Development of MASH Computer Simulated Steel Bridge Rail and Transition Details

Task 3B
NETC 3-Bar w/ HSS6x4x5/16
Test 4-10

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

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Task 3B – MASH Test 4-10 Evaluation of NETC 3-Bar Bridge Rail

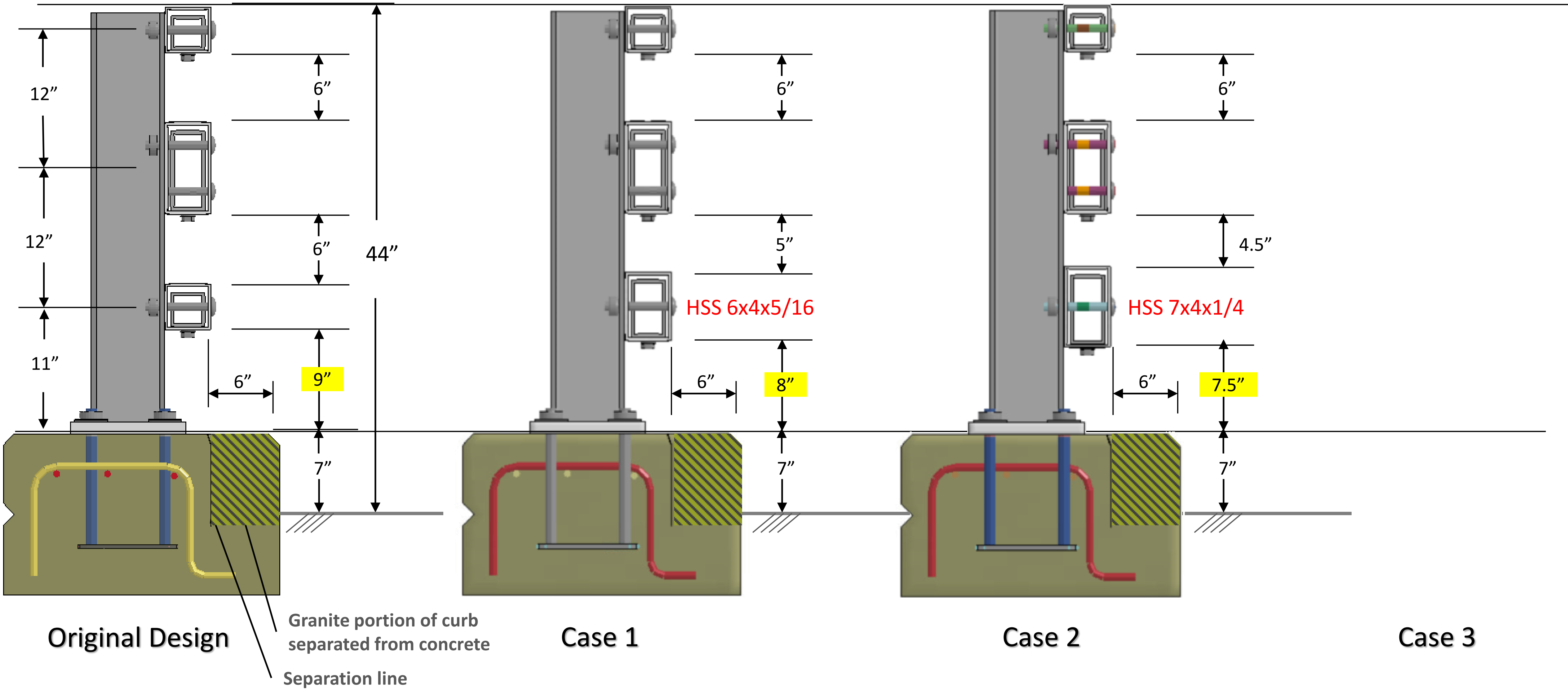
- The objective of this task is to use FEA simulations to determine if increasing the size and/or strength of the lower railing on the NETC 3-Bar bridge rail will improve crash performance for MASH Test 4-10,
- The evaluation of the 3-Bar bridge rail was performed in Task 3.
- FEA simulations showed that the mid-span deflections for the rails for the 2-Bar and 3-Bar systems lead to pocketing, particularly for Test 4-10 in which the forces from the small car were largely concentrated on the lower HSS 4 x 4 x ¼” rail.
- The maximum dynamic deflection of the lower rail for that case was 3.35 inches and resulted in peak longitudinal and lateral accelerations of 26 G and 30 G, respectively. Changing the size of the lower rail to increase stiffness may improve crash performance of the system for the small car test.
- For this study, the NETC 3-Bar bridge rail model was modified to include a larger HSS section for the lower rail to:
  - Increase stiffness and lower deflection
  - Increase rail dimension in vertical direction to provide additional contact width at the lower portion of the bridge railing and reduce potential for wheel-snag on the posts.

Design Options and Comparison

	Bar Size	Area (in^2)	% Change Area	Zy	% Change Zy	% Change Zy % Change A
Original	HSS 4 x 4 x ¼	3.59	-	4.97	-	-
	HSS 5 x 4 x ¼	4.09	14%	5.9	19%	1.36
*	HSS 5 x 4 x 5/16	4.98	39%	7.05	42%	1.08
	HSS 6 x 4 x ¼	4.59	28%	6.84	38%	1.36
*	HSS 6 x 4 x 5/16	5.61	56%	8.21	65%	1.16
*	HSS 7 x 4 x ¼	5.09	42%	7.78	57%	1.36
	HSS 7 x 4 x 5/16	3.23	74%	9.36	88%	1.19

** Selected for evaluation*

Three Analysis Cases Evaluated



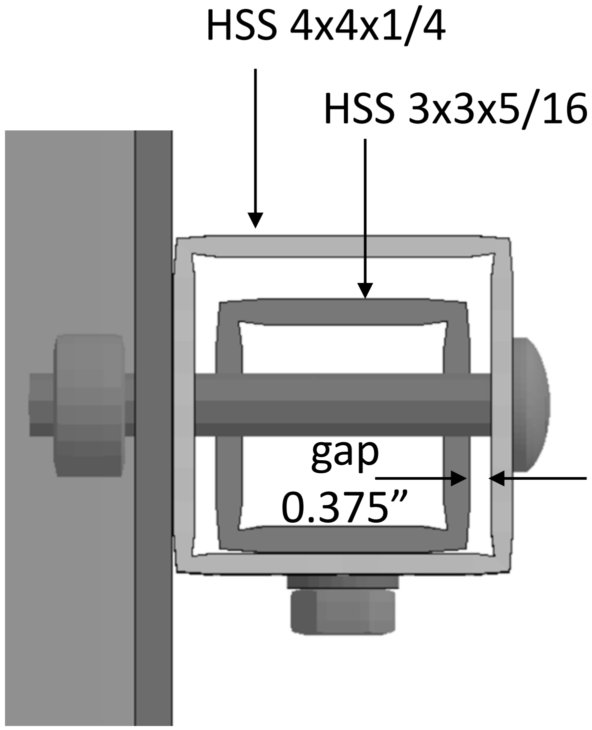
Original Design

Case 1

Case 2

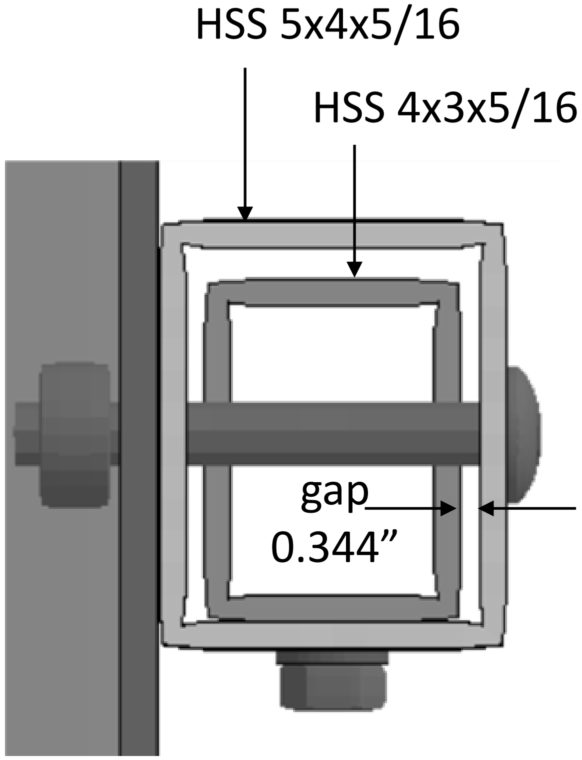
Case 3

Corresponding Splice Gaps for Each Case



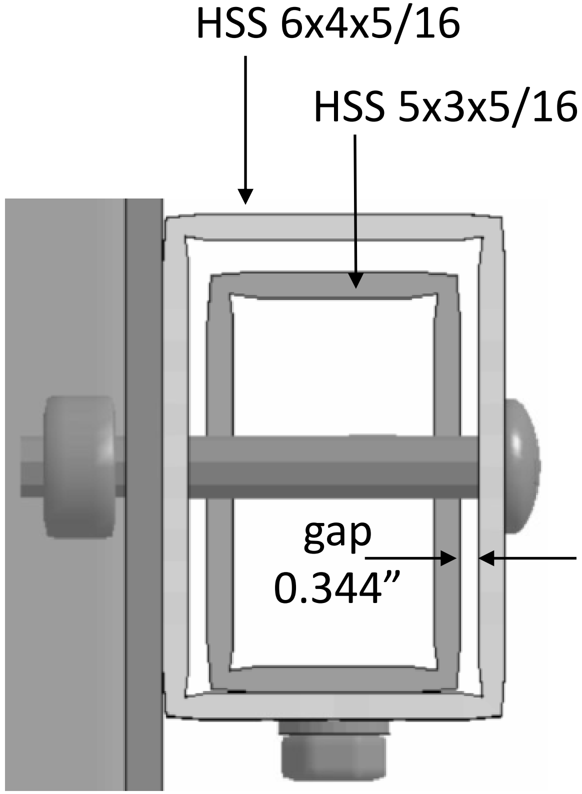
Total gap = 0.75” (19.1 mm)

Original Design



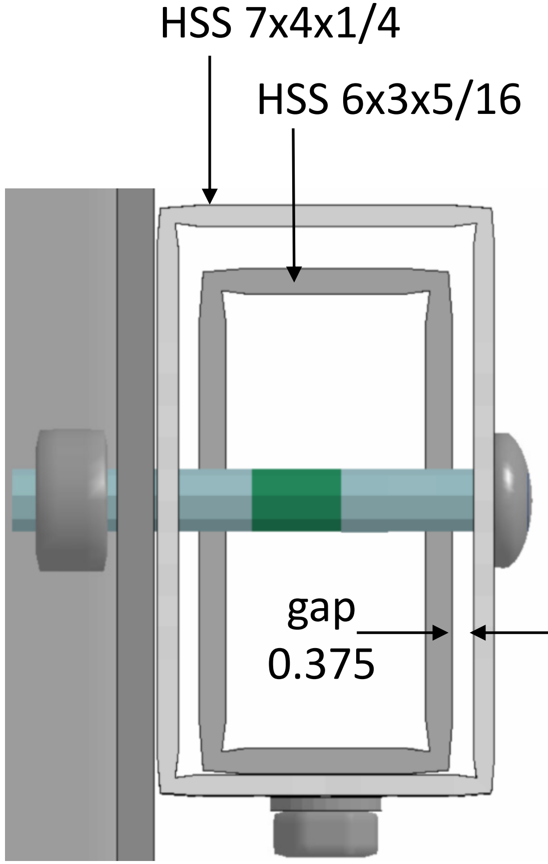
Total gap = 0.688” (17.5 mm)

Case 1



Total gap = 0.688” (17.5 mm)

Case 2



Total gap = 0.75” (19.1 mm)

