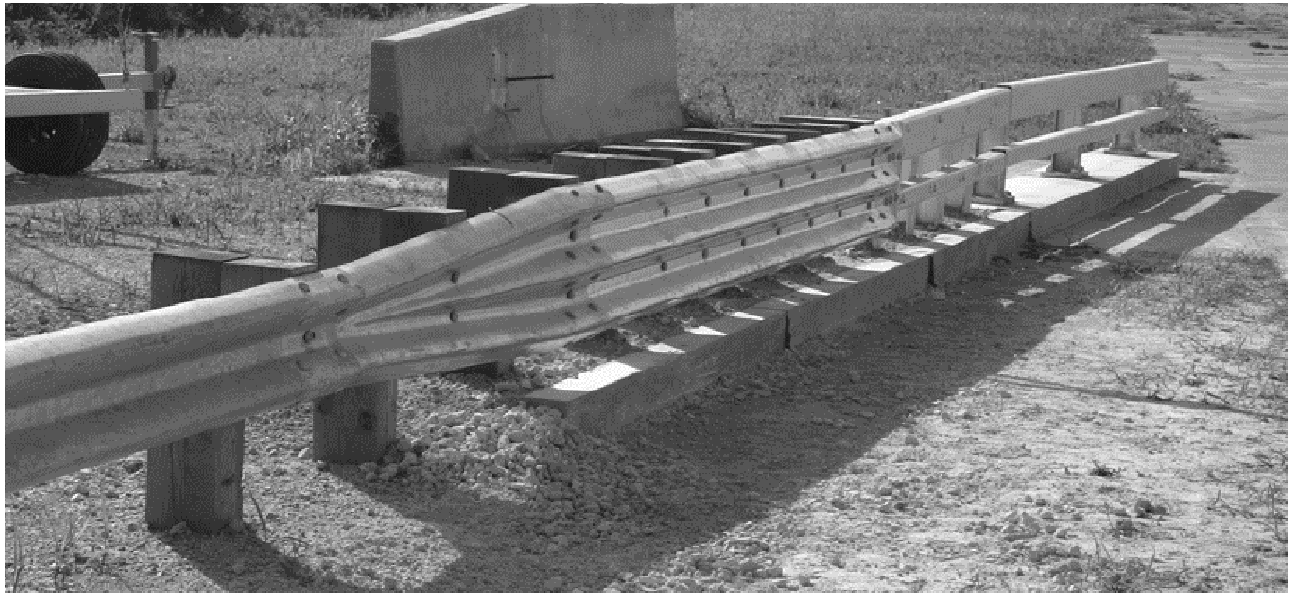
Development of MASH Computer Simulated Steel Bridge Rail and Transition Details



Task 2b – AGT Validation (Model 2)

Project # : NETC 18-1
Federal Project No. : 2343018

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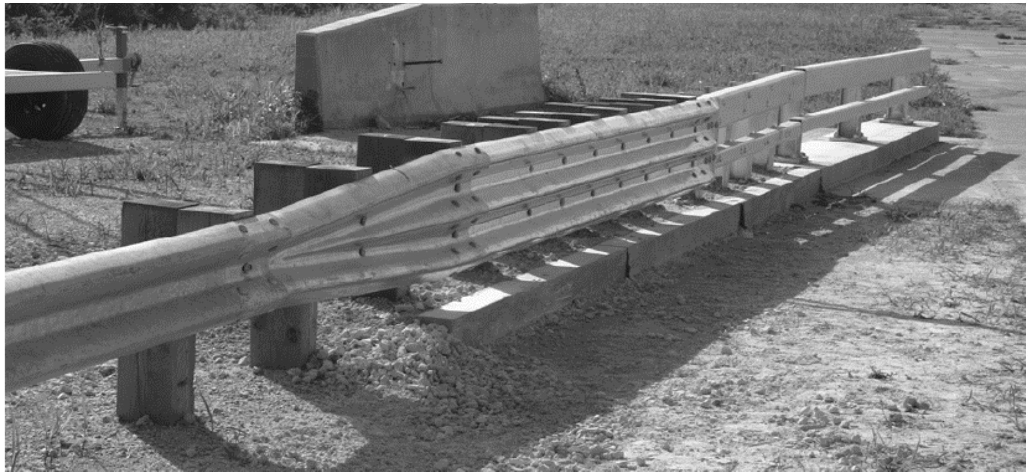
Roadsafe LLC

April 1, 2019

NETC 2-Bar to Thrie-Beam AGT

Report 350 Test Level 3

	401181-1	Preferred Limits
Test Designation	Test 3-21	
Test Vehicle	2000 Chevrolet 2500	
Gross Vehicle Weight (lb)	4,706	
Impact Speed (mph)	63.6	
Impact Angle (deg)	24.9	
Exit Speed (mph)	52.9	
Exit Angle (deg)	11.7	
Occupant Impact Velocity		
Longitudinal (ft/s)	17.1	< 30 ft/s
Lateral (ft/s)	24.6	
Ridedown Accel		
Longitudinal (g's)	8.3	< 15 G
Lateral (g's)	10	
Maximum 50 msec Avg Accel		
Longitudinal (g's)	8.1	
Lateral (g's)	13.5	
Max Deflection (in)	7.87	
Vehicle Trajectory		
Maximum YawAngle (deg)	56	
Maximum Roll Angle (deg)	14	< 75°
Maximum Pitch Angle (deg)	19	
NCHRP Report 350 Evaluation		
Structural Adequacy	Pass	
Ocupant Risk	Pass	
Vehicle Trajectory	Pass	



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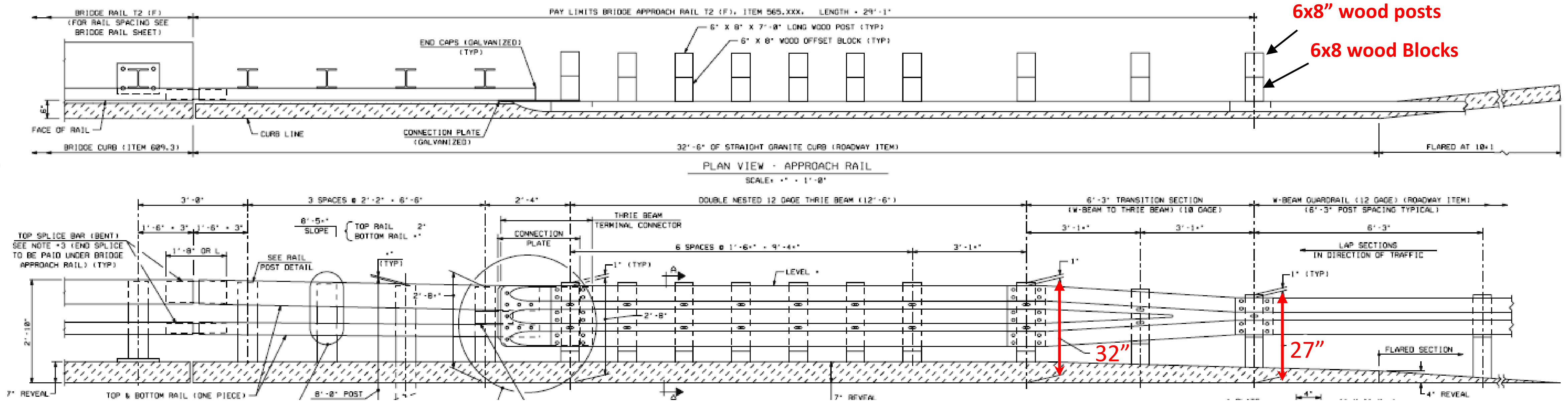
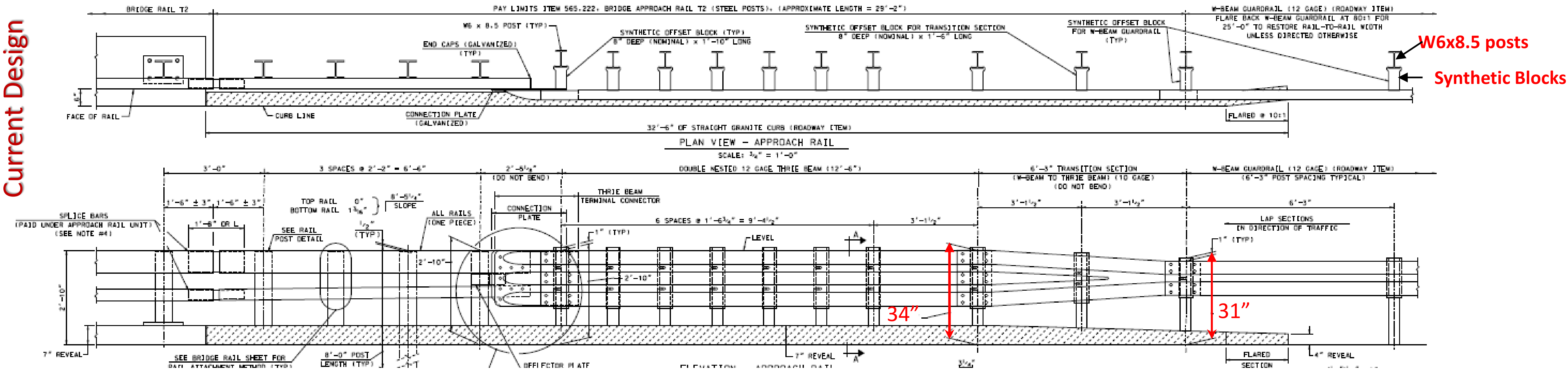
Tested System vs. Current System

Tested Design



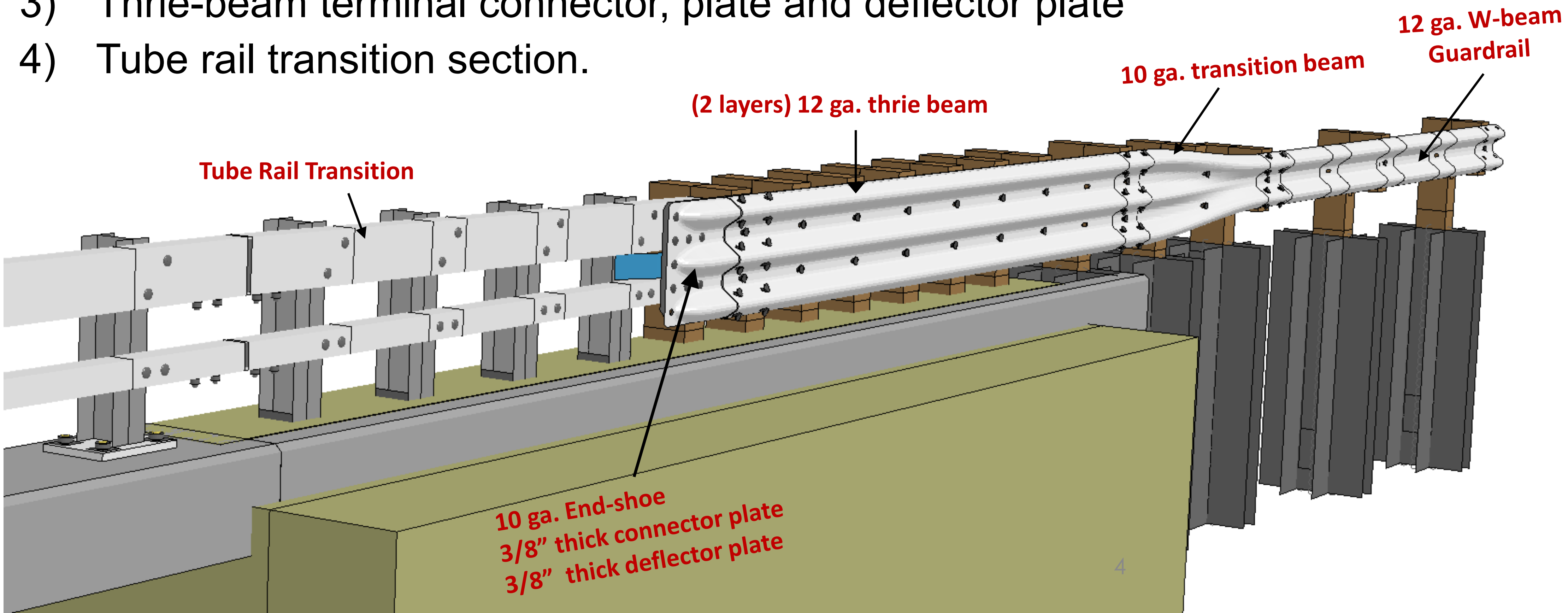
Current Design



Model Development of the AGT for the NETC 2-Bar

The AGT design includes four primary elements:

1) 10-gauge w-beam to thrie-beam transition with decreased post-spacing,
2) A two-layer, 12-gauge thrie-beam section with further decreased post spacing,
3) Thrie-beam terminal connector, plate and deflector plate
4) Tube rail transition section.

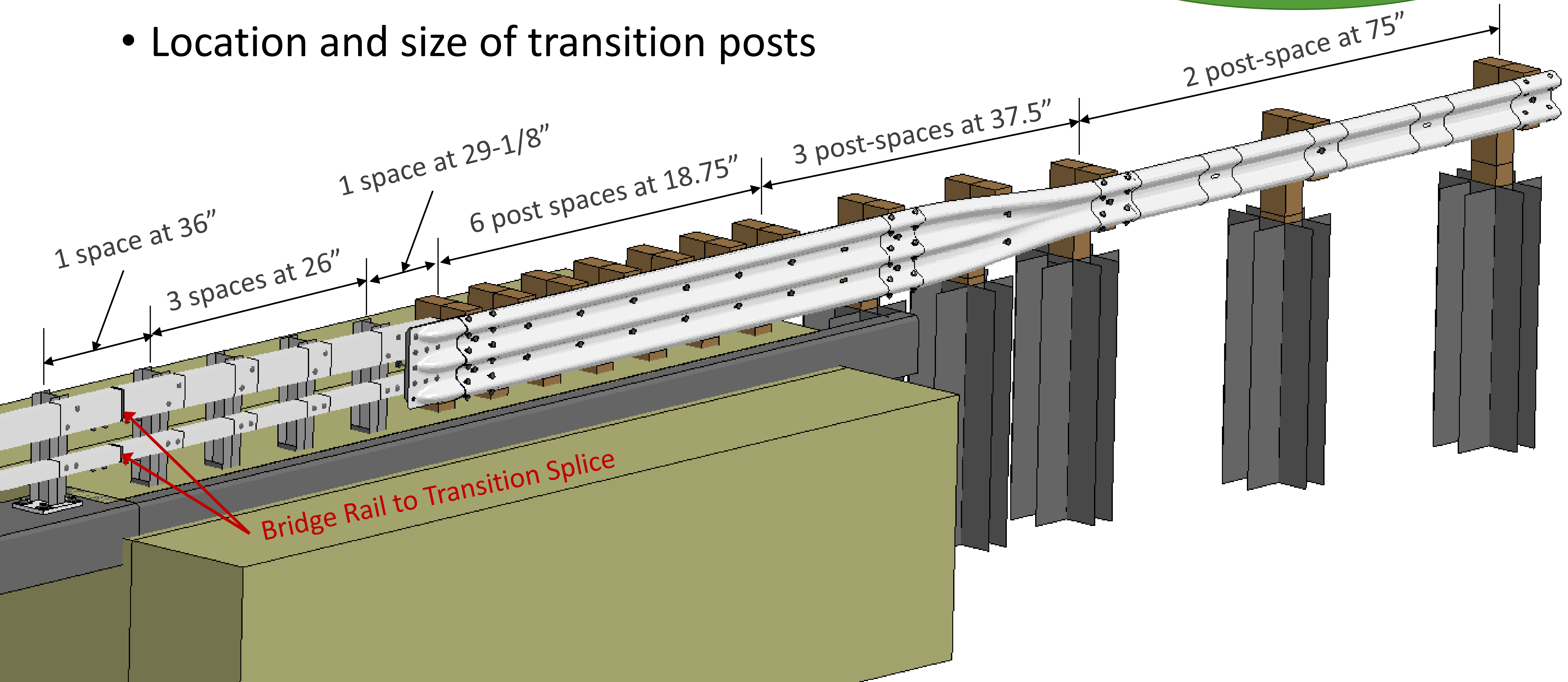


Barrier Model

Timber Posts are 6”x8” – 7’ long

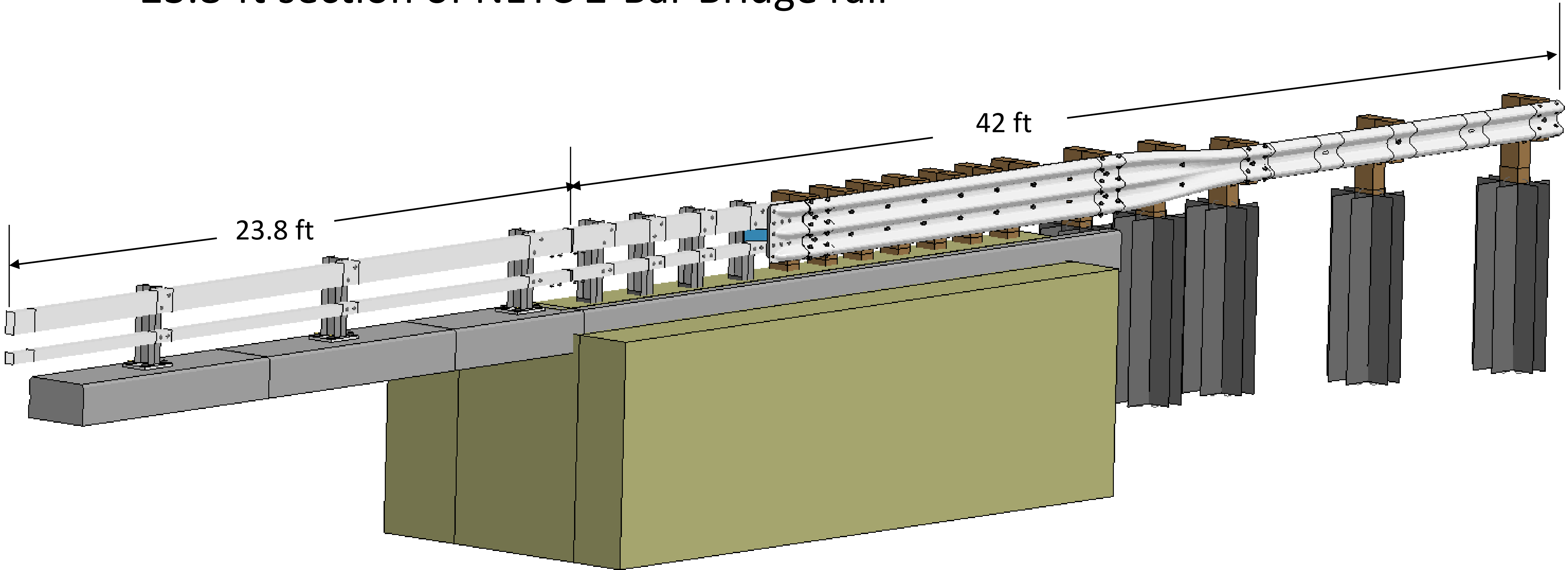
Steel Posts W6x25 - 8’ long

- Location and size of transition posts



FEA Model

- 42-ft section of the curb-mounted transition
- 23.8-ft section of NETC 2-Bar Bridge rail

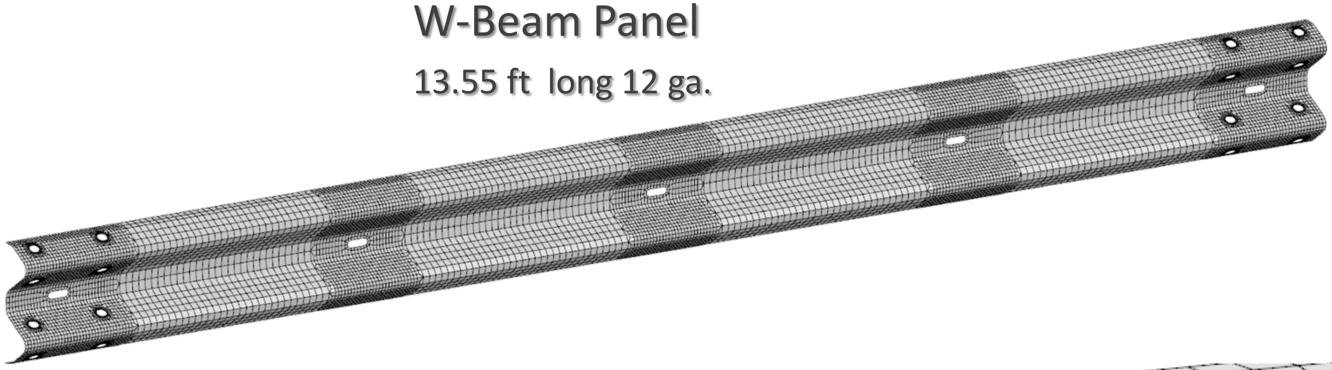


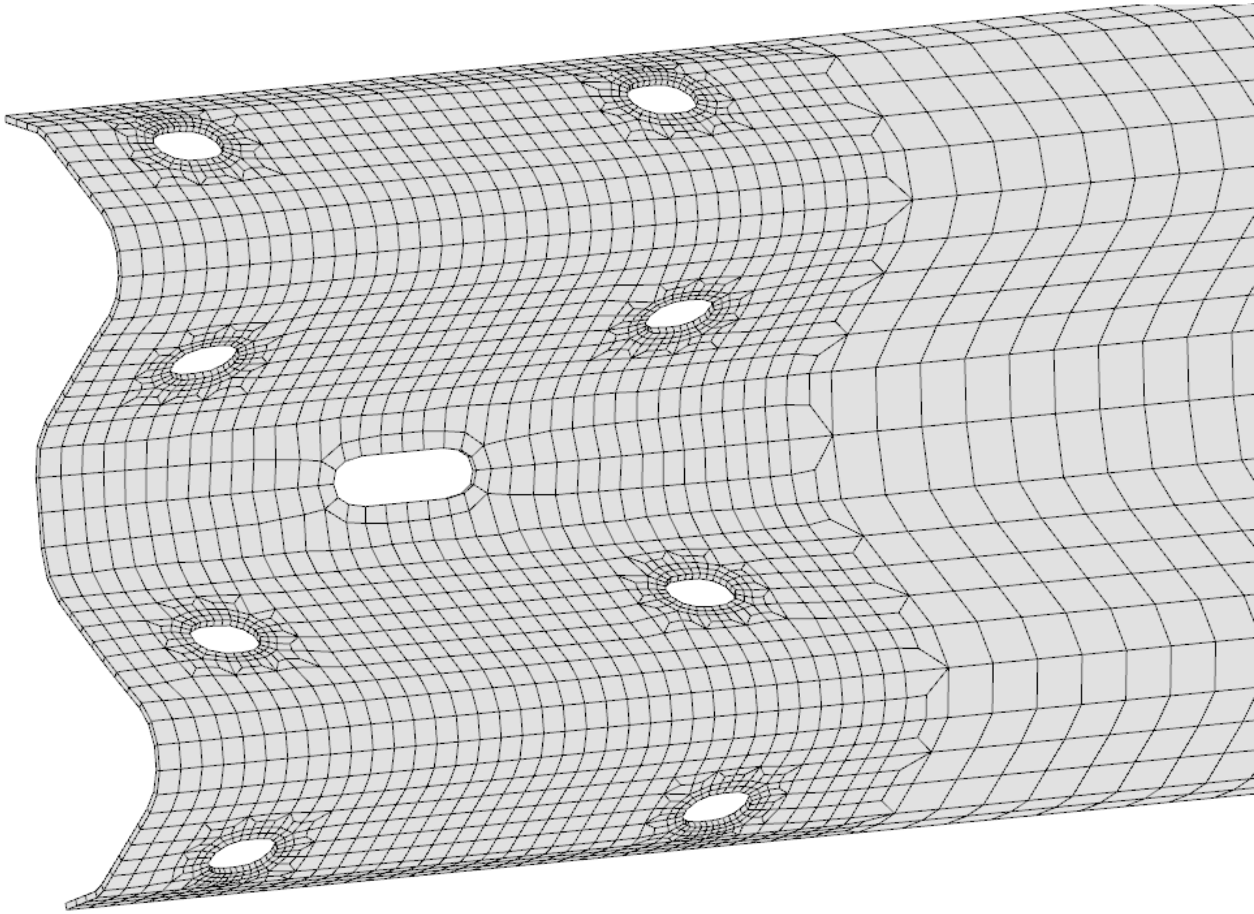
W-Beam Panel

- Standard w-beam rail with dimensions and thickness conforming to AASHTO RWM03a.
- The material for the w-beam was modeled as AASHTO M180 Class A Type II.
- The rail was modeled with thin-shell Belytschko-Tsay elements (Type 2 in LS-DYNA) with three integration points through the thickness.
  - The sections of rail between post connection points were meshed with a nominal element size of 0.79 x 0.83 inches.
  - The sections at the post connection points were meshed with a nominal element size of 0.39” x 0.39”.
  - The elements around the edge of the splice-bolt holes were meshed with nominal element size of 0.12 inches.

