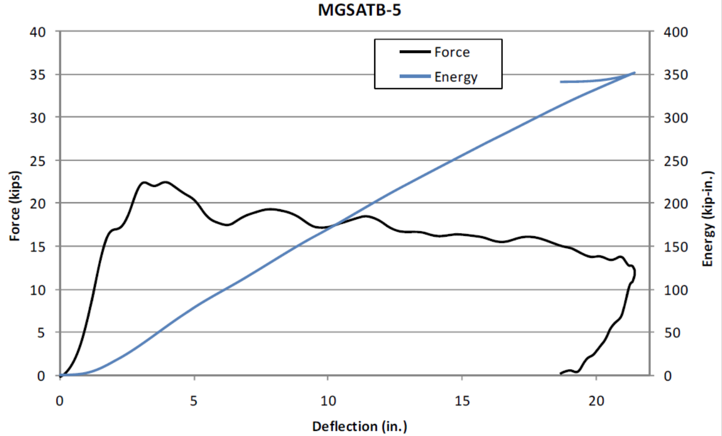
DOT Survey

- 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
  - FY2022 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

Component Testing

- Iterative approach
  - Weld specification (multi-pass?)
  - Compression flange weakening
    - Holes
    - Chamfers
  - Compression flange welding
  - Base plate thickness
  - Base plate length

Round 2 Testing Results

Test	Weld	Post	Anchors	Baseplate	F_{ave} (kips)
AGTRB-1	3-Pass	-	Ø7/8" x 10"	1"	25.19
AGTRB-2	3-Pass	No comp. flange welding	Ø7/8" x 6"	1"	20.99
AGTRB-3	¼" fillet	-	Ø7/8" x 6"	¾"	19.86
AGTRB-4	3-Pass	Ø1¼" holes	Ø7/8" x 6"	1"	23.27
AGTRB-5	3-Pass	1.5" chamfers	Ø7/8" x 6"	1"	26.66
AGTRB-6	¼" fillet	-	Ø1" x 6"	¾"	26.04
AGTRB-7	¼" fillet	Ø1¼" x 3" slots	Ø7/8" x 6"	1"	19.34
MGSABT-5				na	16.92
MGSATB-6				na	17.92

Test	Weld	Post	Anchors	Baseplate
AGTRB-7	¼” fillet	1¼” x 3” slots	Ø7/8” x 6”	1”

AGT Post Retrofit Options

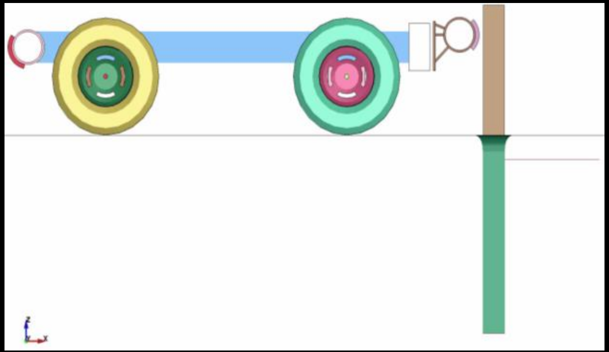
- Remaining Tasks
  - Slab and footing requirements
  - Simulation analysis of new posts within full AGT

MGS over Low-Fill Culverts

- Objective
  - Evaluate use of MGS w/ reduced post embedment & potentially w/ reduced post spacing to satisfy MASH TL-2 & TL-3 when installed over low-fill culverts
    - Identify shallowest post configuration for TL-2 and TL-3
- Recent developments
  - Completed report TRP-03-468-22
  - Lead: Mojdeh Pajouh; mojdeh.pajouh@unl.edu

MGS over Low-Fill Culverts

- Recall
  - Conduct 6 bogie tests on W6x8.5 w/ 36”, 32”, and 28”
  - Conduct 3 bogie tests on W6x16 w/ 40”, 34”, and 28”
  - Used bogie test results to calibrate soil spring models in LS-DYNA simulations
  - Used calibrated models in full MSG models