Case 3

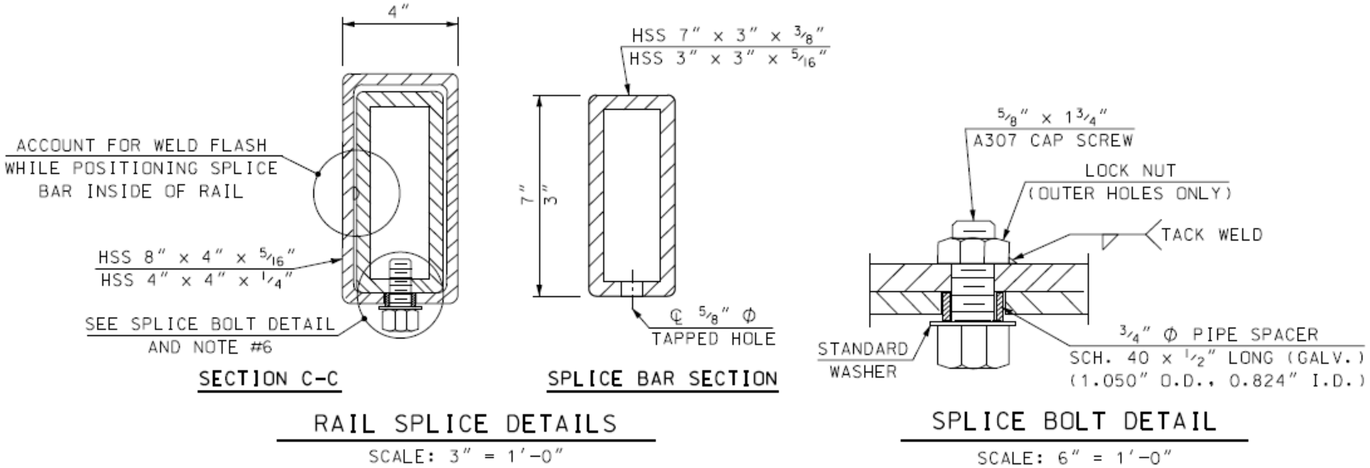
Summary

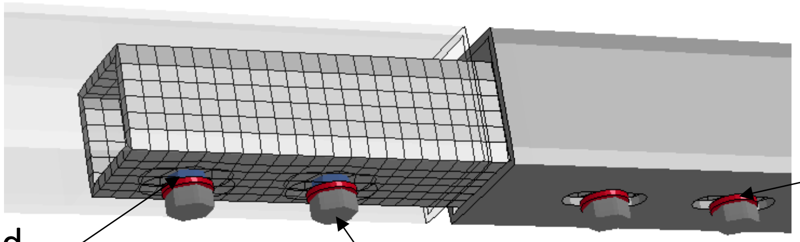
- HSS 7x4x1/4:
  - Pros
    - Greatest stiffness per added cost (i.e., 57%/42%)
    - Largest contact area.
  - Cons
    - Largest splice gap (3/4”)
- HSS 5x4x5/16
  - Pros
    - Lowest cost solution
    - Adequate to reduce pocketing
  - Cons
    - Lowest stiffness per added cost (i.e., 39%/42%)
    - Splice gap same as original design (11/16”)

Drawings and images correspond to original design

Splice Model

- The model includes
  - Correct cap-screw dimensions,
  - Bushing-spacers for the cap screws on one side of the splice, and
  - Proper clamping force for the cap screws on the opposite side of the splice.





Washer Only
(bolt tension = 20 kip)

Washer and Bushing/Spacer

5/8"-Diameter A307 Cap Screws

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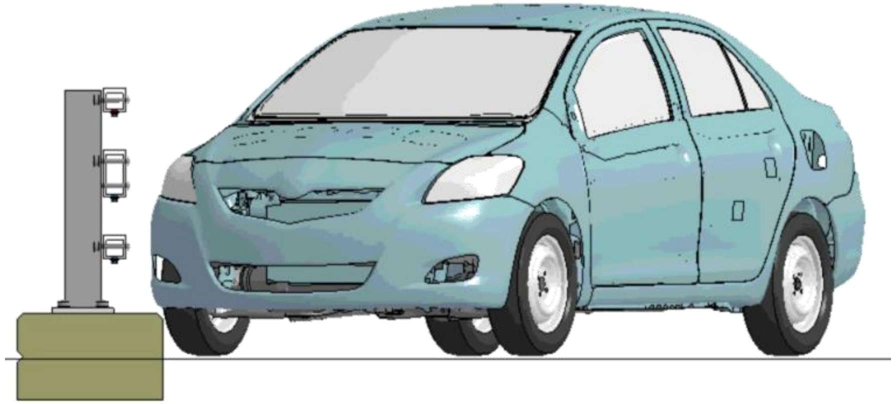
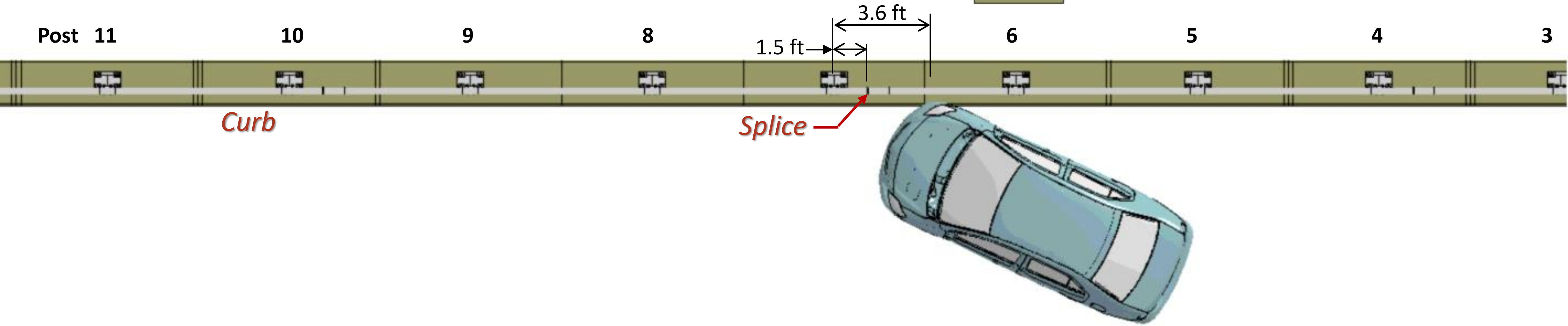
Materials

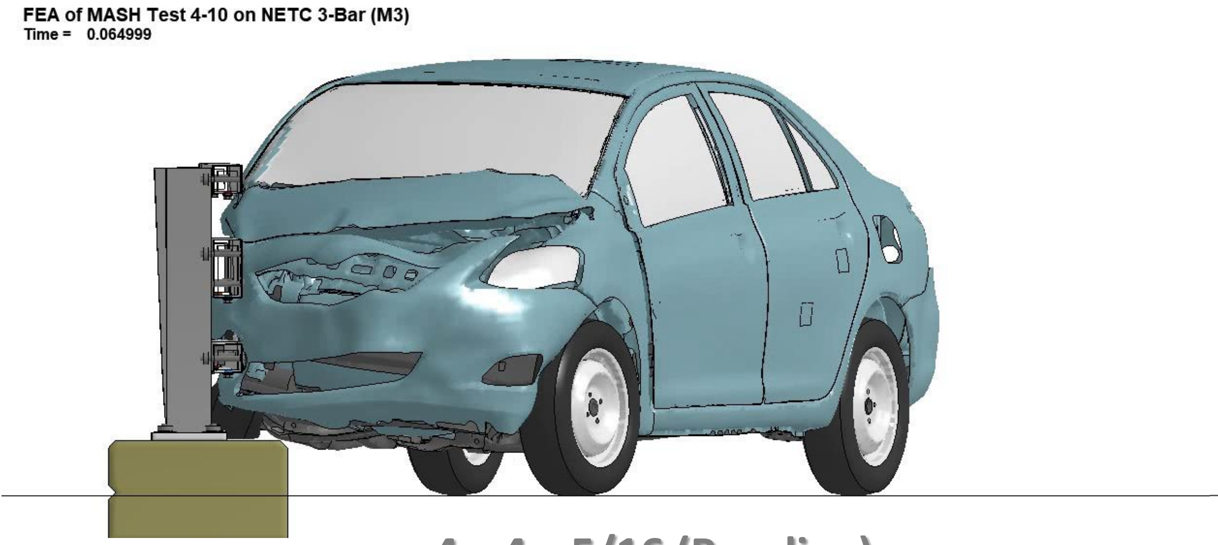
- **All steel materials were modeled in LS-DYNA using material model *Mat_Piecewise_Linear_Plasticity.** The Young's modulus was set to 29,000 ksi and Poisson's ratio was set to 0.33. The piecewise-linear stress-strain characterization for each component varied depending on steel type and grade.
- The 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.

MASH Test 4-10 Simulation on the Modified NETC 3-Bar

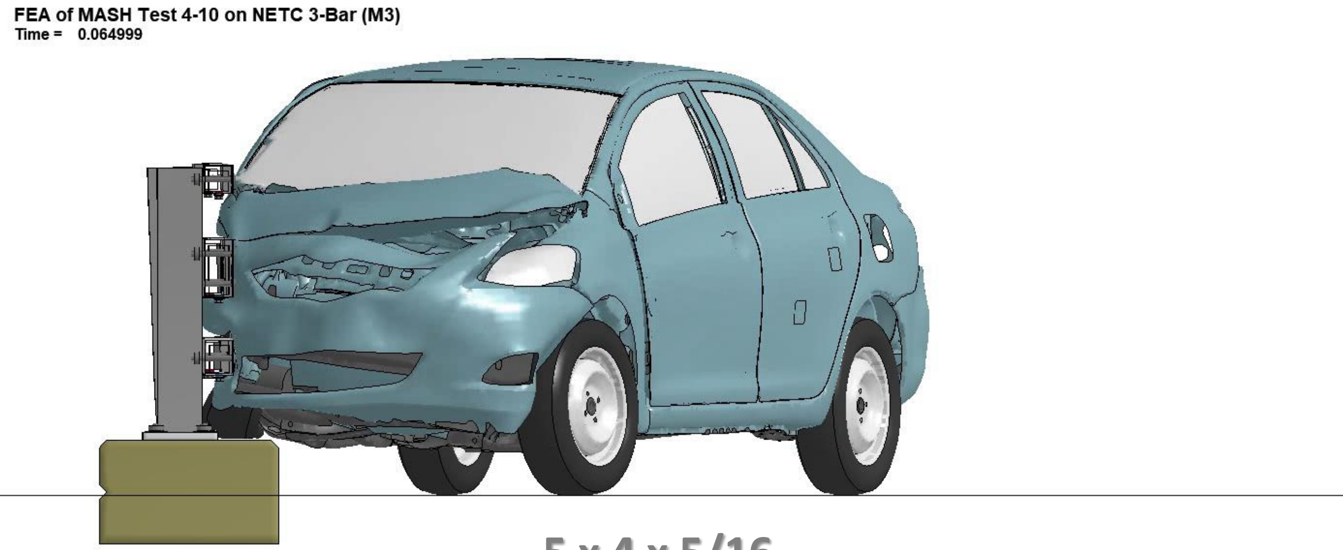
- Impact Conditions
  - Impact Speed = 62.1 mph (100 km/hr)
  - Impact Angle = 25 degrees
  - Impact Point (*MASH 2016 suggested CIP*)
    - IP01 = 3.6 ft upstream from critical Post
    - IP02 = 3.6 ft upstream from splice
- Vehicle Model
  - YarisC_V1l_R160407.k
  - Vehicle Mass = 1,177 kg (2,595 lb)



