

Development of MASH Computer Simulated Steel Bridge Rail and Transition Details

Validation of NETC 4-Bar BR Model



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

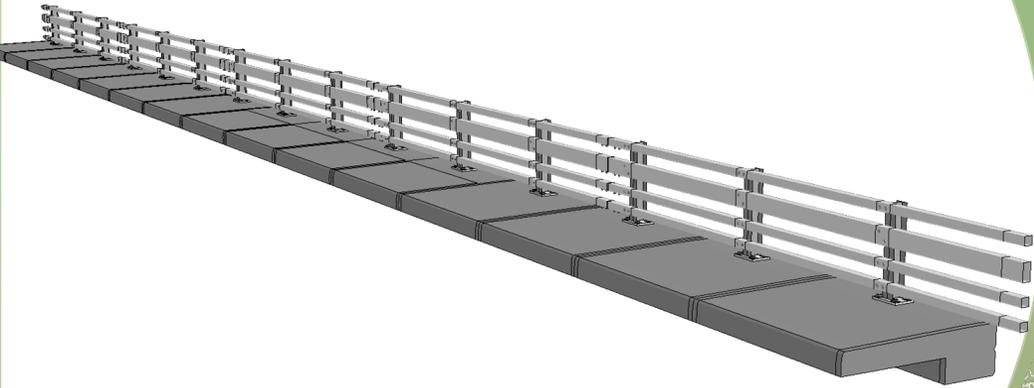
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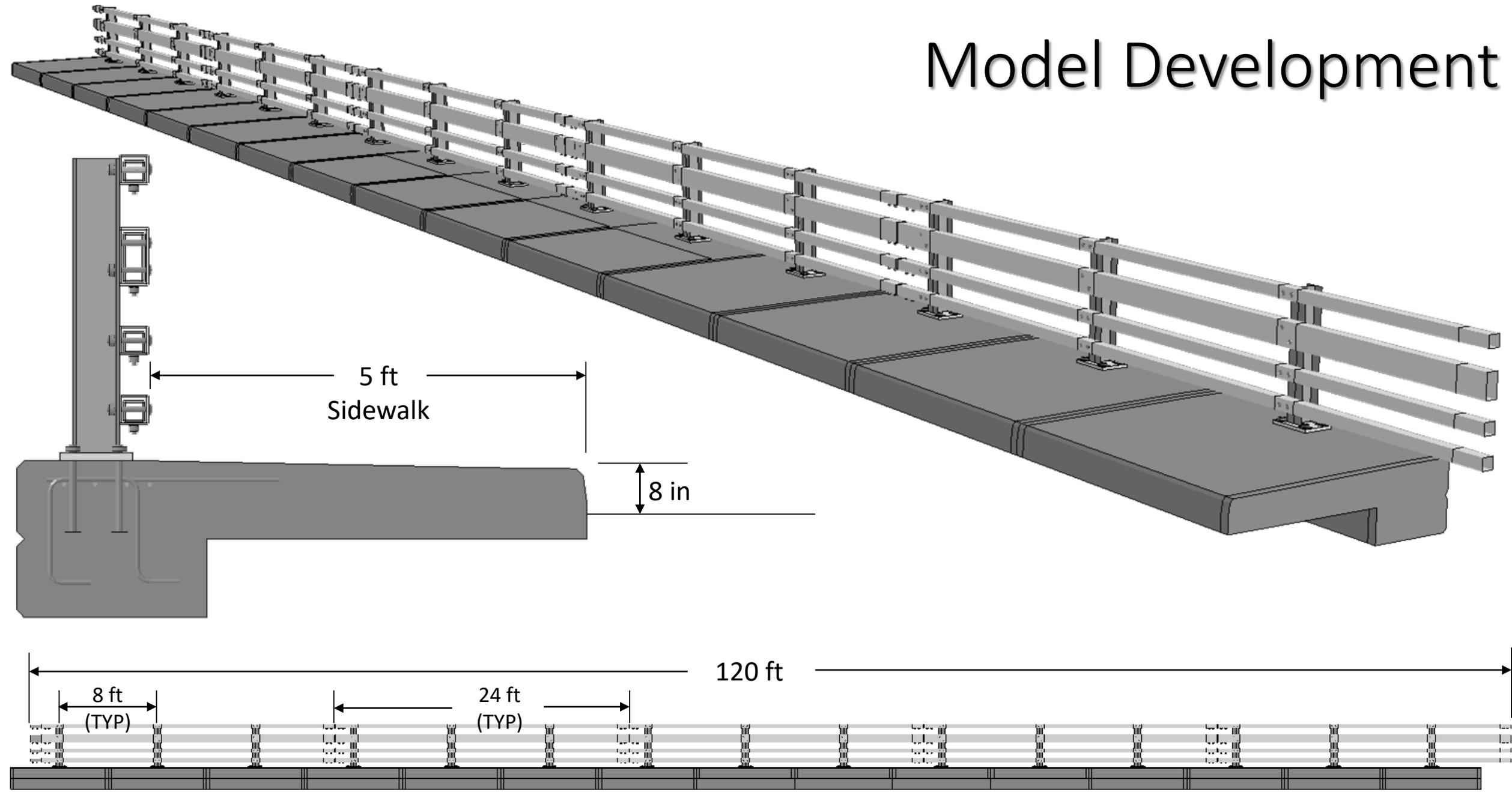
Model Development of NETC 4-Bar Bridge Rail

Basic Components

- Fifteen (15) W6x25 posts,
- One (1) 12"x10"x1" post-base plate at each post,
- Four (4) anchor bolts at each base plate connecting the base plate to the sidewalk,
- Fifteen (15) HSS 4 x 4 x 1/4" tube rails that are 23.94 feet long (each) and hardware,
- Five (5) HSS 8 x 4 x 5/16" tube rails that are 23.94 feet long (each) and hardware,
- Twenty (20) splice tubes, 20 inches long (each) made from 3/8-inch thick steel plate, and bolt hardware,
- Concrete sidewalk and short length of bridge deck, including steel reinforcing.