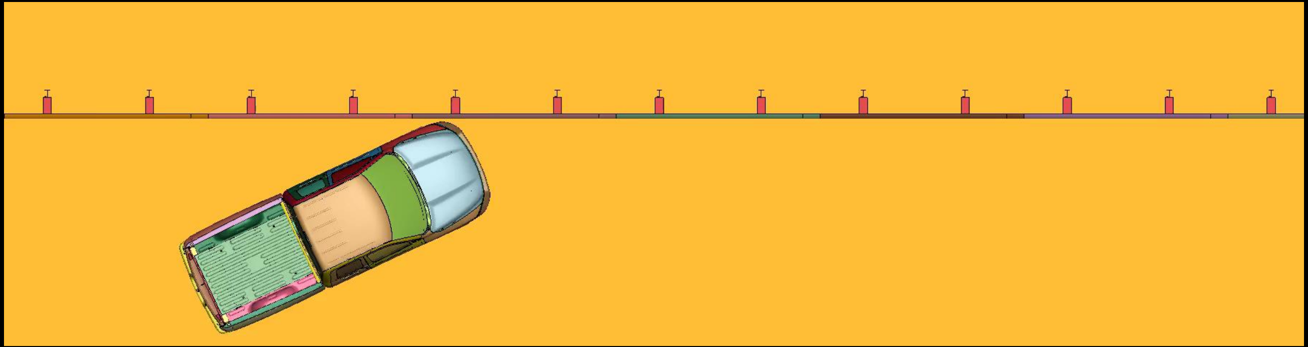


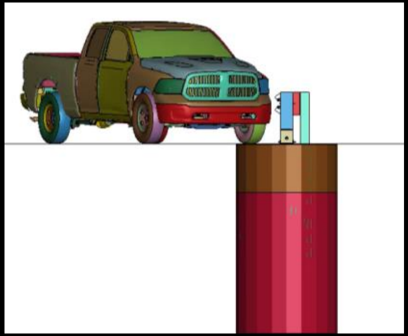
Soil Strength Ranges for Simulation

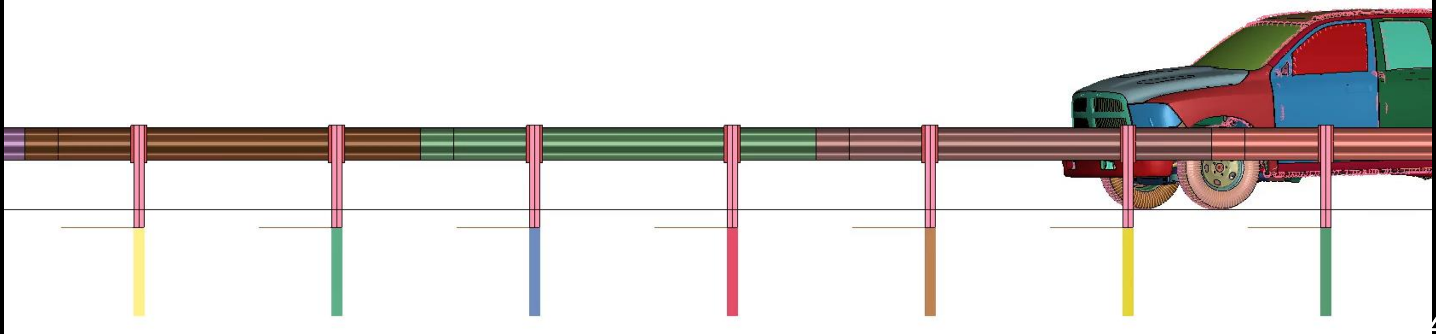
- Bracket MGS soil response
- Upper bound soil strength
  - Soil curve from LFCB test series
- Lower bound soil strength
  - Soil curve based on MASH
  - 7.5 kips, 5” - 20” post displacement
- Existing, validated MGS model soil falls between the upper and lower bound

MGS Simulation

16 cases in total, example: TL-3 impact on MGS with 40” post, full-post spacing, and w/ lower bound soil curve (MASH limit)