W-Beam Panel

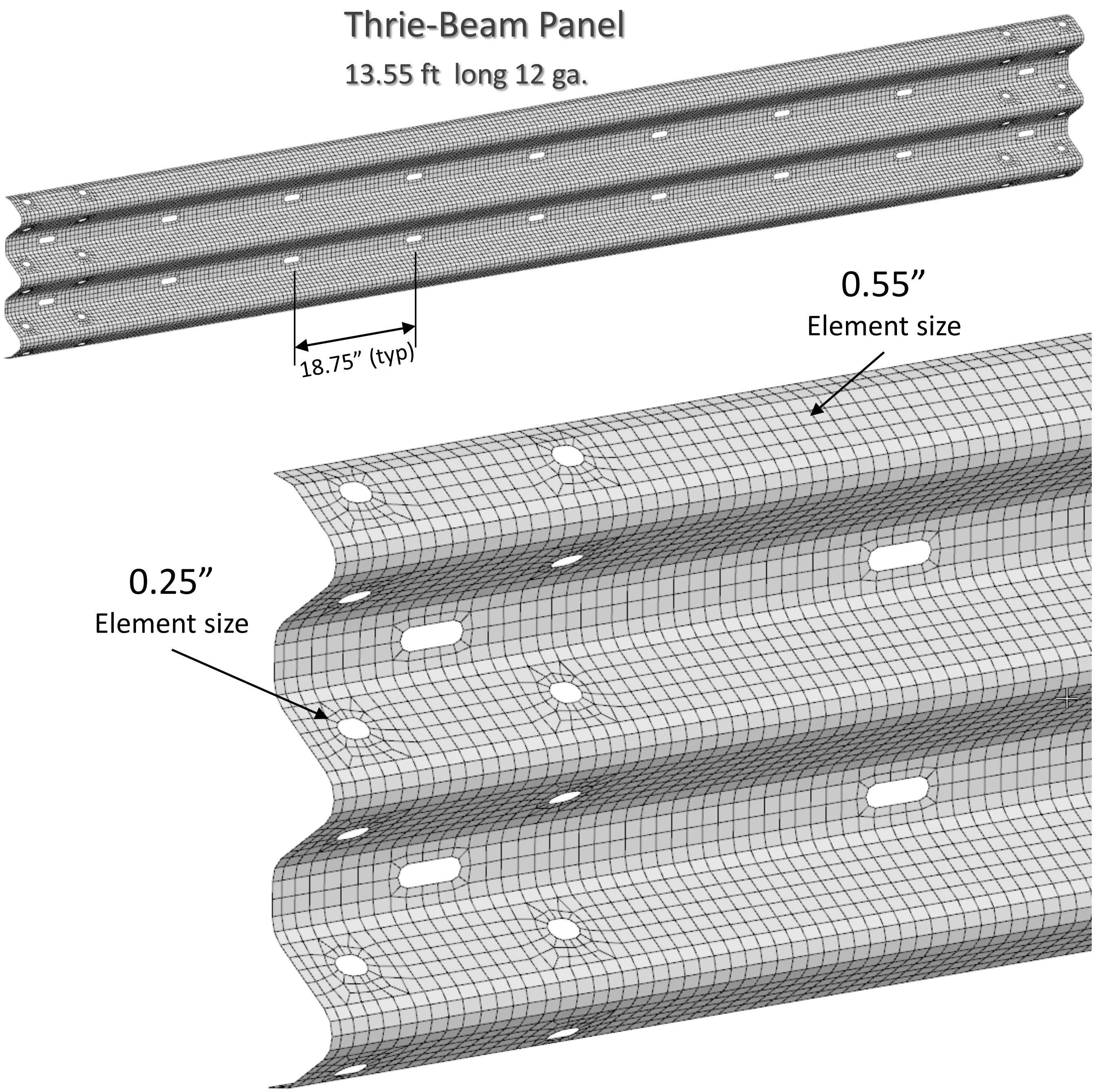
13.55 ft long 12 ga.





Thrie-Beam Panel

- The thrie-beam panel was modeled 13.55 ft long with 12-ga thickness.
- Slotted post-bolt holes were located at nine (9) locations on the panel at 18.75-inch spacing.
- The material was modeled as AASHTO M180 Class A Type II steel.
- The rail was modeled with thin-shell Belytschko-Tsay elements (Type 2 in LS-DYNA) with five (5) integration points through the thickness.
  - The panel was meshed with a nominal element size of 0.55 x 0.55 inches.
  - The elements around the edge of the splice-bolt holes were meshed with nominal element size of 0.25 inches.

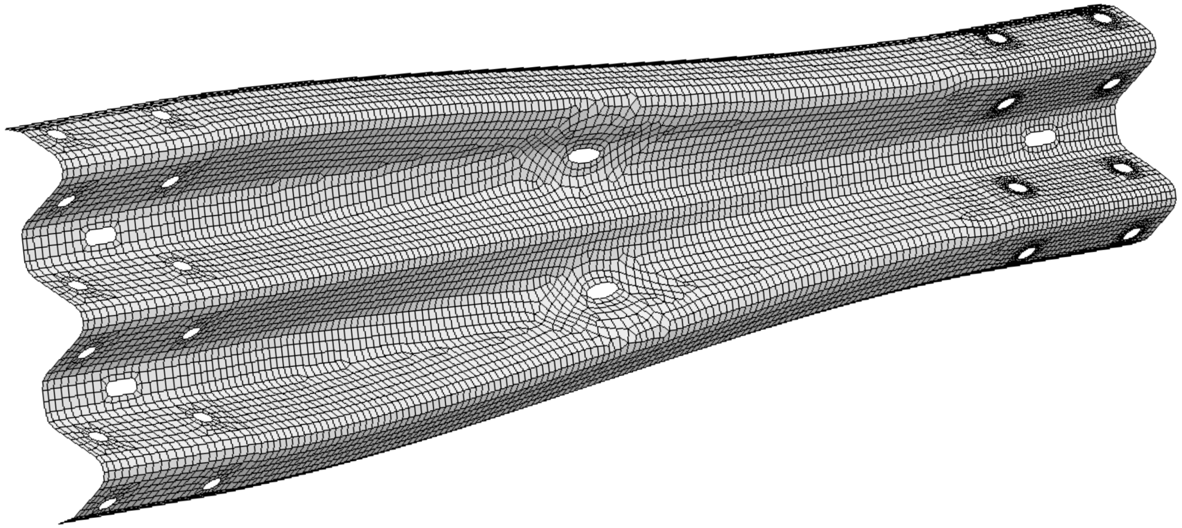


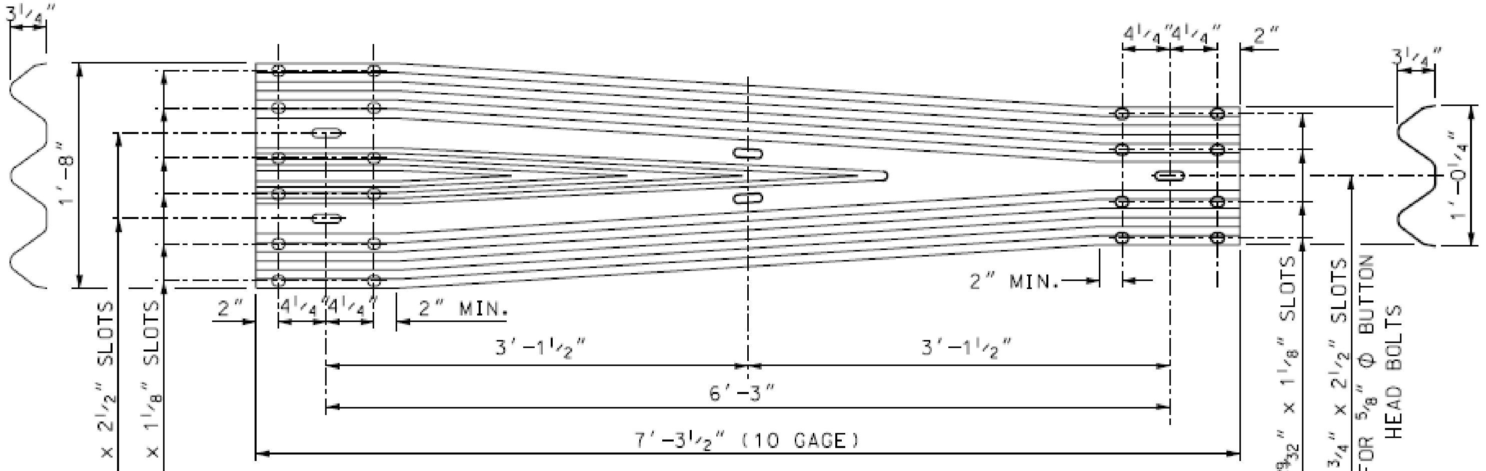
Transition Panel

7.29 ft long 10 ga.

Thrie-Beam Transition Panel

- The geometry for the transition panel created in AutoCAD by the research team based on the dimensions in the detail drawings.
- The material was modeled as AASHTO M180 Class A Type II steel.
- The rail was modeled with thin-shell Belytschko-Tsay elements (Type 2 in LS-DYNA) with three integration points through the thickness.
  - The W-Beam section was meshed identical to the standard w-beam model at the post connection points (see previous slide).
  - The remainder of the panel was meshed with a nominal element size of 0.55 x 0.55 inches.
  - The smallest elements were located around the edge of the splice-bolt holes with nominal element size of 0.25 inches.





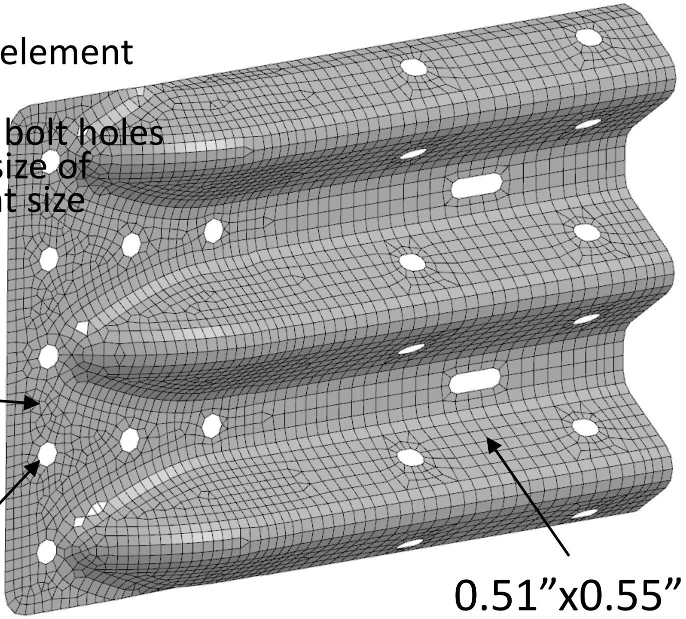
THRIE-BEAM TO W-BEAM TRANSITION SECTION

Thrie-Beam Terminal Connector

- The geometry for the thrie-beam terminal connector was developed in a previous project and conforms to the dimensions in the detail drawings.
- The material was modeled as AASHTO M180 Class A Type II steel.
- The part was modeled with thin-shell Belytschko-Tsay elements (Type 2 in LS-DYNA) with five (5) integration points through the thickness.
  - The part was meshed with a nominal element size of 0.51 x 0.55 inches.
  - The elements around the edge of the bolt holes were meshed with nominal element size of 0.38 inches, with the smallest element size being 0.25.

Terminal Connector

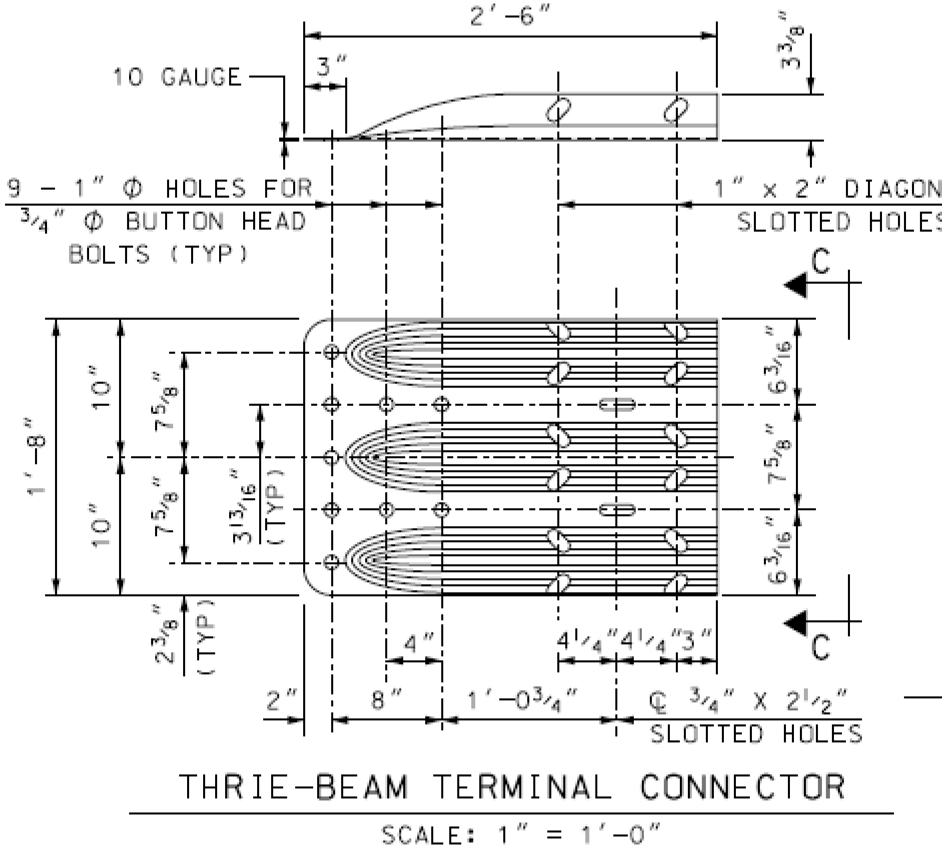
2.5 ft long 10 ga.



0.25”
Smallest element size

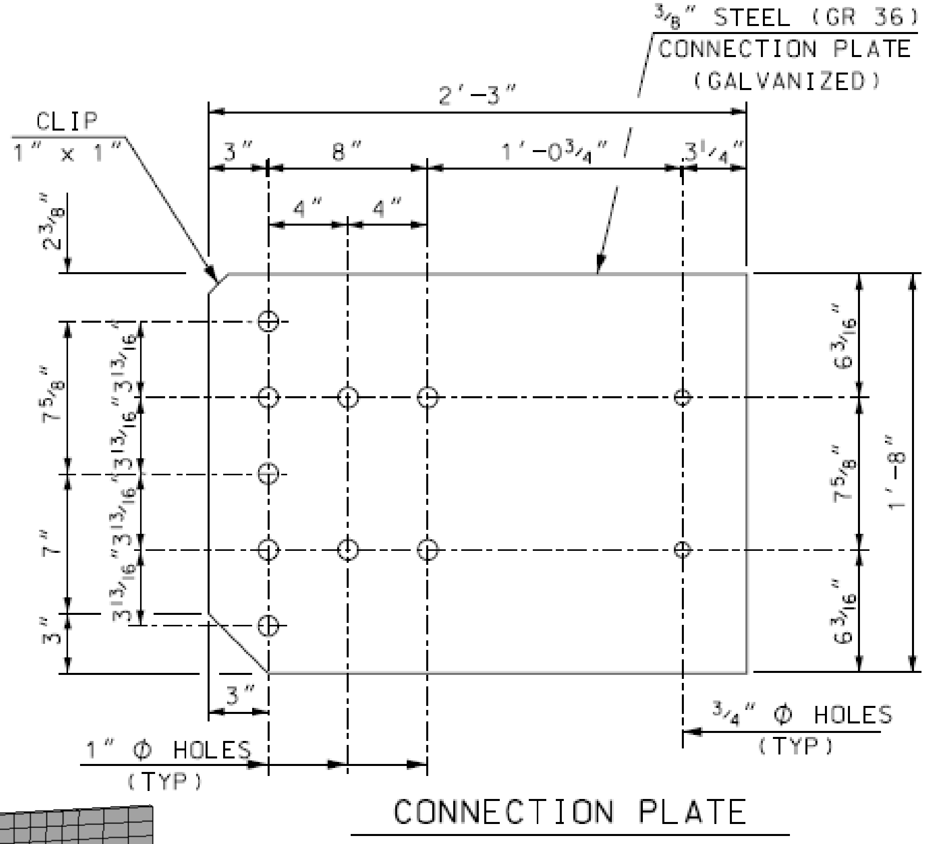
0.38”
Element size

0.51”x0.55”
Element size



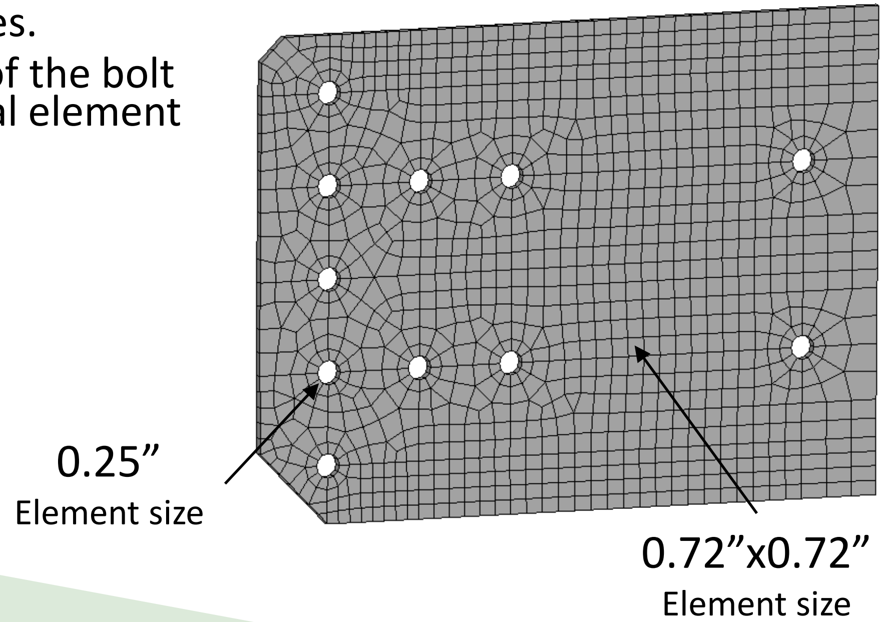
Connection Plate

- The geometry for the connection plate was developed based on the dimensions in the detail drawings.
- The material was modeled as AASHTO M183 (A36).
- The part was modeled with thin-shell Belytschko-Tsay elements (Type 2 in LS-DYNA) with five (5) integration points through the thickness.
  - The part was meshed with a nominal element size of 0.72 x 0.72 inches.
  - The elements around the edge of the bolt holes were meshed with nominal element size of 0.25 inches.