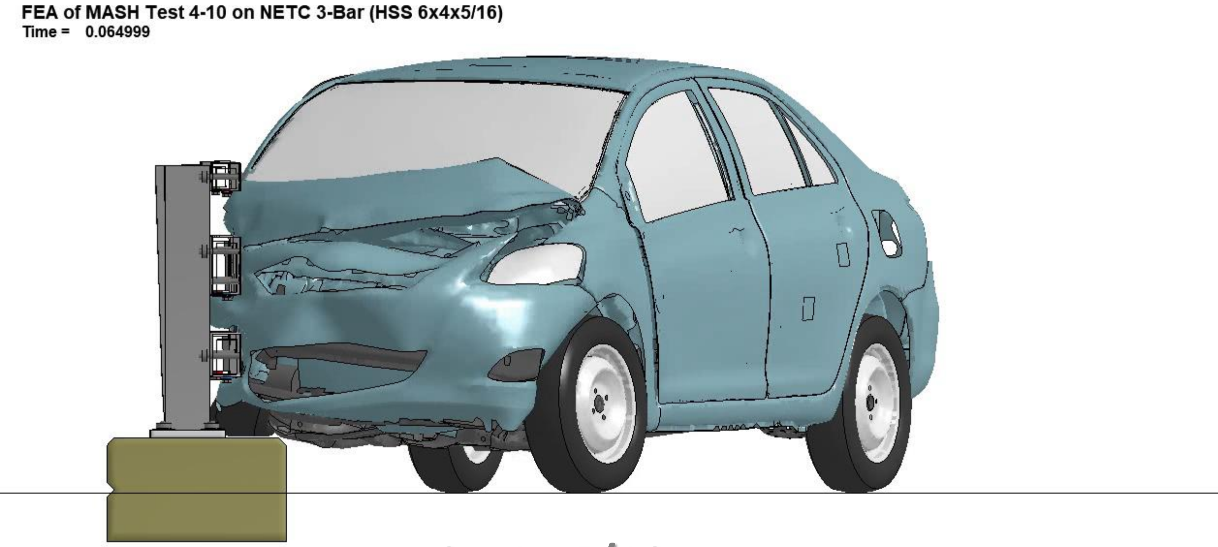




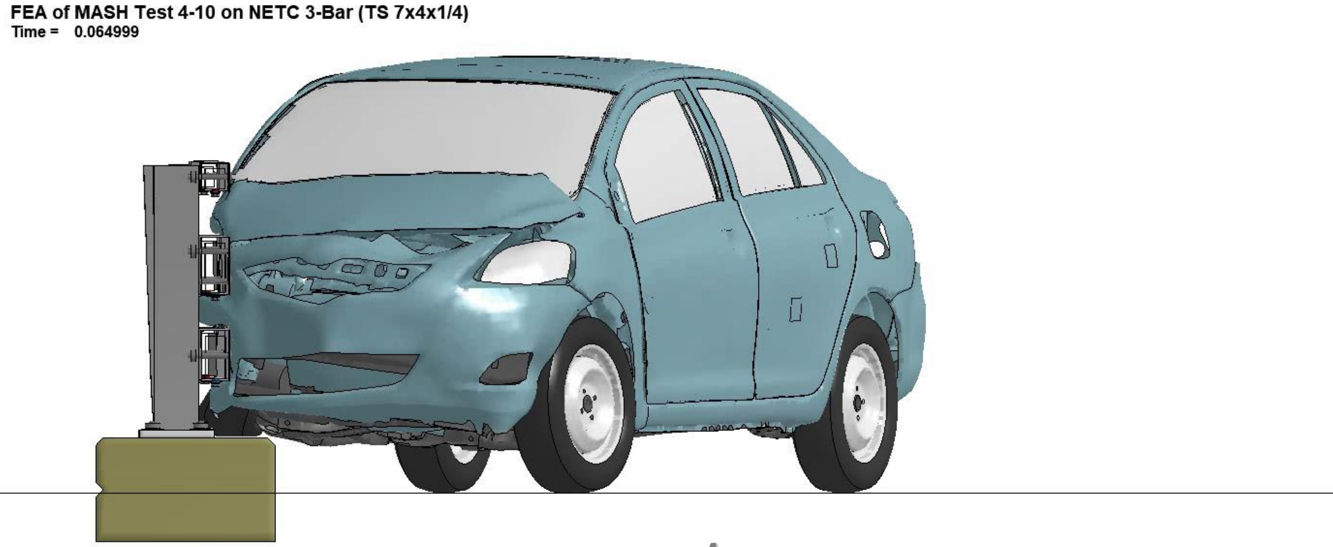
4 x 4 x 5/16 (Baseline)