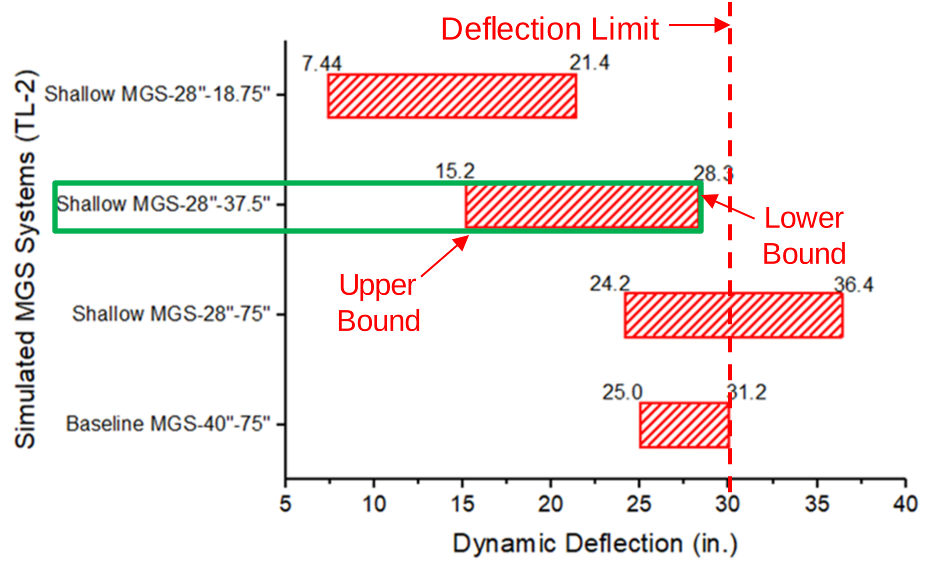






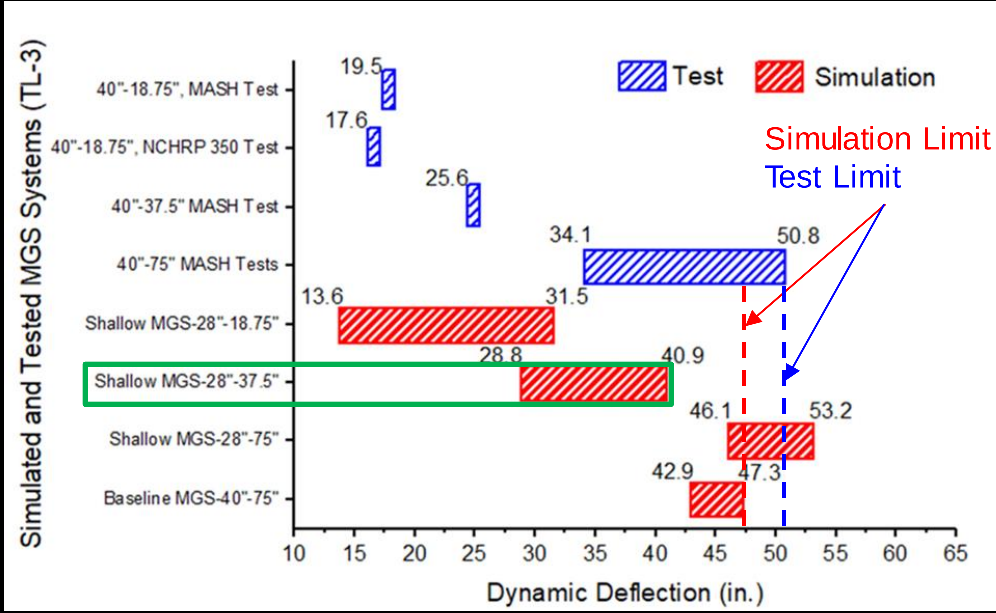
TL-2 Simulation Results

- No TL-2 crash test data available
- Deflection limit based on MGS with 40-in. embedment, standard post spacing, and lower bound soil
- MGS w/ 28-in. embedment post and half-post spacing recommended
  - 75-in. post spacing may meet MASH with increased deflection



TL-3 Simulation Results

- Simulation deflection limit based on MGS with 40-in. embedment, standard post spacing, and lower bound soil
- Test deflection limit based on highest comparable MGS crash test with 40-in. embedment and standard post spacing
- MGS w/ 28-in. embedment post and half-post spacing recommended
  - 75-in. post spacing may meet MASH with increased deflection and risk



MGS over Low-Fill Culverts

- Phase II crash testing still required
  - Recommend evaluation of MGS w/ 28-in. post & half-post spacing with MASH test no. 3-11

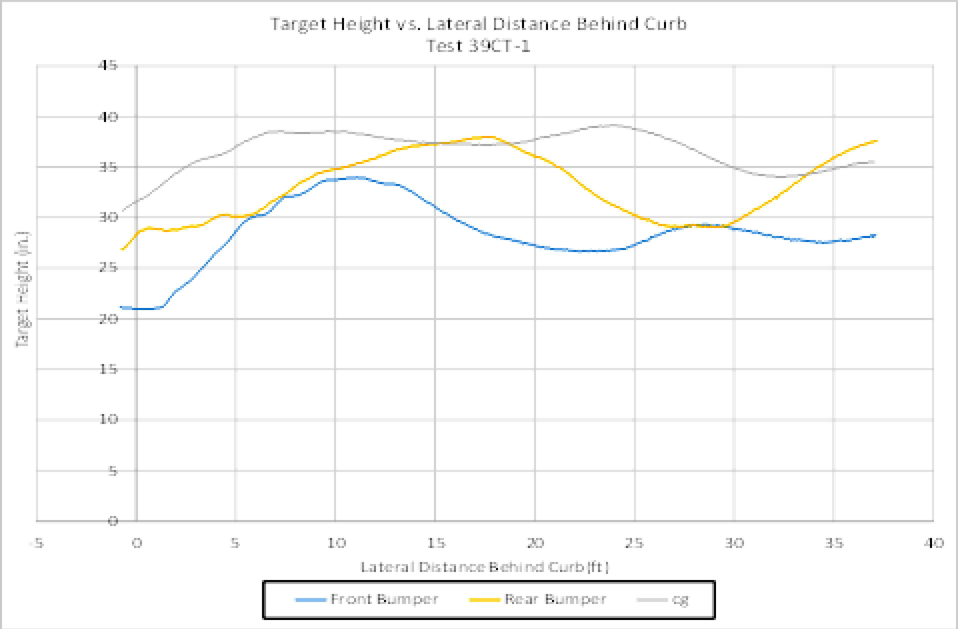
FY 2021: AGT's Behind Elevated Sidewalks

- Objective
  - Evaluation of Approach Guardrail Transitions placed behind elevated sidewalks to MASH TL-2 and TL-3
  - Phase I: LS-DYNA simulation
- Recent Developments
  - 2270P vehicle model improvements and calibration of curb traversals (NCHRP 22-39)
- Lead Engineer: Scott Rosenbaugh