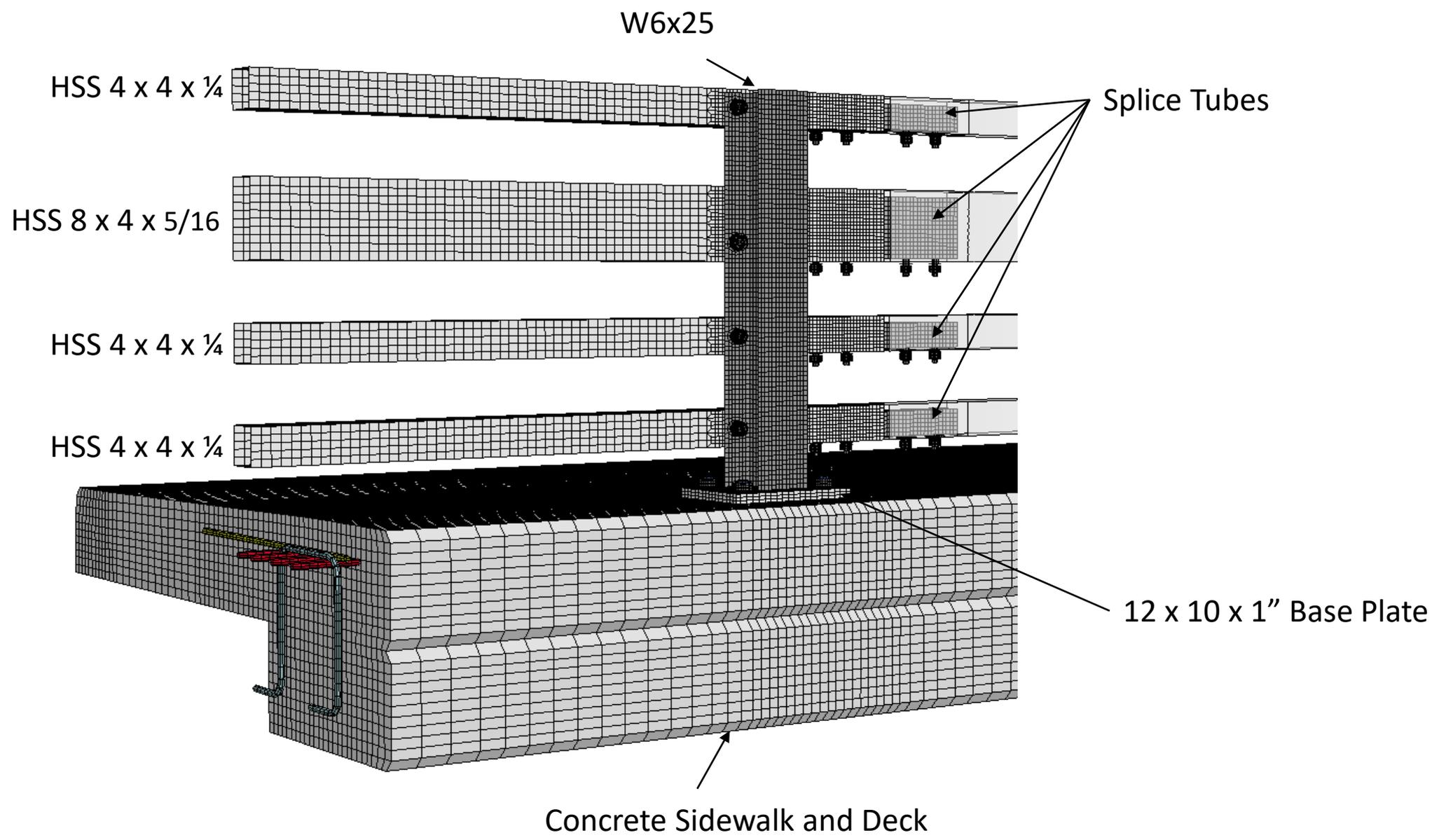


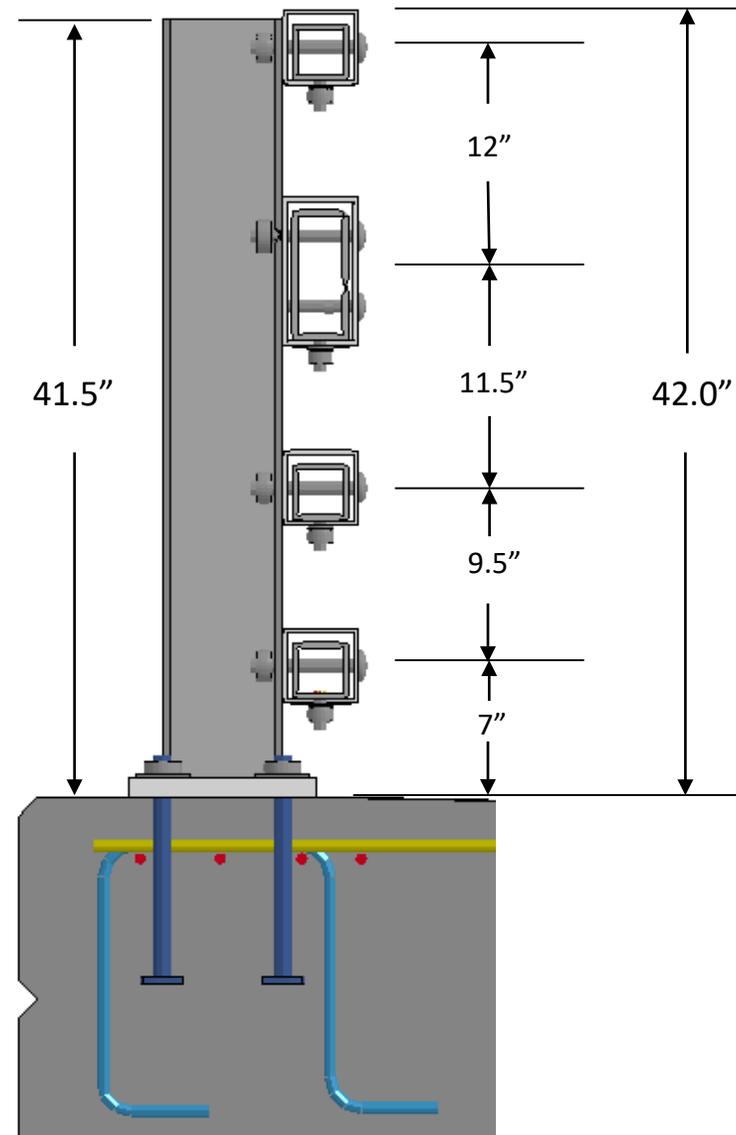
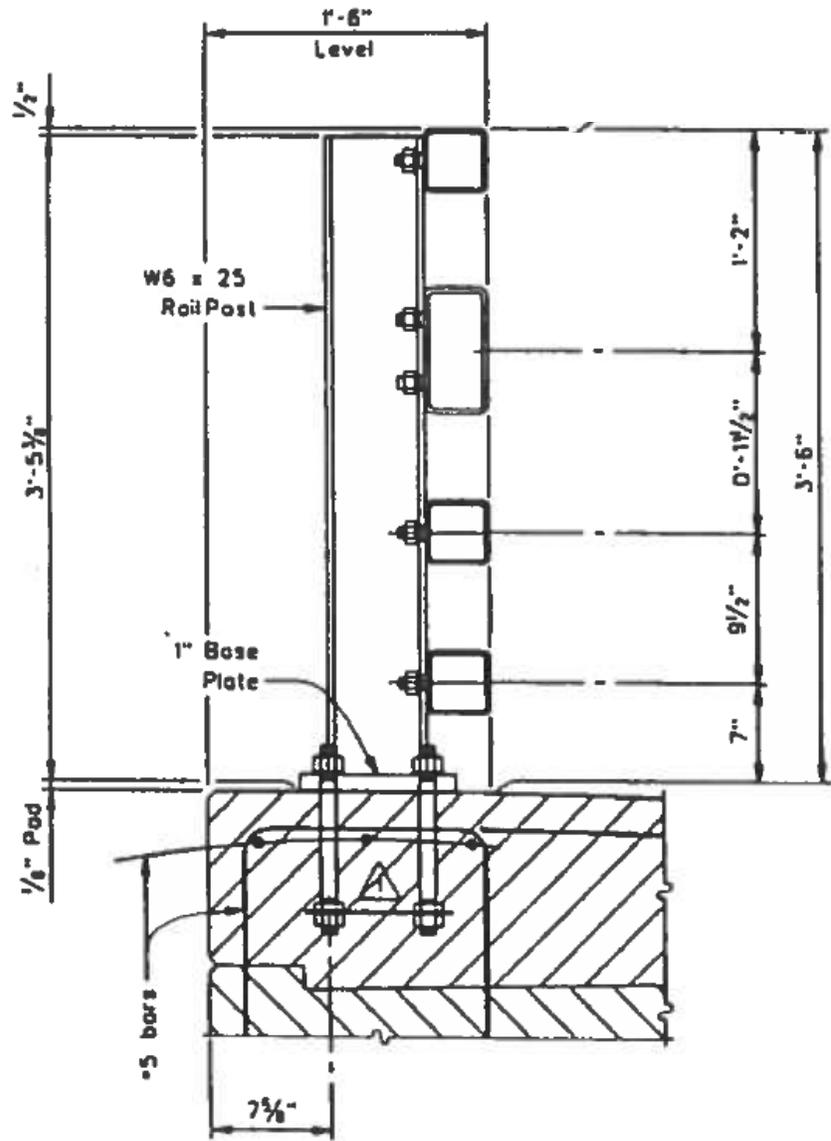
Model Development



Materials

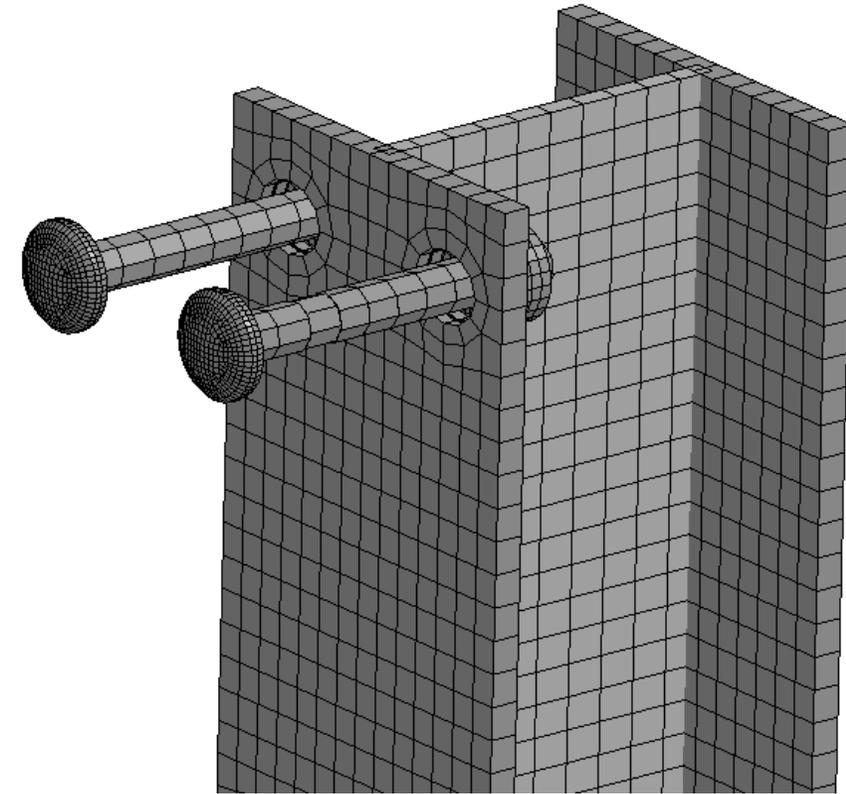
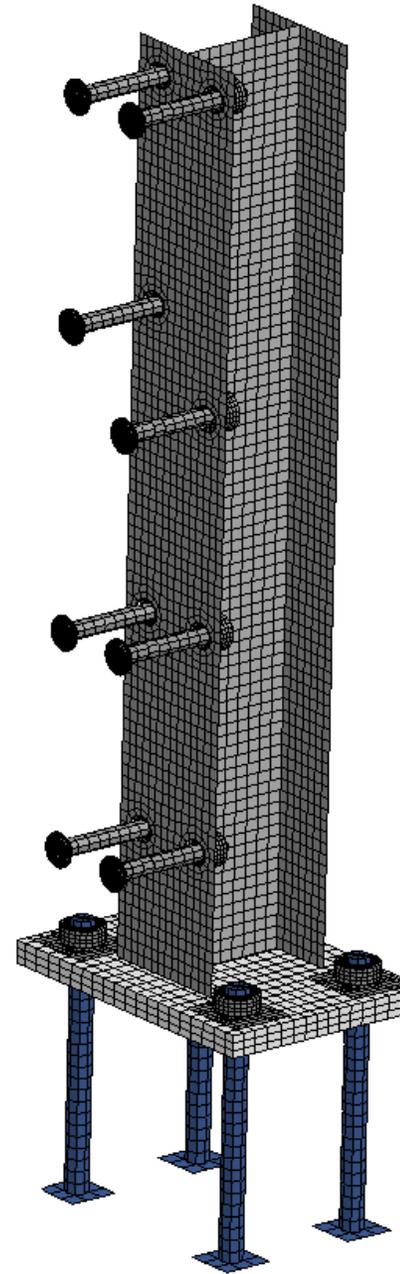
- **All steel materials were modeled in LS-DYNA using material model *Mat_Piecewise_Linear_Plasticity.** The Young's modulus was set to 29,000 ksi and Poisson's ratio was set to 0.33. The piecewise-linear stress-strain characterization for each component varied depending on steel type and grade.
- The tubular rail sections were modeled with material conforming to **ASTM A500 Grade B.** The minimum yield and tensile strength for the structural tube material is 46 ksi and 58 ksi, respectively.
- All **posts and plates** were modeled as **ASTM A572 Grade 50** steel; the material characterization was based on stress-strain curves from tensile tests conducted at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia in an earlier study performed by Roadsafe. **Yield and tensile strength was 50.6 ksi and 70 ksi, respectively.**
 - Note: Coupon samples from other manufacturers have resulted in 60 ksi yield [*REF MwRSF*].
- All the **post-bolts** in the were modeled as **ASTM A325** with yield strength of 92 ksi and ultimate strength of 120 ksi (engineering stress).
- All anchor rods were modeled as **ASTM A449** with yield strength of 92 ksi and ultimate strength of 120 ksi (engineering stress).
- **Concrete in impact region** was modeled in LS-DYNA using material model ***MAT_RHT** with properties corresponding to **4,000 psi concrete (Impact Zone Only).**
- **Concrete outside impact region** was modeled with rigid material properties.