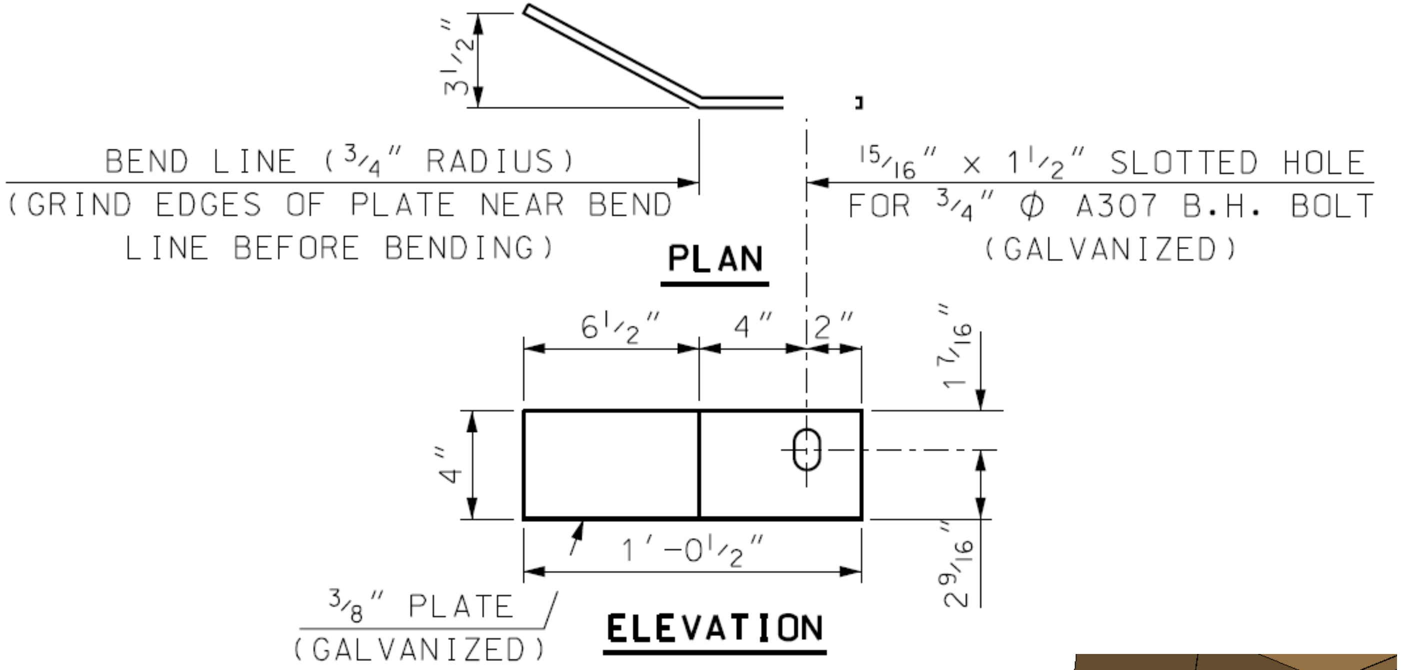
Connection Plate

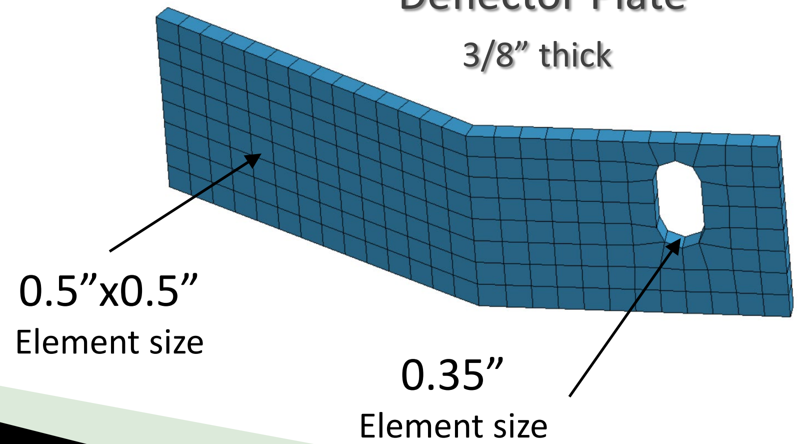
2.5 ft long 3/8" thick

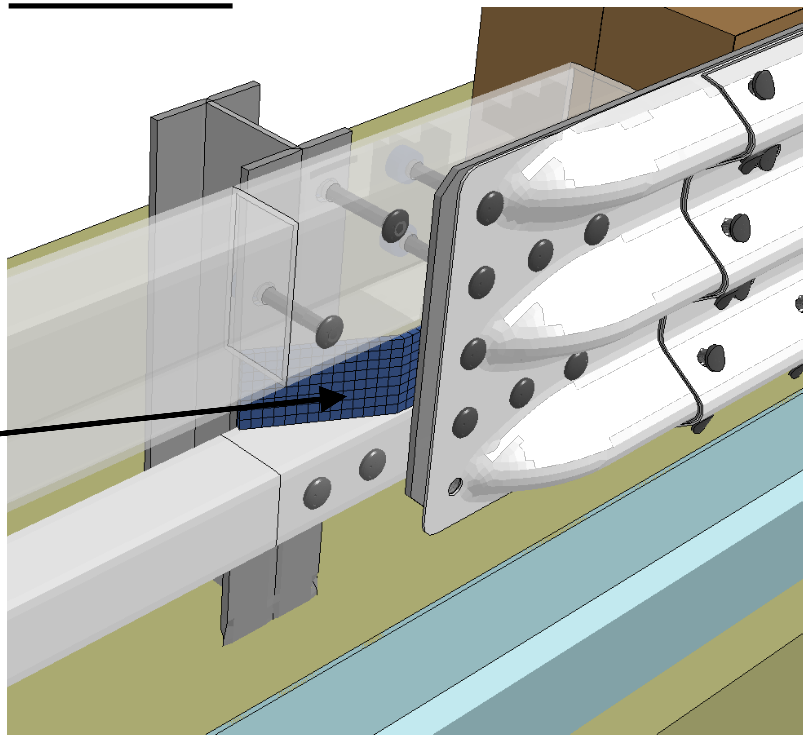


Deflector Plate

- The geometry for the deflector plate was developed based on the dimensions in the detail drawings.
- The material was modeled as AASHTO M183 (A36).
- The part was modeled with thin-shell Belytschko-Tsay elements (Type 2 in LS-DYNA) with five (5) integration points through the thickness.
    - The part was meshed with a nominal element size of 0.5 x 0.5 inches.
    - The elements around the edge of the bolt holes were meshed with nominal element size of 0.35 inches.

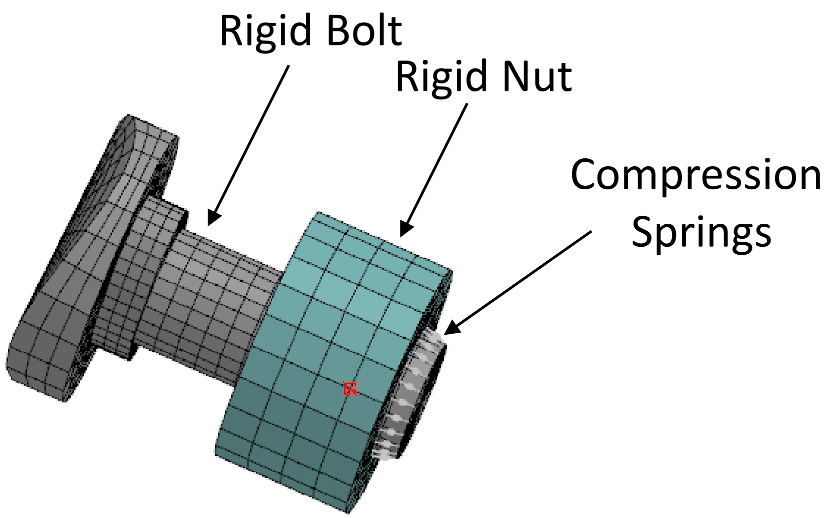


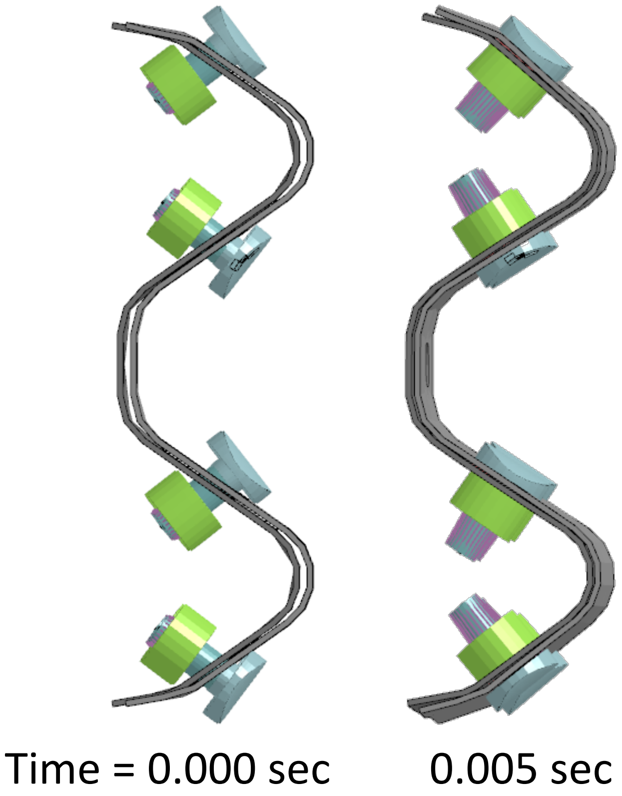




Splice Bolts

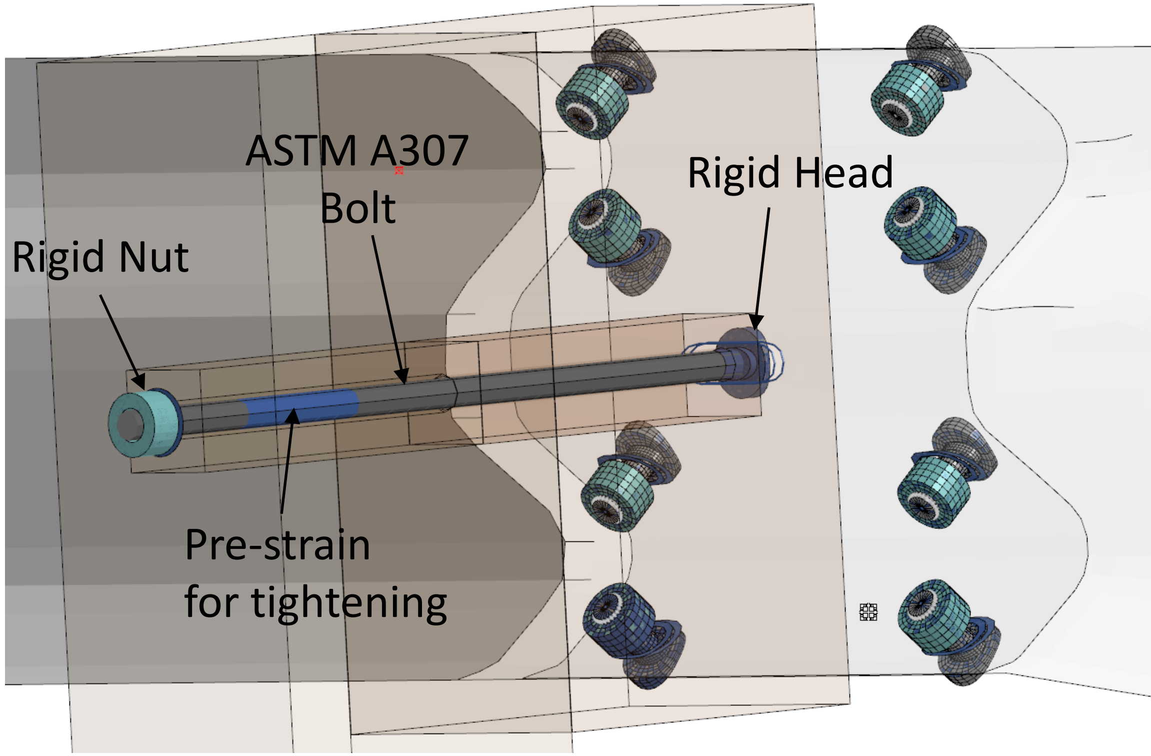
- Splice-bolt hardware seldom fails during impact, thus the material properties for the bolts and nuts were modeled with rigid material behavior.
  - Failure of the splice connection is generally due to the “rigid” bolts rotating and tearing through the relatively thin w-beam material.
  - Therefore, the bolts were modeled with geometric fidelity in order to obtain accurate force distribution and stress concentrations in the w-beam splice holes.
- The dimensions of the bolt hardware were modeled according to the standard drawing FBB01 for guardrail bolt and recessed nut (designation from AASHTO’s *A Standardized Guide to Highway Barrier Hardware*).
- Compression springs and dampers were attached between the end of the bolt and the nut to push the nut onto the bolt and clamp the rail panels together.
- The dampers are modeled as one-way dampers that “lock” the nut onto the bolt by preventing the nut from reversing direction.
- The images on the left show the bolt and rail position at time equal zero and at time equal 0.005 seconds.





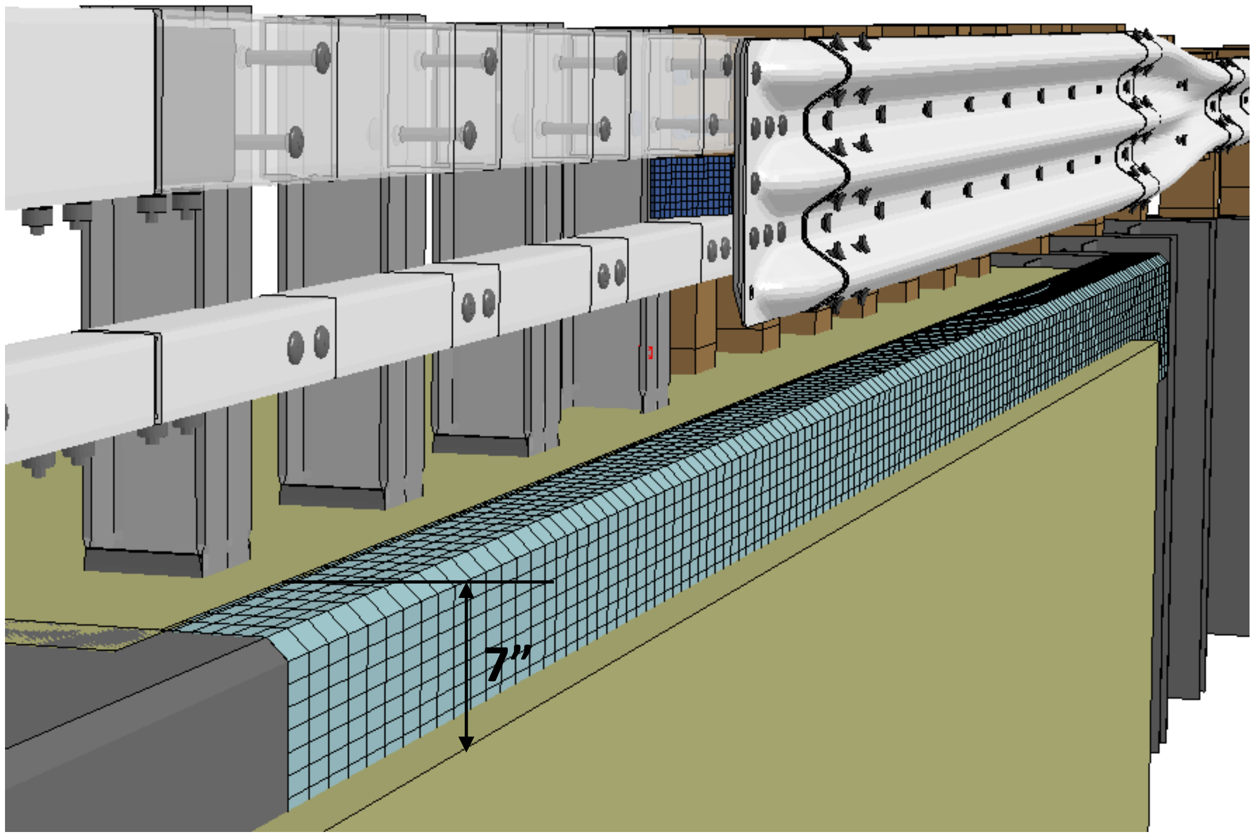
Post Bolts

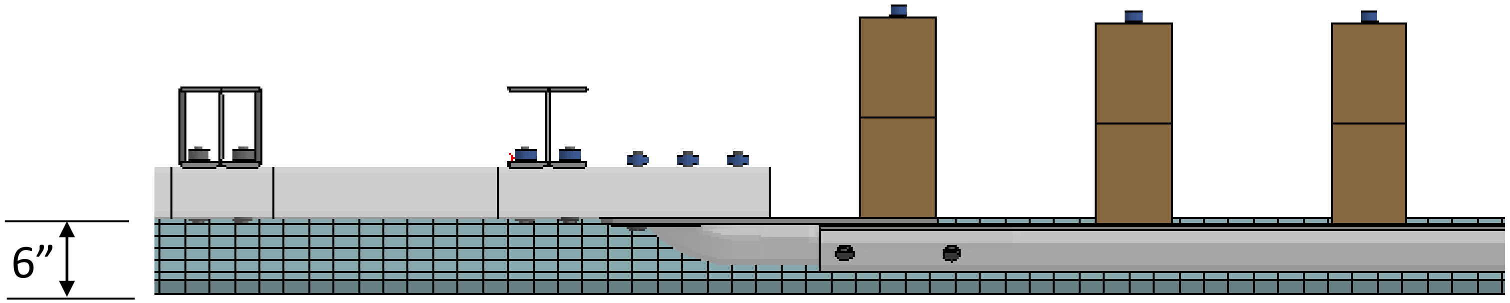
- The 5/8-inch diameter button-head post bolts were modeled with Hughes-Liu beam elements (Type 1 in LS-DYNA) with properties corresponding to ASTM A307.
- The bolt-head, nut and the washer were modeled with rigid material properties, since the effects of deformation of these components were expected to be negligible compared to the effects of bolt deformations.
- To tighten the bolt and clamp the rail to the post:
  - The nut was rigidly constrained to the end of the bolt,
  - A gradual pre-strain condition was then applied to 3-inch long section of the bolt in order to shrink the bolt approximately 3/8 inch in approximately 0.01 seconds.



Curb

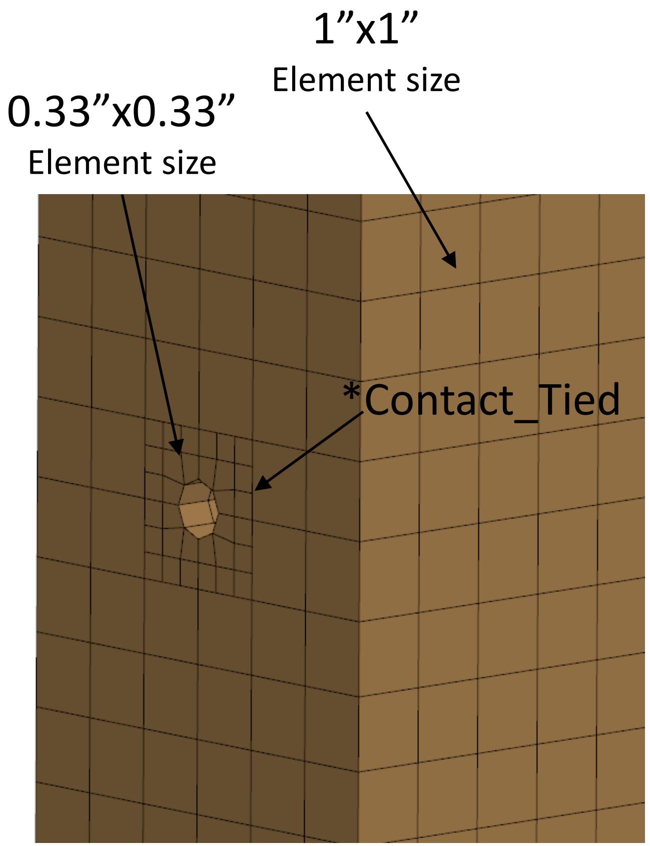
- The granite curb was modeled model based on the shape of the bridge rail curb.
- The curb was 7 inches tall.
- The curb face was offset 6 inches from the face of the transition tube rails (consistent with the bridge rail).
- This resulted in a curb face offset of 1.25” from the face of the thrie-beam rail.
- It was assumed that the deformation and damages to the curb would be negligible; thus rigid material properties were used.

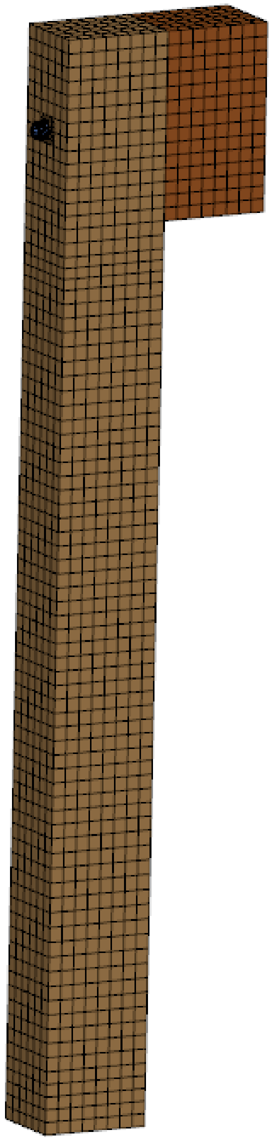




Wood Posts and Blockouts

- The posts in the transition were wood with cross-section of 6”x8”.
- Post length was 7 feet.
- The material was modeled as Grade 1 Pine. This material model was calibrated and validated for guardrail posts in an earlier project [*Plaxico2015*].
- The post was modeled with solid elements with single integration point.
  - The post and blockout parts were meshed with a nominal element size of 1”x 1”.
  - The mesh in the post-bolt region was meshed with a nominal element size of 0.33”x0.33”.
  - The mesh of the post-bolt region was “tied” to the elements of the post using the *Contact_Tied option in LS-DYNA.





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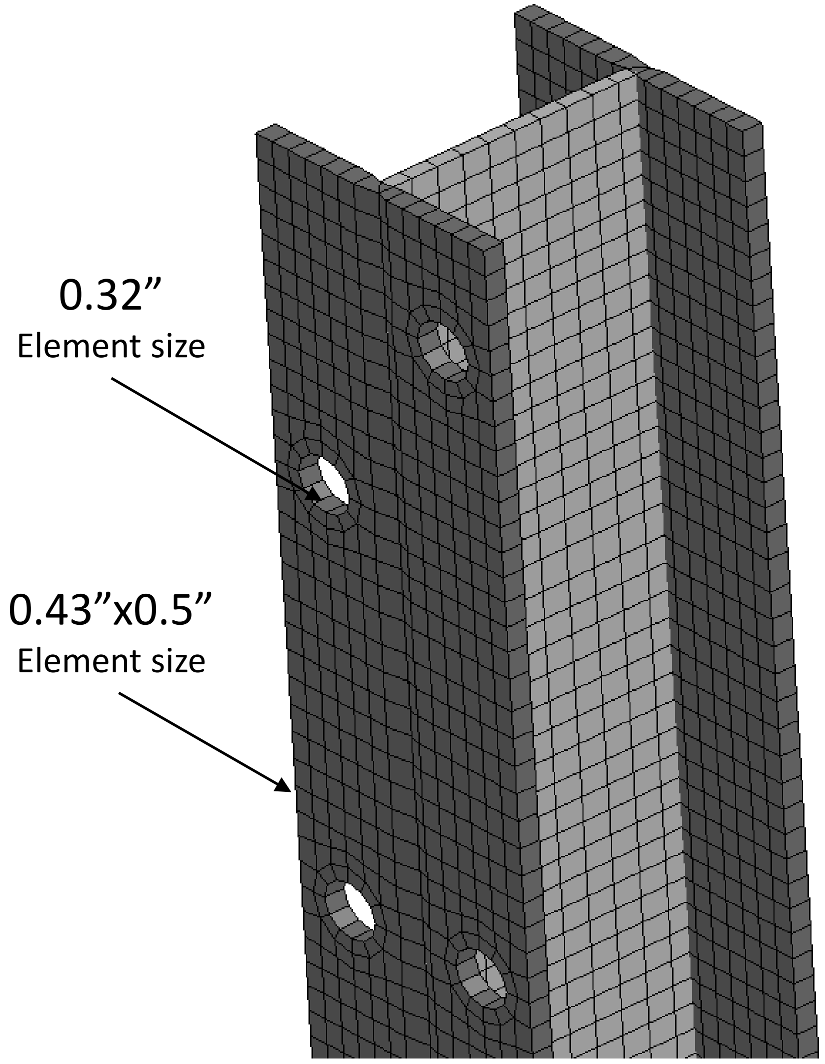
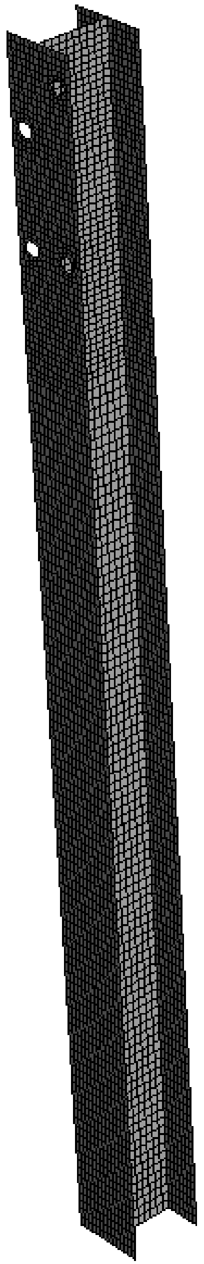
Steel Posts

- The posts in the transition were modeled as W6x25 and 8 feet long.
- The material for the post model conformed to ASTM A572 Grade 50 steel.
- The post was modeled with thin-shell Belytschko-Tsay elements (Type 2 in LS-DYNA) with five (5) integration points through the thickness.
- The flange and web were meshed with a nominal element size of 0.43 x 0.5 inches.
- The elements around the edge of the mounting holes were meshed with nominal element size of 0.32 inches.