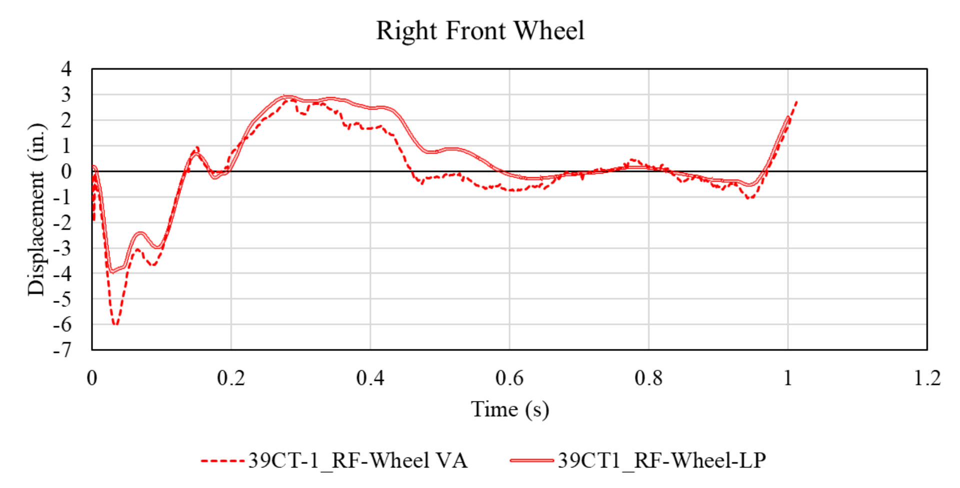
Ram 1500 Suspension Updates

- NCHRP 22-39: Installation Guidance for MGS in Combination with Curbs
  - Full-scale curb traversal tests for vehicle trajectory
  - LS-DYNA simulation of MGS with curbs to determine offsets

Ram 2270P Curb Traversal Results



Vertical Vehicle Displacement from Video Analysis



Wheel Motion from Video Analysis and Linear Potentiometer

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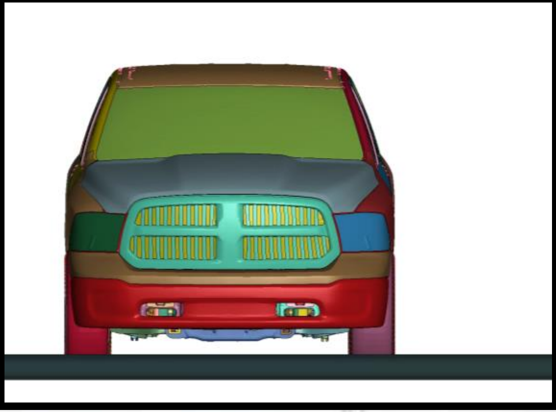
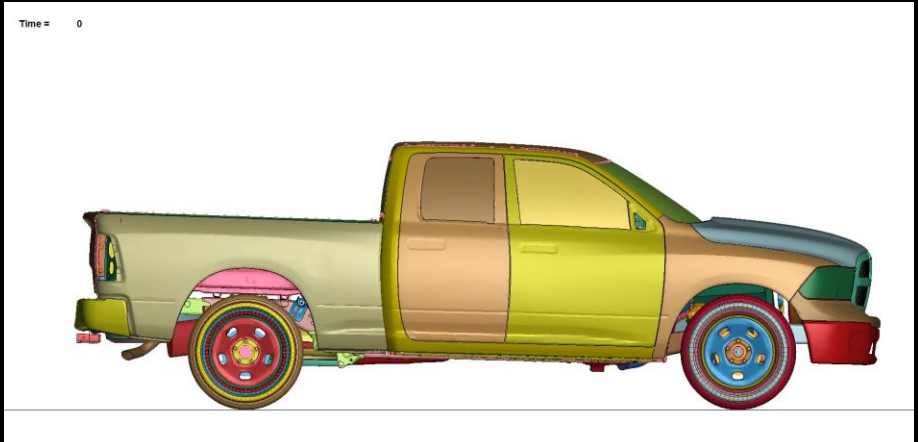
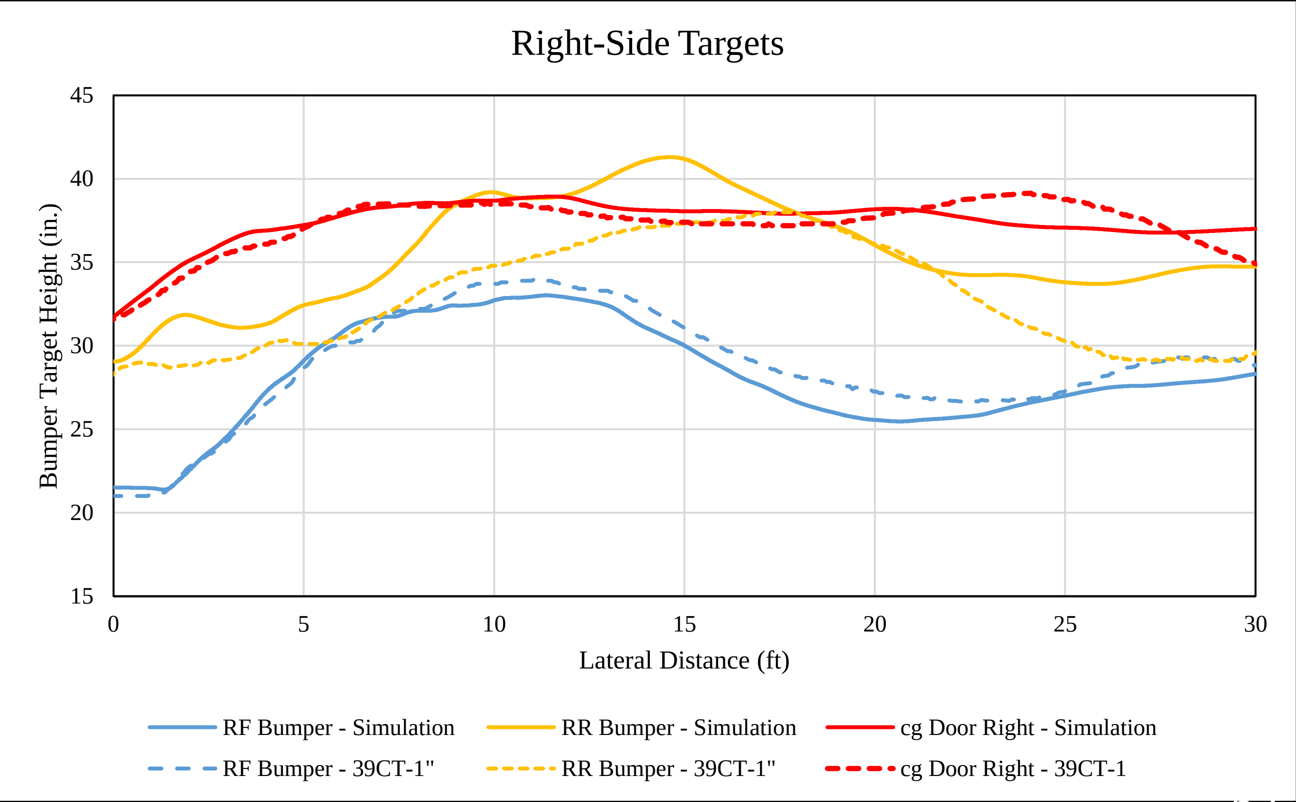
Simulation Model





