Development of MASH Computer Simulated Steel Bridge Rail and Transition Details

Task 4: 3-Bar Transition MASH TL4

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

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Roadsafe LLC

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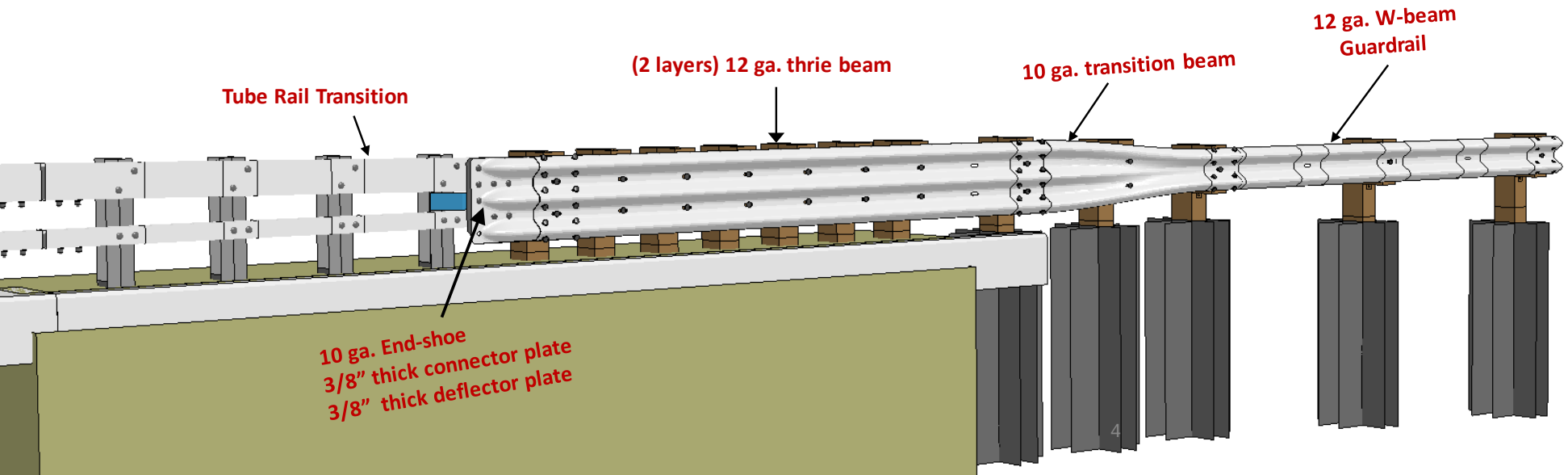
Task 4 – MASH TL-4 Evaluation of NETC 3-Bar Transition

- The finite element model of the NETC 2-Bar system was developed in Task 2b
- That model was used as a baseline for developing the NETC 3-Bar transition.

<u>Primary Model Modifications for Development of 3-Bar System:</u>

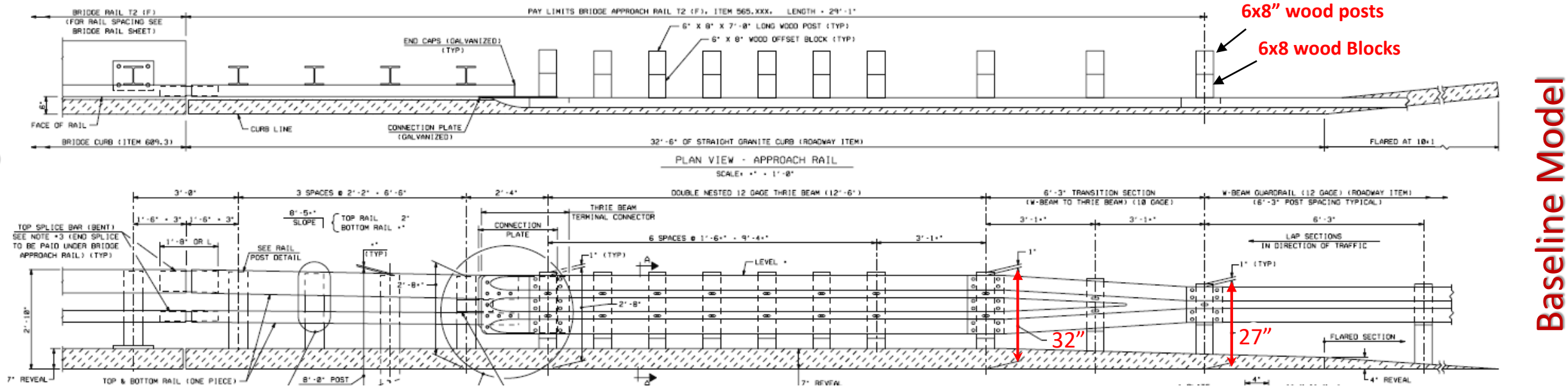
- Replacing 6x8” wood posts with W6x8.5 steel posts
- Increasing w-beam rail height from 27” to 31”
- Increasing Thrie-beam rail height from 32” to 34”
- Adding 3rd rail and repositioning mounting holes for post attachments
- Removing the deflector plate
- Extending the continuum soil model to include all posts in the thrie-beam region.
- Including NETC 3-Bar bridge rail model



Baseline Model (2-Bar System)

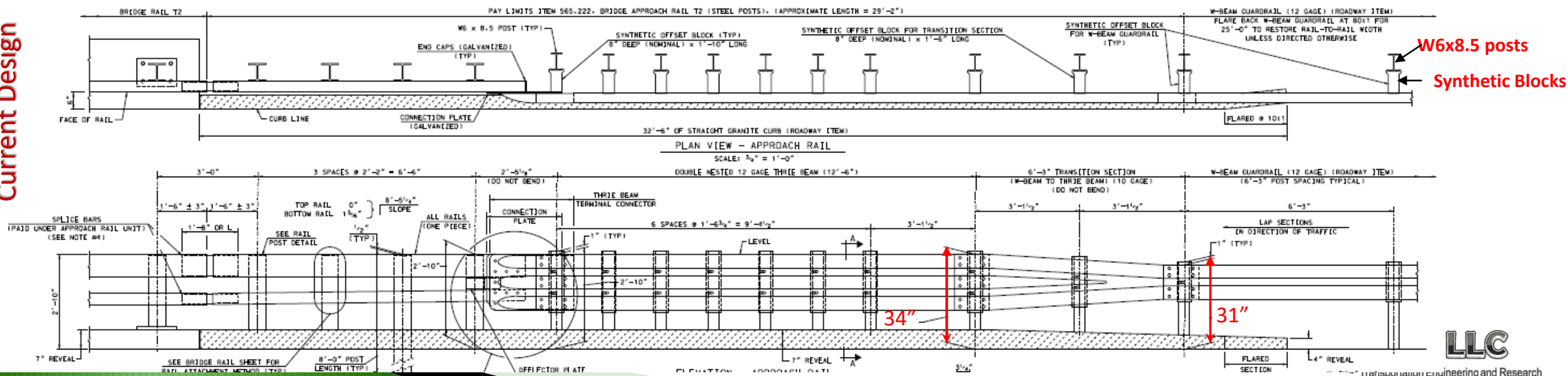
Comparison of Tested System vs. Current System