5 x 4 x 5/16

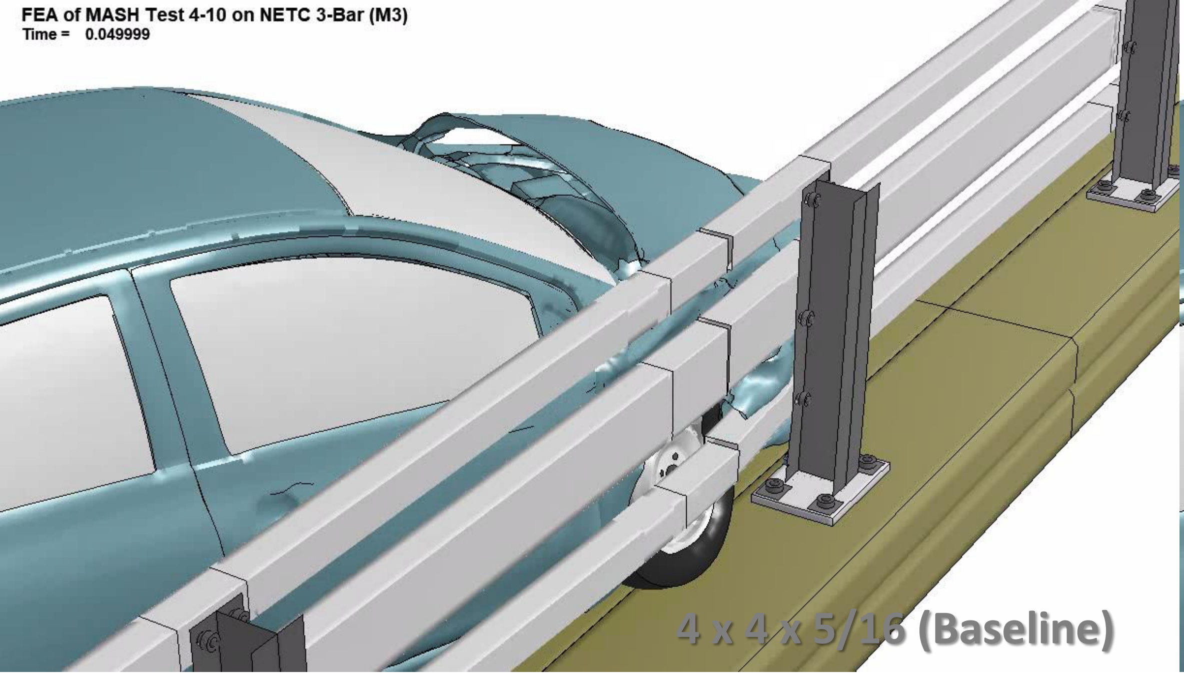


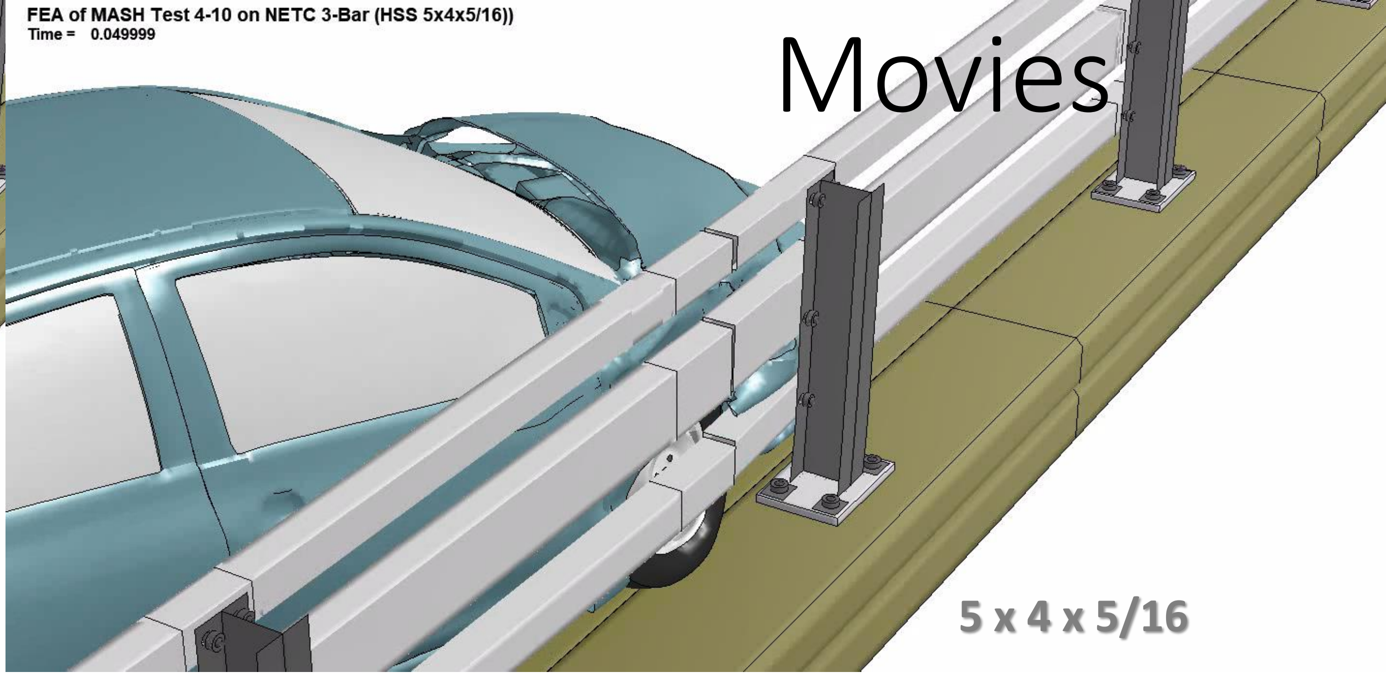
6 x 4 x 5/16

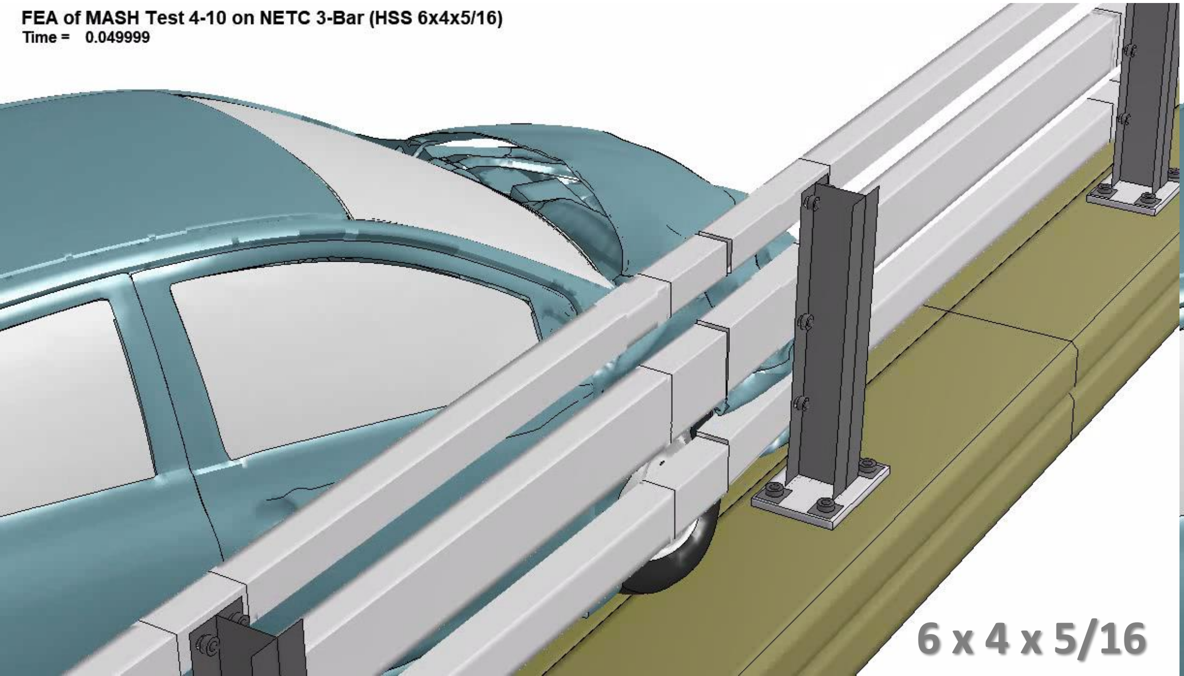


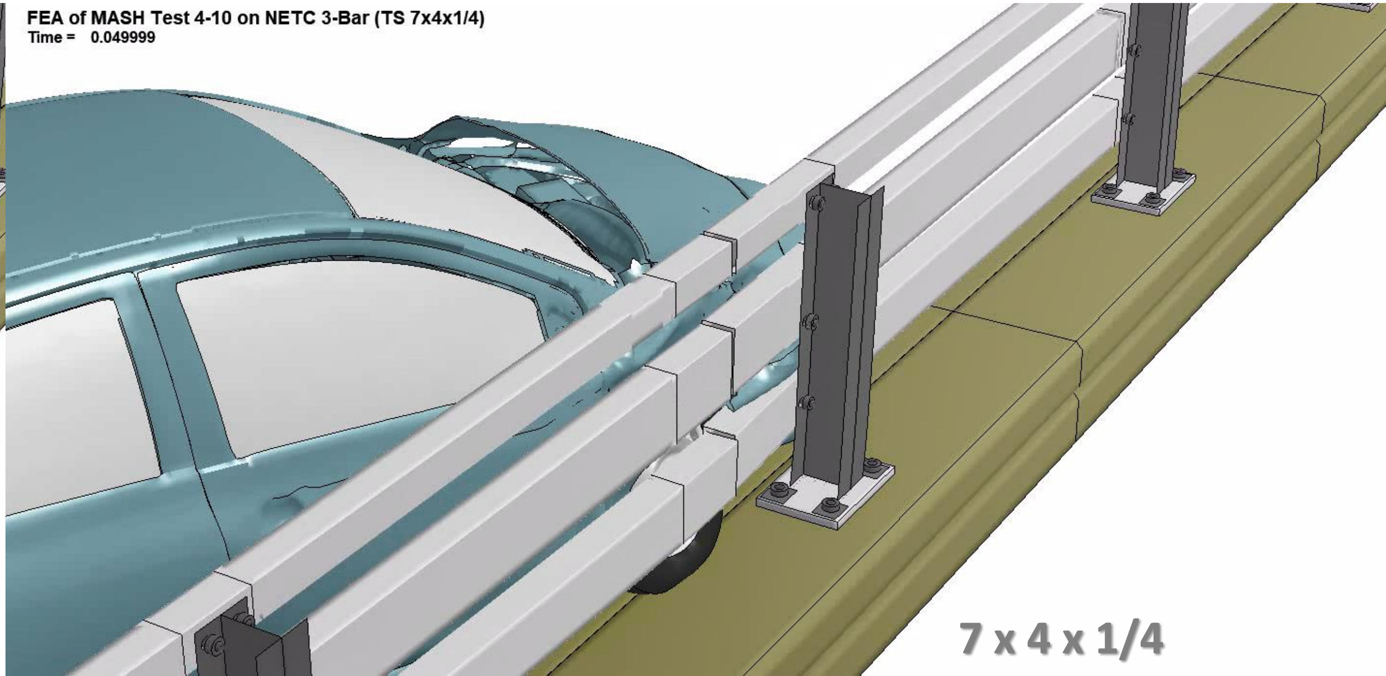
7 x 4 x 1/4

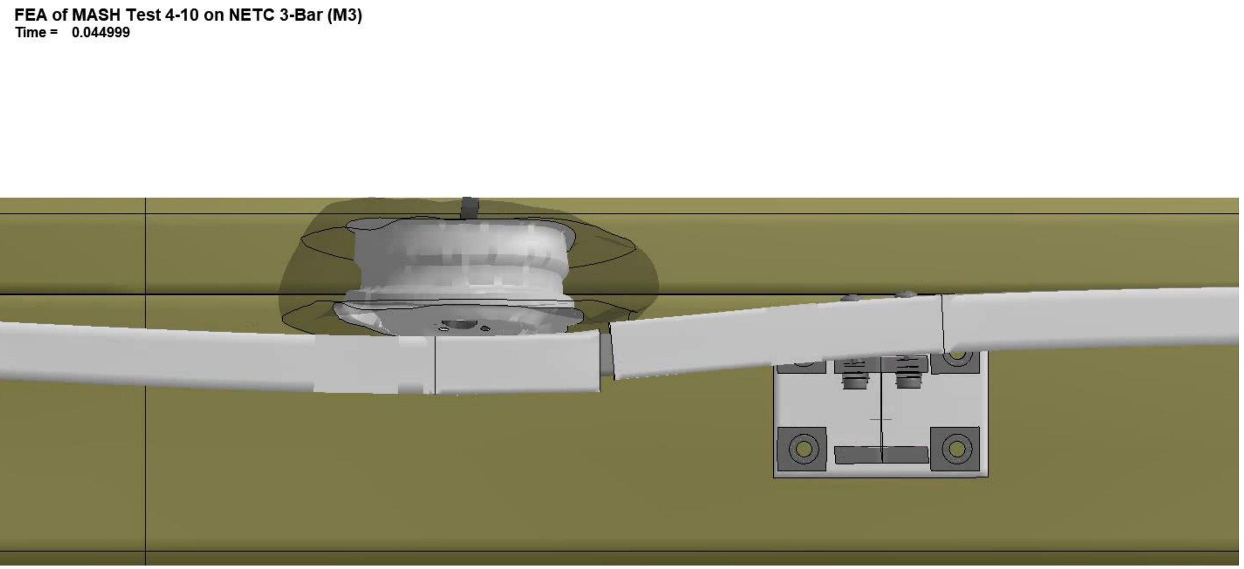
Movies


FEA of MASH Test 4-10 on NETC 3-Bar (M3)
Time = 0.049999
4 x 4 x 5/16 (Baseline)

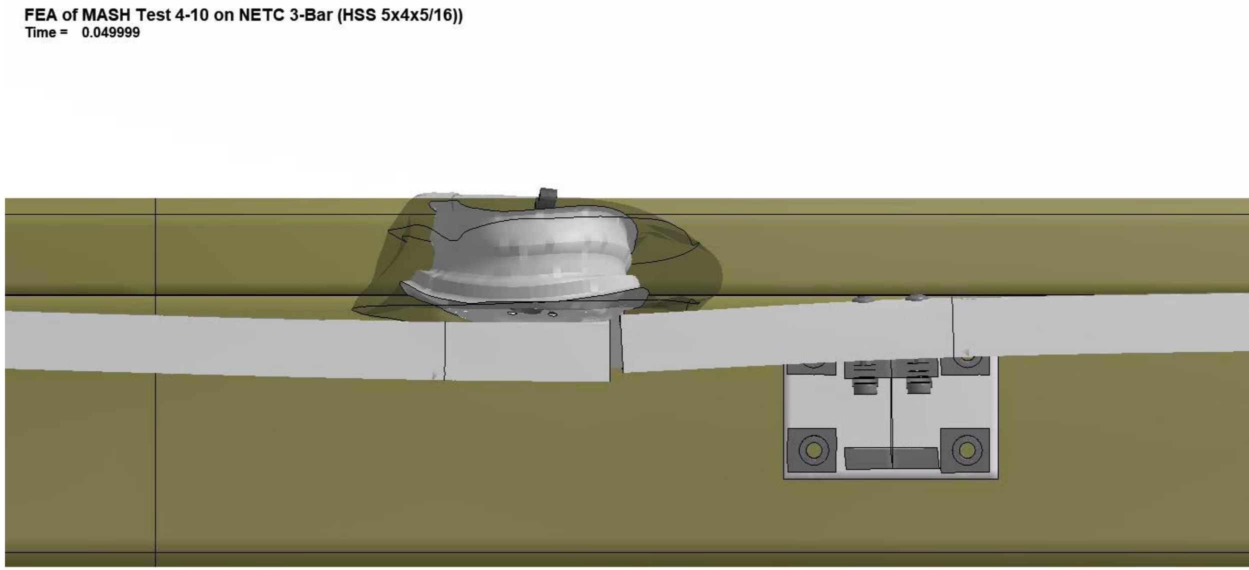

FEA of MASH Test 4-10 on NETC 3-Bar (HSS 5x4x5/16))
Time = 0.049999
5 x 4 x 5/16


FEA of MASH Test 4-10 on NETC 3-Bar (HSS 6x4x5/16)
Time = 0.049999
6 x 4 x 5/16

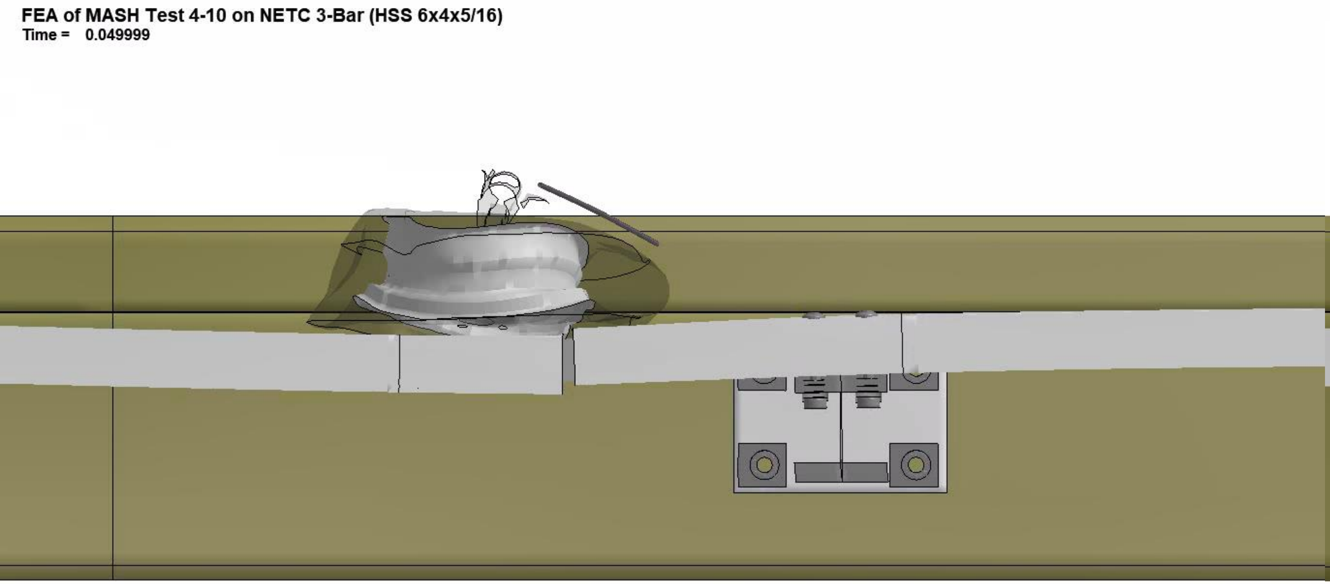

FEA of MASH Test 4-10 on NETC 3-Bar (TS 7x4x1/4)
Time = 0.049999
7 x 4 x 1/4



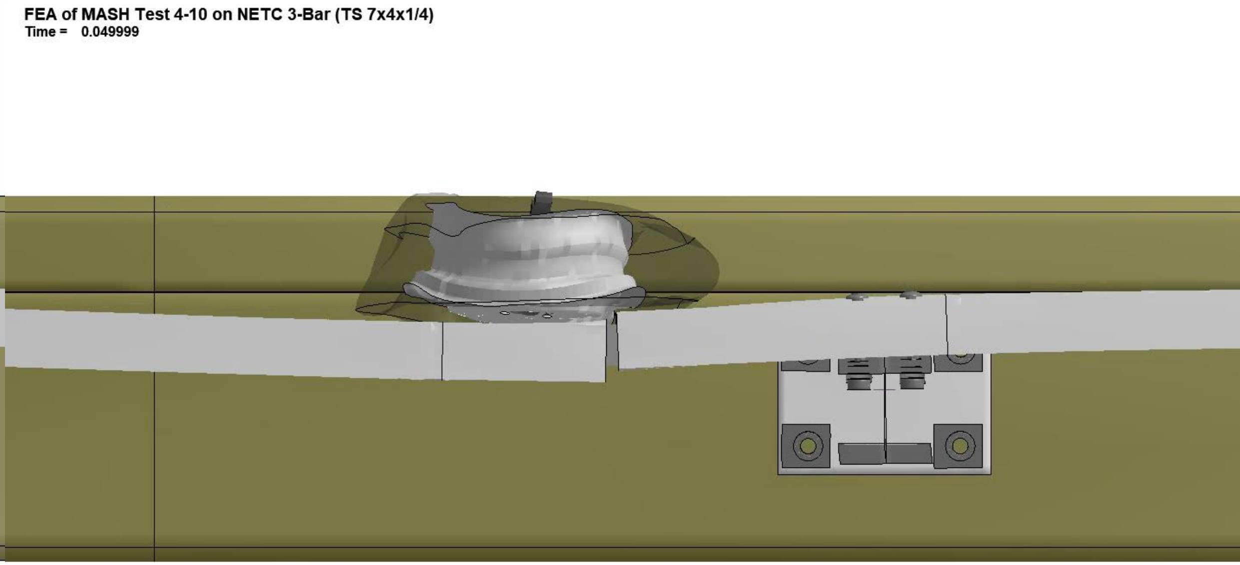
4 x 4 x 5/16 (Baseline)