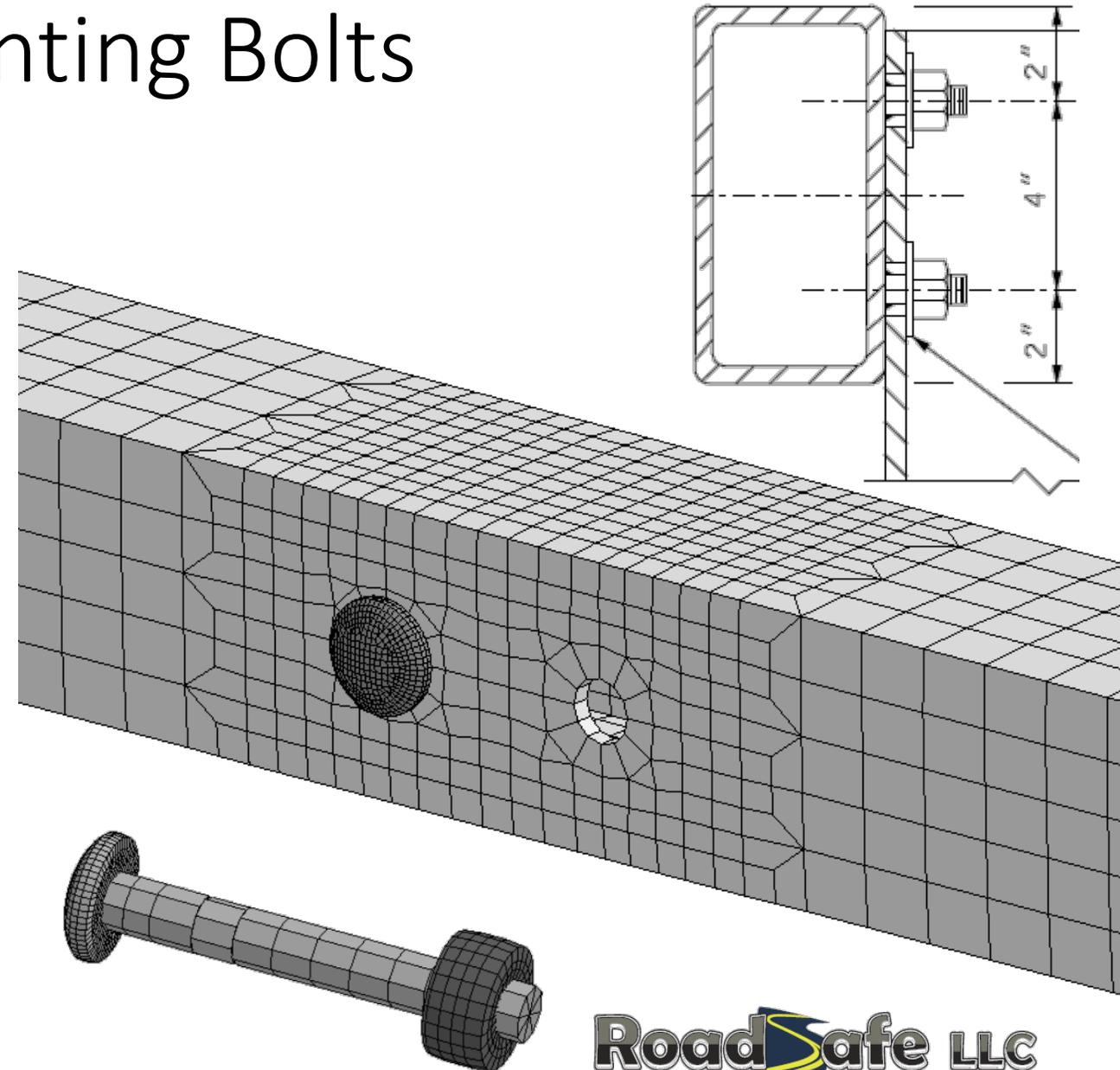
Posts

- The geometry of the post was modeled according to the drawings in the test report and State drawings and included six (6) horizontally slotted mounting holes in the flanges with dimensions 1-1/8" x 1-3/8".
- 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.



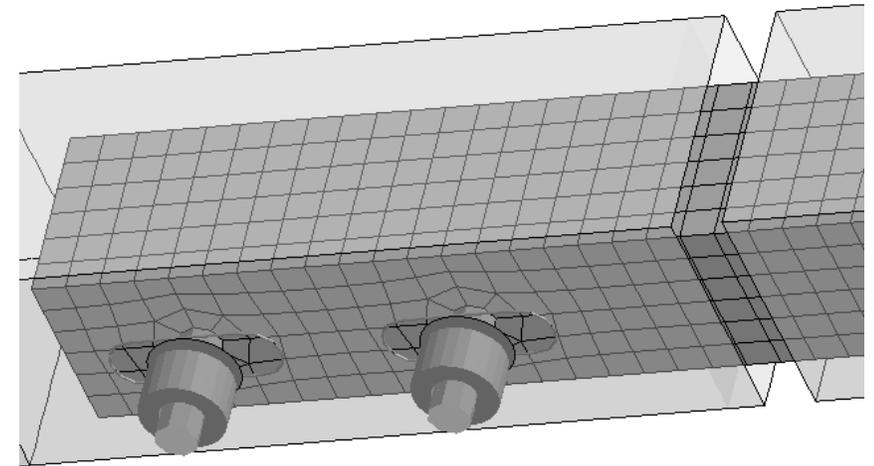
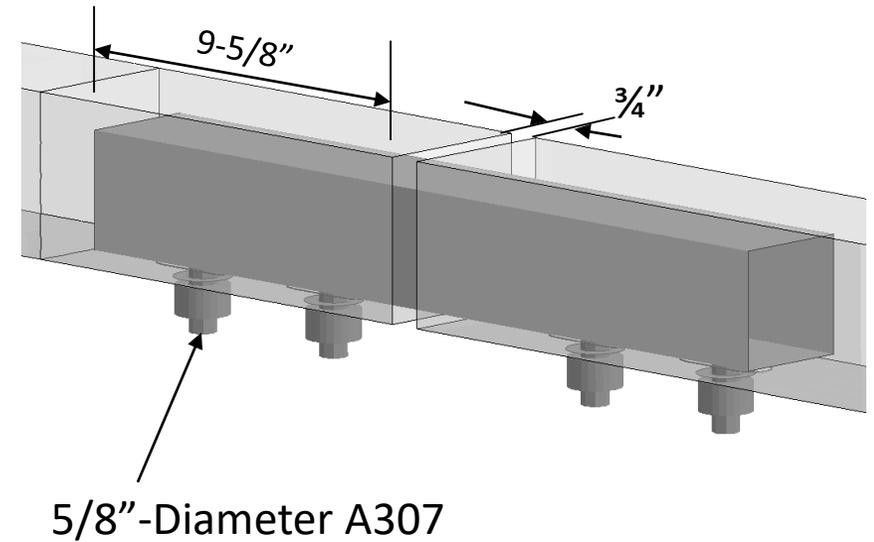
Tubular Rails and Mounting Bolts

- The tubular rail sections were modeled according to the dimensional specifications for HSS 4"x4"x0.25" and HSS 8"x4"x0.3125".
- The material for all tube railing conformed to ASTM A500 Grade C.
- 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.