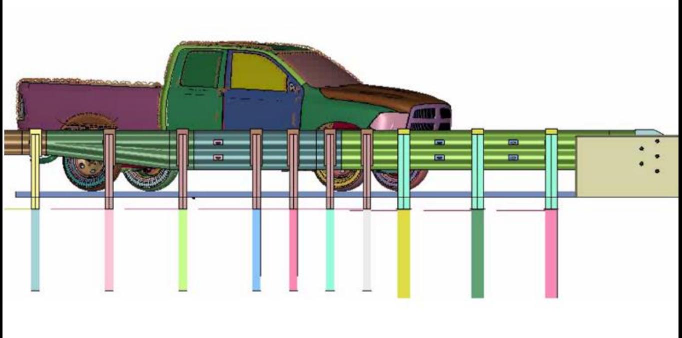
Simulation Model

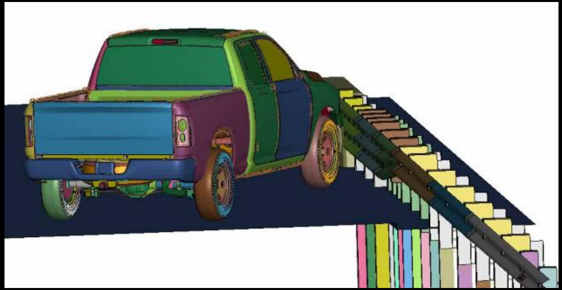
- Right-Front Bumper Target
  - Test = 34.0 in.
  - Model = 33.0 in.
- Right-Rear Bumper Target
  - Test = 38.0 in.
  - Model = 41.3 in.



AGTs Behind Elevated Sidewalks

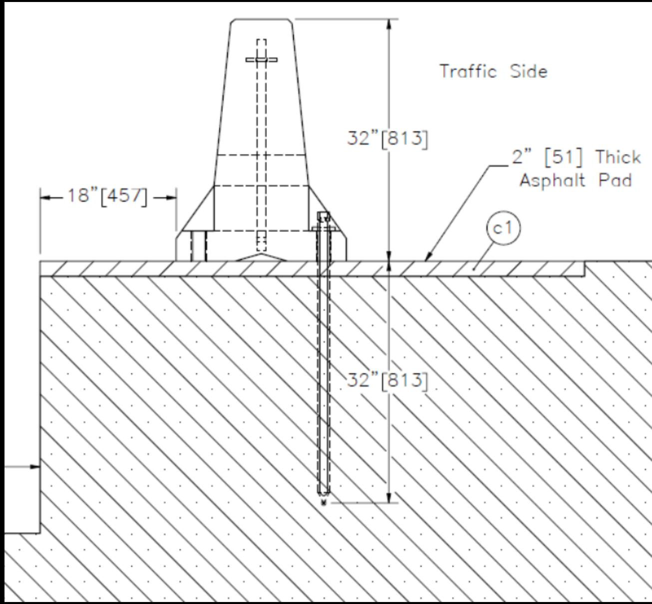
- Future Work
  - Simulation efforts
    - Combine revised 2270P vehicle model with existing AGT model
      - Add elevated sidewalk
      - Various curb offsets (sidewalk width)
    - MASH TL-2 and TL-3 impacts
  - Recommendations for crash testing
  - Summary report