Tested Design



Baseline Model

Current Design



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NETC 3-Bar Transition Model

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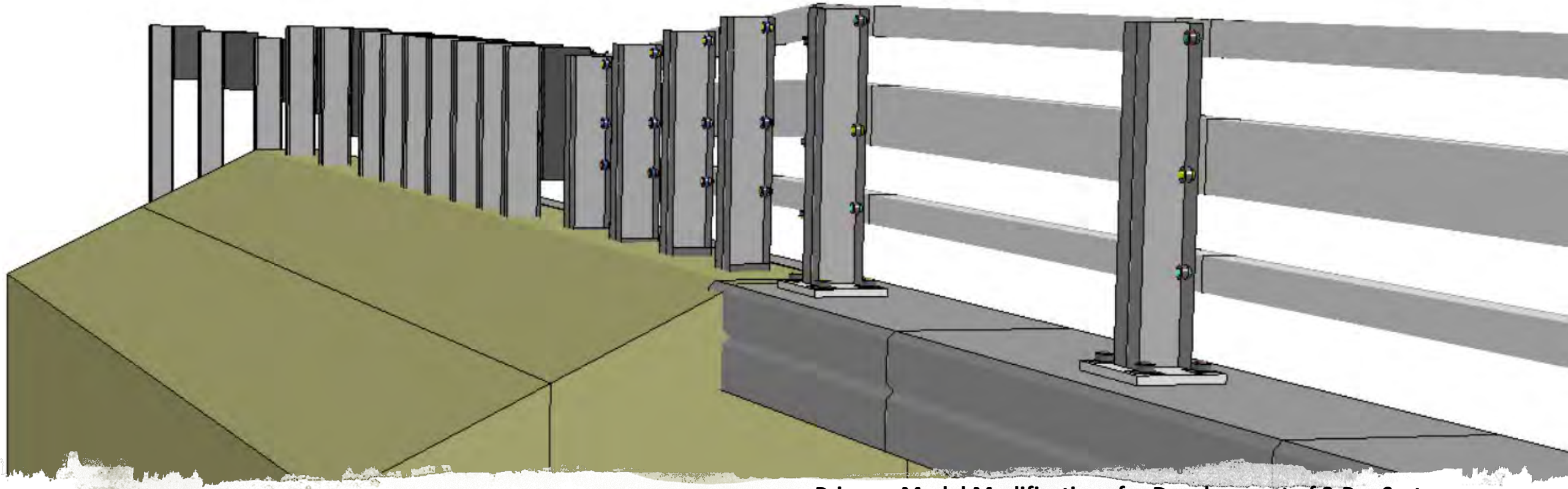

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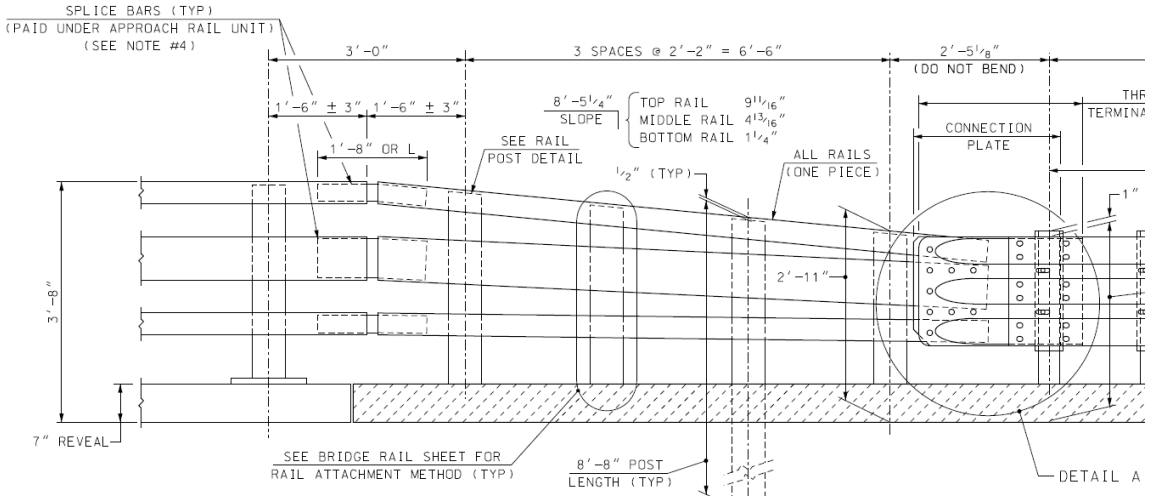
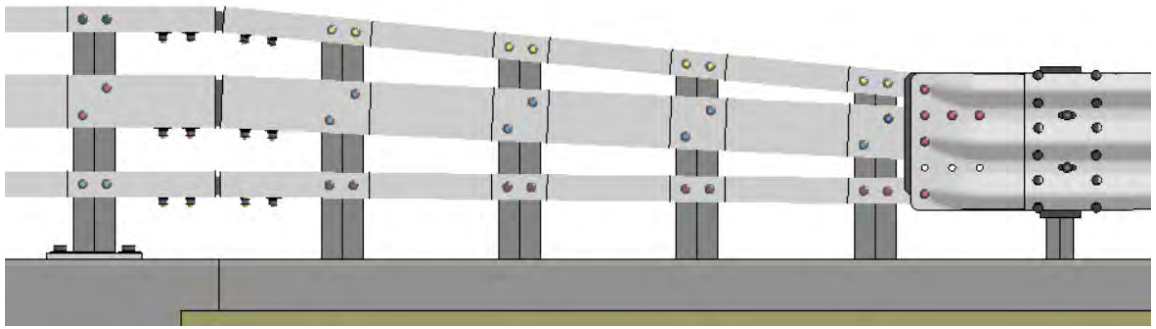
Tube Rail Transition

The tube-rail section of the transition was modeled based on the detailed drawing from NHDOT