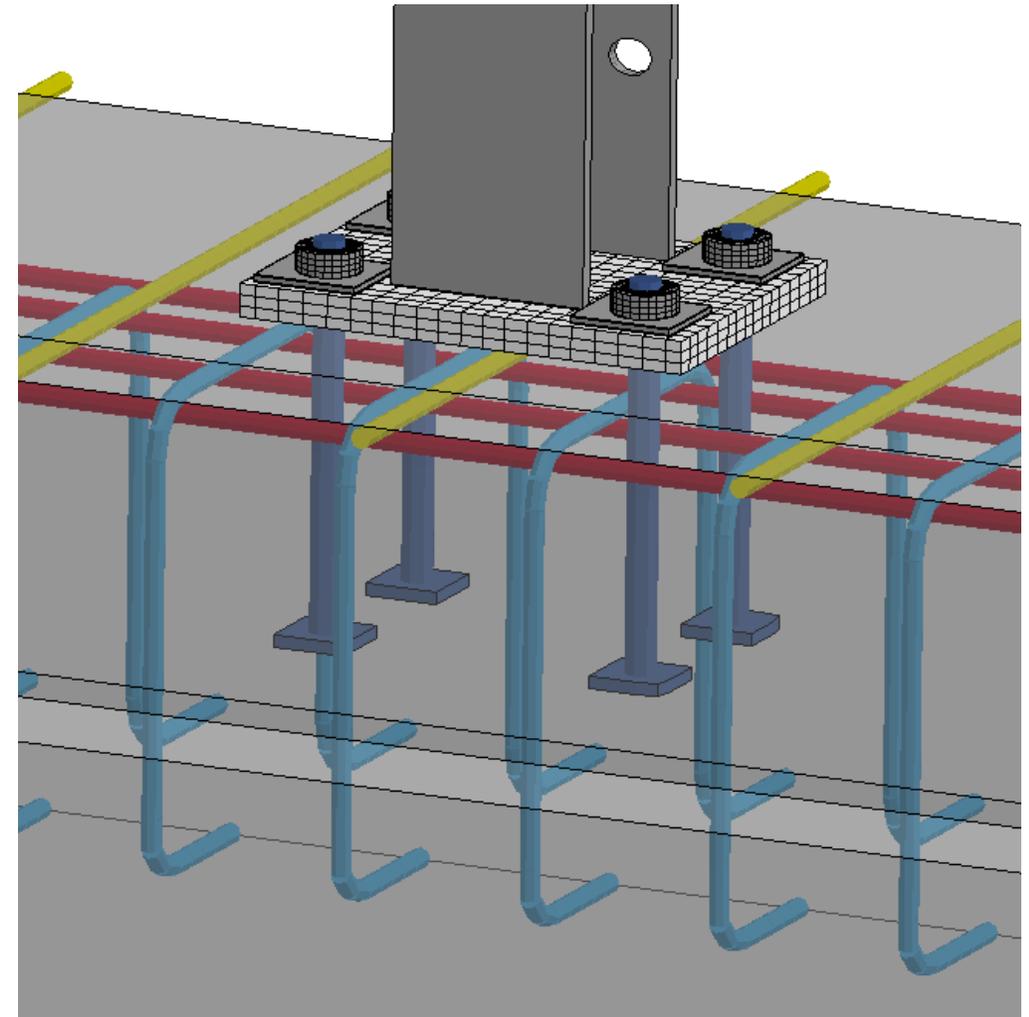
Rail Splice

- The splice connection of the adjoining tube rails included a 20-inch long tubular sleeve inserted 9.625 inches into the upstream and downstream ends of the main rails.
- The cap-screw connections of the splice to the rail bars was modeled as four 5/8" diameter stud-bolts (rigidly fastened to the splice tube) and fastened to the rail bars with nuts and washers.
- The properties for the cap screws were modeled as ASTM A307.
- The slotted openings in the rail bars for the cap screws were 1-1/8" x 2-1/2".
- A 3/4-inch gap between the adjoining main-rail sections was included at the splice according to design.
- The splice tubes were modeled with the same material properties and mesh details as the main rail tubes.



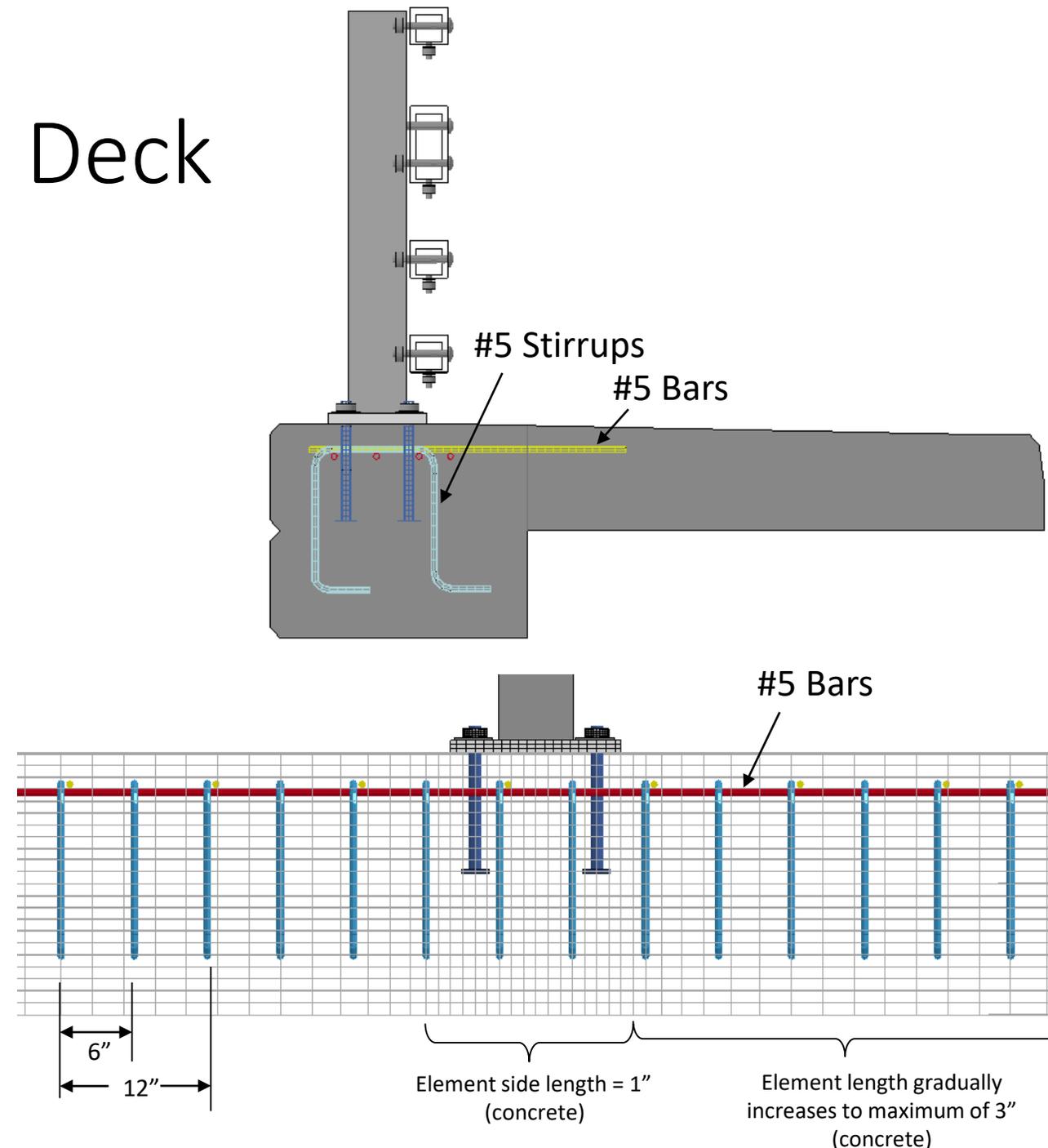
Base Plate and Anchor Bolts

- The base plate was modeled with dimensions 12" x 10" x 1" and with material properties conforming to ASTM A572 Grade 50.
- The part was meshed with Type 2 (selective reduced 2x2 in-plane integration) thick shell elements.
- The welded connection of the post to the base plate was modeled using continuous *Constrained_spotwelds around the perimeter of the base of the post.
- The 1" diameter anchor bolts were modeled with Type 1 beam elements in LS-DYNA. Length = 12".
- The material for the anchor bolts conformed to ASTM A449, which has a minimum yield of 92 ksi, ultimate strength of 120 ksi, and 14 percent elongation.
- The nuts and washers were modeled as rigid.
- The anchor bolts extended into the rigid deck, as illustrated in the image.
- The bolts were anchored inside the deck using the *Constrained_Beam_in_Solid option in LS-DYNA.



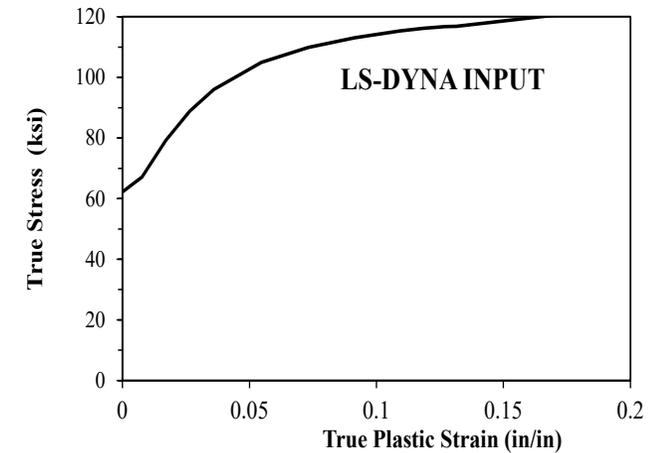
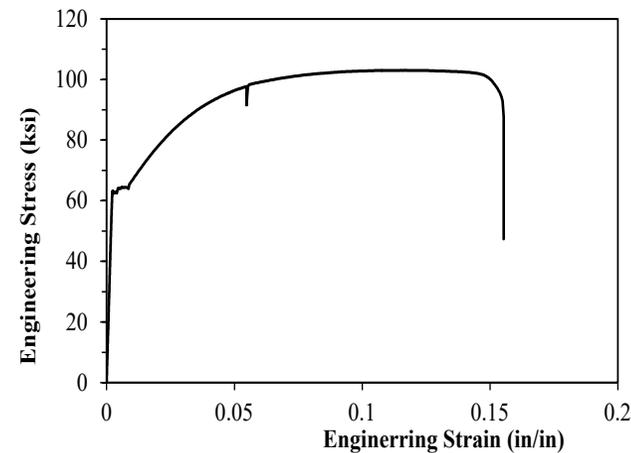
Concrete Sidewalk and Deck

- The materials for the sidewalk and deck components were modeled using *Mat_RHT in LS-DYNA, with default material properties based on an unconfined compressive strength of 4,000 psi.
- The concrete was modeled with Type 1 brick elements in LS-DYNA with nominal element size of 1" x 1" x 1" at the post locations and with the element side length then gradually increasing to approximately 3 inches at maximum distance from the post.
- The longitudinal reinforcement (relative to the bridge rail) at the top of the sidewalk near the anchor bolts was modeled with four #5 bars.
- The longitudinal steel running lateral to the bridge rail was modeled with #5 bars at the top of the sidewalk with 12" spacing.
- The stirrups were also modeled with #5 bars with 6-inch spacing.