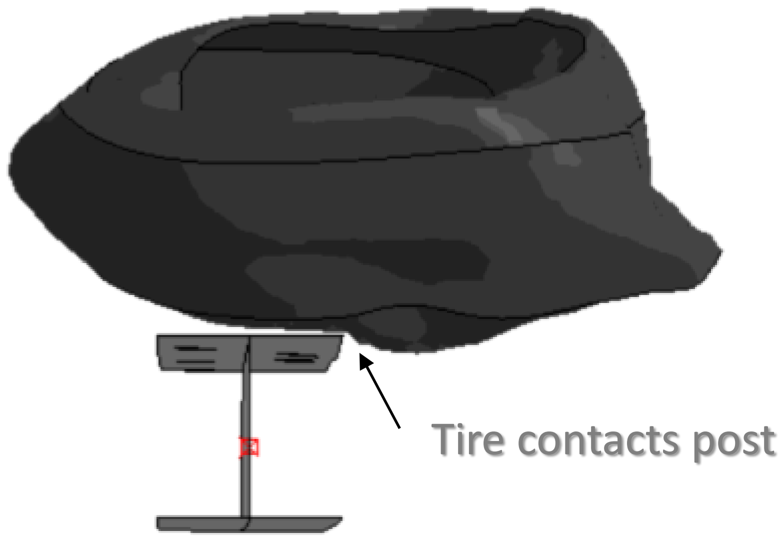
5 x 4 x 5/16



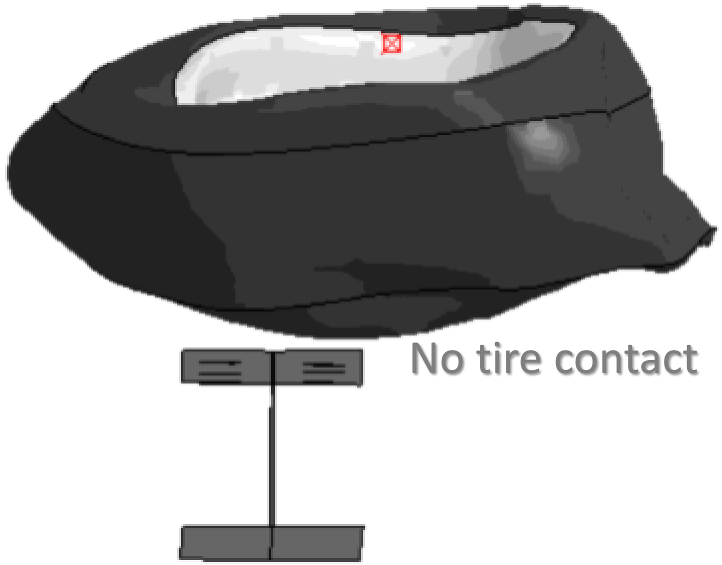
6 x 4 x 5/16



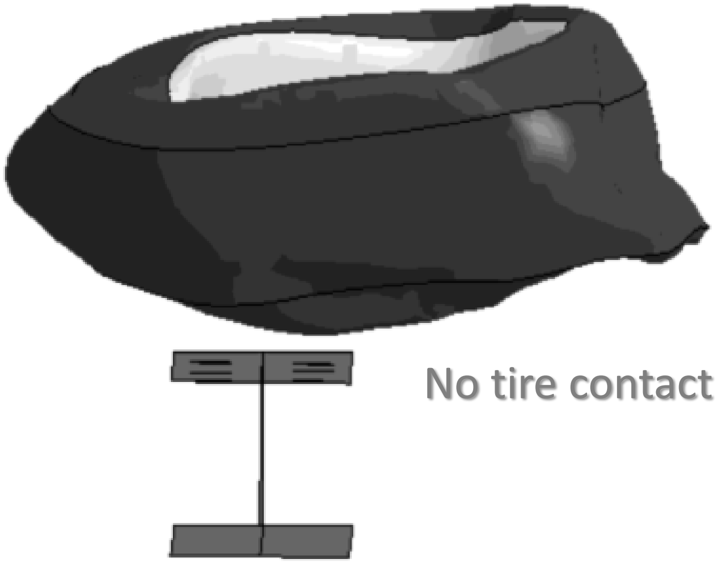
7 x 4 x 1/4



4 x 4 x 5/16 (Baseline)



5 x 4 x 5/16



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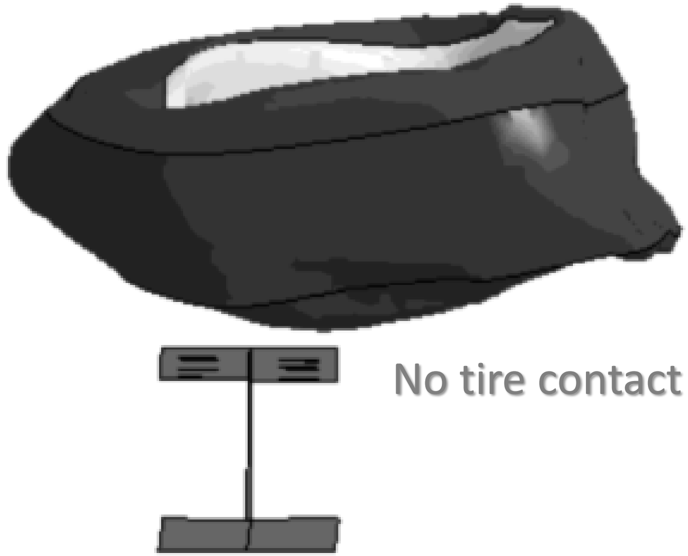
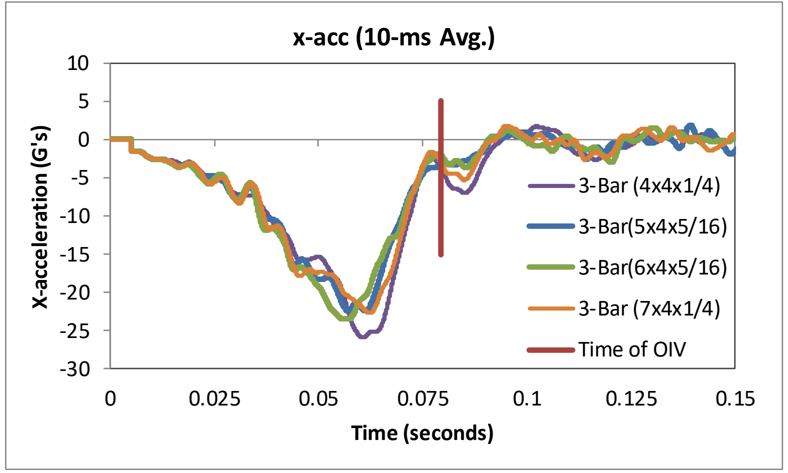
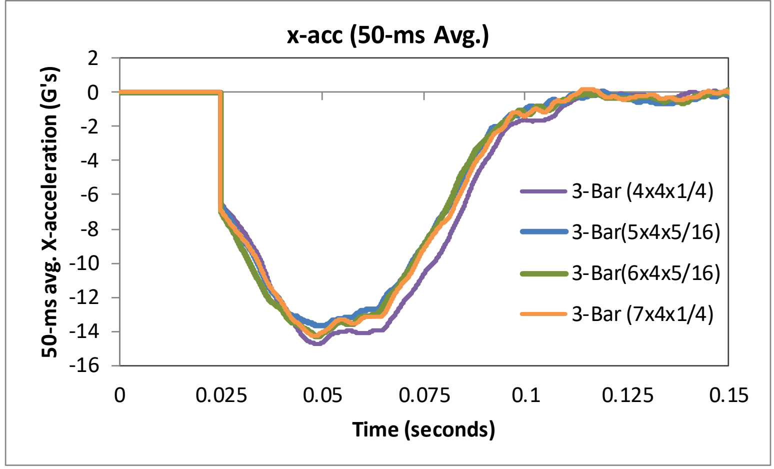
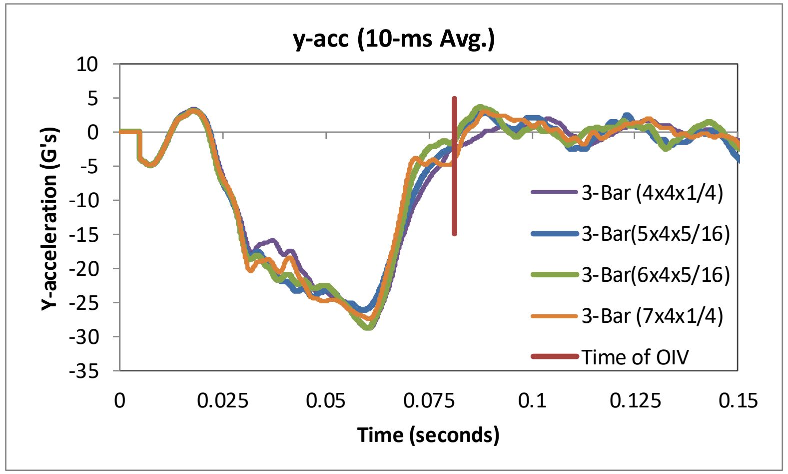