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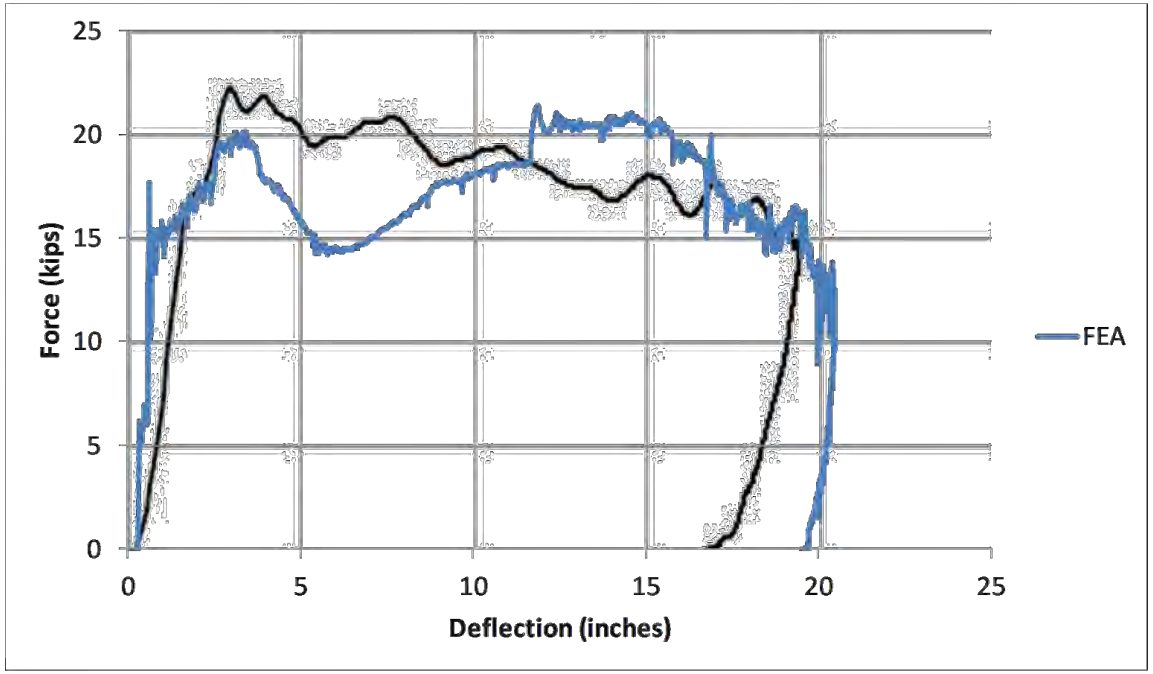
Additional Soil Validation

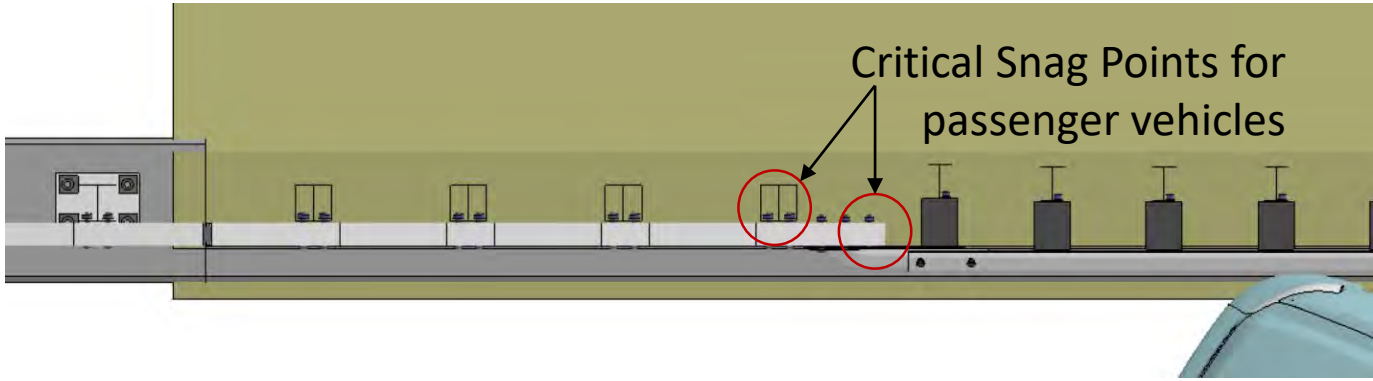
Test No.	Post Size	Post Material	Soil Density (as modeled) (pcf)	Embedment Depth (inches)	Impact Mass (lb)	Impact Speed (mph)
MGSATB-1	W6x15	AASHTO M180	126	54	1810	19.22
MGSATB-2	W6x15	AASHTO M180	126	54	1810	19.71
MGSATB-5	W6x15	AASHTO M180	126	54	1816	21.9
MGSATB-6	W6x15	AASHTO M180	126	54	1816	21.7

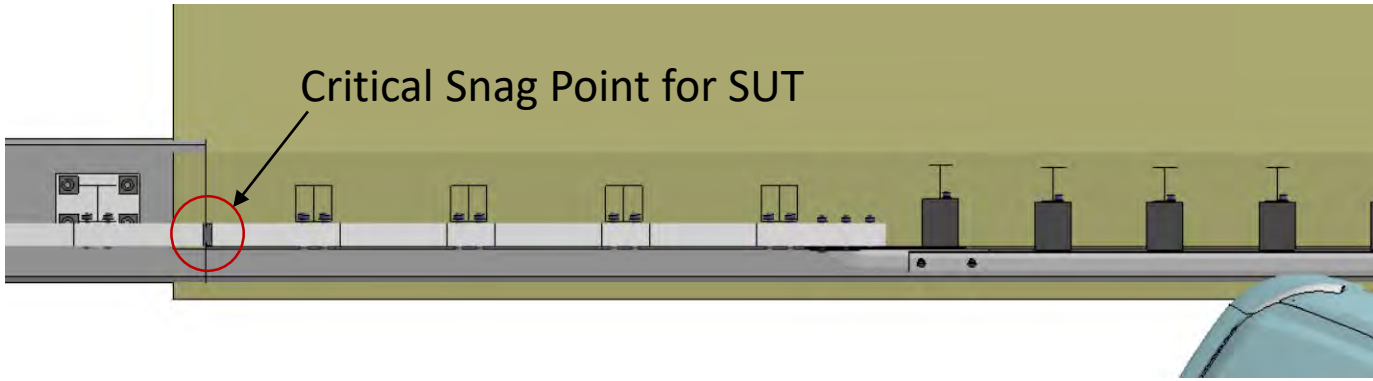


Same test series as shown on Slide 22 of Task Report Task2b_V1(190307).pptx but with steel posts

Determining Critical Impact Point

- Test 4-20 (small Car) and
- Test 4-21 (pickup):
  - Maximize potential for snag on end of transition tube railing
  - Maximize potential for snag on first post of tube rail transition
- Test 4-22 (SUT):
  - Maximize potential for snag on end of bridge rail
    - (i.e., TL4 end of the transition)