Steel Reinforcing

- All reinforcing bars were modeled with Type 1 beam elements with a nominal element length of 1 inch.
- The material properties for the reinforcing steel conformed to ASTM A615 Grade 60 steel with properties measured at Turner Fairbanks Highway Research Center.
- The interaction of the reinforcing steel within the concrete curb/deck was modeled using the *Constrained_Beam_in_Solid option in LS-DYNA.
- Unfortunately, slip of the anchor bolts in the concrete cannot be simulated with this method unless the concrete fails around the rebar;
- However, it is apparent from the drawings that the anchor bolts cannot physically “slip” unless they break from the anchor plate which is buried deep inside the sidewalk/deck.



Validation Test Case

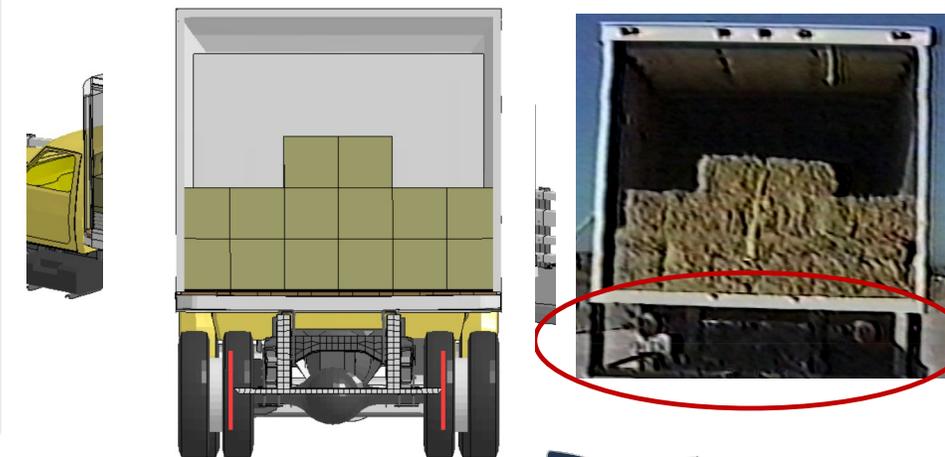
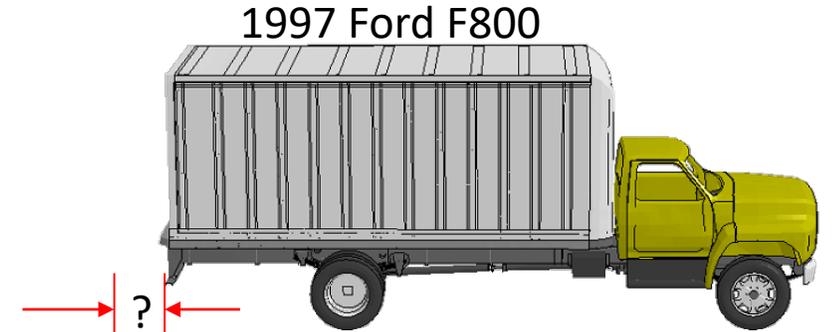
Sidewalk-Mounted NETC 4-Bar Bridge Rail

- Test No. NETC-3 on the bridge rail was performed by SwRI on 12/18/1997.
- Total length of bridge rail was 108 feet.
- Impact conditions:
 - Mass = 17,875 lb (8,108 kg)
 - Speed = 49.8 mph (80.1 km/hr)
 - Angle = 15 deg.
 - Impact point = 2 ft (0.61 m) upstream of Post 6.



Issues and Limitations of Test Data

- The validation effort was limited by the amount of data available from the full-scale test.
- The test was conducted in December 1997 and, unfortunately, the retention time for test data at SwRI is only three years.
- Copies of the test videos were obtained from NETC and the FHWA;
- However, the electronic time-history data from the vehicle-mounted accelerometers, which are required for quantitative validation, were no longer available.
- Test-vehicle properties measurements were not reported
 - The cargo-box for the test vehicle was:
 - Visibly longer than the FEA model
 - Appears to have relatively stiff/heavy rear bumper section
 - Ballast appears to be only hay, but not sure.
 - Modeled with approximate overall dimensions of the visible ballast and density set to achieve overall ballasted mass of vehicle.



MASH Test Vehicles (Examples)