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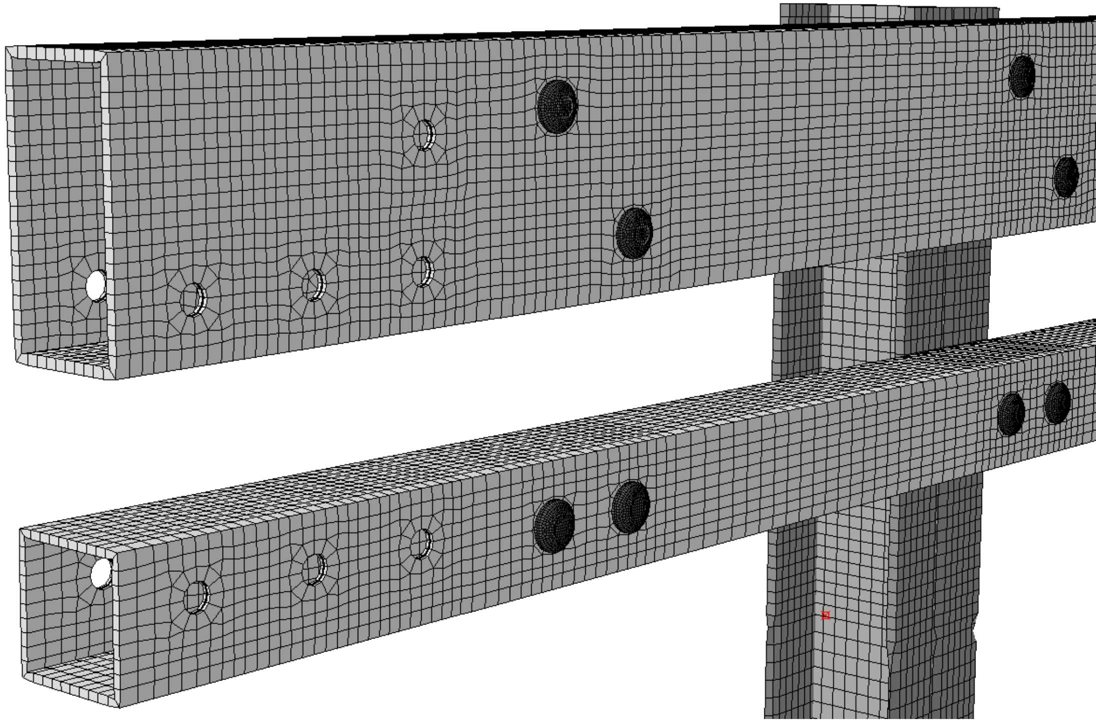
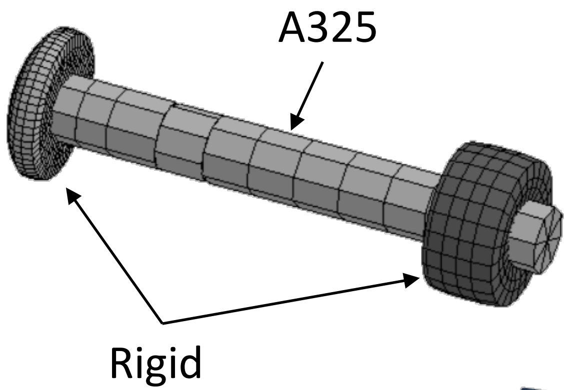
Transition Rail Tubes

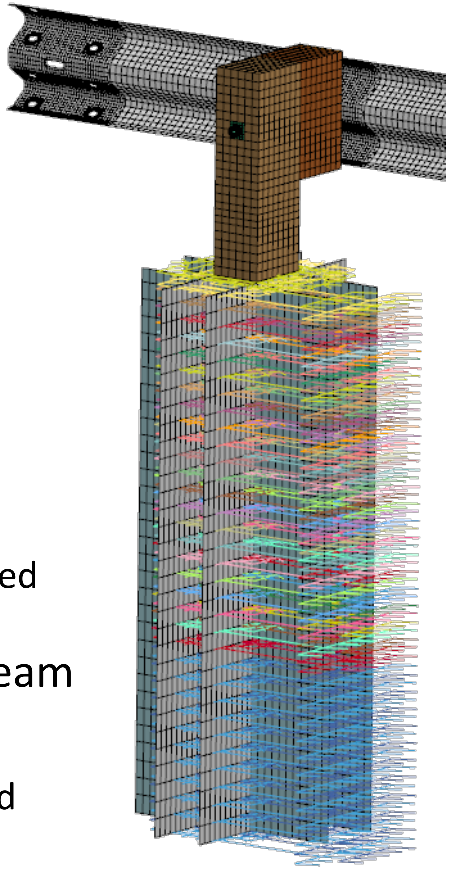
- The tubular rail sections were modeled according to the dimensional specifications for **HSS 4"x4"x ¼"** and **HSS 8"x4"x 5/16"**.
- The material for all tube railing conformed to **ASTM A500 Grade B.**
- The tube rails were modeled with Type 2 elements with five (5) integration points through the thickness.
- The nominal element size for the mesh is 0.75 x 1 inches for the span of rail between the posts and 0.4 x 0.4 inches for the section of rail in contact with the posts.
- **The mounting holes in the rail were 7/8" diameter**.
- The mesh around the slotted holes were meshed with a nominal element length of 0.25 inches.
- **The 3/4-inch diameter button head mounting bolts** were modeled with Hughes-Liu beam elements (Type 1 in LS-DYNA) with properties corresponding to **ASTM A325**.
- **The head of the bolts, as well as the nuts and washers were modeled with rigid material properties**, since the effects of deformation of these components were expected to be negligible compared to the effects of bolt deformations.
- **The bolts were given a pre-strain condition to tighten the railing onto the post.**



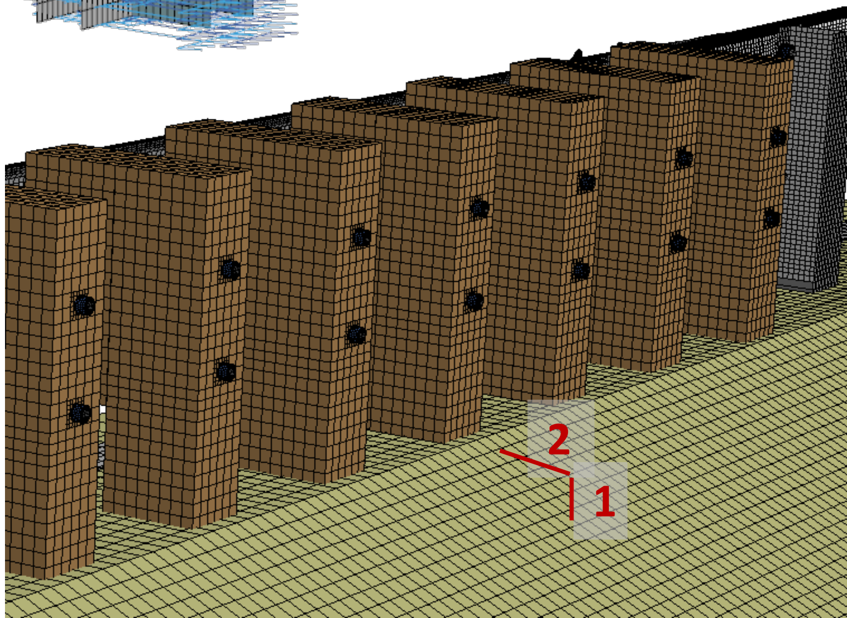


Soil Model

- There are several approaches that may be used for modeling the soil in analyses of guardrail posts embedded in soil.
- Some common approaches include:
  - Posts embedded in a soil continuum of solid finite elements,
  - Posts embedded in a continuum of meshless finite elements, and
  - Subgrade reaction approach in which the post is supported by an array of uncoupled springs.
- Each of the methods mentioned above have been used by the research team with reasonable success.
  - Some advantages of the discrete element approach are that the soil model can undergo large deformations without effecting numerical accuracy and stability, and fewer calculations are required with discrete elements making the solution much more efficient.
  - The continuum method is reasonably accurate for low to moderate soil displacement but has the advantage of modeling soil interaction between neighboring posts.
- For the current study, two methods were used:
  - The discrete elements method (i.e., springs and dampers) was used to model the soil in the w-beam section (computational efficiency).
  - The soil continuum method (solid elements) was used in the impact region on the transition were the posts were closely spaced (i.e., thrie-beam and tube-rail sections).
  - The continuum soil model included a 2:1 slope starting just behind the thrie-beam posts.



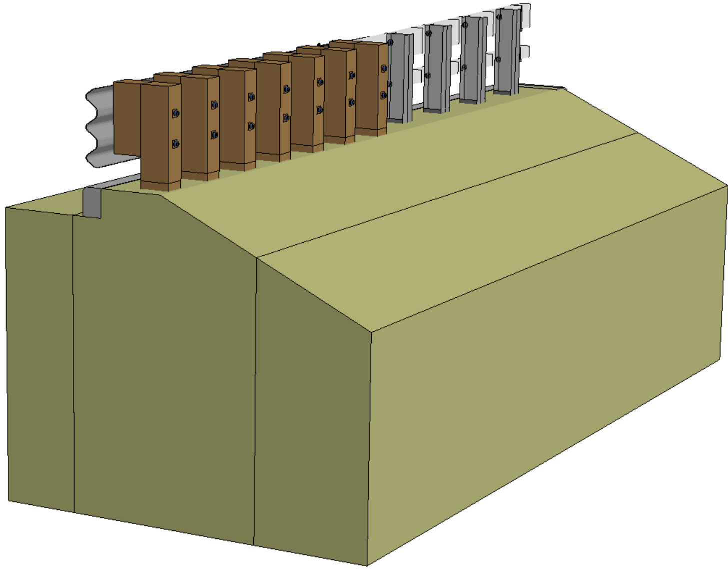
Soil Spring Model

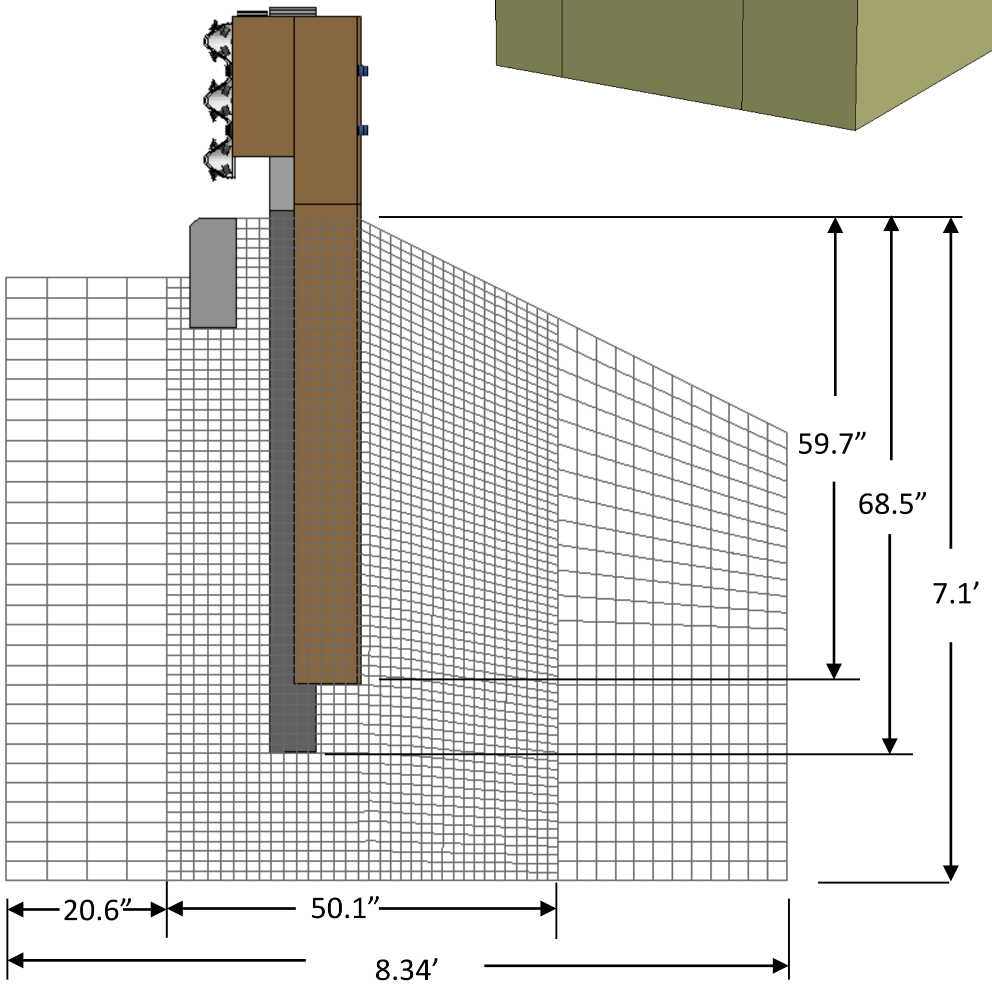


Soil Continuum Model

Soil Model

- Soil continuum model
  - Length = 21.7 feet
  - Lateral width = 8.34 feet
  - Vertical depth = 7.1 feet
- The material was modeled using the Drucker-Prager material model. This material model was calibrated based on comparison to full-scale tests (see following slides).
- The post was modeled with solid elements with single integration point.
  - The soil in the immediate post region was meshed with element side lengths of approximately 1.3 – 1.6 inches.
  - The soil at the father extents was meshed with element side lengths of 2.5 – 3 inches.
  - The refined-mesh region was “tied” to the elements of the coarse-mesh region using the *Contact_Tied option in LS-DYNA.



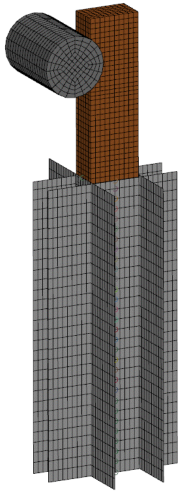


Soil Spring Model Validation

- The soil model was qualitatively validated based on comparison with impact tests on wood guardrail posts performed at the Midwest Roadside Safety Facility (MwRSF) [*Rosenbaugh11*]
- The properties of the spring elements were defined using a soil density of 126 pcf.
- A total of five (5) test cases were simulated which are listed in the Table to the left.
- In all cases, the impact point was at 24.9 inches above ground on the face of the post with loading in the strong bending direction for the post.
- The striker that was used in the tests was the MwRSF bogie with rigid nose.
  - The mass and impact speed of the striker varied slightly from test to test with a nominal mass and speed of 1,835-lb and 20 mph, respectively.
- A finite element model of the bogie vehicle was not available to the research team, so the striker was modeled as a simple rigid mass with a semi-rigid head.

Dynamic test cases used for model validation.

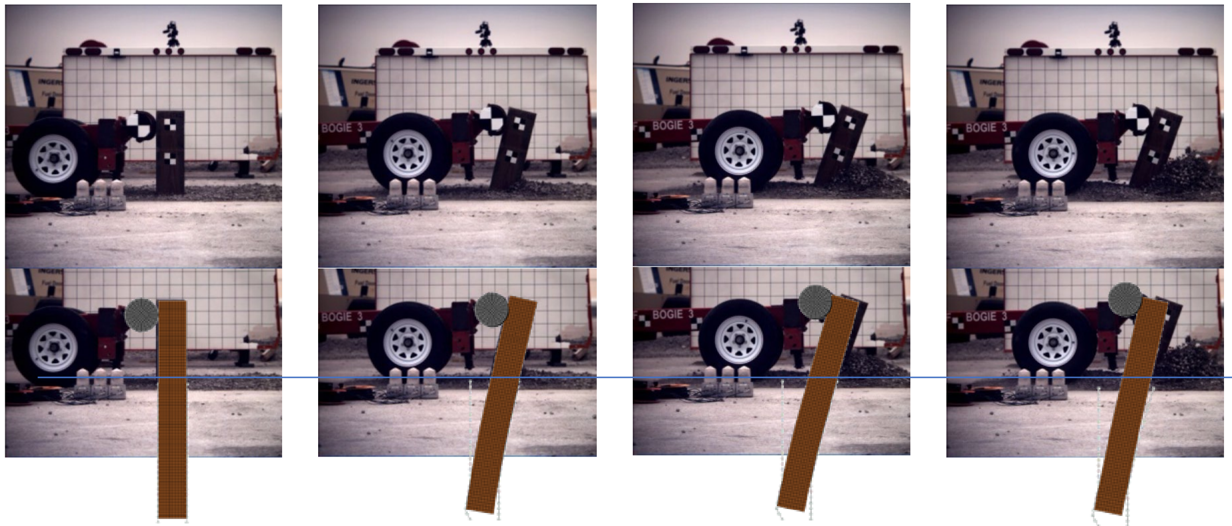
Test No.	Post Size (in. x in.)	Post Grade (as Modeled)	Soil density (as modeled) (pcf)	Embedment Depth (in.)	Impact Mass (lb)	Impact Speed (mph)
MGSATB-13	8 x 10	Grade 1	126	48	1,812.0	20.24
MGSATB-14	8 x 10	Grade 1	126	48	1,817.9	19.69
MGSATB-18	6 x 10	Grade 1	126	52	1,835.0	20.98
MGSATB-18	6 x 10	DS-65	126	52	1,835.0	20.98
MGSATB-19	6 x 10	Grade 1	126	52	1,835.0	19.73



FEA Model

Soil Spring Model Validation

- The response of the soil-spring model matched well with the test results.
- The upper part of each figure shows sequential views of the test, followed by sequential views of the FEA overlaid onto the test images.
- Comparisons of FEA and test results regarding force versus displacement and energy versus displacement for each case are also provided.
- Test cases MGSATB-13 and MGSATB-14 were very similar (i.e., 8x10 post, similar impact mass and similar impact speed).
- The results from the FEA, accordingly, were very similar for both cases. The results, however, differed somewhat for the two test cases, with MGSATB-14 being approximately 4 kips stronger than case MGSATB-13.
- The FEA results tended to match better with the results of Test MGSATB-13 over the first 5 inches of deflection, and tended to match better with Test MGASTB-14 at higher deflections (see next slide).



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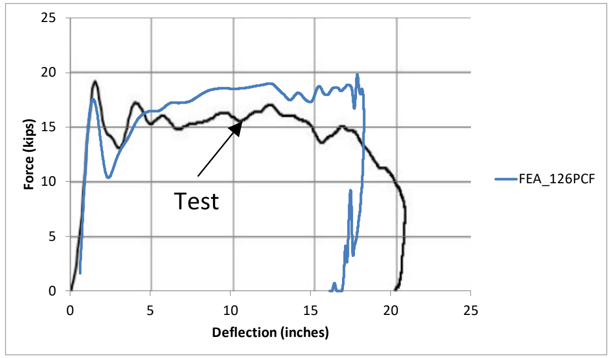
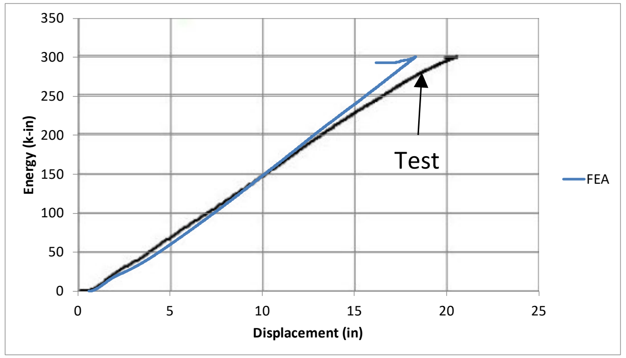
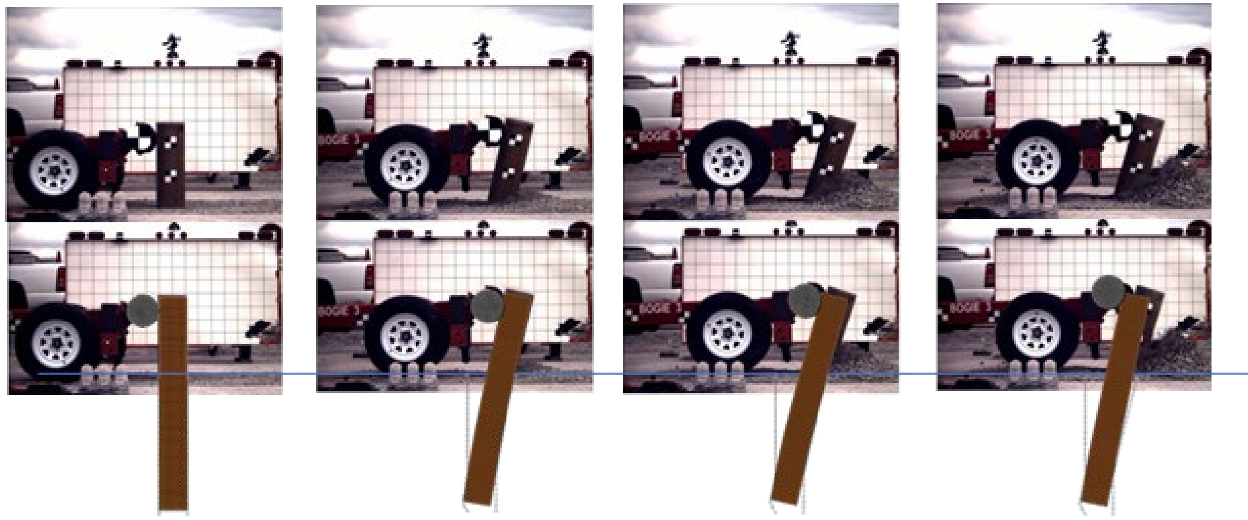




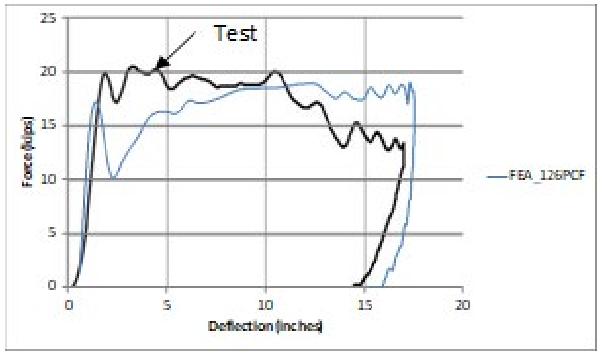
MGSATB-13 (Grade 1 Posts)

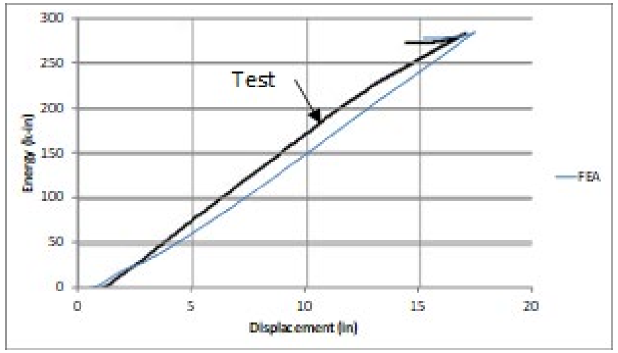
Soil Spring Model Validation

- The response of the soil-spring model matched well with the test results.
- The upper part of each figure shows sequential views of the test, followed by sequential views of the FEA overlaid onto the test images.
- Comparisons of FEA and test results regarding force versus displacement and energy versus displacement for each case are also provided.
- Test cases MGSATB-13 and MGSATB-14 were very similar (i.e., 8x10 post, similar impact mass and similar impact speed).
- The results from the FEA, accordingly, were very similar for both cases. The results, however, differed somewhat for the two test cases, with MGSATB-14 being approximately 4 kips stronger than case MGSATB-13.
- The FEA results tended to match better with the results of Test MGSATB-13 over the first 5 inches of deflection (see previous slide), and tended to match better with Test MGASTB-14 at higher deflections.