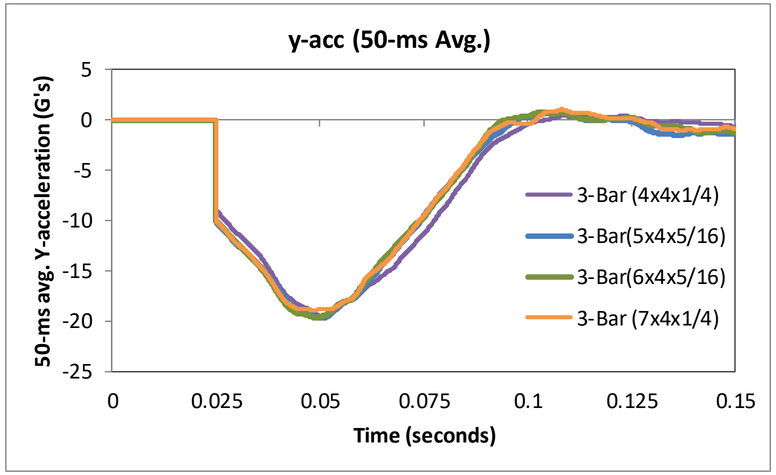
7 x 4 x 1/4

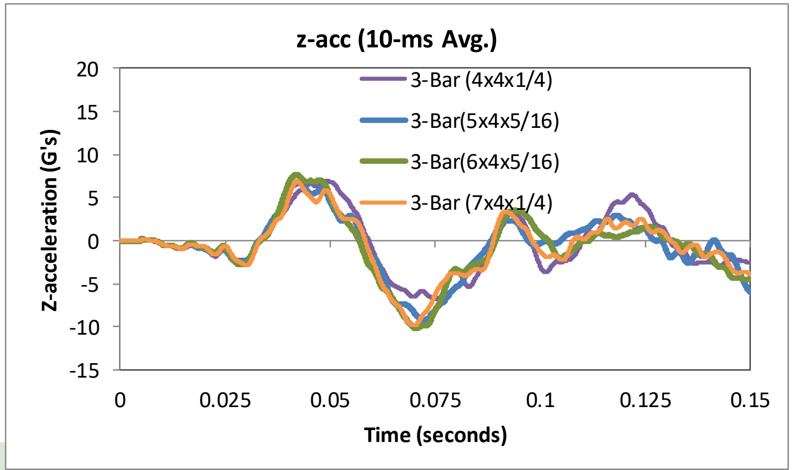
Acceleration Plots

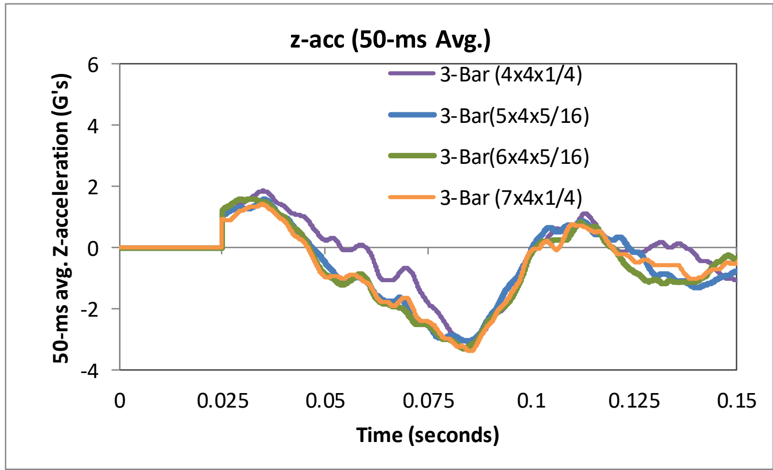




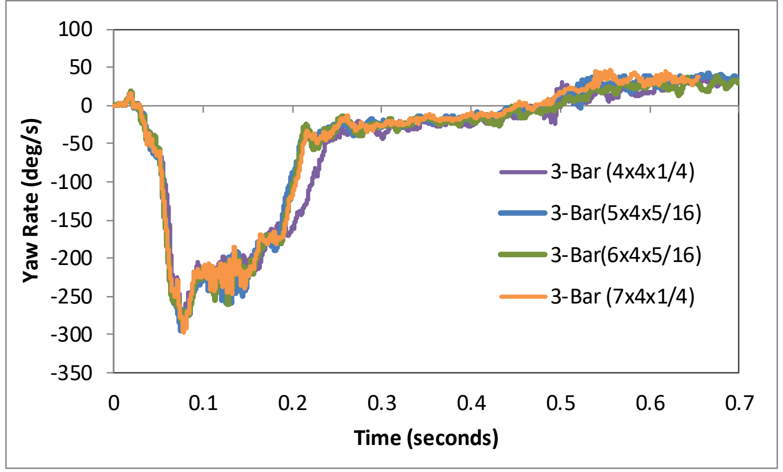


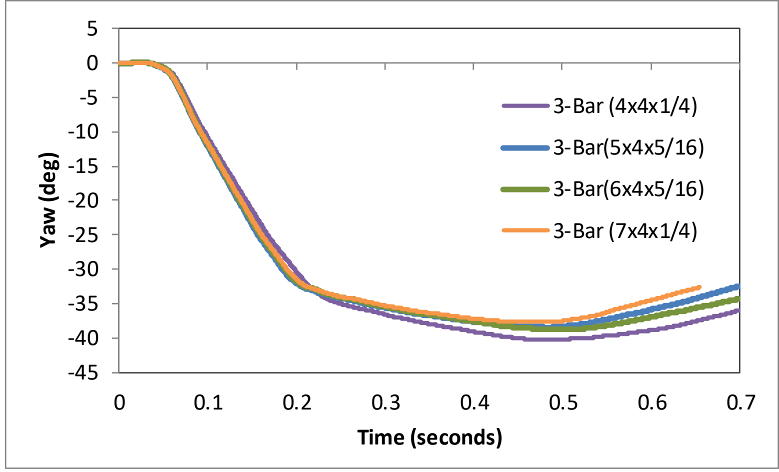


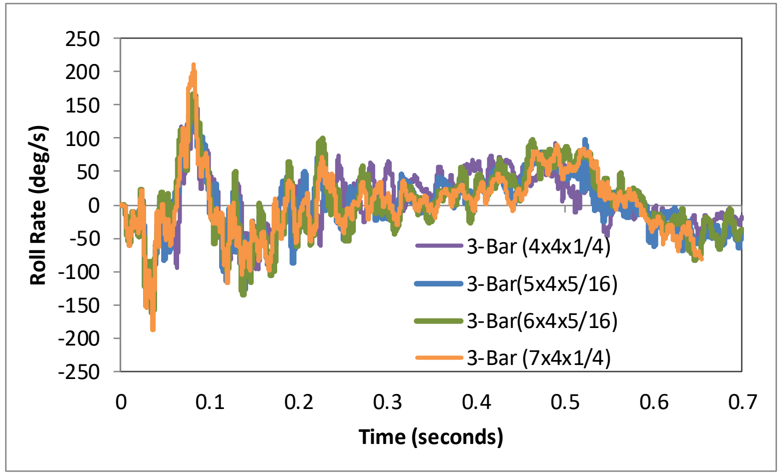


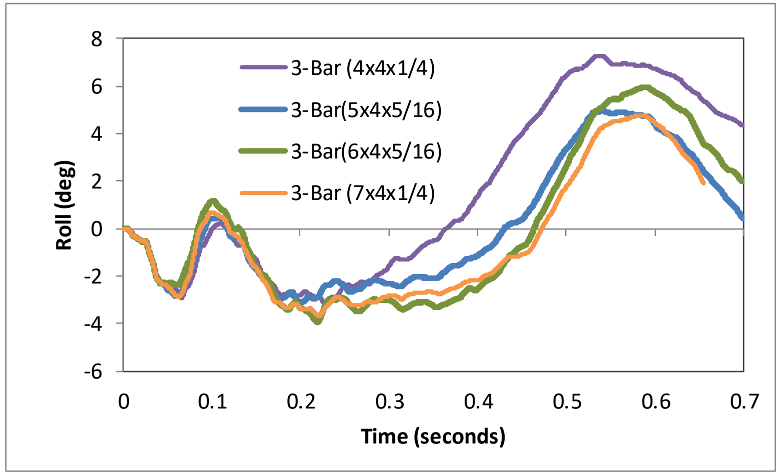


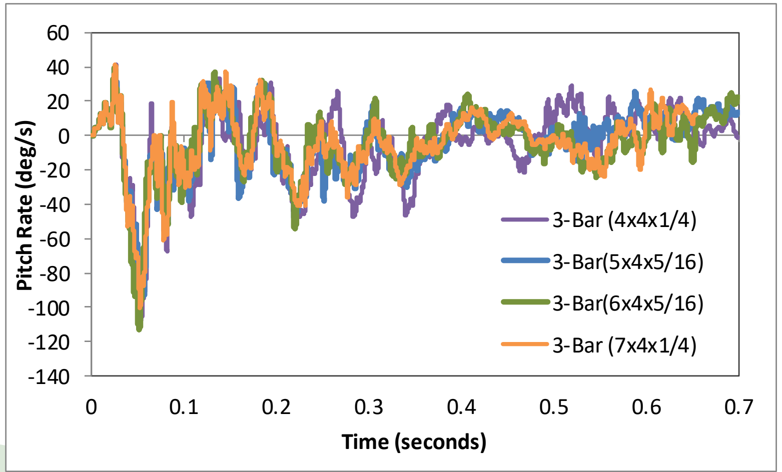
Angular Rate and Displacement Plots

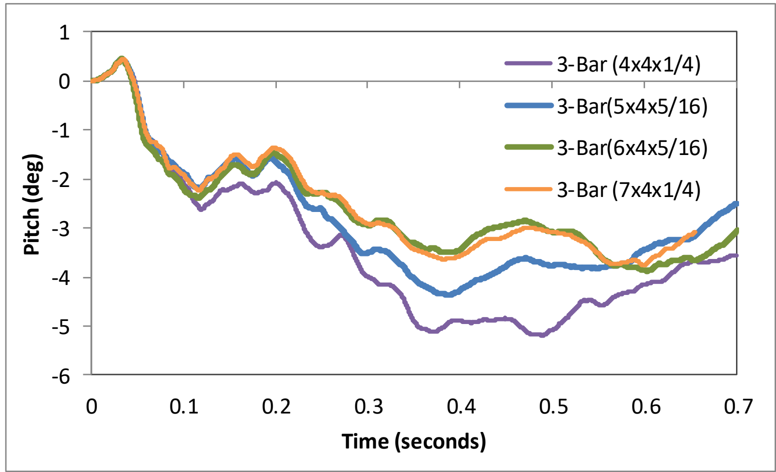






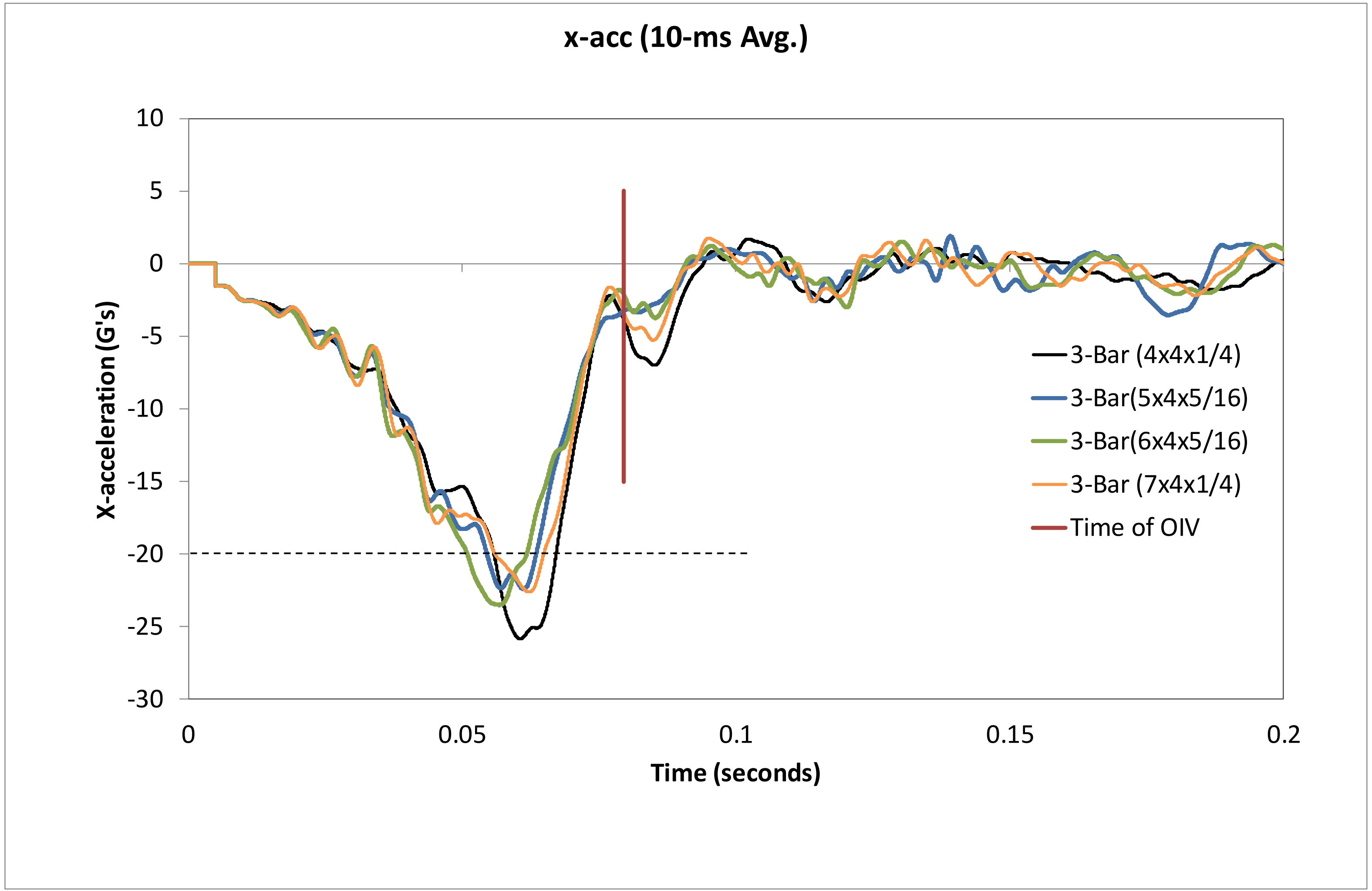






X-acceleration

	Peak Accelerations	
Design	X-acc (G)	Y-acc (G)
3-Bar (4x4x1/4)	25.87	28.86
3-Bar(5x4x5/16)	22.42	26.18
3-Bar(6x4x5/16)	23.51	28.83
3-Bar (7x4x1/4)	22.62	27.46