1991 International 4700



Test 420020-9b
3/10//2011

1999 Ford F-800

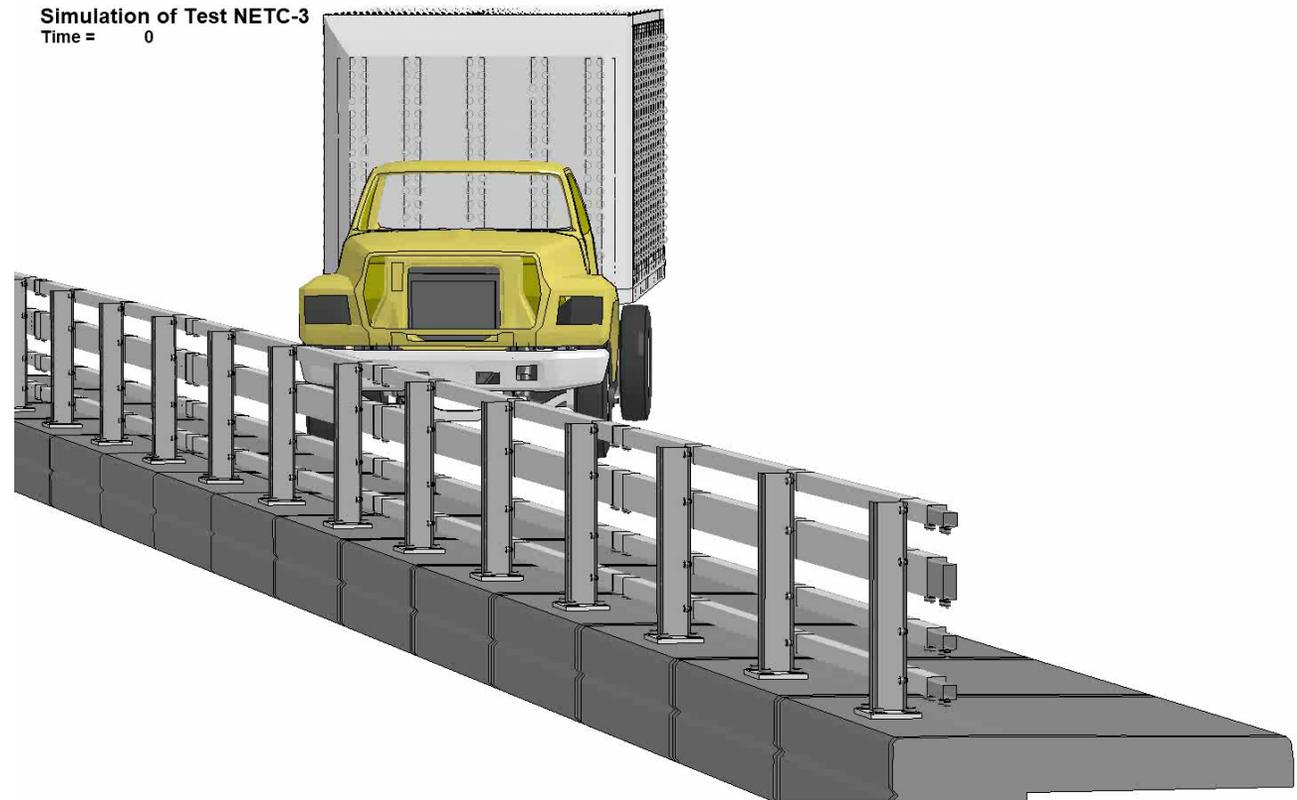


Test RF476460-1
2/19/2008

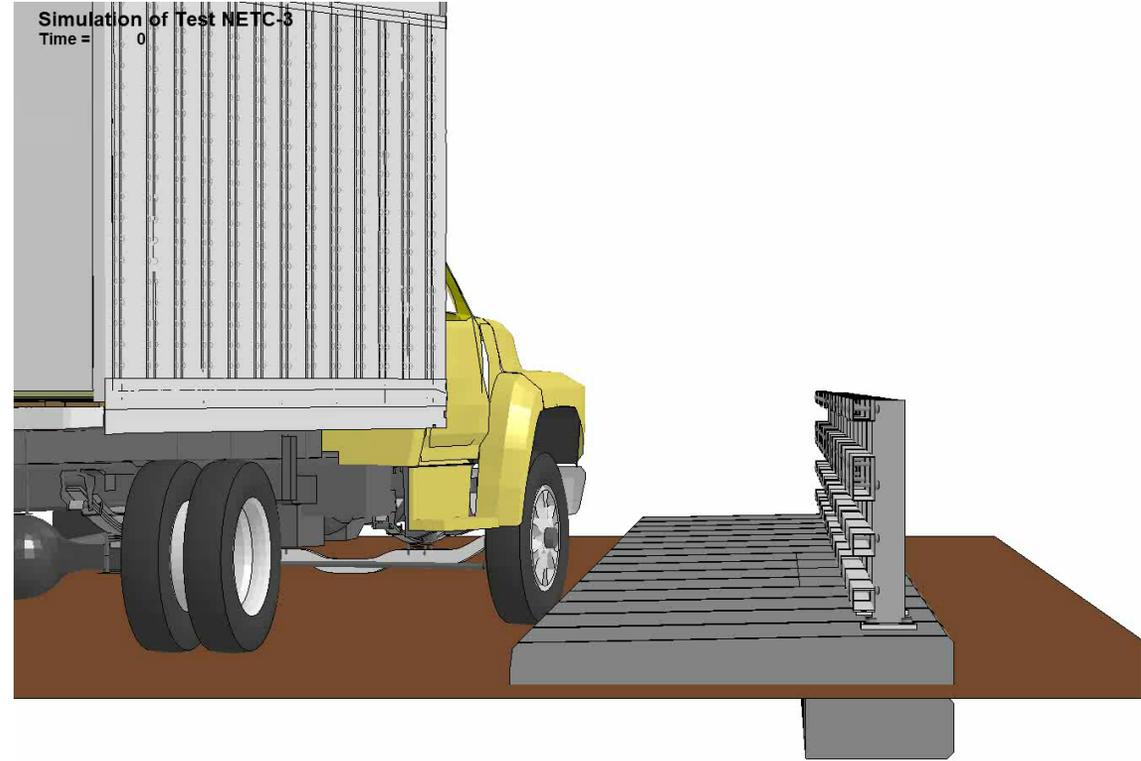
Video Comparison



Bumper snag affects the pitch of the vehicle

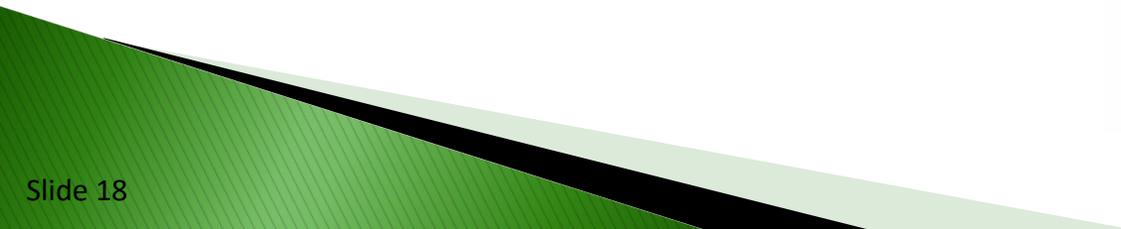
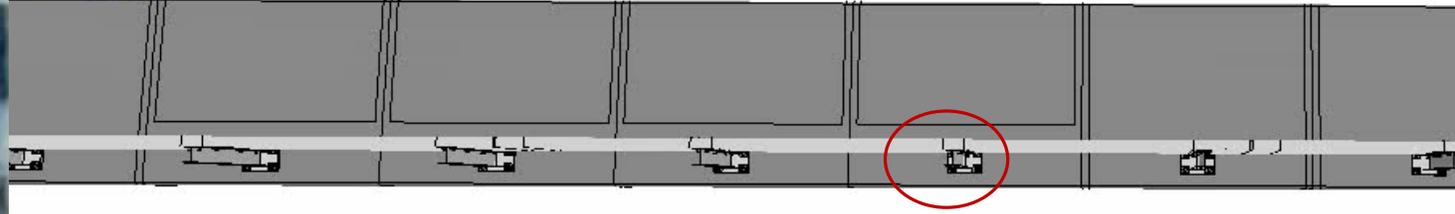
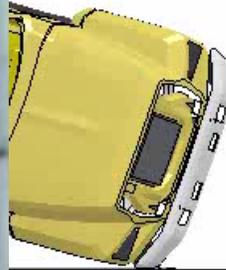
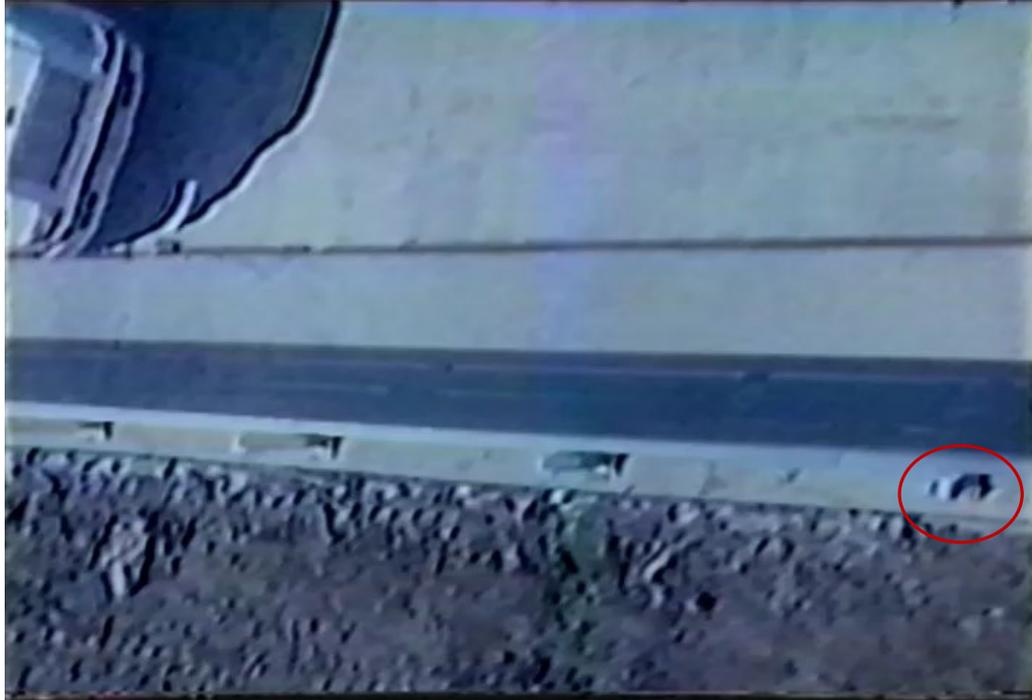


Video Comparison

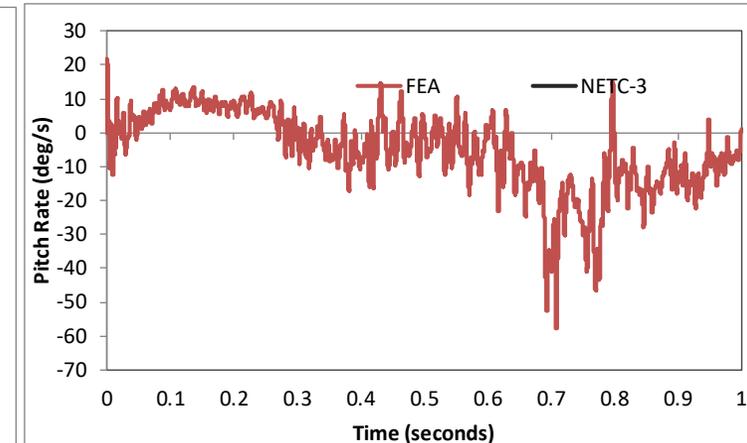
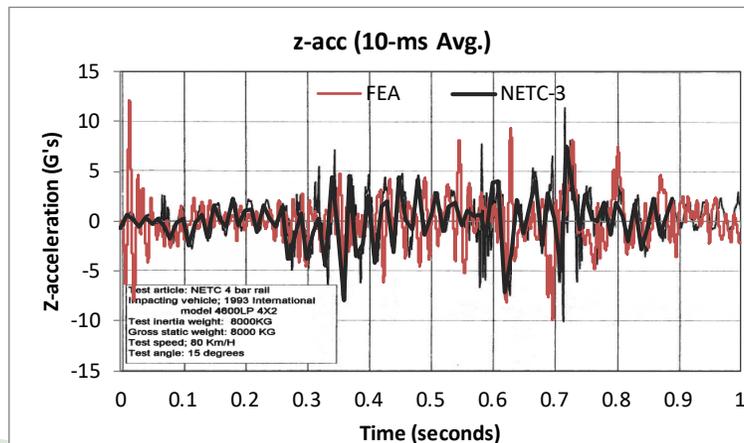
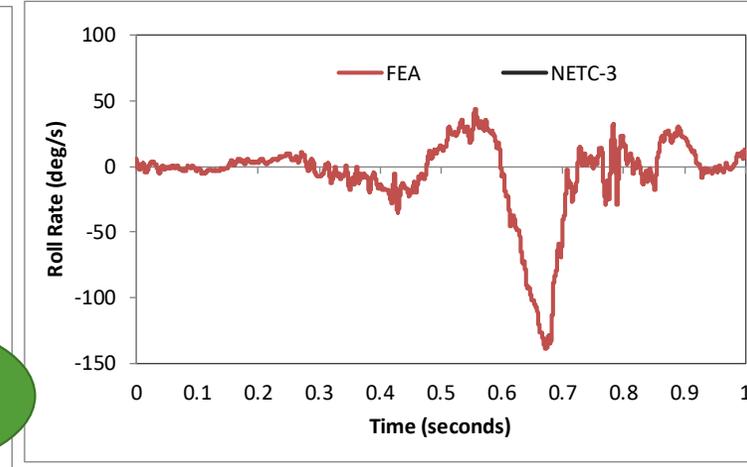
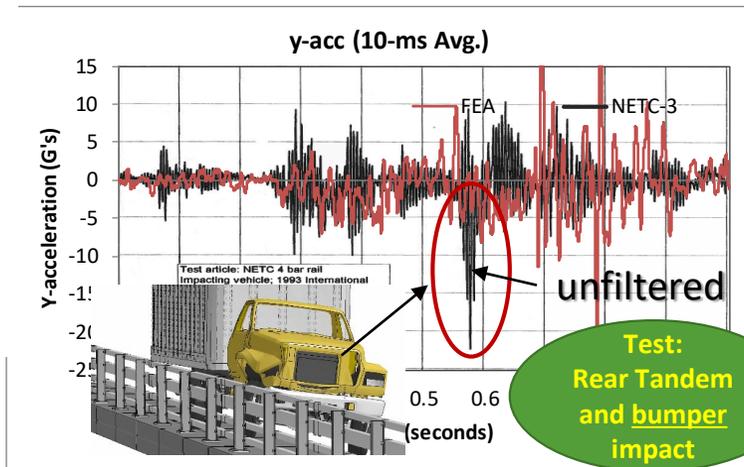
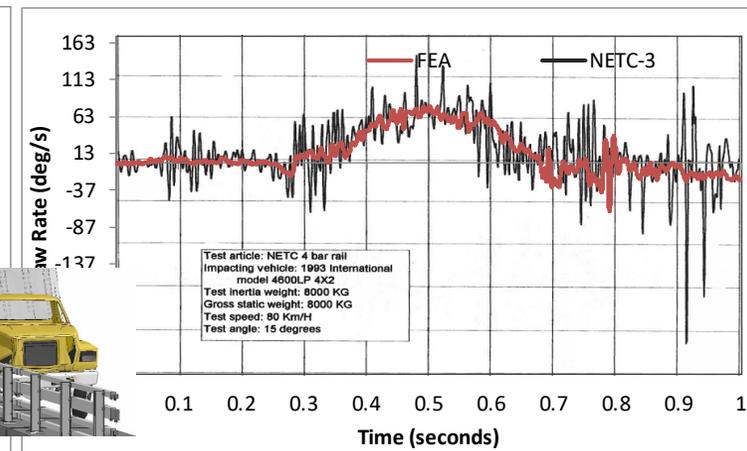
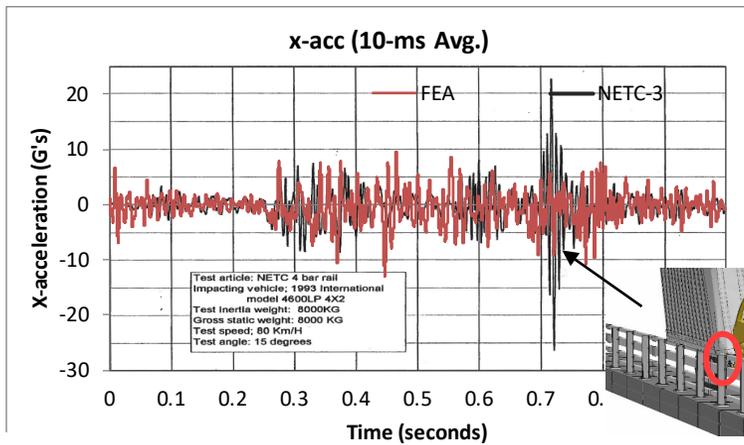
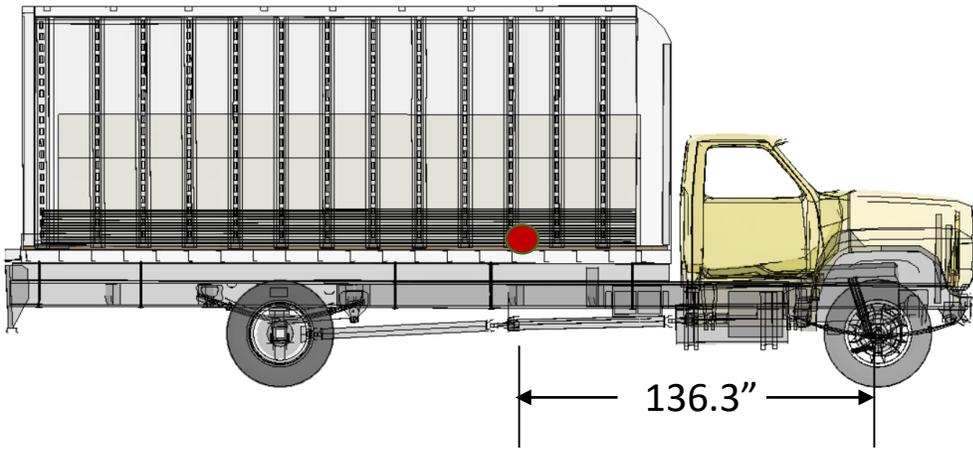