Time = 0.00 sec Time = 0.05 sec Time = 0.10 sec Time = 0.15 sec

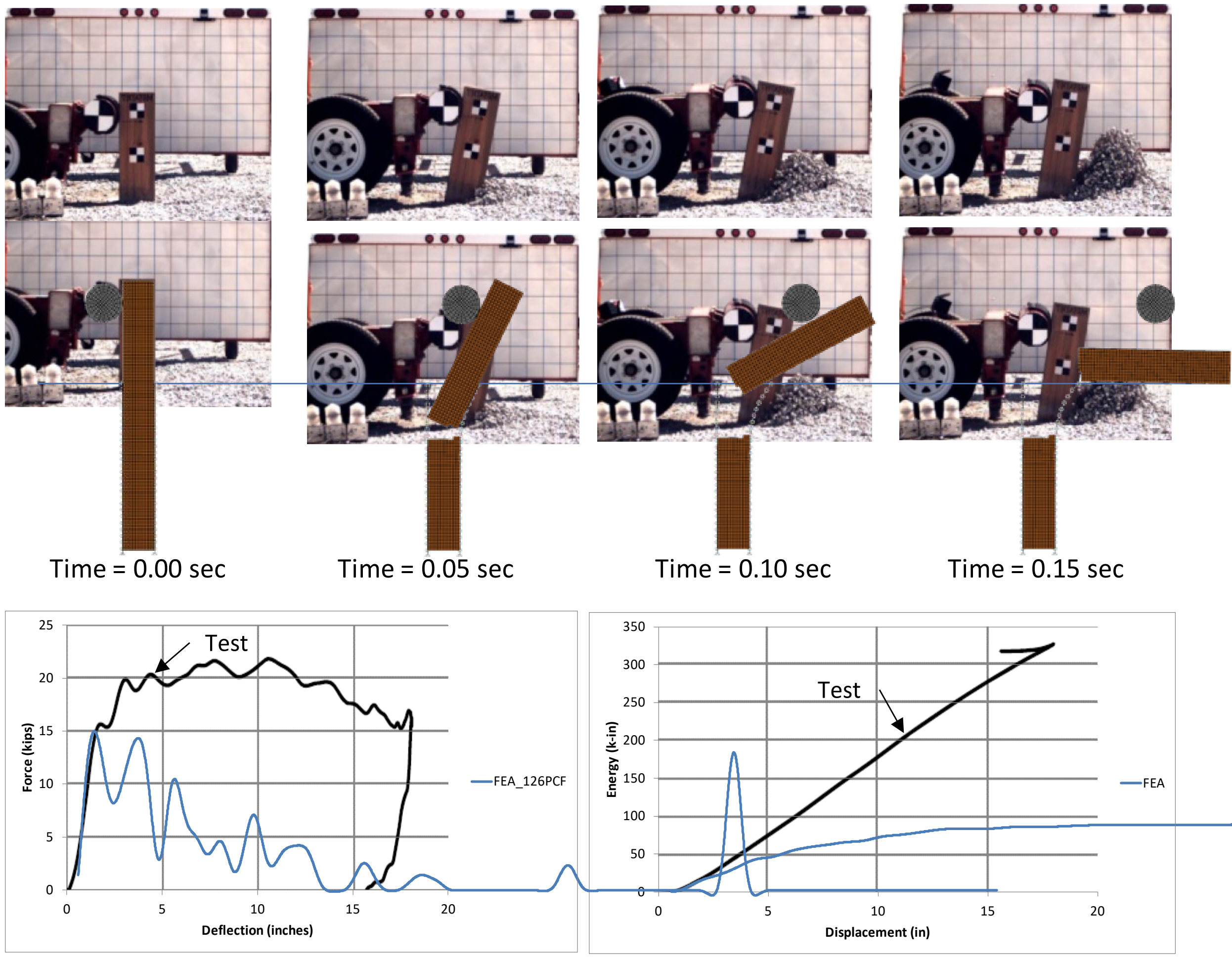




MGSATB-14 (Grade 1 Posts)

Soil Spring Model Validation

- Test cases MGSATB-18 and MGSATB-19 were also very similar (i.e., 6x10 post, identical impact mass, similar impact speed), but resulted in very different results.
- In the initial FEA simulation, using Grade 1 properties for the post, the post broke off at 16.4 inches below ground; whereas, the post did not break during the physical test for this case.

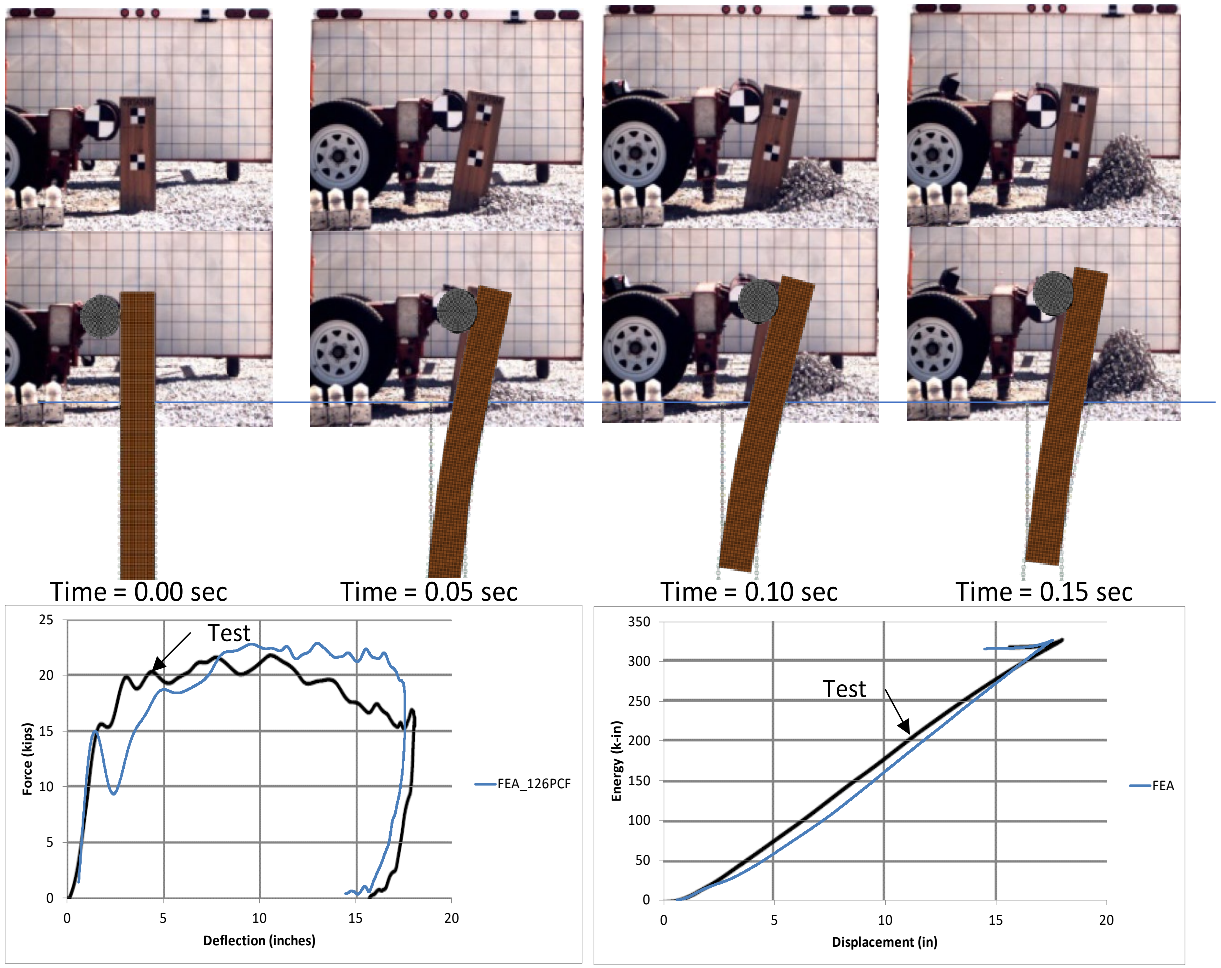


MGSATB-18 (Grade 1 Posts)

RoadSafe LLC Transportation Engineering and Research

Soil Spring Model Validation

- The results of the model for Test MGSATB-18 (i.e., 6x10 post) matched well.
- DS-65 post (stronger than Grade 1) used in the analysis.



MGSATB-18 (DS-65 Posts)

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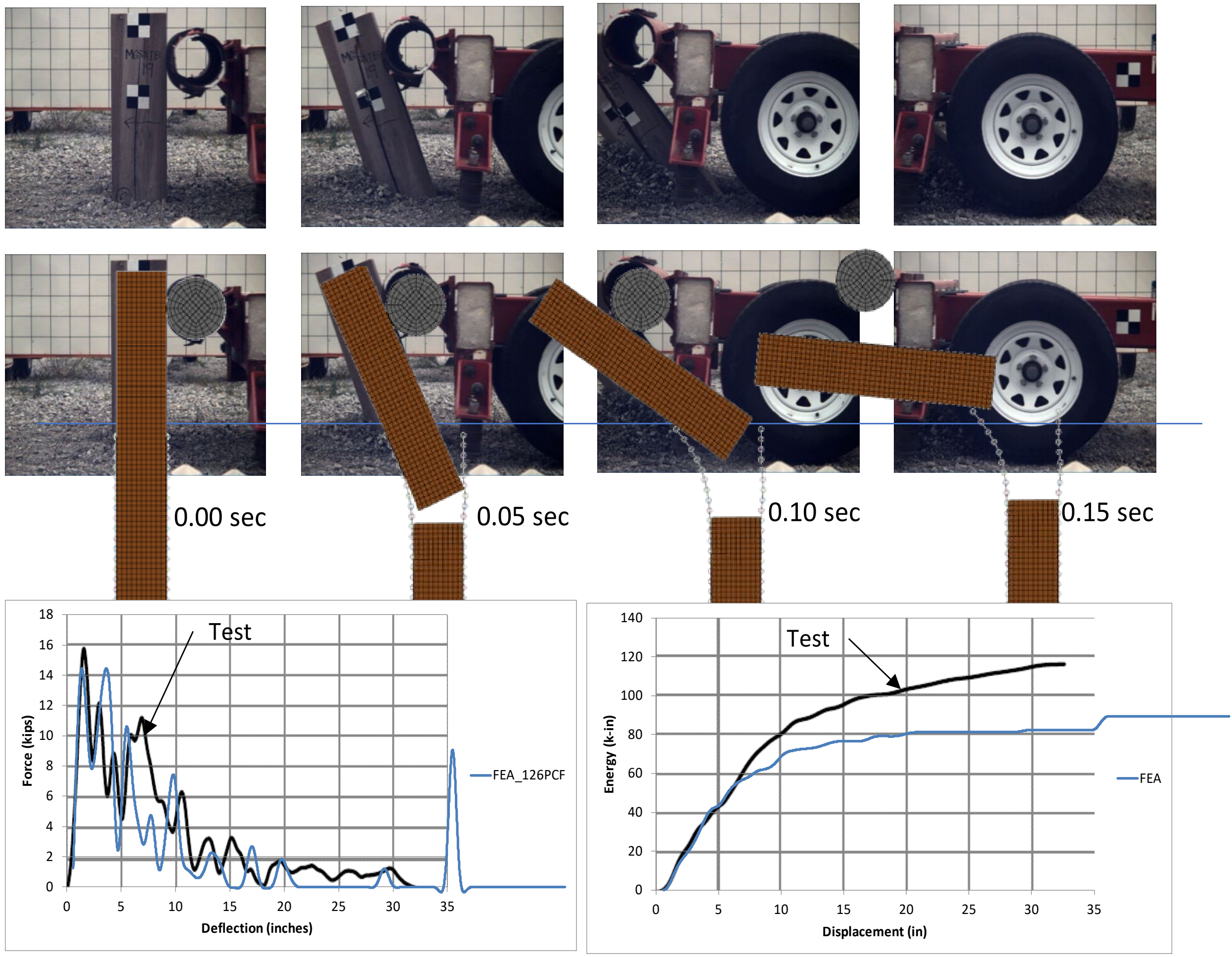
Soil Spring Model Validation

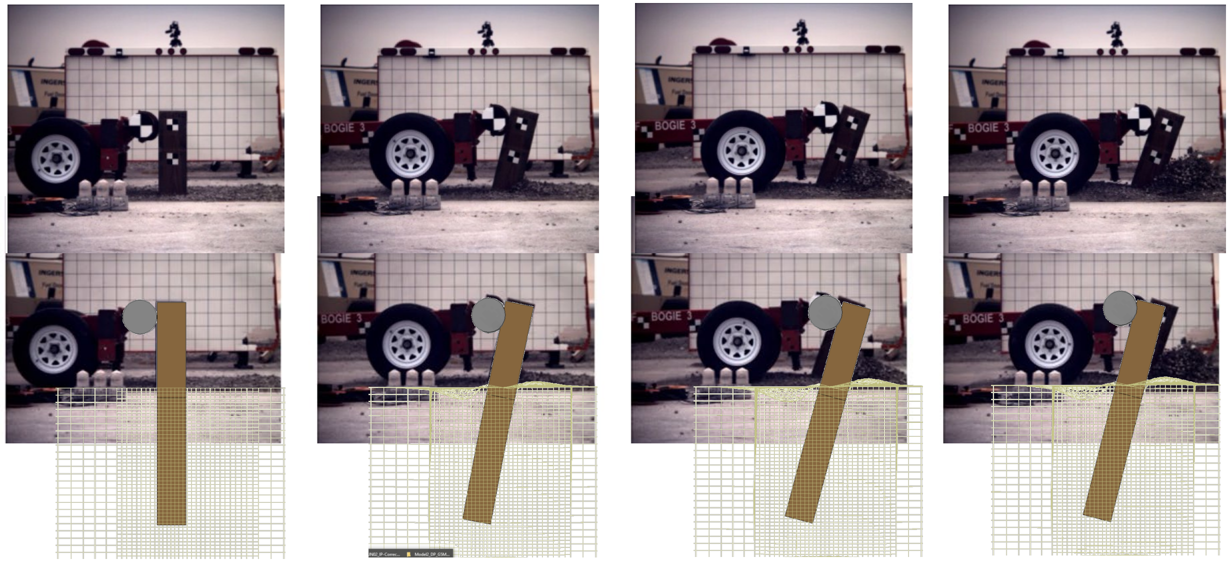
- The results of the model for Test MGSATB-19 also matched reasonably well, with the post rupturing at 16.4 inches below grade.
- In the full-scale test, the post was split into three pieces with a break at 8 inches below grade.
- The overlay of the sequential views in Figure 35 show that the timing of the break and the overall speed of the striker throughout the event was similar for both FEA and test.

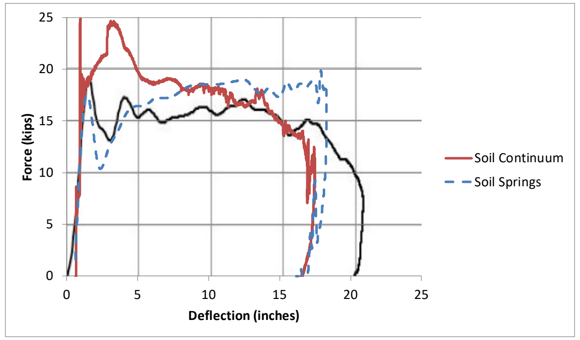


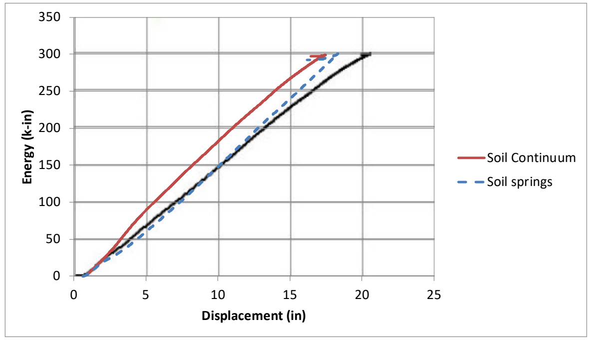
MGSATB-19 (Grade 1 Posts)

Soil Continuum Model Validation

- Soil Continuum Model Compared with Tests MGSATB-13 and MGSATB-14
- Recall these test were very similar (i.e., 8x10 post, similar impact mass and similar impact speed).
- Sequential views of FEA vs. test is shown.
- The force-displacement and energy-displacement results are compared for the continuum model, soil spring model, and test.
- **Soil spring** model matches best for **MGSATB-13**.







MGSATB-13 (Grade 1 Posts)

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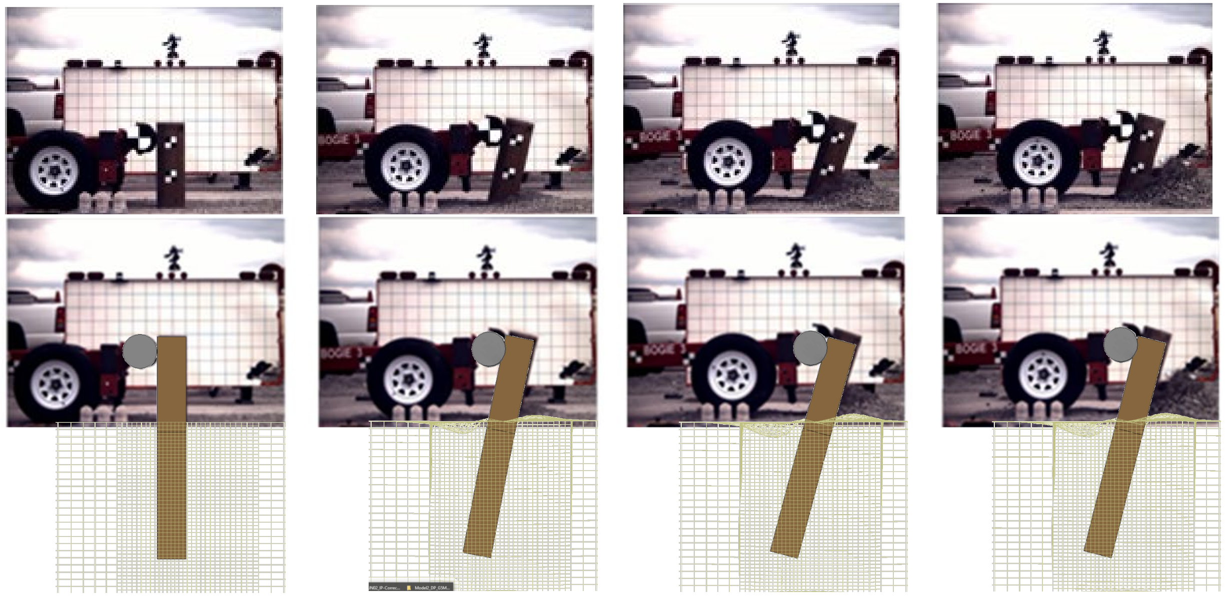
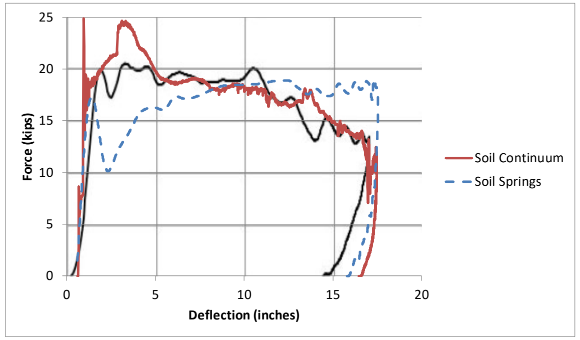
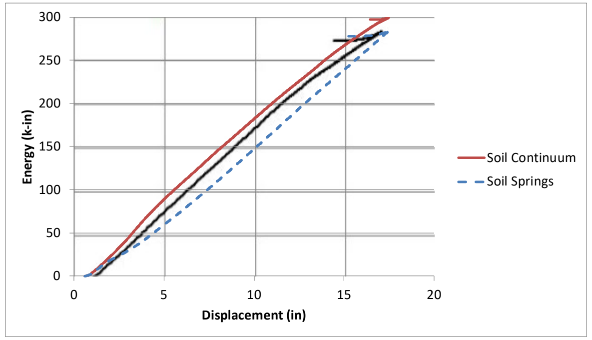
Soil Continuum Model Validation

- Soil Continuum Model Compared with Tests MGSATB-13 and MGSATB-14
- Recall these test were very similar (i.e., 8x10 post, similar impact mass and similar impact speed).
- Sequential views of FEA vs. test is shown.
- The force-displacement and energy-displacement results are compared for the continuum model, soil spring model, and test.
- **Continuum model** matches best for **MGSATB-14**.







MGSATB-14 (Grade 1 Posts)

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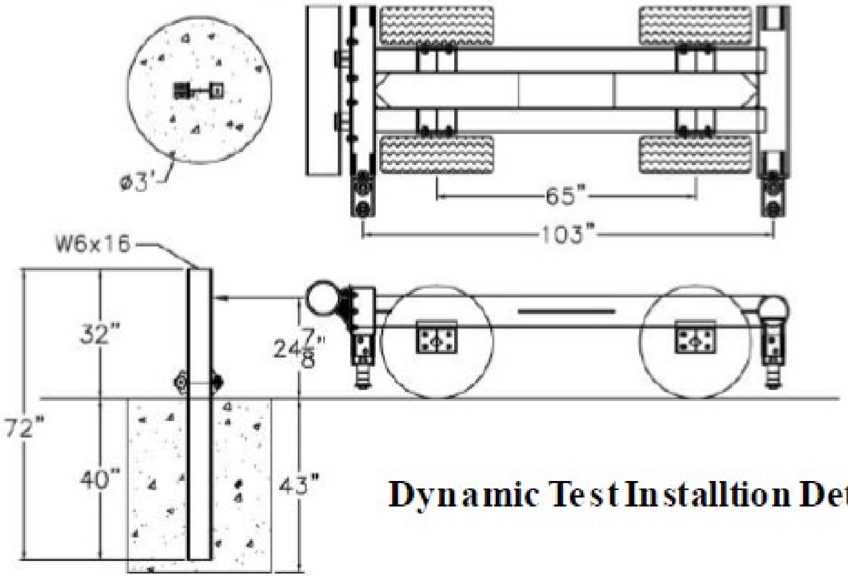
Soil Continuum Model Validation

- A secondary validation was performed for the continuum soil model based on a recent full-scale test of for the MGS stiffness transition with curb.[Winkelbaurer14]
- *“During the installation of a soil dependent system, additional **W6x16 posts are to be installed near the impact region utilizing the same installation procedures as used for the system** itself. Prior to full-scale testing, a dynamic impact test must be conducted to verify a **minimum dynamic soil resistance of 7.5 kips** at post deflections between 5 and 20 in., as measured at a height of 25 in.”*
- The soil properties were the same as used in the previous comparison.
- Impact Conditions:
  - MwRSF bogie with rigid nose.
  - Mass = 1,843-lb
  - Impact Speed = 20 mph.
  - Impact Point = 24.9 inches above ground.