MASH Evaluation of Modified PCB Anchorage

- Objective
  - 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
  - FE modeling of saddle caps completed
  - Selection of final design for full-scale crash testing
  - Full-scale crash test WITD-4 (3-11)
- Lead: Brandon Perry – brandon.perry@unl.edu



3 pins per barrier segment

Previous MASH Testing

- WITD-2
  - Original NCHRP 350 system
  - 6” offset to drop-off
  - Open floor pan
  - Wheel well and toe pan deformation = 13.5 in. (MASH < 9 in.)
- WITD-3
  - Increased barrier offset to 18”
  - Open floor pan
  - Wheel well and toe pan deformation = 10.4 in. (MASH < 9 in.)

Saddle Cap

- Resists relative joint motion and snag on PCB end
- Final design
  - 16” tall x 12” wide x ¼” plate
  - ½” inner cap tolerance
  - 1-1/4” dia. pin
  - 52.0 lbs


500 fps / 00:00:00.126
WITD-4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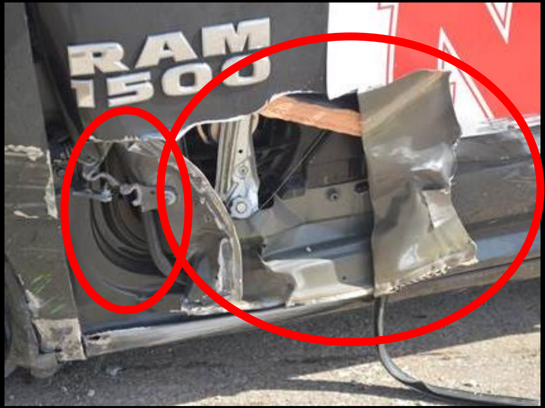
WITD-4
MwRSF

WITD-4

- Vehicle stayed upright
- Front-left wheel pushed rearward
- Door snagged on saddle cap
- Barrier cracks and bolt pocket breakout

WITD-4



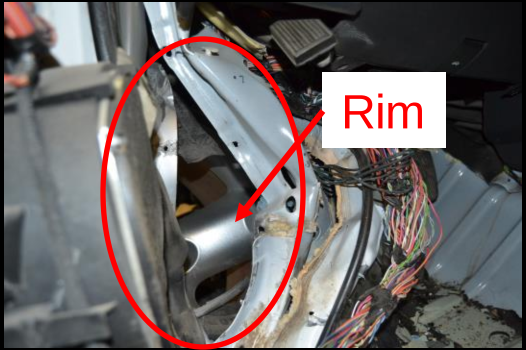
- Door snag caused outer door panel to peel back and away
  - Door displaced rearward 1.5”and outward 2”
  - Saddle cap leading edge was not bent outward toward vehicle

Door Opening

- MASH
  - "penetration occurs when a component of test article actually penetrates **<u>into</u>** the occupant compartment"
  - "it is generally believed that an opening in the occupant compartment by and of itself does not result in injury to the occupants unless it is accompanied by an object moving toward the occupant"
- Door opening in WITD-4 not considered penetration

Testing Comparison

WITD-2



Toe pan deformation = 13.5”

WITD-3

Toe pan deformation = 10.4”

WITD-4

Toe pan deformation = 1.8”