Video Comparison

Simulation of Test NETC-3
Time = 0



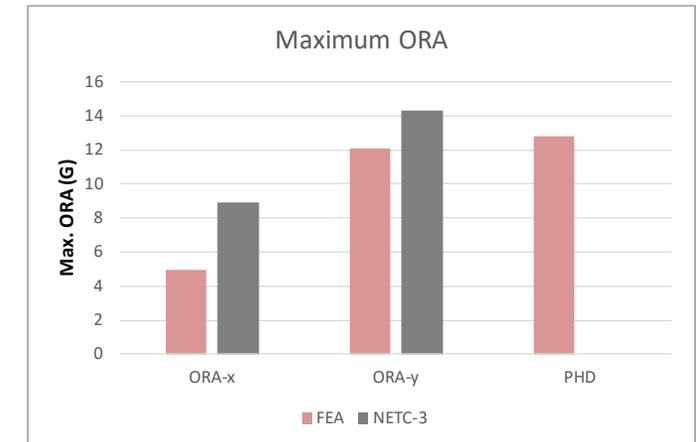
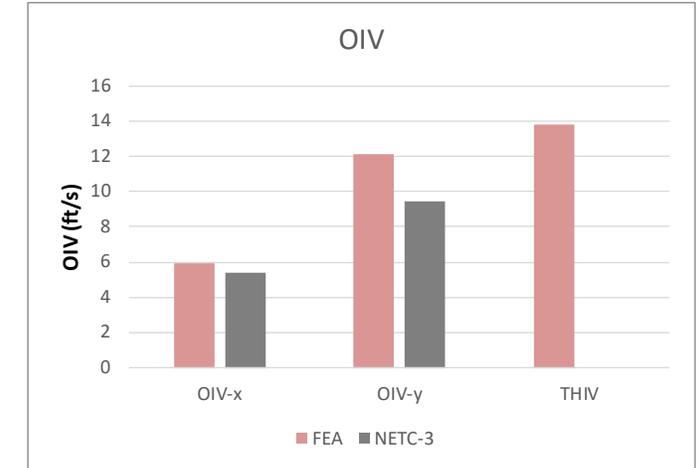
Time History Data at C.G.



Occupant Risk Measures

Occupant Risk Factors		MASH Test 3-11		Error		W179 Criteria	
		NETC-3	FEA				
		(0 - 1.0 seconds)	(0 - 1.0 seconds)	%	Absolute	Criteria	Pass
Occupant Impact Velocity (ft/s)	x-direction	5.4	5.9	9.1%	0.49212	<20% or < 6.6 f/s	Y
	y-direction	-9.5	-12.1	28.0%	2.657448	<20% or < 6.6 f/s	Y
	at time		at 0.4455 seconds on left side of interior				
THIV (m/s)			13.8 at 0.4411 seconds on left side of interior	-	13.77936	<20% or < 6.6 f/s	-
Ridedown Acceleration (g's)	x-direction	8.95	4.95 (0.5490 - 0.5590 seconds)	44.7%	4	<20% or < 4G	Y
	y-direction	-14.3	-12.1 (0.6883 - 0.6983 seconds)	15.4%	2.2	<20% or < 4G	Y
PHD (g's)			12.8 (0.6882 - 0.6982 seconds)	-	12.8	<20% or < 4G	-
ASI			0.42 (0.5880 - 0.6380 seconds)	-	0.42	<20% or < 0.2	-
Max 50-ms moving avg. acc. (g's)	x-direction	-2.72	-2.2 (0.6603 - 0.7103 seconds)	19.1%	0.52	<20% or < 4G	Y
	y-direction	5.9	3.8 (0.6073 - 0.6573 seconds)	35.6%	2.1	<20% or < 4G	Y
	z-direction		-1.2 (0.2700 - 0.3200 seconds)	-	1.2	<20% or < 4G	-
Maximum Angular Disp. (deg)	Yaw	14.77	16.2 (0.6784 seconds)	9.7%	1.43	<20% or < 5 deg	Y
	Roll	20*	14.7 (1.4987 seconds)	26.5%	5.3	<20% or < 5 deg	N
	Pitch	-5.0*	-5.4 (1.0139 seconds)	8.0%	0.4	<20% or < 5 deg	Y

* Approximate

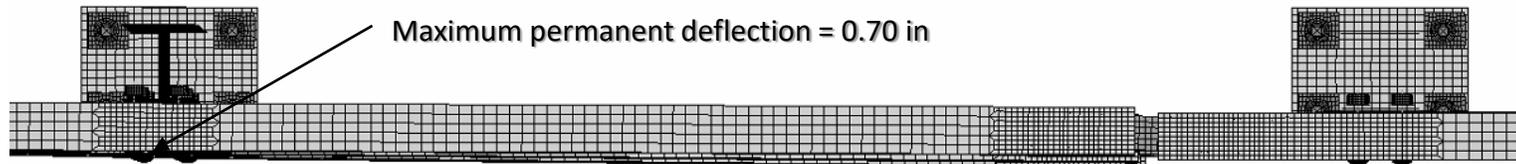




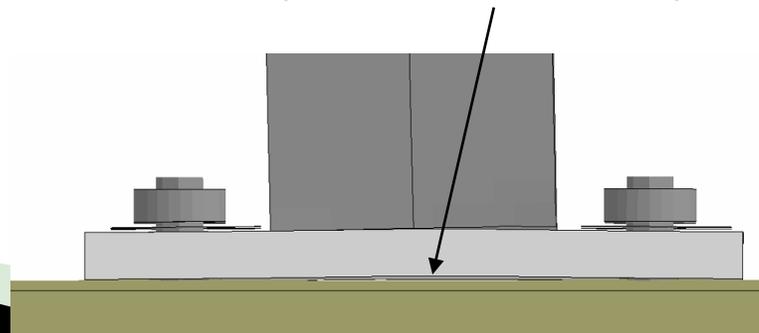
Damage to rear bumper frame:
Likely source of high x-acceleration peaks

Damage to Bridge Rail

- The test resulted in only minor scuffing of the rail and tire marks.
- The maximum dynamic deflection of the bridge rail model occurred at the top rail at the splice connection between posts 6 and 7.
 - FEA = 1.77 in (45 mm)
 - Test = 1.00 in (25 mm)
- The resulting permanent deflection at this location was:
 - FEA = 0.7 in (17.5 mm)
 - Test = 0.5 in (13 mm).
- Posts 6 and 7 were tilted back and the base plates of both posts were raised upward at the center:
 - FEA: Dynamic = 0.28 in (7 mm) ; Permanent = 0.11 in (2.75 mm)
 - Test: Dynamic = (not reported) ; Permanent = 0.14 in (3.5 mm).