Dynamic Set up

Post-Test Photo of Post



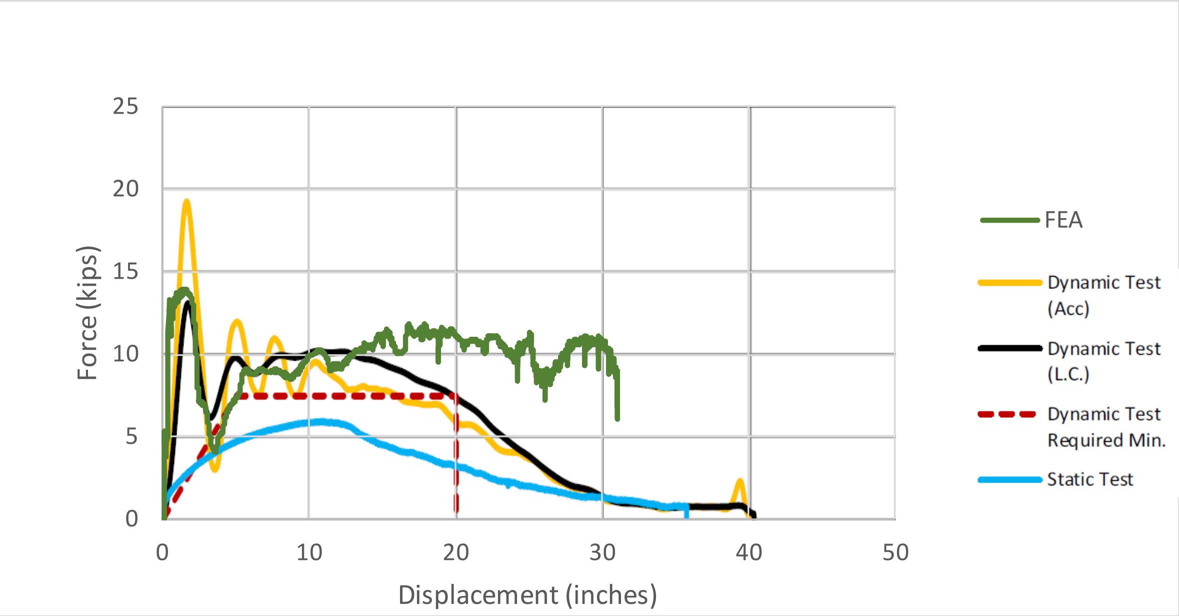
Dynamic Test Installtion Details

Soil Continuum Model Validation

- The results show that the continuum model matches well for the first 15 inches of displacement.
- But then shows stiffer response.
- *It should be noted that these tests correspond to calibration tests for the test-soil system.*
- *Actual stiffness on the day of testing varied for the three full-scale tests, with one case resulting in 67% stiffer soil conditions.*

Dynamic Set up

Post-Test Photo of Post



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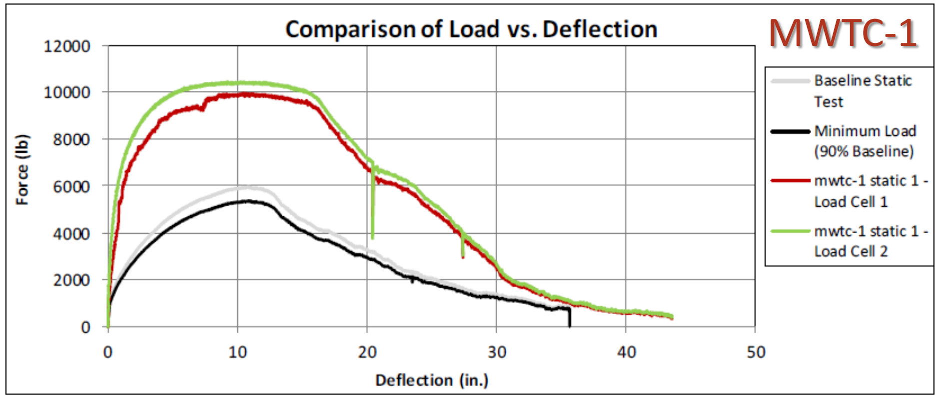
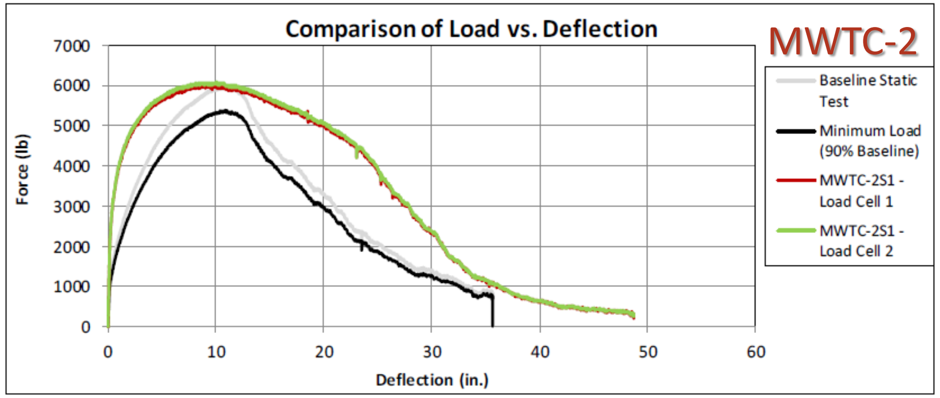
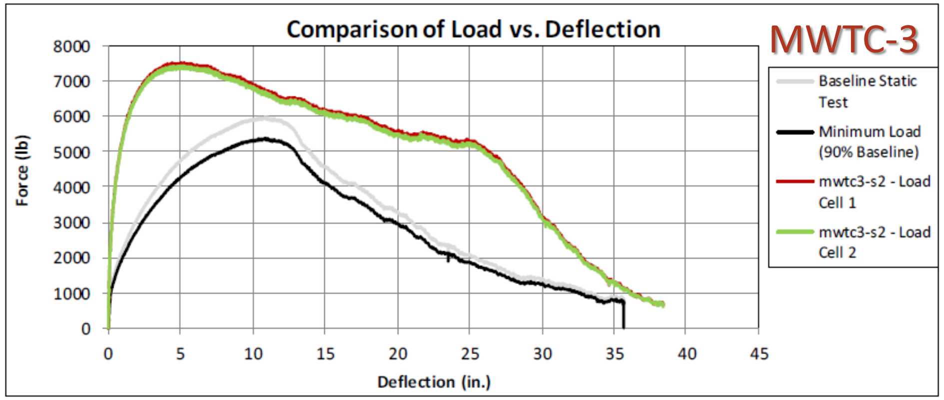
Baseline Soil Response Compared to Subsequent Test Soil Response

- MwRSF subsequently performed 3 full-scale tests on a transition design:
  - MWTC-1: MASH Test 4-20 (small car)
  - MWTC-2: MASH Test 4-20 (small car)
  - MWTC-3: MASH Test 4-21 (pickup)
- The preliminary static post-soil test for each of those test cases is shown here with comparison to baseline strength.
- The results show that the initial stiffness of the soil for the full-scale test cases was significantly higher than the baseline.
- The peak force for each cases was:
  - MWTC-1: 67% higher than baseline.
  - MWTC-2: Equal to baseline.
  - MWTC-3: 25% higher than baseline.



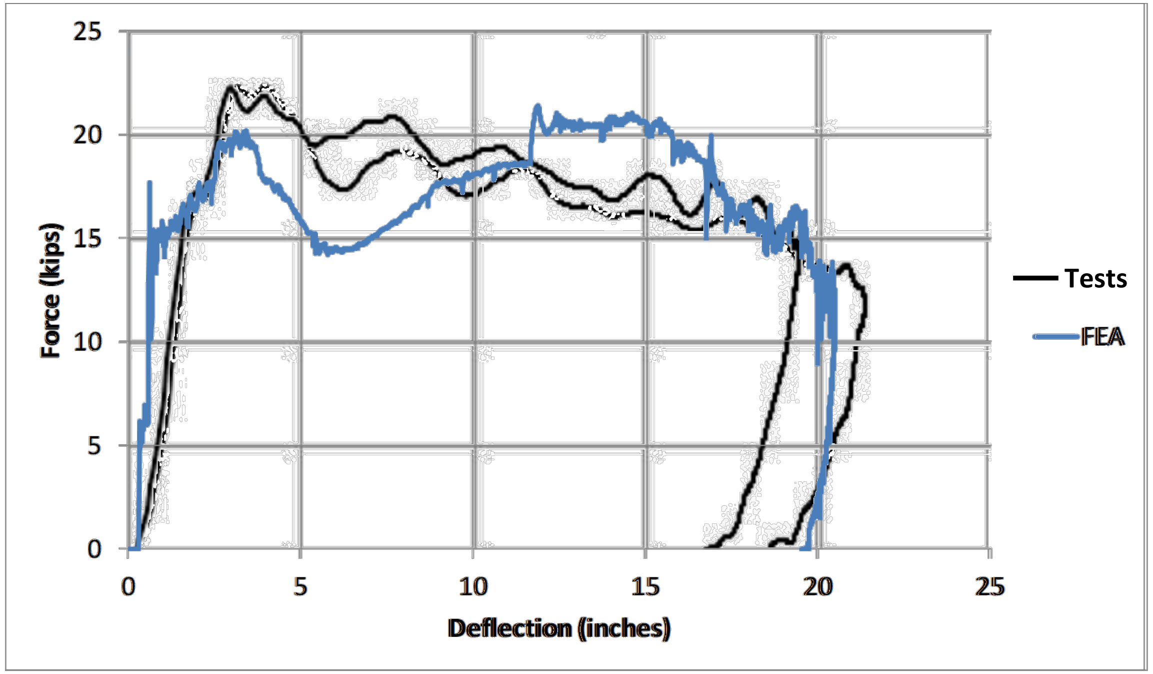


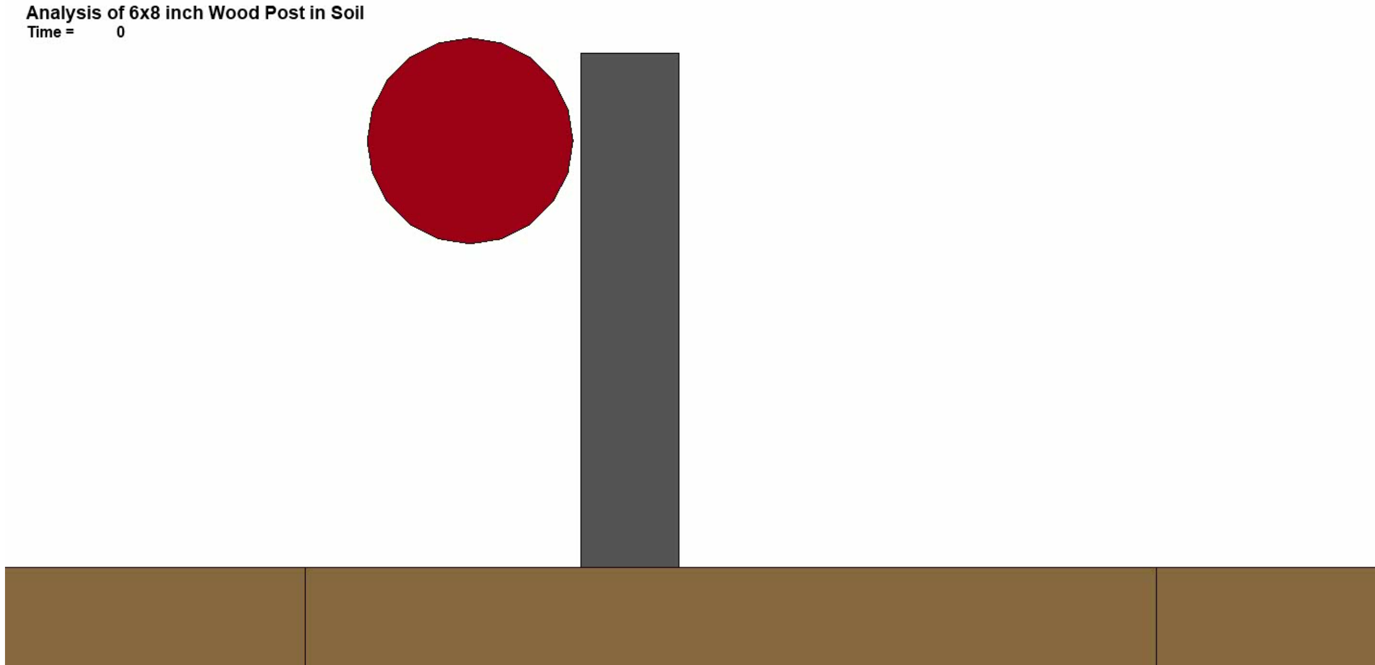


MGSATB-5 and MGSATB-6

Test No.	Post Size	Post Material	Soil Density (as modeled) (pcf)	Embedment Depth (inches)	Impact Mass (lb)	Impact Speed (mph)
MGSATB-1	W6x15	AASHTO M180	126	54	1810	19.22
MGSATB-2	W6x15	AASHTO M180	126	54	1810	19.71
MGSATB-5	W6x15	AASHTO M180	126	54	1816	21.9
MGSATB-6	W6x15	AASHTO M180	126	54	1816	21.7

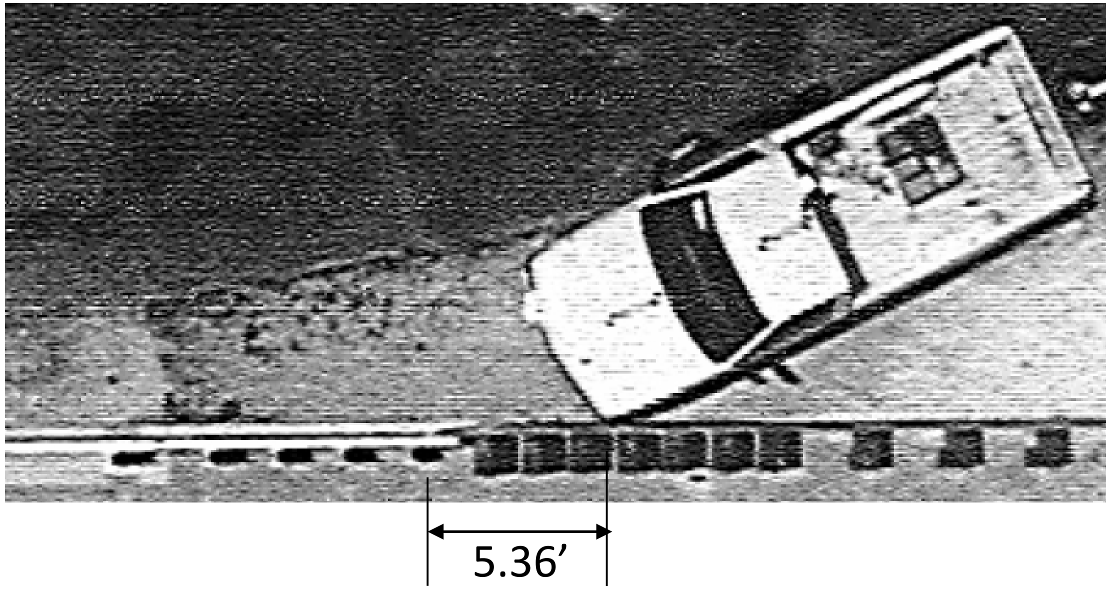
Same test series as shown on Slide 22 but with steel posts

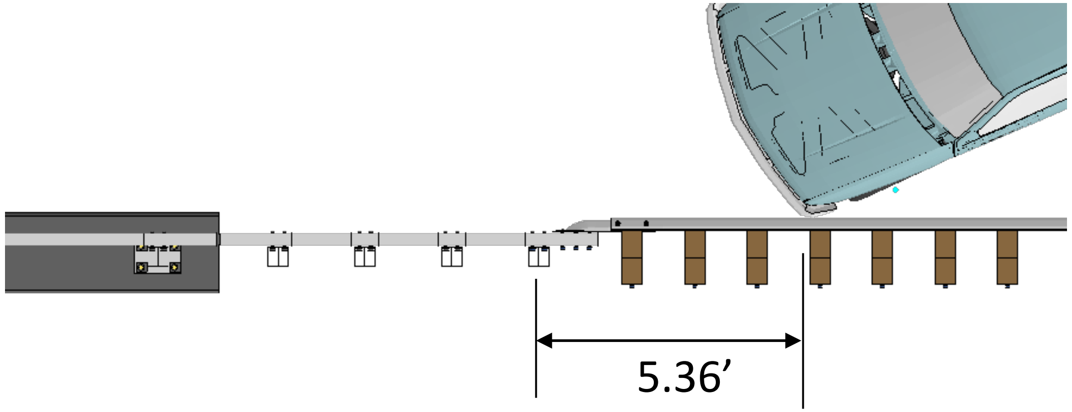




Validation Test Case
AGT for the NETC 2-Bar Bridge Rail

- Test No. 401181-1 on the transition was performed by TTI on 4/14/2005.
- Impact conditions:
  - Vehicle = 2000 Chevrolet 2500 (2000P)
  - Mass = 4,707 lb (2,135 kg)
  - Speed = 63.6 mph (102.3 km/hr)
  - Angle = 24.9 deg.
  - Impact point = 5.36 ft (1.635 m) upstream of first tube-rail post .





Test Video (Test 401181-1)

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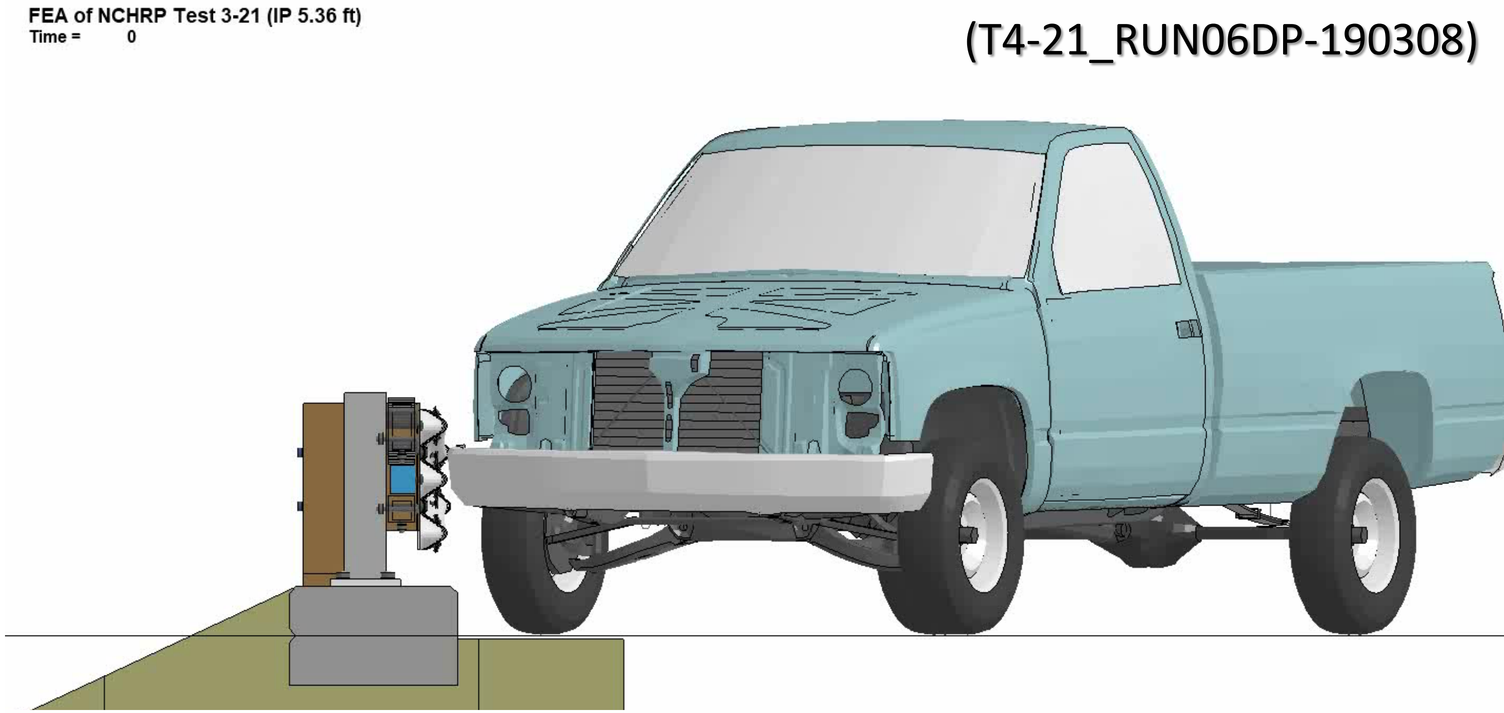
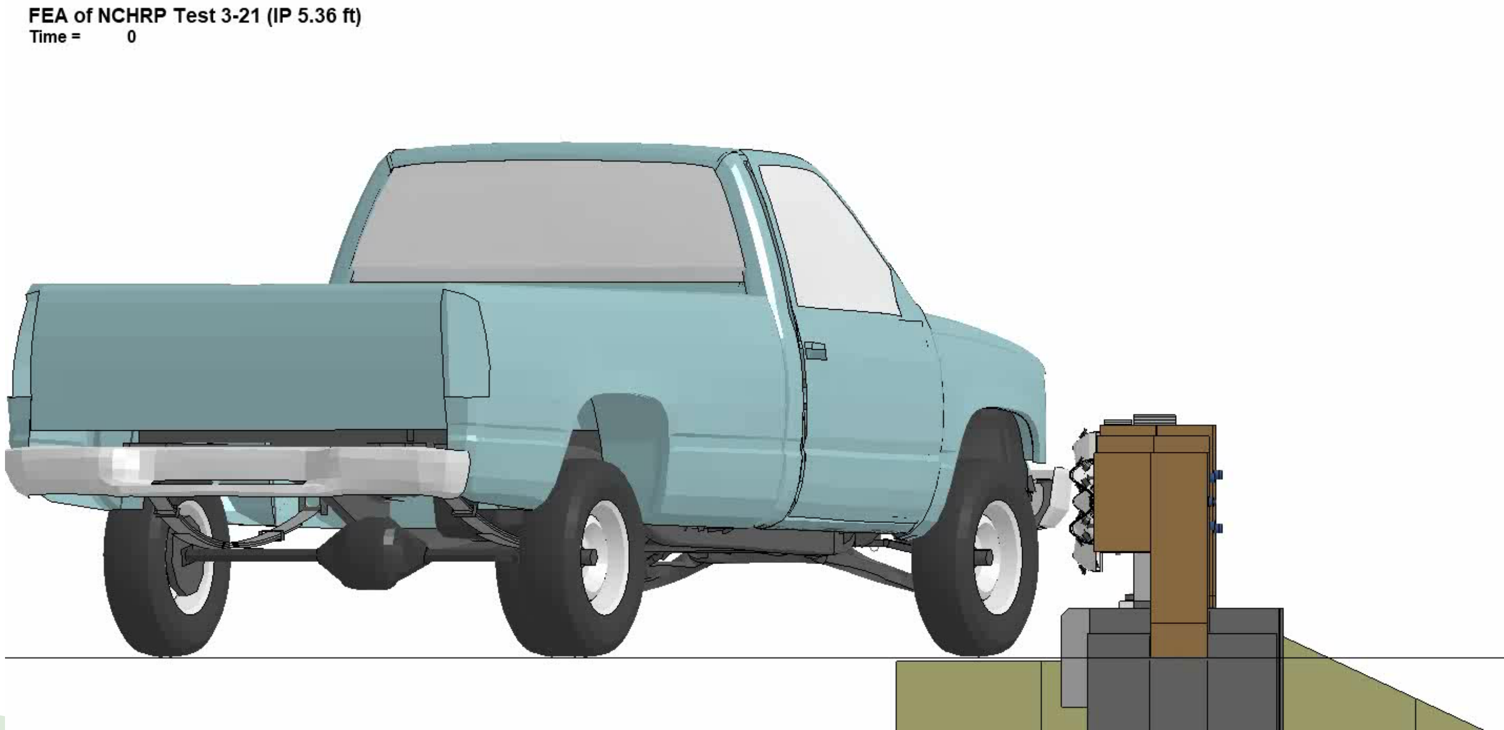
FEA Videos

(T4-21_RUN05DP-190222)