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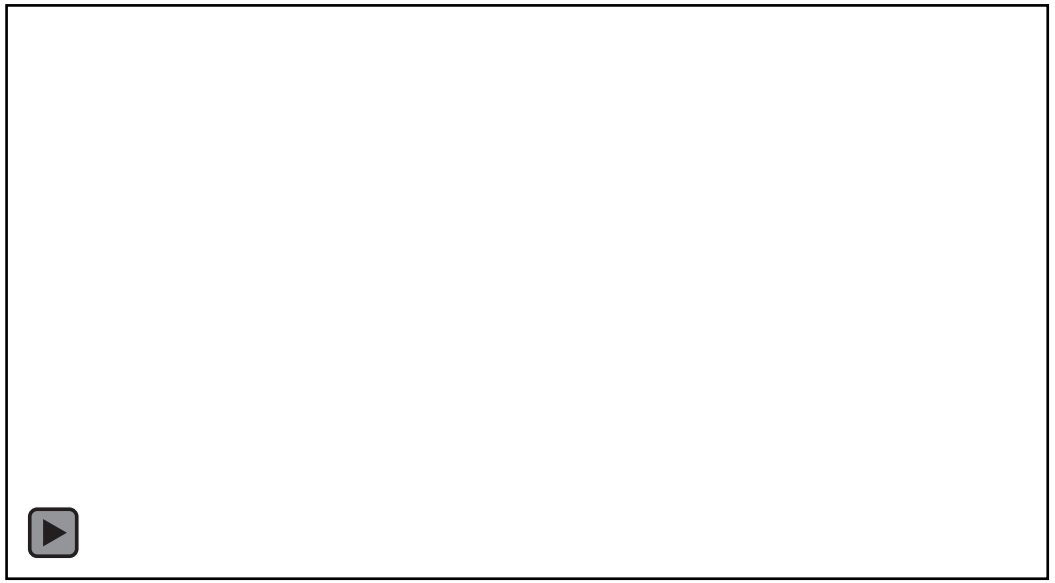
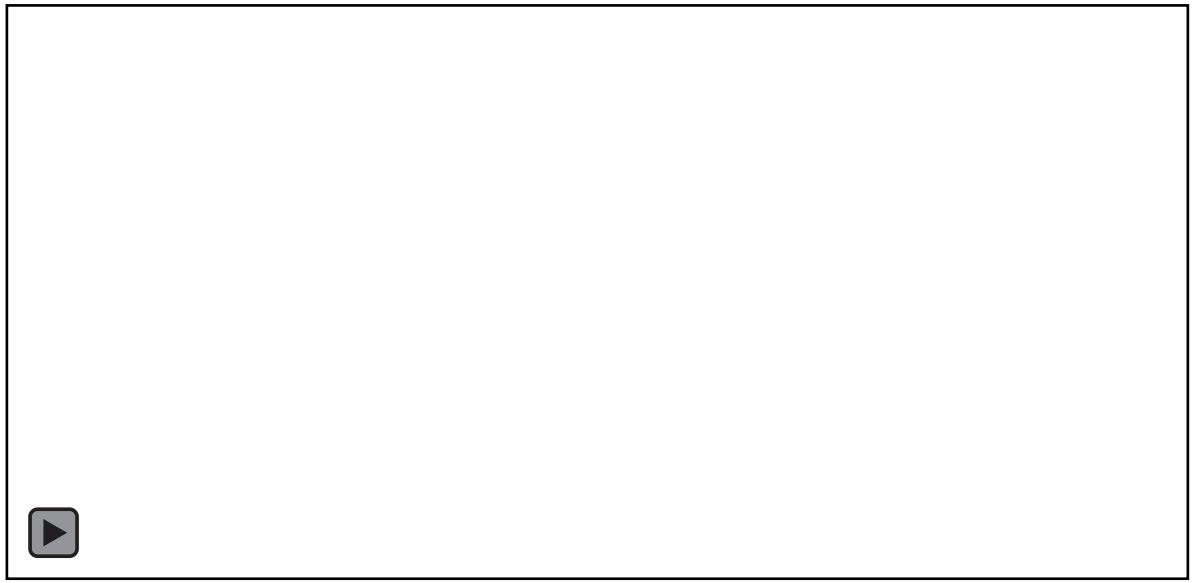
Determination of CIP for Test 4-21

- CIP was determined using FEA based with respect to maximizing potential for snag on the end of the tubular transition rails.
  - Pocketing
    - (i.e., relative deflection between tube rail and thrie-beam near the critical reference point)
  - Peak accelerations relative to critical snag point
    - Peak longitudinal acceleration (e.g., generally identifies snag)
    - Peak lateral acceleration (e.g., point of highest lateral force)
  - Impact severity at time of impact with critical snag point
  - Vehicle stability (e.g., roll, pitch)
- Vehicle stability was only partially evaluated.
  - Complete evaluation would require simulation of at least 1 second of the impact for each possible impact point (not feasible under current budget).
- Analysis Cases (10 cases):
  - Impact points 5.7 ft, 6.2 ft, 7.2 ft, 8.2 ft, 8.7 ft, 9.2 ft, 9.7 ft, 10.2 ft, 10.7 ft and 11.7 from the end of the tube rail.
  - These analyses were conducted for 0.15 seconds of impact for the purpose of determining the critical impact point for maximizing vehicle accelerations and maximizing forces on the barrier at the junction point of the thrie-beam and the tubular rail section.