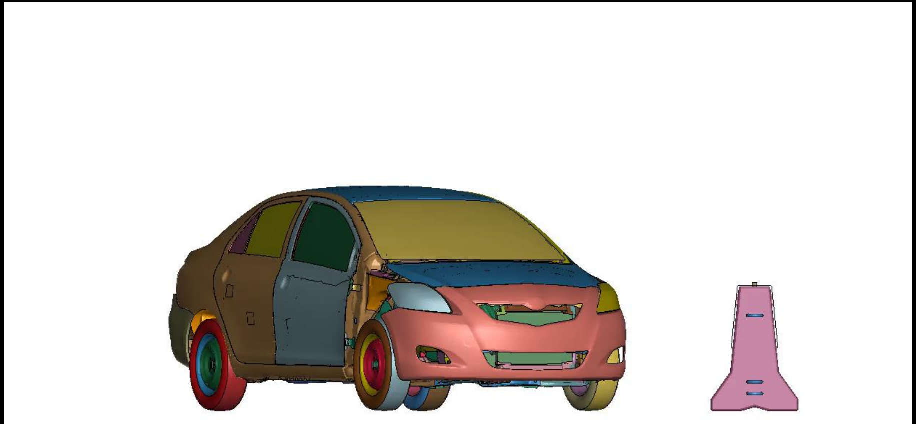
WITD-4

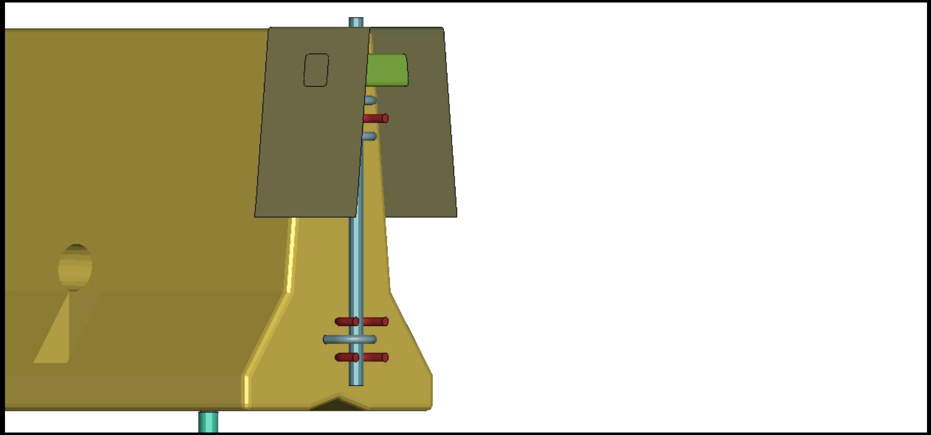
Impact Speed		61.9 mph
Impact Angle		24.6°
Max. Roll		-37.6°
Max. Pitch		-13.4°
OIV	Longitudinal	-13.6 ft/s
	Lateral	-21.9 ft/s
ORA	Longitudinal	-6.6 g's
	Lateral	-11.7 g's
Occupant Compartment Intrusion		1.8" < 9" (toe pan)
Overall Result		Pass

- Concern for similar door snag on 1100C vehicle
  - Occupant risk
  - Vehicle stability

1100C Vehicle Simulation

Yaris

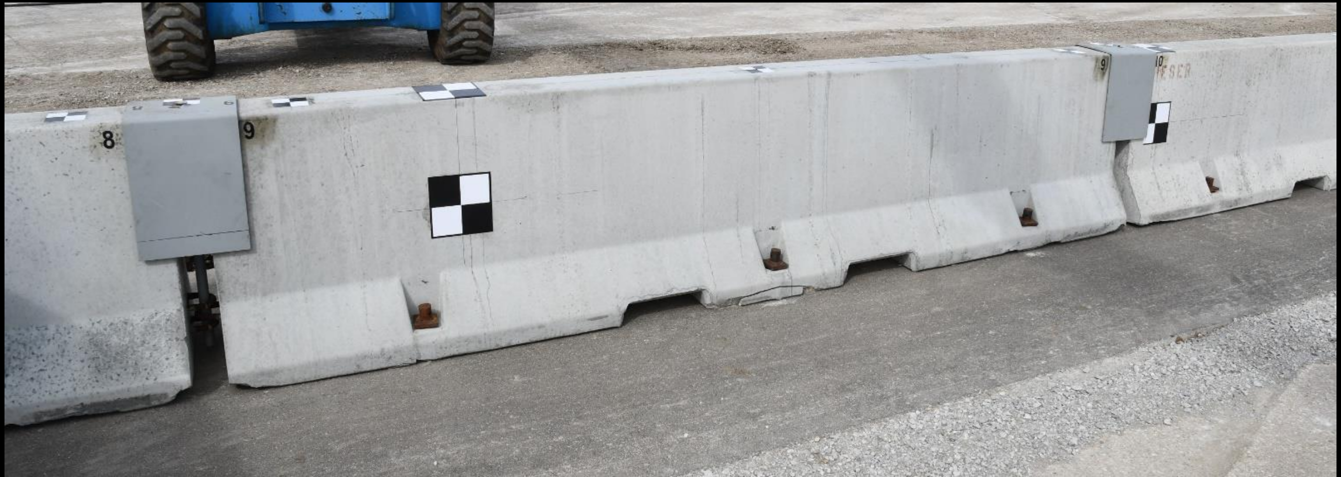




- Increased 1100C climb and roll
- Interaction with saddle cap and 1100C bumper, tire, and vehicle structure observed
- Difficult to determine effect on 1100C impact performance

Anchoring PCBs to Asphalt

- 1100C testing funded by WisDOT



Breakaway Pole Research

- Objective
  - Determine critical configurations for MASH TL-3 compliant breakaway luminaire poles
  - Focus on slip base poles
    - Transformer bases being studied in NCHRP Project nos. 03-119, 22-43, 17-105
- Recent Developments
  - Conducted literature search and survey to PF states
  - Baseline LS-DYNA modeling
  - Lead: Mojdeh Pajouh mojdeh.pajouh@unl.edu

Table K-8 - Percent Use by Breakaway Luminaire Support Type

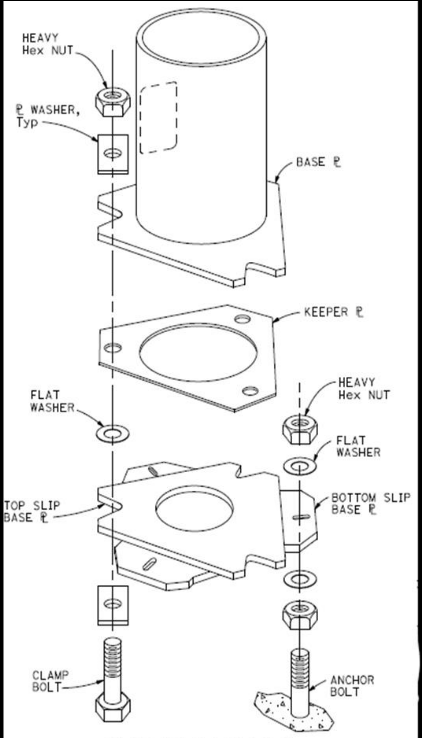
System Type	% of All Bases
Transformer/Pedestal Base/T-Base	60.82%
Coupling	10.32%
3-Bolt Slip Base	17.73%
4-Bolt Slip Base	11.14%
Subtotals	100.00%