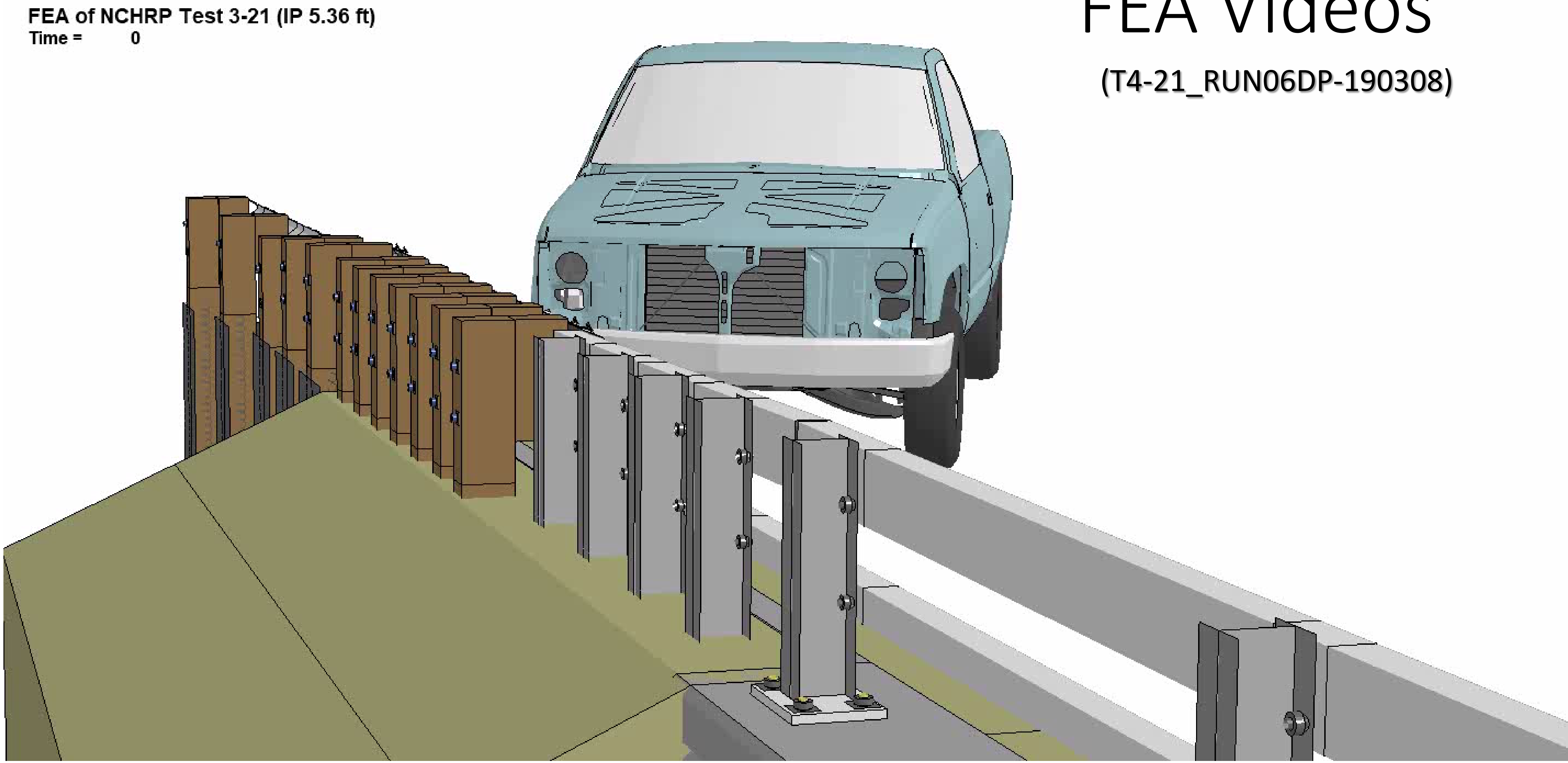
(T4-21_RUN06DP-190308)





FEA Videos

(T4-21_RUN06DP-190308)



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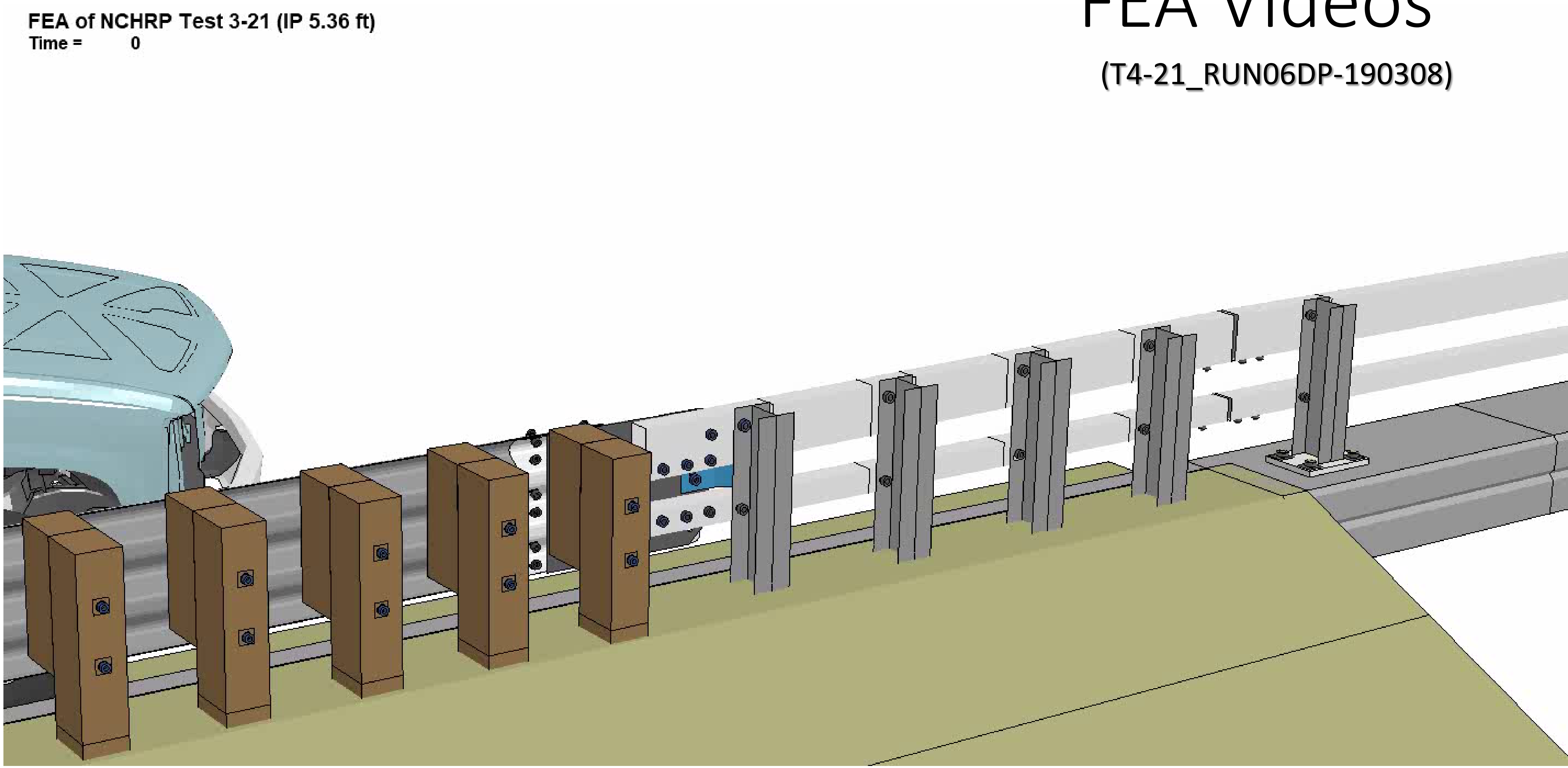
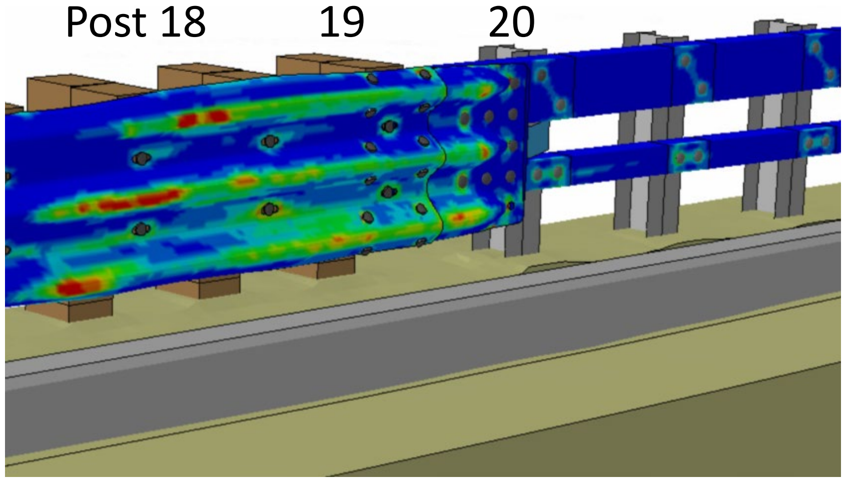
FEA Videos

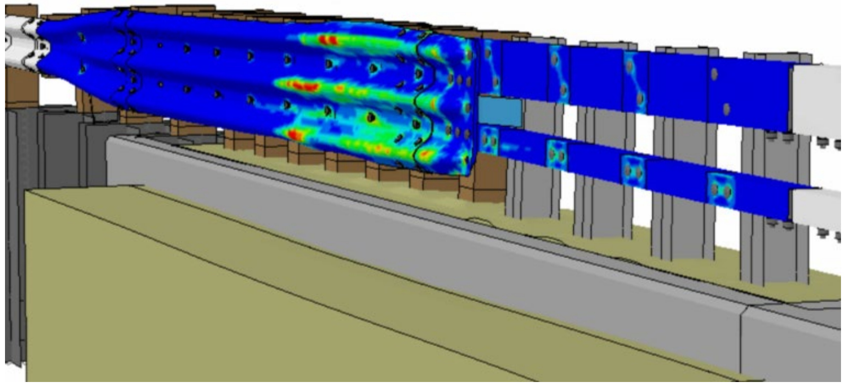
(T4-21_RUN06DP-190308)



Barrier Damages

- The damage to the system was modest.
- The thrie-beam sustained some deformation from the point of impact to the attachment to the thrie-beam terminal connector.
- Maximum dynamic deflection during the impact was:
    - FEA: 5.3 inches at Post 19
    - Test: 8.0 inches at Post 18
- The maximum permanent deflection was:
    - FEA: 4.13 inches
    - Test: 5.8 inches
- The total length of contact of the vehicle with the transition was:
    - FEA: 14.7 feet
    - Test: 14.4 feet





Occupant Risk Measures

Occupant Risk Factors		MASH Test 3-11		Error		W179 Criteria	
		Test 401181-1 (0 - 1.0 seconds)	FEA (0 - 1.0 seconds)	%	Absolute	Criteria	Pass
Occupant Impact Velocity (ft/s)	x-direction	17.06	19.68	15.4%	2.62	<20% or < 6.6 f/s	Y
	y-direction	-24.61	-24.93	1.3%	-0.33	<20% or < 6.6 f/s	Y
	at time	at 0.0948 seconds on left side of interior	at 0.1005 seconds on left side of interior				
THIV (m/s)		29.9 at 0.0948 seconds on left side of interior	31.5 at 0.0986 seconds on left side of interior	5.5%	1.64	<20% or < 6.6 f/s	Y
Ridedown Acceleration (g's)	x-direction	-8.3 (0.1153 - 0.1253 seconds)	-8.3 (0.1018 - 0.1118 seconds)	0.0%	0.00	<20% or < 4G	Y
	y-direction	10 (0.1182 - 0.1282 seconds)	7.5 (0.1388 - 0.1488 seconds)	25.0%	-2.50	<20% or < 4G	Y
PHD (g's)		11.9 (0.1180 - 0.1280 seconds)	9.1 (0.1344 - 0.1444 seconds)	23.5%	-2.80	<20% or < 4G	Y
ASI		1.74 (0.0216 - 0.0716 seconds)	1.48 (0.0355 - 0.0855 seconds)	14.9%	-0.26	<20% or < 0.2	Y
Max 50-ms moving avg. acc. (g's)	x-direction	-8.1 (0.0334 - 0.0834 seconds)	-9.6 (0.0342 - 0.0842 seconds)	18.5%	-1.50	<20% or < 4G	Y
	y-direction	13.5 (0.0216 - 0.0716 seconds)	11 (0.0448 - 0.0948 seconds)	18.5%	-2.50	<20% or < 4G	Y
	z-direction	-7.6 (0.0209 - 0.0709 seconds)	-3.8 (0.0359 - 0.0859 seconds)	50.0%	3.80	<20% or < 4G	Y
Maximum Angular Disp. (deg)	Yaw	55.6 (1.0000 seconds)	48.2 (0.9426 seconds)	13.3%	-7.40	<20% or < 5 deg	Y
	Roll	-19.4 (0.5914 seconds)	-17 (0.4713 seconds)	12.4%	2.40	<20% or < 5 deg	Y
	Pitch	-13.7 (0.6647 seconds)	-16.5 (0.5674 seconds)	20.4%	-2.80	<20% or < 5 deg	Y

MASH Criteria

< 30 ft/s (preferred) ✓
< 40 ft/s (limit)

< 15 G (preferred) ✓
< 20.49 G (limit)

< 75 deg ✓

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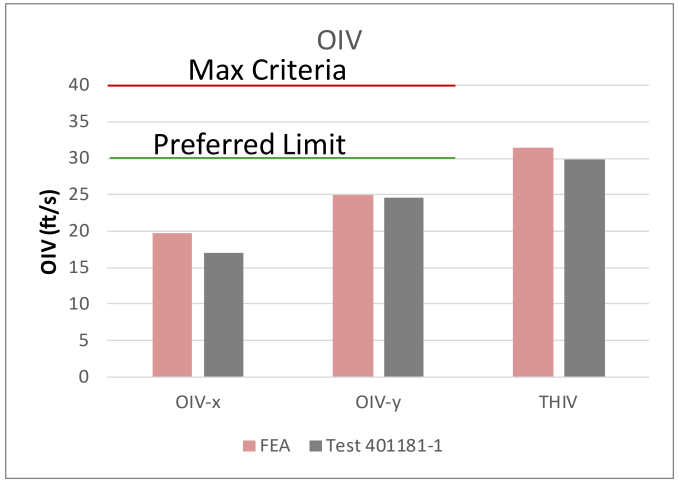
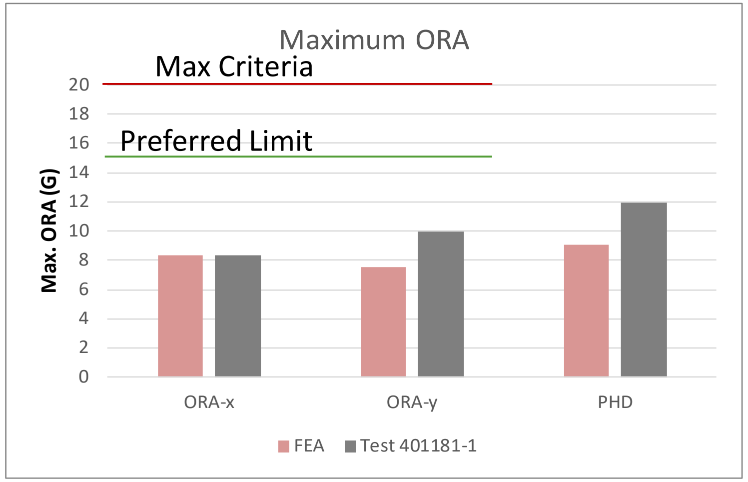
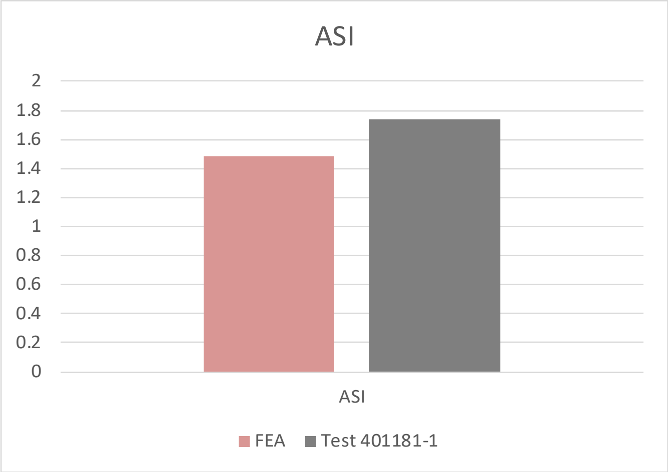
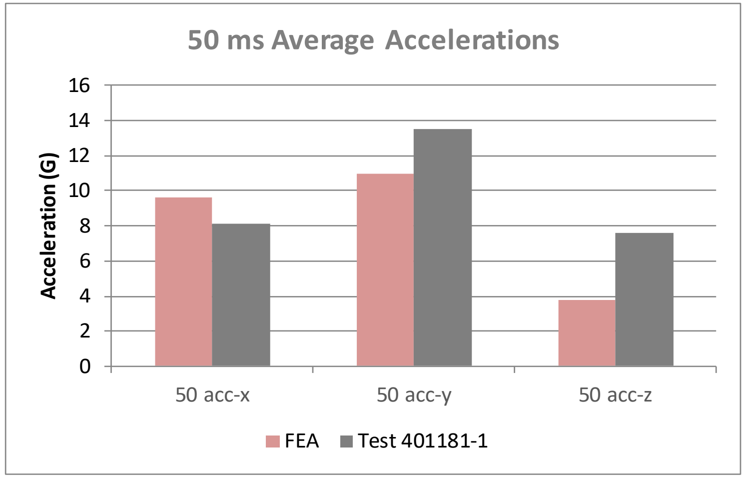
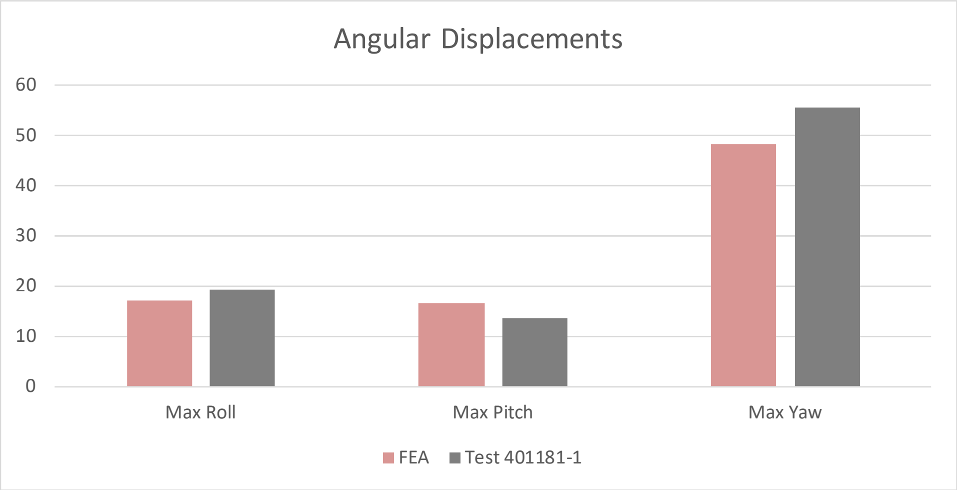
TRAP











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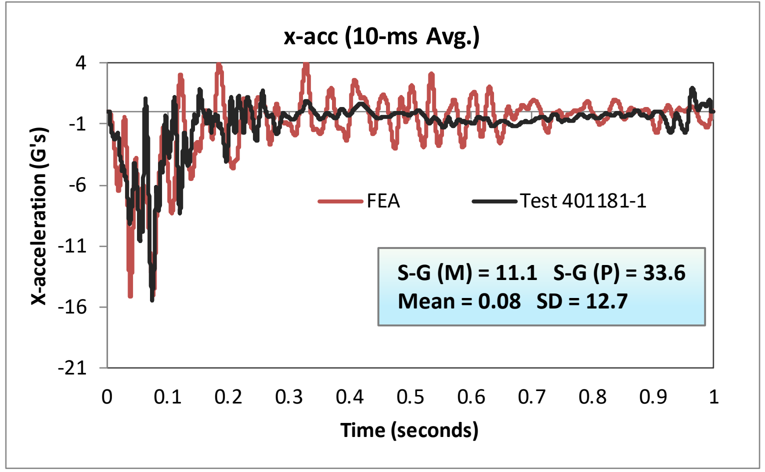
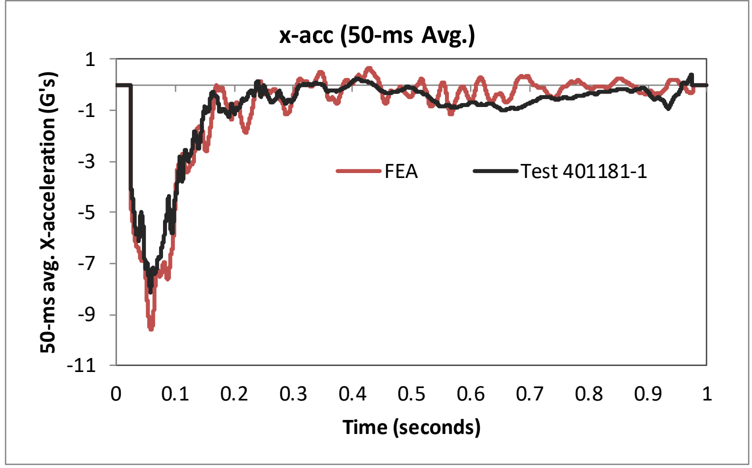
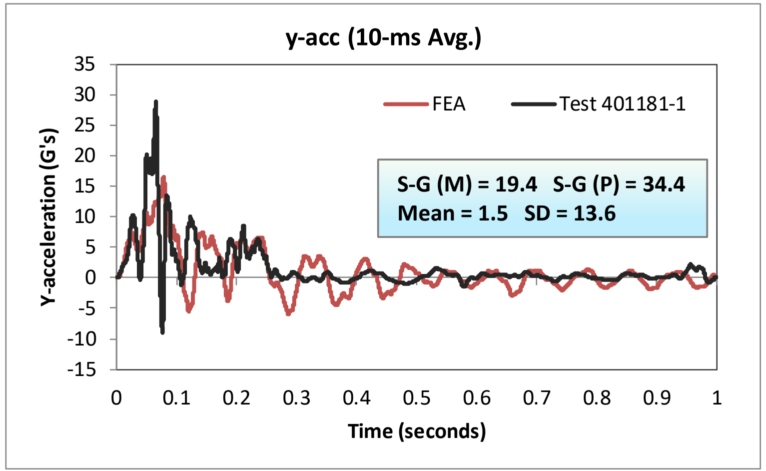
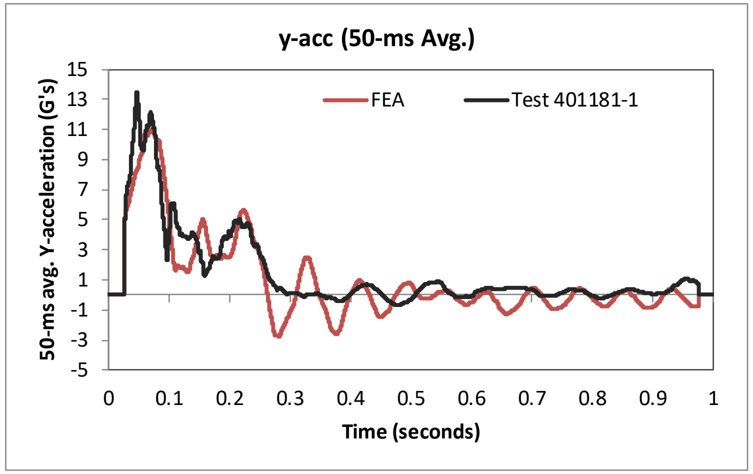
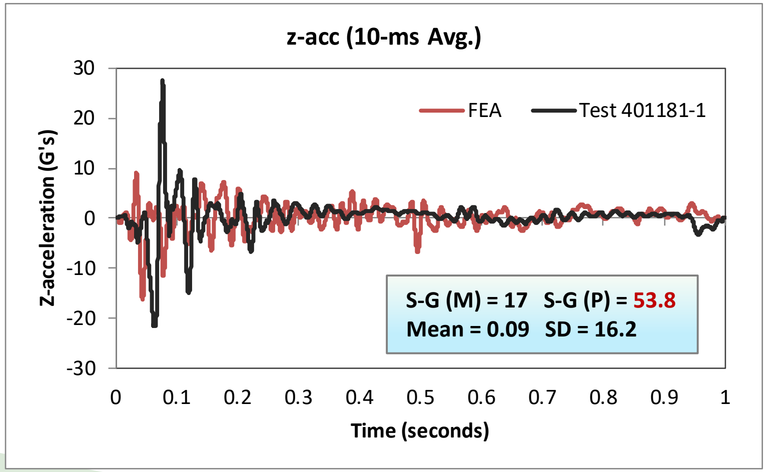
Acceleration Plots