IP 5.7 ft

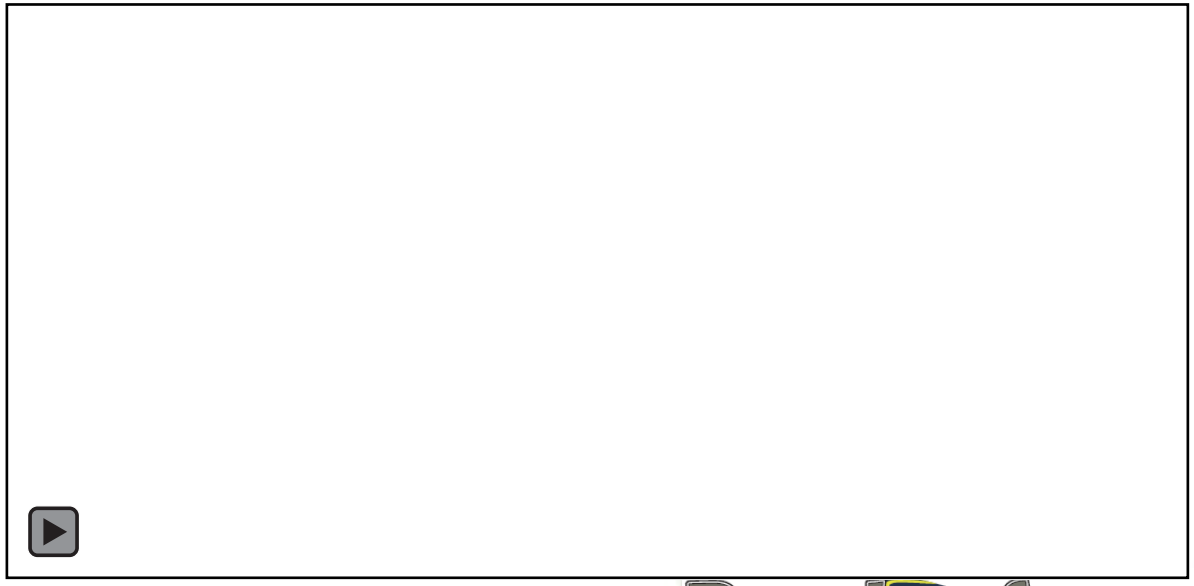


IP 6.2 ft



IP 7.2 ft

IP 8.2 ft



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IP 9.2 ft

IP 9.7 ft

IP 10.2 ft

IP 10.7 ft

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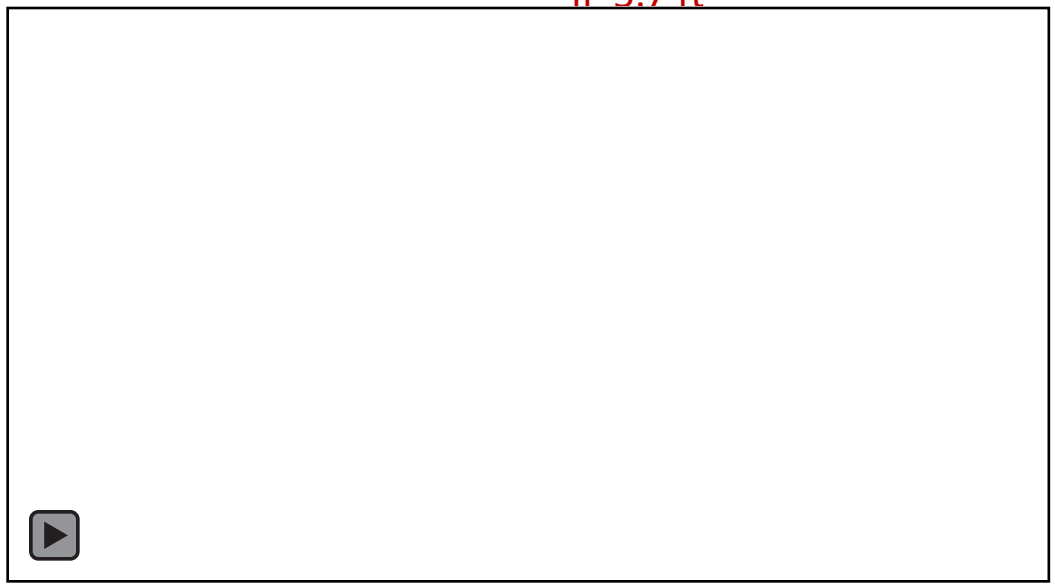
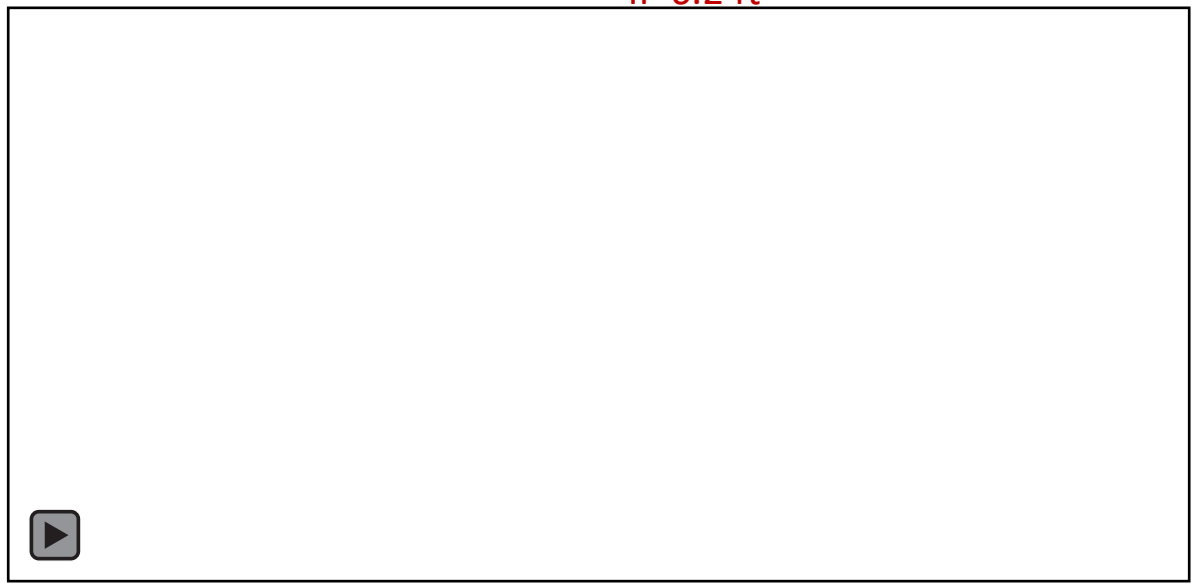
IP 5.7 ft