Research Plan

- Currently developing baseline LS-DYNA models & validate using available crash tests (3- and 4-bolt slip bases)
- Develop simulation matrix
- Simulate possible combinations selectively (i.e., extreme cases, continue modeling combinations, as needed)
- MASH 3-60 was found more critical than MASH 3-61 and 3-62 (based on NCHRP 22-43 simulations)

Potential Parameters for LS-DYNA Analysis

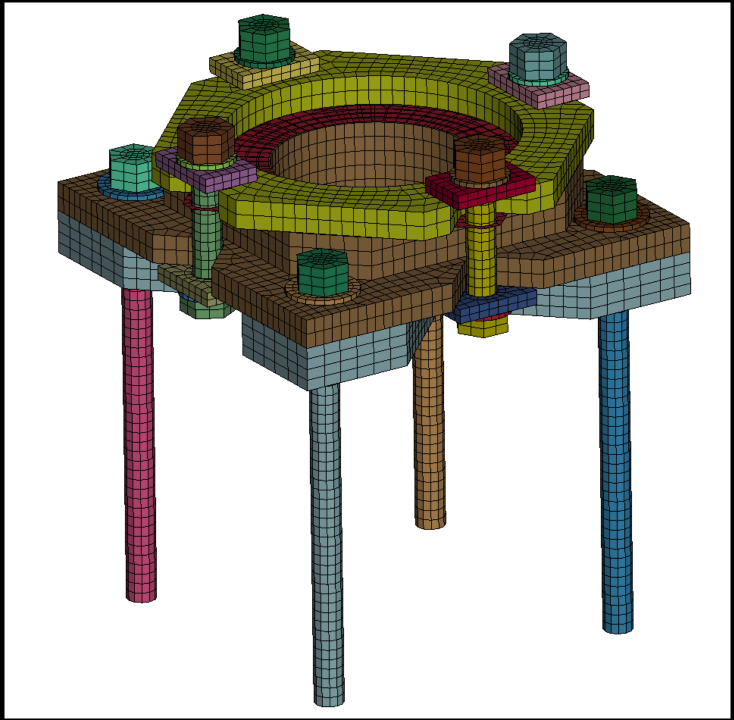
- Pole size
  - Pole height (20'~50')
  - Pole mass up to 1,000lb
- Mast arm configuration
  - Single/dual
  - Mast arm length (6'-16')
- Slip base design
  - 3-bolt and 4-bolt
  - Torque
  - Clamp bolt size
  - Bolt circle diameter
  - Slot angle



SLIP BASE DETAIL
DETAIL F

4-bolt Slipbase Model (ongoing task)

- Utah DOT 4-bolt Slip base
  - Pole base plate 13.5” wide, 1” thick
  - 1” dia. clamp bolt w/ 13” circle bolt dia., 70 lb-ft torque
  - Slot angle 90 deg.
  - Slip plate: top one 1.5” and bottom one 1” (total 2.5”)
  - 1” dia. anchor bolt w/ 16” circle bolt dia., 12” long
  - Keeper plate: 0.0149” thick
  - Grout: sand and cement dry 1.5” thick



Breakaway Pole Research

- Remaining Tasks
  - Complete LS-DYNA validation effort for slip bases
  - Conduct LS-DYNA analysis of parameters/ configurations
  - Provide recommendations for critical pole configurations for full-scale testing
  - Project reporting

FY2022 Projects – started 7/1/23

- Evaluation of Increased Blockout Depth with the Midwest Guardrail System
- Surface Mounted Strong-Post MGS
- Median Approach Guardrail Transition to Concrete Median Barrier
- MASH TL-3 Portable Barrier System – Phase II
- Midwest PCB – Anchored Median Installations - Phase I

FY2023 Projects – started 7/1/23

- Guidelines for Flaring Thrie-Beam Approach Guardrail Transitions - Phase IV (Continuation)
- Modification and Evaluation of the MGS Long Span with Increased Span Length
- Generic End Terminal – Further Development and Evaluation
- Coordination and Collaboration with Vehicle Manufacturers and Automotive Industry
- Continued Revisions to MwRSF Pooled Fund Q & A Website

FY2024 Projects – start fall 2023

- Grade-Separated Concrete Median Barrier
- Guidelines for Concrete Median Barrier Anchorage to Slabs
- W-Beam and Thrie Beam Splice Joint Redesign
- Reduced Grading for the MGS Long-Span Guardrail System
- Development of a Limited Deflection MASH TL-4 Thrie-Beam Guardrail
- Development of a Generic End Terminal - Phase IV
- LS-DYNA Investigation of Electric Vehicles and Roadside Hardware