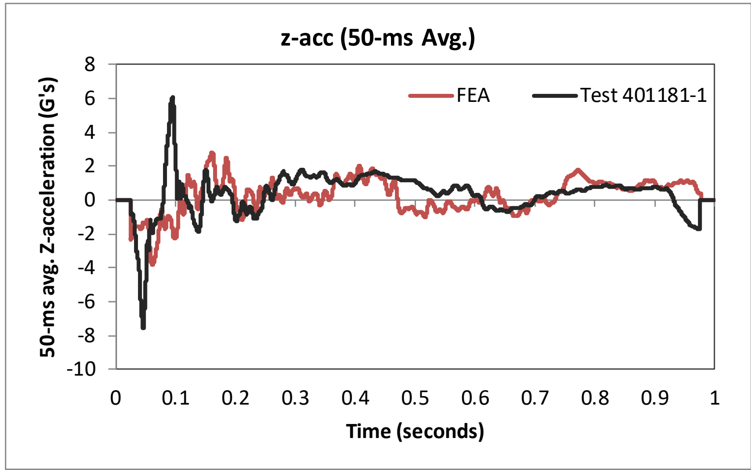




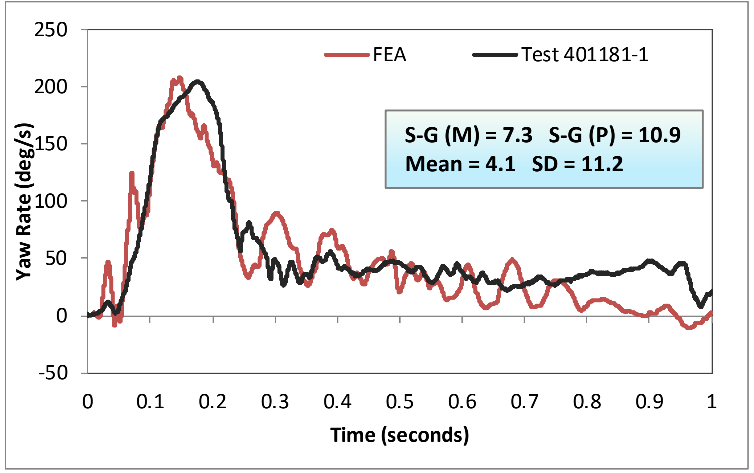


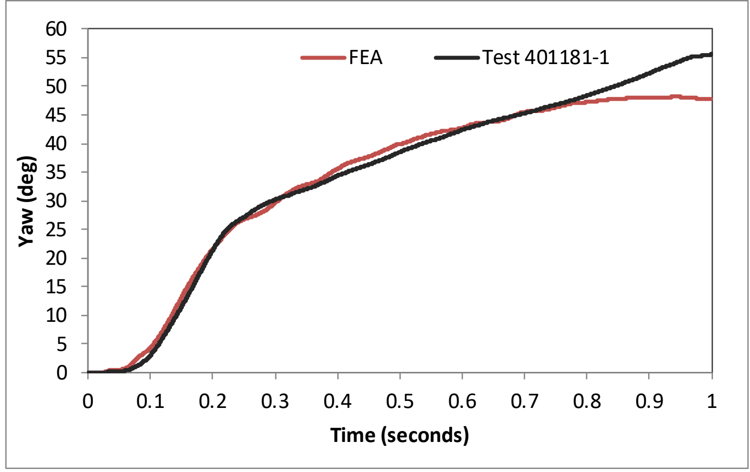


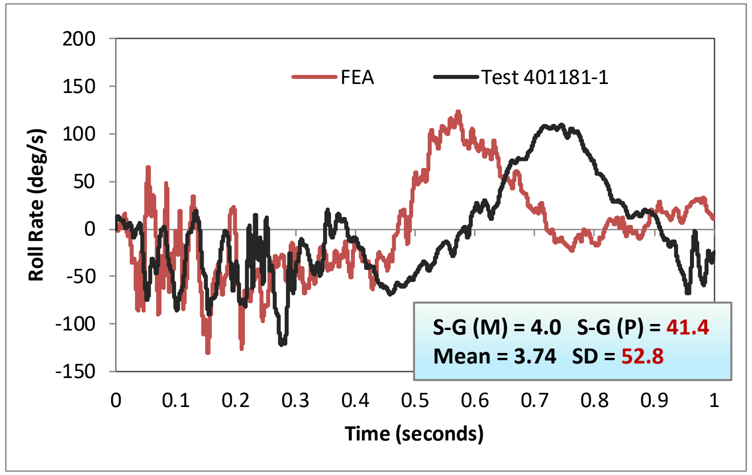


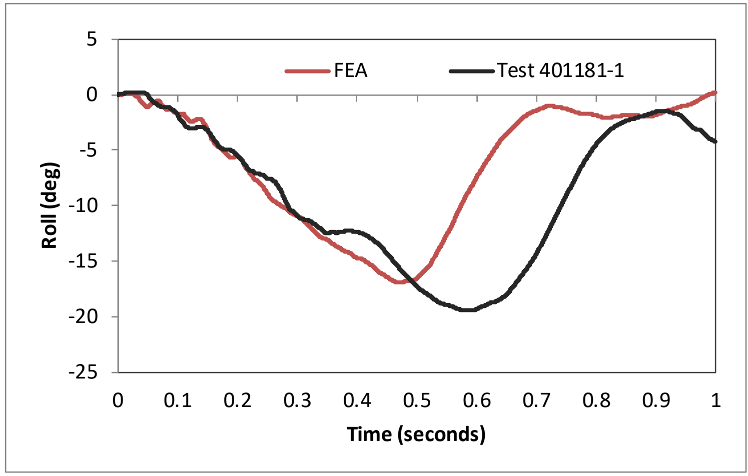


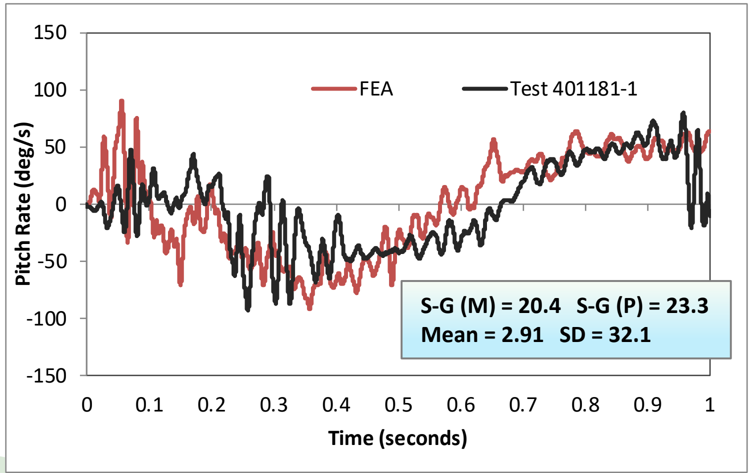
Angular Rate and Displacement Plots

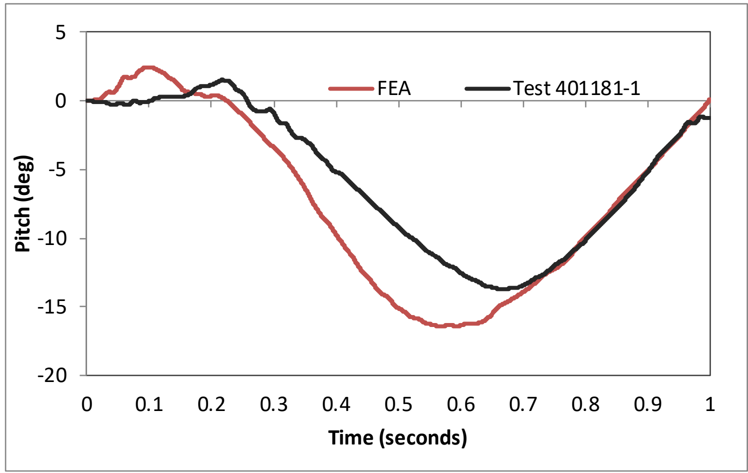












NCHRP W179 Verification & Validation Assessment

Individual Channels

Evaluation Criteria

Time interval [0.00 – 1.0 sec]

Sprague-Geers Metrics

List all the data channels being compared. Calculate the M and P metrics using RSVVP and enter the results. Values less than or equal to 40 are acceptable.

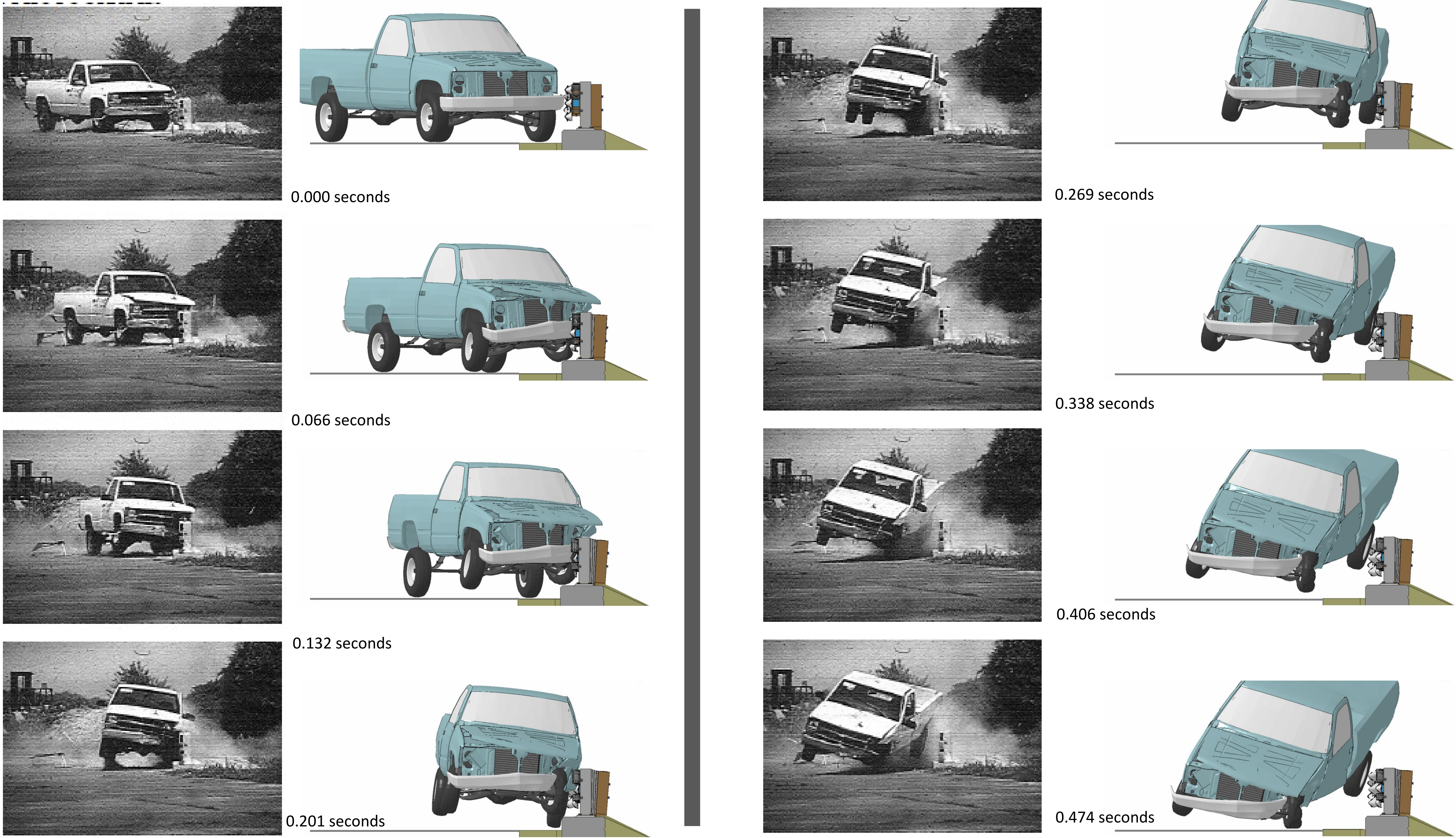
	RSVVP Curve Preprocessing Options								
	Filter Option	Sync. Option	Shift		Drift		M	P	Pass?
			True Curve	Test Curve	True Curve	Test Curve			
X acceleration	CFC 60	none	none	none	none	none	11.1	33.6	Y
Y acceleration	CFC 60	none	none	none	none	none	19.4	34.4	Y
Z acceleration	CFC 60	none	none	none	none	none	17	53.8	N
Yaw rate	CFC 60	none	none	none	none	none	7.3	10.9	Y
Roll rate	CFC 60	none	none	none	none	none	4.0	41.4	≈Y
Pitch rate	CFC 60	none	none	none	none	none	20.4	23.3	Y

P ***ANOVA Metrics***

List all the data channels being compared. Calculate the ANOVA metrics using RSVVP and enter the results. Both of the following criteria must be met:

- The mean residual error must be less than five percent of the peak acceleration ($\bar{e} \leq 0.05 \cdot a_{Peak}$) and
- The standard deviation of the residuals must be less than 35 percent of the peak acceleration ($\sigma \leq 0.35 \cdot a_{Peak}$)

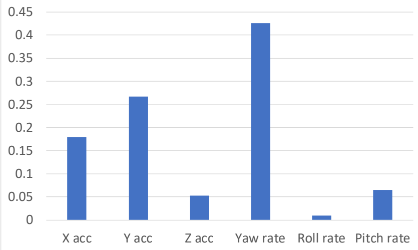
	Mean Residual (%)	Standard Deviation of Residuals	Pass?
X acceleration/Peak	0.08	12.7	Y
Y acceleration/Peak	1.5	13.6	Y
Z acceleration/Peak	0.09	16.8	Y
Yaw rate	4.1	11.2	Y
Roll rate	3.74	52.8	N
Pitch rate	2.91	32.1	Y


0.000 seconds
0.066 seconds
0.132 seconds
0.201 seconds
0.269 seconds
0.338 seconds
0.406 seconds
0.474 seconds

NCHRP W179 Verification & Validation Assessment

Weighted Composite Multi-Channel

<table>
<tr><th colspan="6">Evaluation Criteria (time interval [0.0 – 1.0 seconds])</th></tr>
<tr><td colspan="6">Channels (Select which were used)</td></tr>
<tr><td colspan="2">☒ X Acceleration</td><td colspan="2">☒ Y Acceleration</td><td colspan="2">☒ Z Acceleration</td></tr>
<tr><td colspan="2">☒ Roll rate</td><td colspan="2">☒ Pitch rate</td><td colspan="2">☒ Yaw rate</td></tr>
<tr><td colspan="2">Multi-Channel Weights

- Area II method -</td><td colspan="2">X Channel: 0.180
Y Channel: 0.268
Z Channel: 0.053
Yaw Channel: 0.426
Roll Channel: 0.009
Pitch Channel: 0.065</td><td colspan="2">
</td></tr>
<tr><td rowspan="2" colspan="3">Sprague-Geer Metrics
Values less or equal to 40 are acceptable.</td><td>M</td><td>P</td><td>Pass?</td></tr>
<tr><td>24.6</td><td>27.9</td><td>Y</td></tr>
<tr><td rowspan="2" colspan="3">ANOVA Metrics
Both of the following criteria must be met:
• The mean residual error must be less than five percent of the peak acceleration
$(\bar{e} \leq 0.05 \cdot a_{Peak})$
• The standard deviation of the residuals must be less than 35 percent of the peak acceleration $(\sigma \leq 0.35 \cdot a_{Peak})$</td><td>Mean Residual</td><td>Standard Deviation of Residuals</td><td>Pass?</td></tr>
<tr><td>1.9</td><td>14.1</td><td>Y</td></tr>
</table>

Report 350 Evaluation Criteria

Evaluation Factors		Evaluation Criteria	Applicable Tests
Structural Adequacy	A	Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.	10, 11, 12, 20, 21, 22, 35, 36, 37, 38
	B	The test article should readily activate in a predictable manner by breaking away, fracturing or yielding.	60, 61, 70, 71, 80, 81
	C	Acceptable test article performance may be by redirection, controlled penetration or controlled stopping of the vehicle.	30, 31, 32, 33, 34, 39, 40, 41, 42, 43, 44, 50, 51, 52, 53
Occupant Risk	D	Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone.	All
	E	Detached elements, fragments or other debris from the test article, or vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle. (Answer Yes or No)	70, 71
	F	The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.	All except those listed in criterion G
	G	It is preferable, although not essential, that the vehicle remain upright during and after collision.	12, 22
	H	Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and Lateral: 9 / 12 Longitudinal: 3 / 5	Longitudinal and Lateral: 10, 20, 30,31, 32, 33, 34, 36, 40, 41, 42, 43, 50, 51, 52, 53, 80, 81 Longitudinal: 60, 61, 70, 71
	I	Occupant ridedown accelerations should satisfy the following: Occupant Ridedown Acceleration Limits (g's) Component / Preferred / Maximum Longitudinal and Lateral: 15 / 20	10, 20, 30,31, 32, 33, 34, 36, 40, 41, 42, 43, 50, 51, 52, 53, 60, 61, 70, 71, 80, 81
Vehicle Trajectory	K	After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	All
	L	The occupant impact velocity in the longitudinal direction should not exceed 40 ft/sec and the occupant ride-down acceleration in the longitudinal direction should not exceed 20 G's.	11,21, 35, 37, 38, 39
	M	The exit angle from the test article preferable should be less than 60 percent of test impact angle, measured at the time of vehicle loss of contact with test device.	10, 11, 12, 20, 21, 22, 35, 36, 37, 38, 39
	N	Vehicle trajectory behind the test article is acceptable.	30, 31, 32, 33, 34, 39, 42, 43, 44, 60, 61, 70, 71, 80, 81

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Report 350 Evaluation Criteria

Roadside Safety Phenomena Importance Ranking Table

Structural Adequacy

			Evaluation Criteria	Known Result	Analysis Result	Difference Relative/ Absolute	Agree?
Structural Adequacy	A	1	Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable. (Answer Yes or No)	Y	Y		Y
		2	Maximum dynamic deflection: - Relative difference is less than 20 percent or - Absolute difference is less than 6 inches	8.0 in	5.8 in (0.1 sec)	27.5% 2.2 in	Y
		3	Maximum permanent deflection: - Relative difference is less than 20 percent or - Absolute difference is less than 6 inches	5.8 in	4.3 in	25.9% 1.5 in	Y
		4	Length of vehicle-barrier contact (at initial separation): - Relative difference is less than 20 percent or - Absolute difference is less than 6.6 ft	14.4 ft	14.7 ft	1.5 % 0.22 ft	Y
		5	Number of broken or significantly bent posts is less than 20 percent.	0	0		Y
		6	Did the rail element rupture or tear (Answer Yes or No)	No	No		Y
		7	Was there significant snagging between the vehicle wheels and barrier elements (Answer Yes or No).	N	N		Y
		8	Was there significant snagging between vehicle body components and barrier elements (Answer Yes or No).	N	N		Y

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Report 350 Evaluation Criteria

Roadside Safety Phenomena Importance Ranking Table

Occupant Risk

			Evaluation Criteria	Known Result	Analysis Result	Difference Relative/ Absolute	Agree?
Occupant Risk	D		Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone. (Answer Yes or No)	N	N		Y
	F	1	The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable. (Answer Yes or No)	Y	Y		Y
		2	Maximum roll of the vehicle through 1.0 seconds: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	-19.4 deg	-17 deg	12.4% 2.4 deg	Y
		3	Maximum pitch of the vehicle through 1.0 seconds: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	-13.7 deg	-16.5 deg	20.0 % 2.8 deg	Y
		4	Maximum yaw of the vehicle through 1.0 seconds: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	55.6 deg	48.2 deg	13.3 % 7.4 deg	Y
		5	Did the vehicle remain upright during and after collision	Y	Y		Y
	L	1	Occupant impact velocities: - Relative difference is less than 20 percent or - Absolute difference is less than 6.6 ft/s.				
			• Longitudinal OIV (ft/s)	17.1	19.7	15.2% 2.6 ft/s	Y
			• Lateral OIV (ft/s)	-24.6	-24.9	1.2% 0.3 ft/s	Y
			• THIV (ft/s)	29.9	31.5	5.4% 1.6 ft/s	Y
		2	Occupant accelerations: - Relative difference is less than 20 percent or - Absolute difference is less than 4 g's.				
			• Longitudinal ORA	-8.3	-8.3	0% 0 g	Y
			• Lateral ORA	10.0	7.5	25 % 2.5 g	Y
			• PHD	11.9	9.1	23.5 % 2.8 g	Y
			• ASI	1.74	1.48	14.9 % 0.26	Y

Report 350 Evaluation Criteria

Roadside Safety Phenomena Importance Ranking Table

Vehicle Trajectory

			Evaluation Criteria	Known Result	Analysis Result	Difference Relative/ Absolute	Agree?
Vehicle Trajectory	K	1	The exit angle from the test article preferable should be less than 60 percent of test impact angle, measured at the time of vehicle loss of contact with test device.	47.0%	39.2%		Y
		2	Exit angle at loss of contact: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	11.7 deg (0.41 sec)	8.5 deg (0.37 sec)	27.4% 3.2 deg	Y
	M	3	Exit velocity at loss of contact: - Relative difference is less than 20 percent or - Absolute difference is less than 6.2 mph.	*46.9 mph	44.4 mph	5 % 2.5 mph	Y

** Reported as 52.9 mph. Test data showed 46.9 mph at 0.406 seconds (e.g., TRAP report).*

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Conclusions

- In general, the results of the analyses demonstrated that the finite element model replicated the basic phenomenological behavior of the system for Report 350 Test 3-21 impact conditions.
- There was good agreement between the tests and the simulations with respect to event timing, overall kinematics of the vehicle, barrier damage, and deflections.
- Quantitative comparison of the time-history data indicated that the finite element model sufficiently replicated the results of the baseline crash tests.
- Thus, the model is considered valid and will be used in subsequent tasks for assessing MASH impact performance on this and similar NETC AGT systems.