X-acceleration

	Peak Accelerations	
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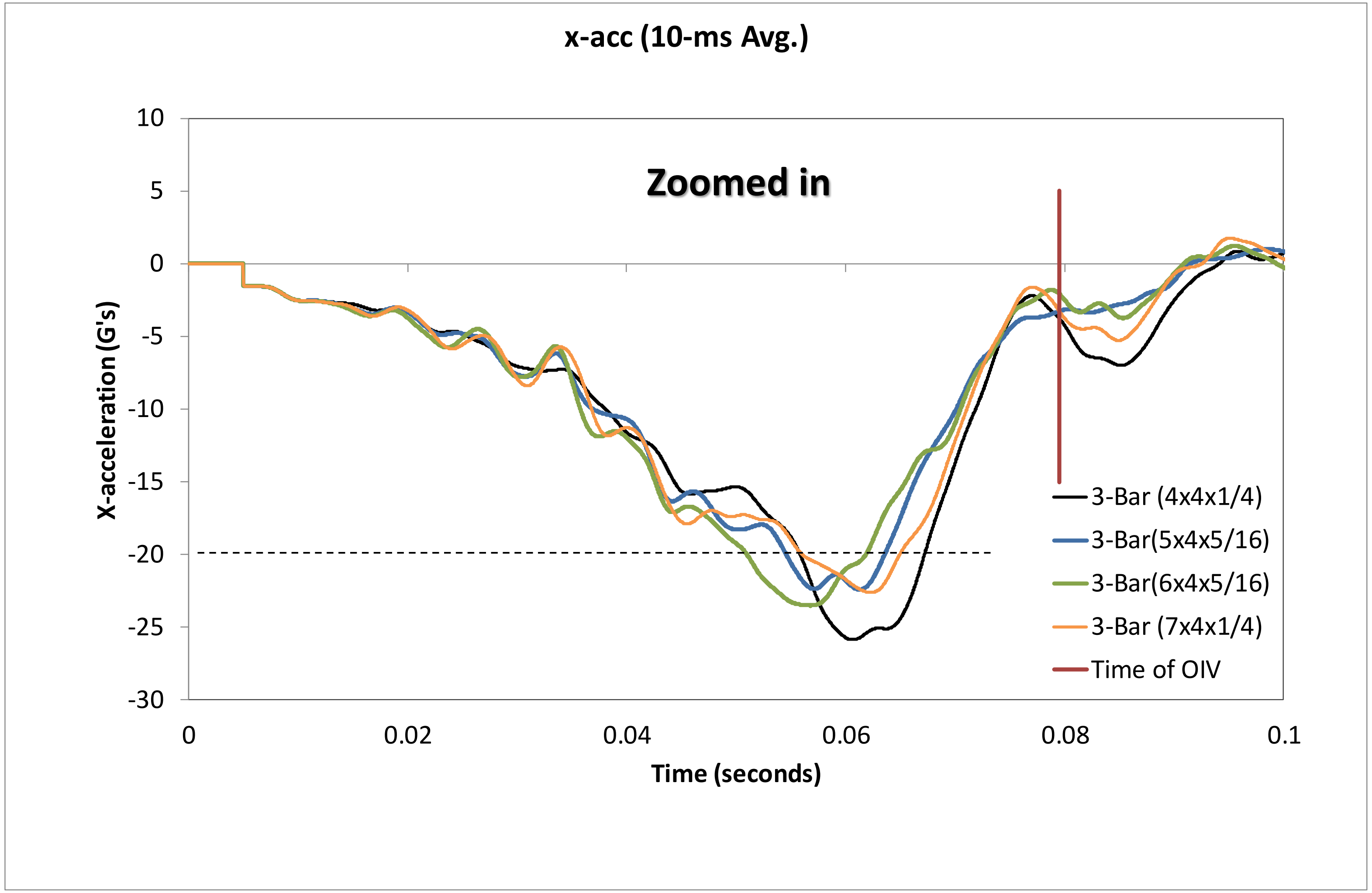

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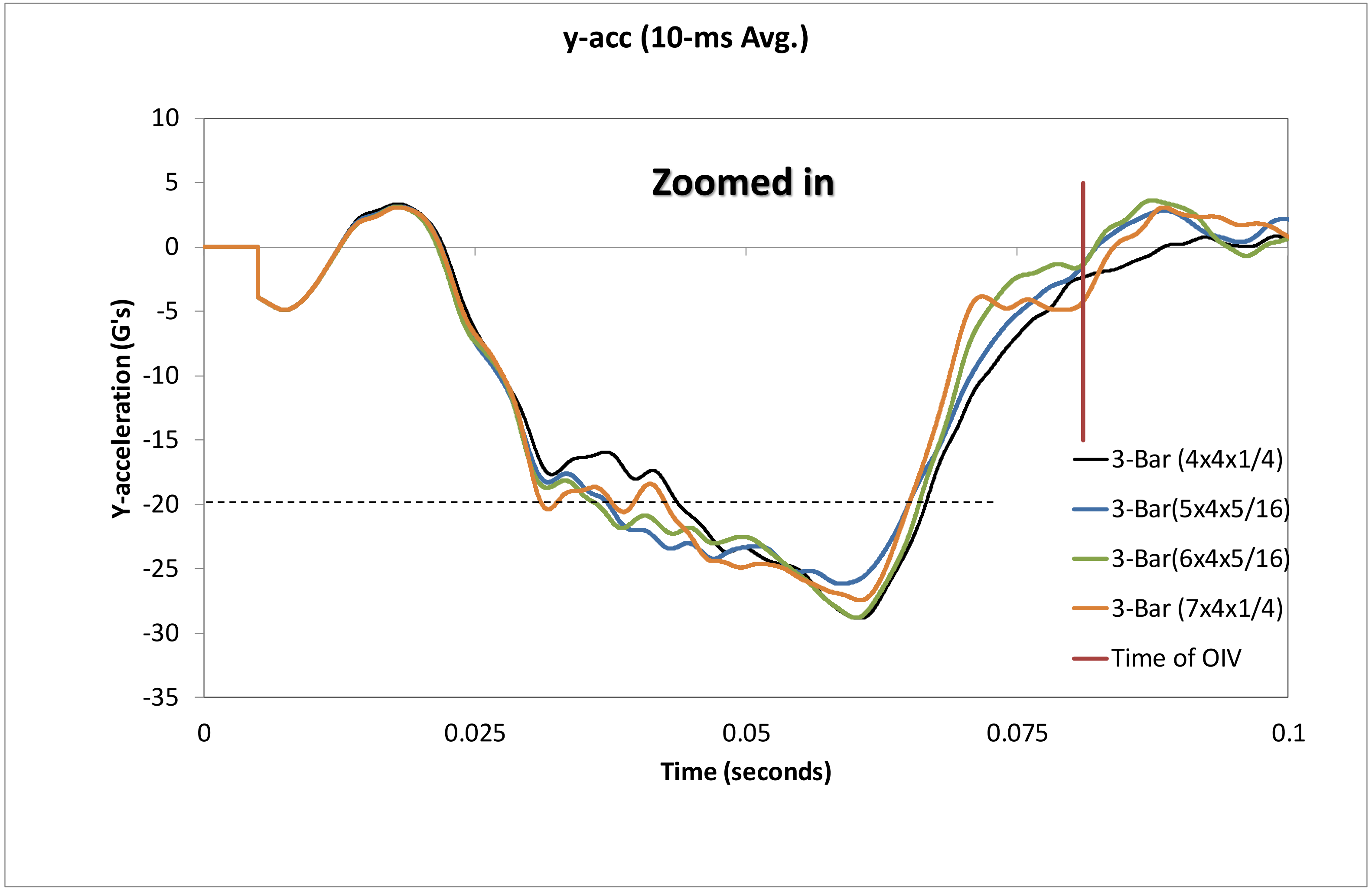
Y-acceleration

	Peak Accelerations	
Design	X-acc (G)	Y-acc (G)
3-Bar (4x4x1/4)	25.87	28.86
3-Bar(5x4x5/16)	22.42	26.18
3-Bar(6x4x5/16)	23.51	28.83
3-Bar (7x4x1/4)	22.62	27.46



Occupant Risk – Summary Table

Occupant Risk Factors		MASH T4-10			
		3-Bar (4x4x1/4)	3-Bar(5x4x5/16)	3-Bar(6x4x5/16)	3-Bar (7x4x1/4)
Occupant Impact Velocity (ft/s)	x-direction	25.6	24.3	24.9	24.6
	y-direction	32.5	32.5	32.5	32.2
	at time	at 0.0792 seconds on right side of interior	at 0.0775 seconds on right side of interior	at 0.0772 seconds on right side of interior	at 0.0777 seconds on right side of interior
THIV (ft/s)		41.3 at 0.0792 seconds on right side of interior	40.4 at 0.0775 seconds on right side of interior	40.7 at 0.0772 seconds on right side of interior	40.4 at 0.0777 seconds on right side of interior
Ridedown Acceleration (g's)	x-direction	-6.7 (0.0811 - 0.0911 seconds)	-3.5 (0.1740 - 0.1840 seconds)	-3.7 (0.0803 - 0.0903 seconds)	-5.3 (0.0799 - 0.0899 seconds)
	y-direction	-6 (0.2306 - 0.2406 seconds)	-7.7 (0.1997 - 0.2097 seconds)	-10.4 (0.1994 - 0.2094 seconds)	-9.7 (0.2030 - 0.2130 seconds)
PHD (g's)		7.1 (0.0800 - 0.0900 seconds)	7.8 (0.2007 - 0.2107 seconds)	10.4 (0.1995 - 0.2095 seconds)	9.7 (0.2030 - 0.2130 seconds)
ASI		2.49 (0.0253 - 0.0753 seconds)	2.47 (0.0255 - 0.0755 seconds)	2.49 (0.0240 - 0.0740 seconds)	2.42 (0.0234 - 0.0734 seconds)
Max 50-ms moving avg. acc. (g's)	x-direction	-14.8 (0.0241 - 0.0741 seconds)	-13.7 (0.0251 - 0.0751 seconds)	-14.3 (0.0238 - 0.0738 seconds)	-14.3 (0.0232 - 0.0732 seconds)
	y-direction	-19.6 (0.0262 - 0.0762 seconds)	-19.7 (0.0256 - 0.0756 seconds)	-19.7 (0.0241 - 0.0741 seconds)	-18.9 (0.0234 - 0.0734 seconds)
	z-direction	-3.1 (0.0602 - 0.1102 seconds)	-3.1 (0.0597 - 0.1097 seconds)	-3.3 (0.0589 - 0.1089 seconds)	-3.4 (0.0605 - 0.1105 seconds)
Maximum Angular Disp. (deg)	Roll	7.3 (0.5359 seconds)	4.9 (0.5399 seconds)	6 (0.5894 seconds)	4.8 (0.5812 seconds)
	Pitch	-5.2 (0.4892 seconds)	-4.4 (0.3878 seconds)	-3.9 (0.6024 seconds)	-3.8 (0.5986 seconds)
	Yaw	-40.3 (0.4954 seconds)	-38.4 (0.4838 seconds)	-38.8 (0.4982 seconds)	-37.7 (0.4714 seconds)