IP 6.2 ft



IP 7.2 ft

IP 8.2 ft

IP 9.2 ft

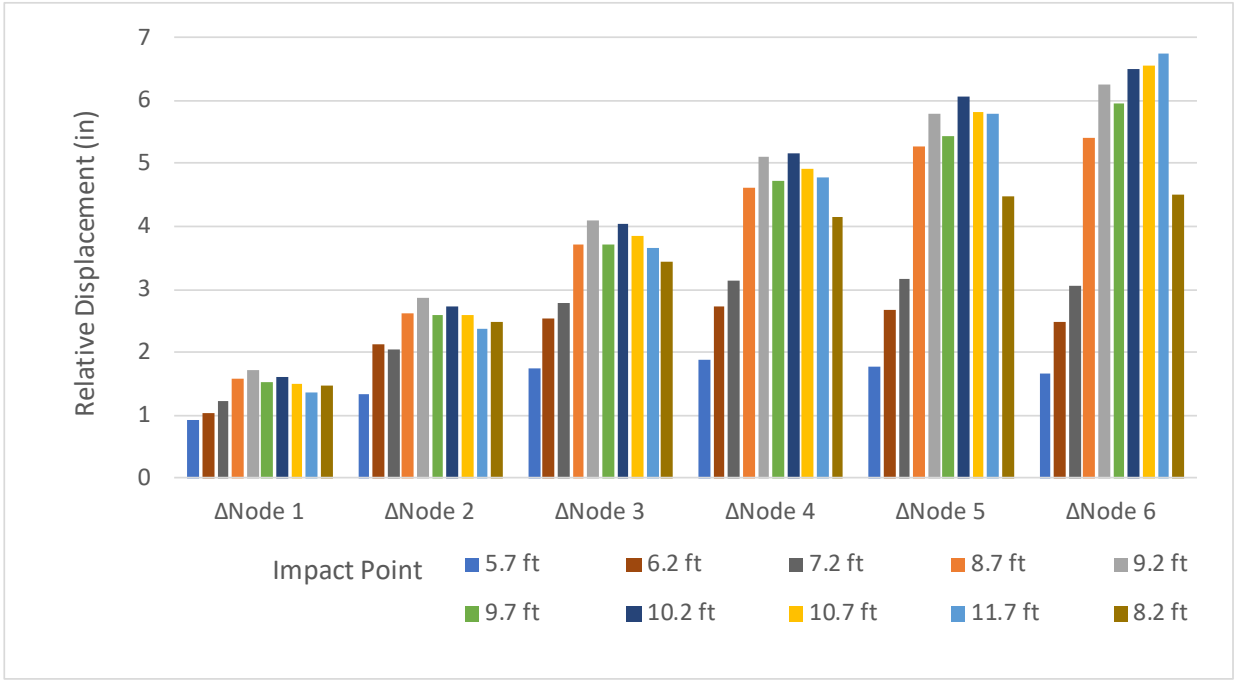
IP 9.7 ft

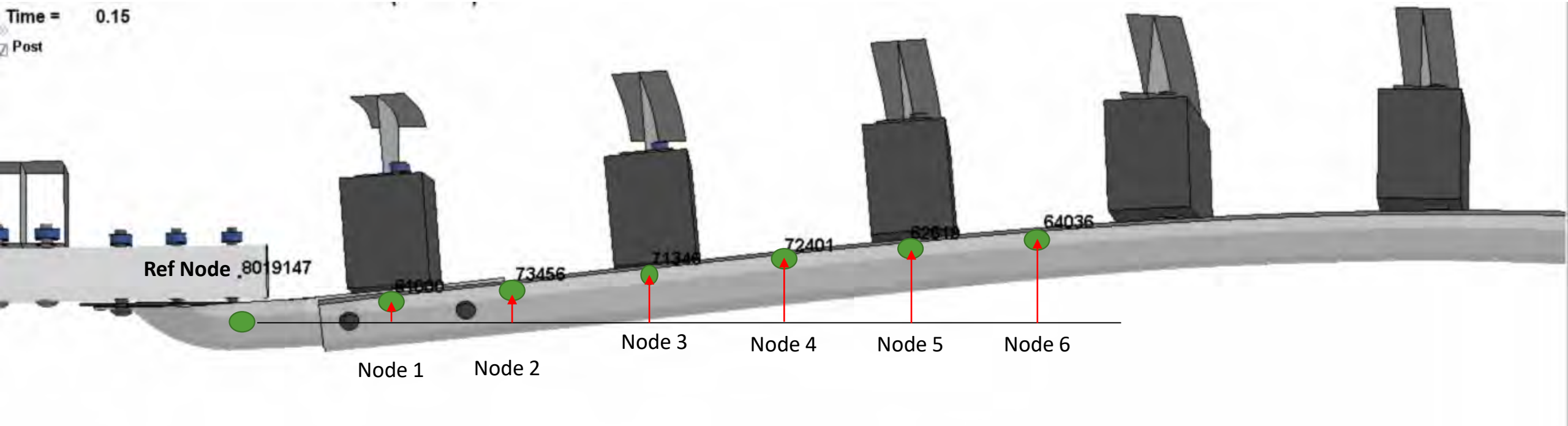
IP 10.2 ft

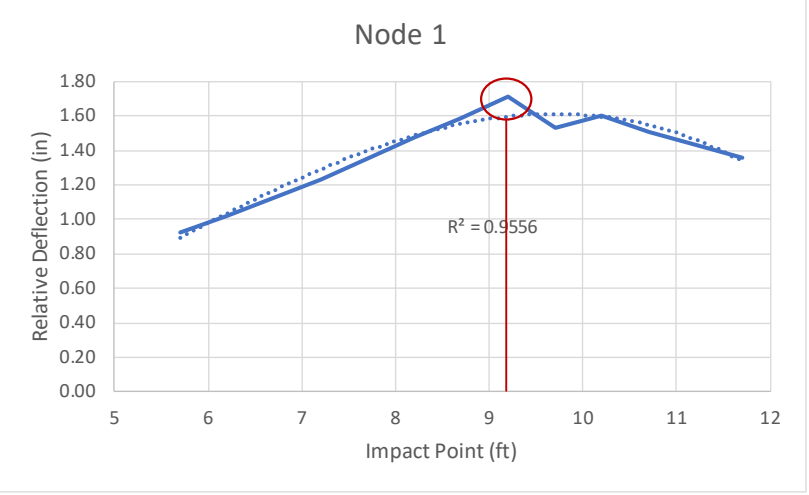
IP 10.7 ft

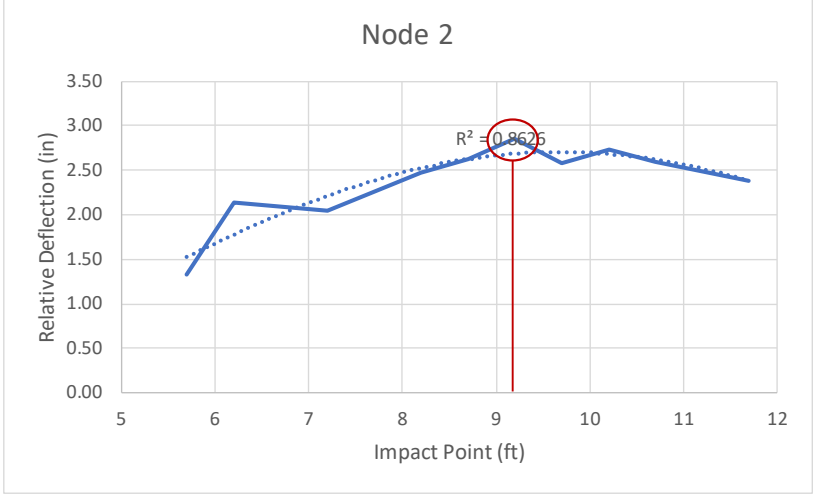
Pocketing

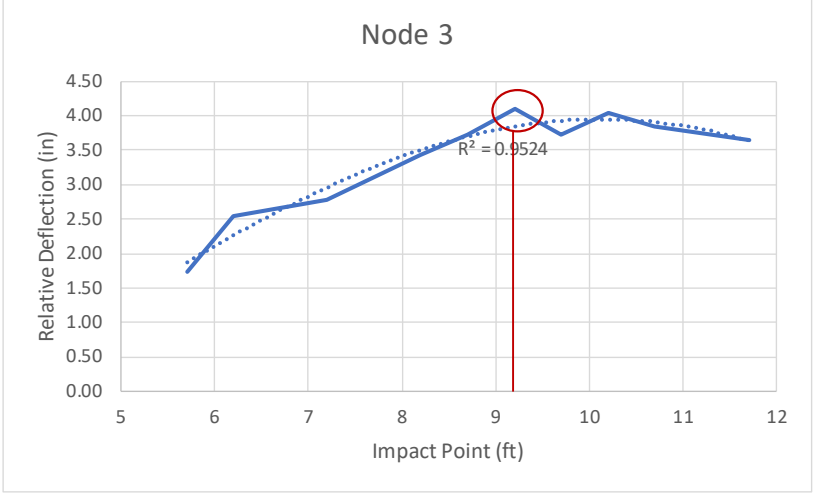
IP (ft)	Max Pocket ΔNode 1 (in)	ΔNode 2 (in)	ΔNode 3 (in)	ΔNode 4 (in)	ΔNode 5 (in)	ΔNode 6 (in)
5.7 ft	0.92	1.33	1.73	1.89	1.76	1.67
6.2 ft	1.02	2.13	2.54	2.74	2.68	2.49
7.2 ft	1.23	2.04	2.79	3.13	3.16	3.07
8.2 ft	1.47	2.47	3.44	4.16	4.49	4.51
8.7 ft	1.59	2.62	3.72	4.61	5.27	5.40
9.2 ft	1.71	2.86	4.09	5.12	5.80	6.26
9.7 ft	1.53	2.58	3.72	4.72	5.42	5.94
10.2 ft	1.60	2.74	4.04	5.16	6.05	6.49
10.7 ft	1.51	2.60	3.84	4.93	5.83	6.54
11.7 ft	1.36	2.38	3.65	4.78	5.78	6.75