Maximum permanent deflection of base plate = 0.11 in



Crash Test PIRT

Structural Adequacy Comparison

		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	1.0 in	1.77 in	0.77 in	Y
		3	Maximum permanent deflection: - Relative difference is less than 20 percent or - Absolute difference is less than 6 inches	0.51 in	0.7 in	0.19 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	N.R. Posts 6-11	42 ft Posts 6-11		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	Concrete curb/deck failure	No	No		Y
		8	Was there significant snagging between the vehicle wheels and barrier elements (Answer Yes or No).	N	N		Y
		9	Was there significant snagging between vehicle body components and barrier elements (Answer Yes or No).	N*	N		Y

* There was a probable snagging between the bumper and the rail in the test that could not be captured in the FE model due to differences in bumper width.

N.R. – Not Reported

Crash Test PIRT

Occupant Risk Comparison

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.	*20.0 Deg	14.7 deg	26.5 % 5.3 deg	N
		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.	*5.0 deg	5.4 deg	8.0 % 0.4 deg	Y
		4	Maximum yaw of the vehicle through 0.446 seconds: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	14.8 deg	16.2 deg	9.7 % 1.4 deg	Y
	G	1	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)	5.4	5.9	9.1% 0.5 ft/s	Y
			• Lateral OIV (ft/s)	-9.5	-12.1	28% 2.7 ft/s	Y
		• THIV (ft/s)	N.R.	13.8			
		2	Occupant accelerations: - Relative difference is less than 20 percent or - Absolute difference is less than 4 g's.				
			• Longitudinal ORA	8.95	4.95	44.7 % 4 g	Y
			• Lateral ORA	14.3	12.1	15.4 % 2.2 g	Y
• PHD	N.R.		12.8				
• ASI	N.R.	0.42					

N.R. – Not Reported

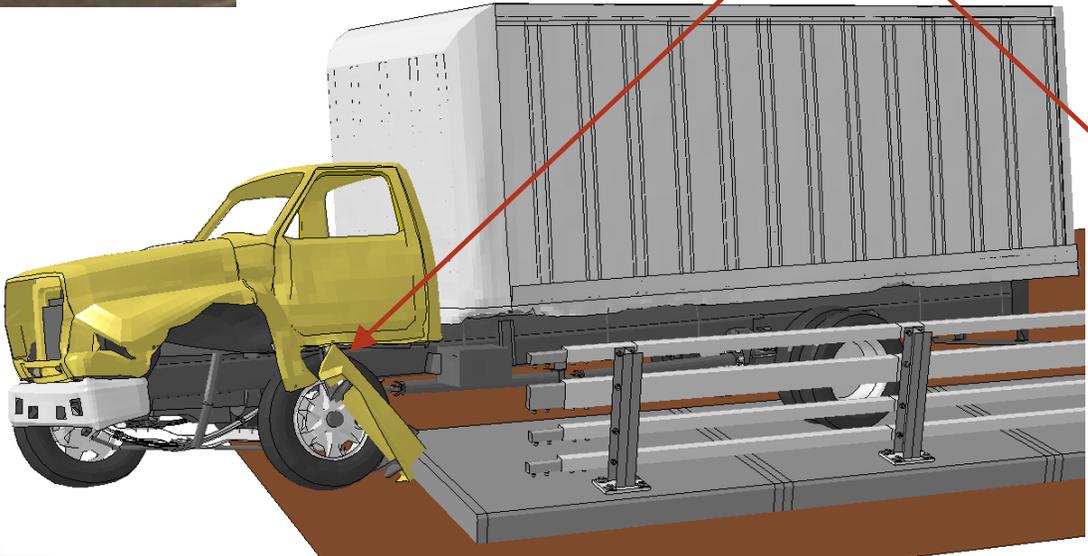
* Reported as "approximate"

Crash Test PIRT

Post Trajectory Comparison



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.	1.3%	8.0%	X	Y
		2	Exit angle at loss of contact: - Relative difference is less than 20 percent or - Absolute difference is less than 5 degrees.	4.1 deg	1.2 deg	2.9 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.	35.8 mph	40.3 mph	12.8 % 4.6 mph	Y
		4	Front axle disconnected from suspension	Y	Y		Y



Conclusions

- **Noted Issues with the Validation:**

- The physical properties of the test vehicle were not included in the test report but were visibly different than that of the FEA model (noting that the FEA model is more consistent with typical test vehicles) ...
 - The cargo box for the test vehicle was visibly longer than the FEA model
 - The rear bumper for the test vehicle extended the full width of the truck bed.
- Quantitative comparison of the time-history data could not be performed, since the test data was not available.

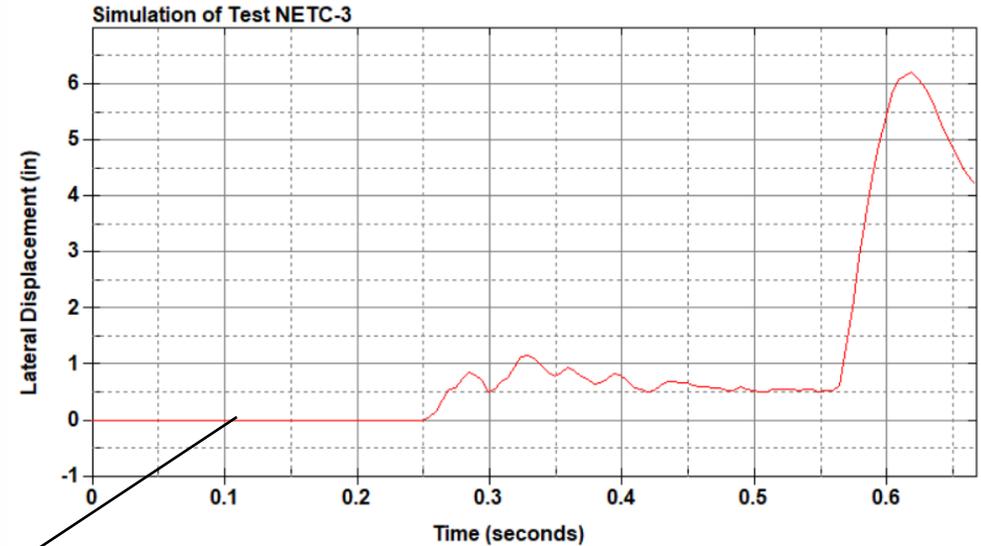
- **General Assessment Regarding Validity**

- In general, the model results replicated the basic phenomenological behavior of the system for Report 350 Test 4-12 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.
- One exception involved the rear bumper snagging on the bridge rail resulting in higher longitudinal deceleration of the vehicle than occurred in the FEA.
- The model is, however, considered adequately “valid” and will be used as a baseline model for developing and evaluating MASH impact conditions for the NETC bridge rails.

Supplemental Slides

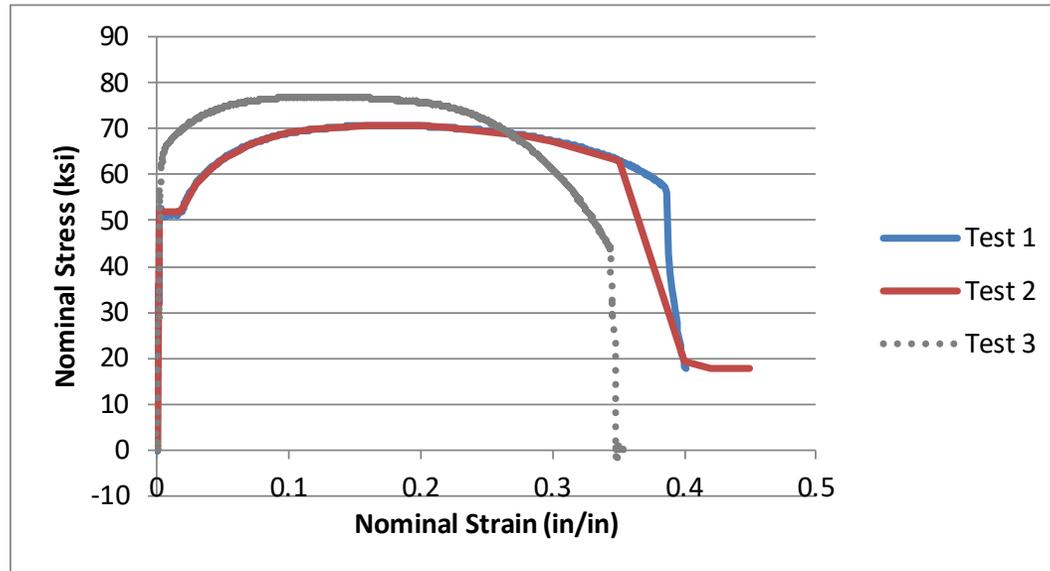
When truck bed engages top rail

Simulation of Test NETC-3
Time = 0



Lateral Deflection of Critical Post

Material Strength Range for ASTM 572-50



- When evaluating the higher loads from the MASH vehicle, it may be necessary to use a range of strength properties for the post.
- The plot shown here includes:
 - Test 1 and 2 from coupons cut from a W6x25 post from one manufacturer
 - Test 3 from coupons cut from another manufacturer.
- Both strengths are possible for posts installed in the field and in full-scale test installations.
- The weaker strength post will assess maximum post plasticity
- The stronger will assess greater loading on the anchor and concrete.