MASH Criteria

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

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

< 75 deg

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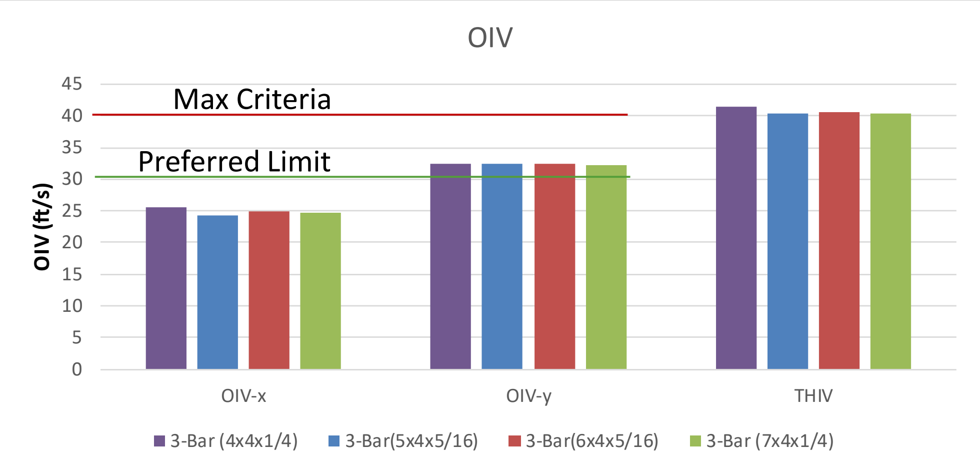
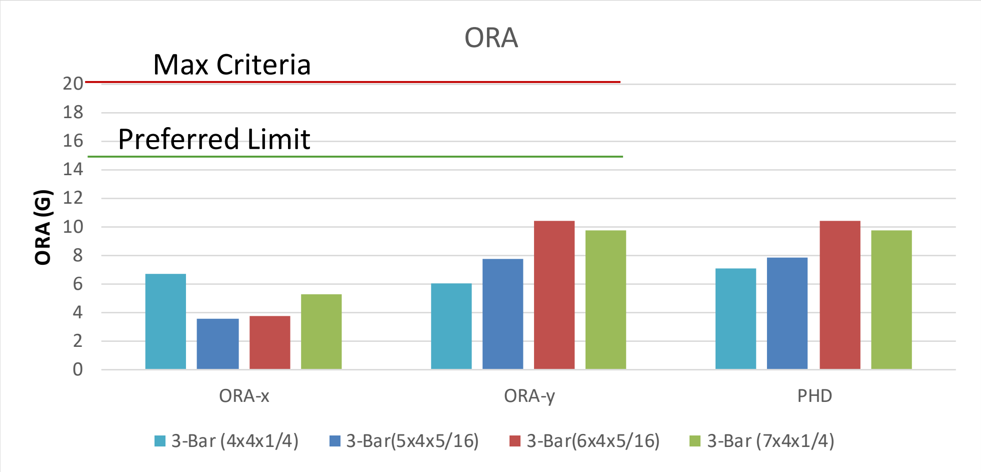
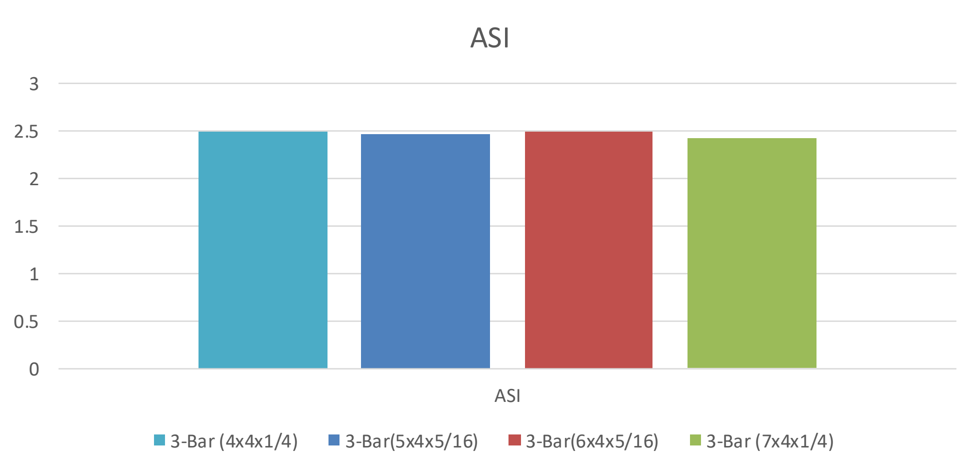
TRAP



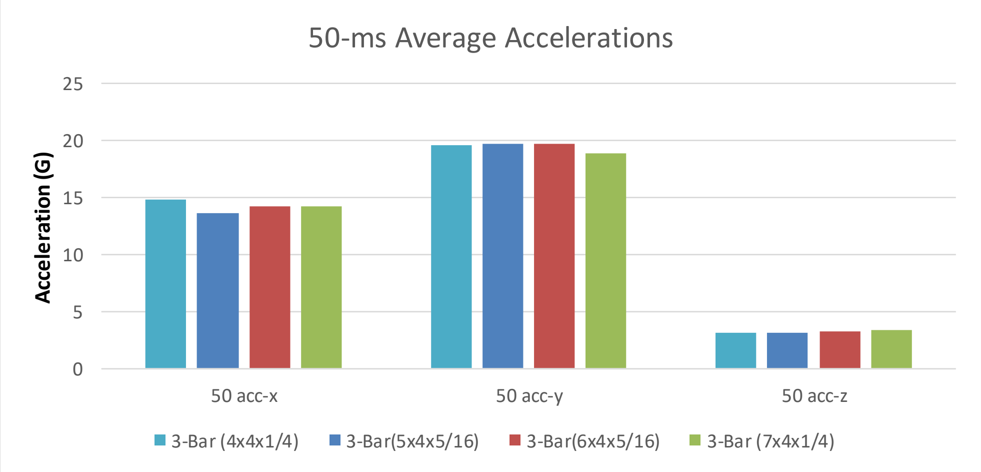
OIV
OIV (ft/s)
45
40
35
30
25
20
15
10
5
0
Max Criteria
Preferred Limit
OIV-x
OIV-y
THIV
3-Bar (4x4x1/4)
3-Bar(5x4x5/16)
3-Bar(6x4x5/16)
3-Bar (7x4x1/4)



ORA
ORA (G)
20
18
16
14
12
10
8
6
4
2
0
Max Criteria
Preferred Limit
ORA-x
ORA-y
PHD
3-Bar (4x4x1/4)
3-Bar(5x4x5/16)
3-Bar(6x4x5/16)
3-Bar (7x4x1/4)

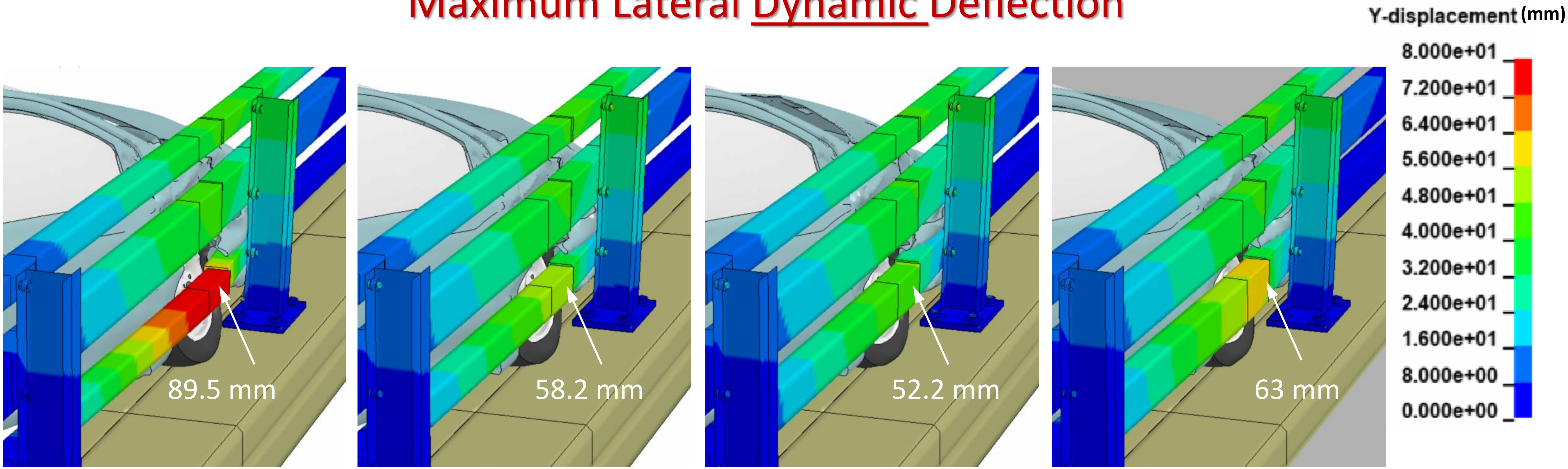


ASI
3
2.5
2
1.5
1
0.5
0
ASI
3-Bar (4x4x1/4)
3-Bar(5x4x5/16)
3-Bar(6x4x5/16)
3-Bar (7x4x1/4)



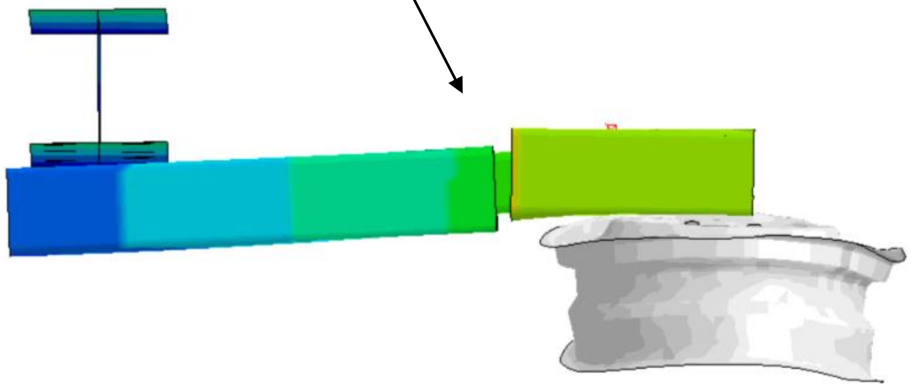
50-ms Average Accelerations
Acceleration (G)
25
20
15
10
5
0
50 acc-x
50 acc-y
50 acc-z
3-Bar (4x4x1/4)
3-Bar(5x4x5/16)
3-Bar(6x4x5/16)
3-Bar (7x4x1/4)

Maximum Lateral Dynamic Deflection



4 x 4 x 5/16 (Baseline) | 5 x 4 x 5/16 | 6 x 4 x 5/16 | 7 x 4 x 1/4

The deflection for the 7x4 case was expected to be less than the 5x4 case based on stiffness (e.g., Z_p = 7.78 vs. 7.05, respectively). However, deflection in all cases could be reduced by reducing the gap-space in the splice.



Conclusions Regarding Test 4-10 on the Modified NETC 3-Bar with Larger Lower Rail

- The modified NETC 3-Bar system with larger lower rail showed improved performance for all cases evaluated.
- The deflection of the lower rail was reduced 30% - 42%.
- The peak longitudinal acceleration was reduced 9.3% - 13.5%.
- Wheel snag still occurred for all cases, which likely affected peak acceleration magnitudes.
- Much of the deflection could be mitigated by minimizing the internal gap-space in the splice (recall that tested design only had 1/8" total gap-space).
- The ORAx was least sensitive to time of occupant impact for the HSS 5x4x5/16 case (refer to Slide 17).
- It is recommended that the HSS 5x4x5/16 be used for the lower rail; however, the overall improvement may not be significant enough to warrant changing the design.

	Physical Properties					Results					
	Area		Zy		Splice Gap	Deflect	Peak Acc_x	OIV_X	OIV_y	ORA_x	ORA_y
Bar Size	(in^2)	% Change	(in^3)	% Change	(in)	(in)	(G)	(ft/s)	(ft/s)	(G)	(G)
HSS 4 x 4 x ¼	3.59	-	4.97	-	3/4	89.5	25.9	25.6	32.5	6.7	6
HSS 5 x 4 x 5/16	4.98	39%	7.05	42%	11/16	58.2	22.4	24.3	32.5	3.5	7.7
HSS 6 x 4 x 5/16	5.61	56%	8.21	65%	11/16	52.2	23.5	24.9	32.5	3.7	10.4
HSS 7 x 4 x ¼	5.09	42%	7.78	57%	3/4	63	22.6	24.6	32.2	5.3	9.7

MASH Results for Test 4-10
Modified NETC 3-Bar with Larger Lower Rail

Evaluation Factors		Evaluation Criteria	Results
Structural Adequacy	A	Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	Pass
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 undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, to occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E.	Pass
	F	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	Pass
	H	The longitudinal and lateral occupant impact velocity (OIV) shall not exceed 40 ft/s (12.2 m/s), with a preferred limit of 30 ft/s (9.1 m/s)	Pass
	I	The longitudinal and lateral occupant ridedown acceleration (ORA) shall not exceed 20.49 G, with a preferred limit of 15.0 G	Pass

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