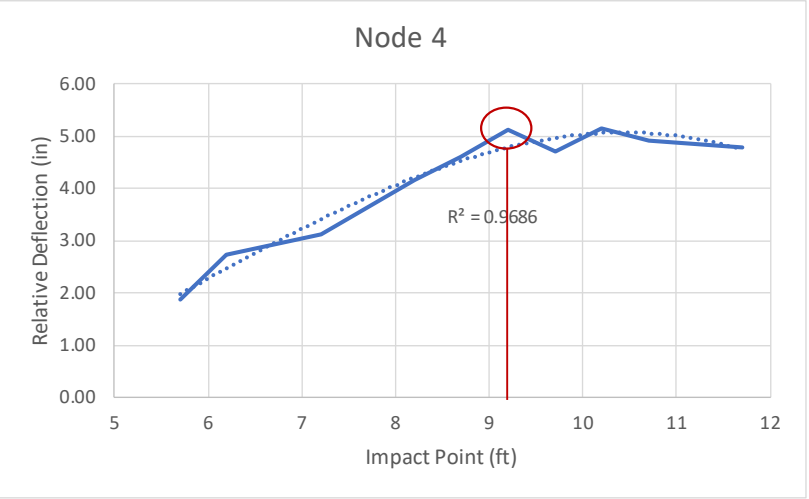


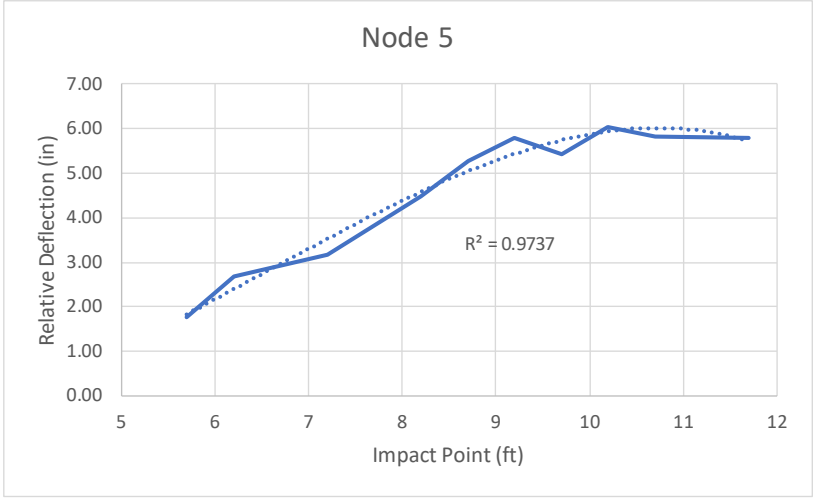


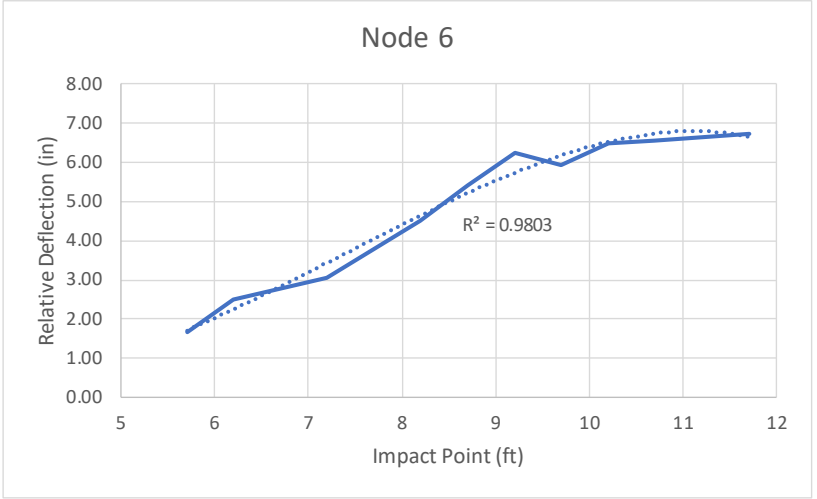

Node 1
Relative Deflection (in)
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
5
6
7
8
9
10
11
12
Impact Point (ft)
R² = 0.9556

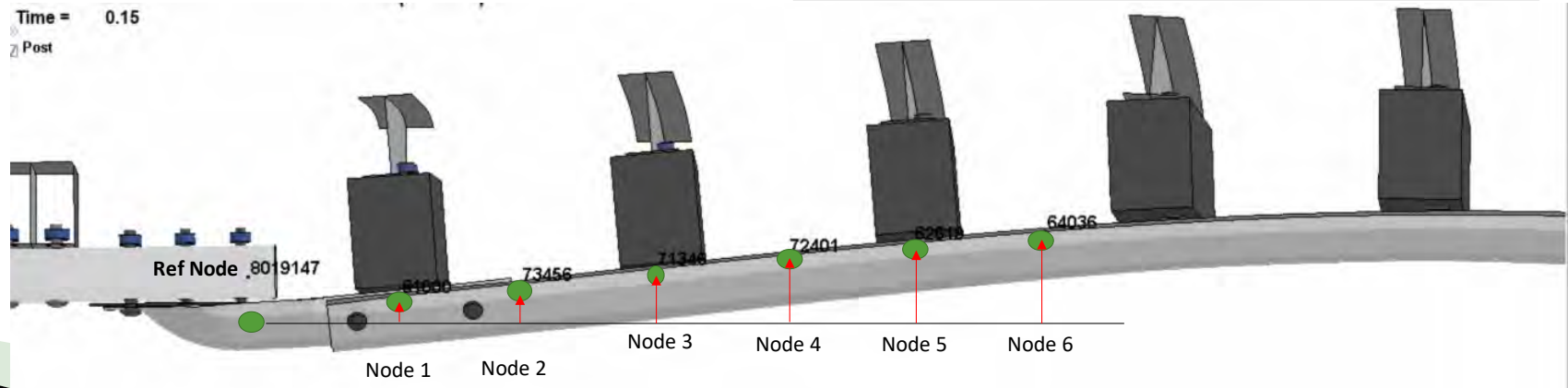

Node 2
Relative Deflection (in)
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
5
6
7
8
9
10
11
12
Impact Point (ft)
R² = 0.9625


Node 3
Relative Deflection (in)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
5
6
7
8
9
10
11
12
Impact Point (ft)
R² = 0.9524

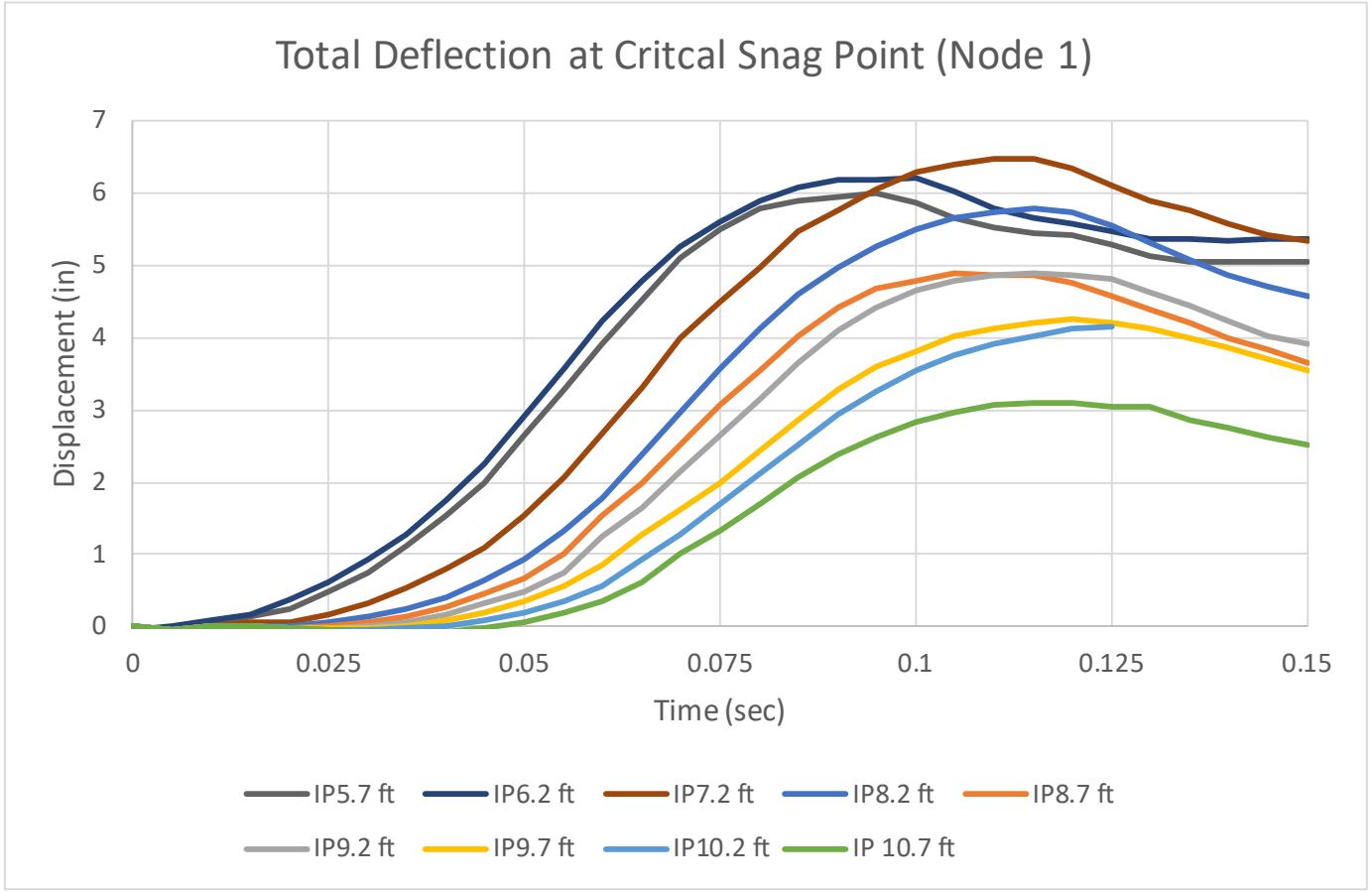

Node 4
Relative Deflection (in)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
5
6
7
8
9
10
11
12
Impact Point (ft)
R² = 0.9686


Node 5
Relative Deflection (in)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
5
6
7
8
9
10
11
12
Impact Point (ft)
R² = 0.9737


Node 6
Relative Deflection (in)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
5
6
7
8
9
10
11
12
Impact Point (ft)
R² = 0.9803


Time = 0.15
Post
Ref Node 8019147
64036
Node 1
Node 2
Node 3
Node 4
Node 5
Node 6

Rail Deflection at Critical Snag Point (node 1)



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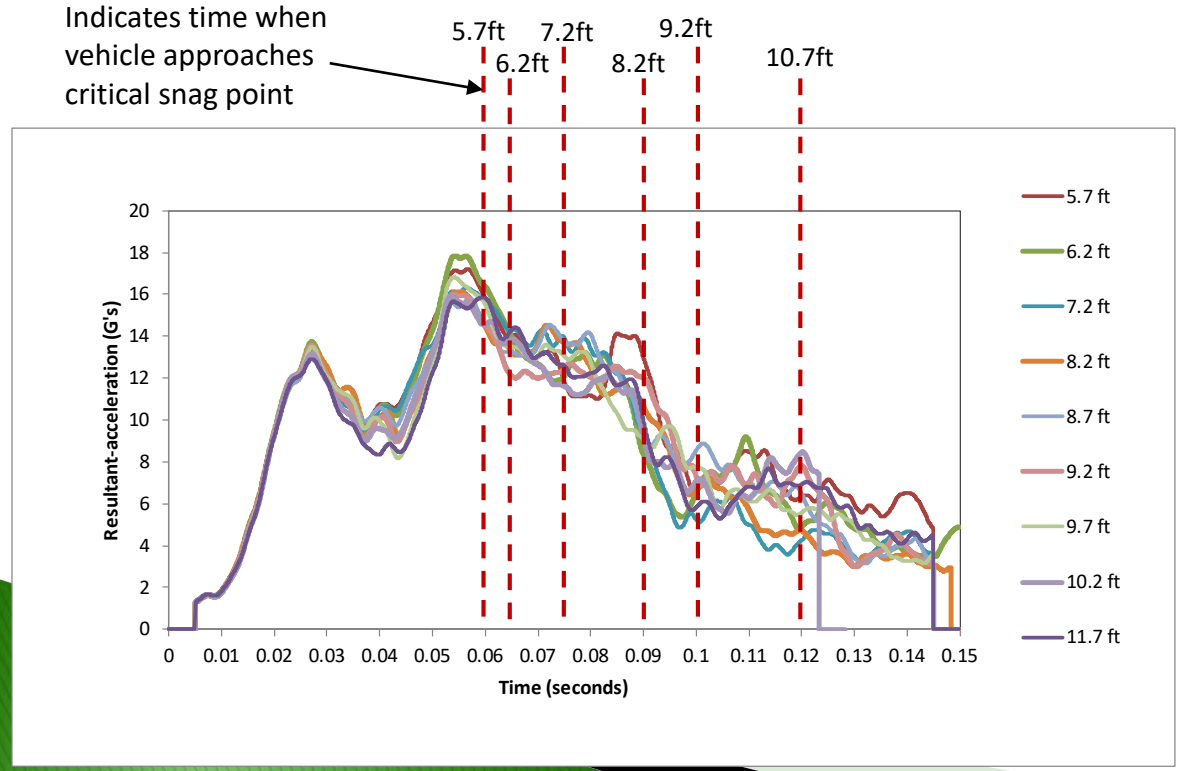
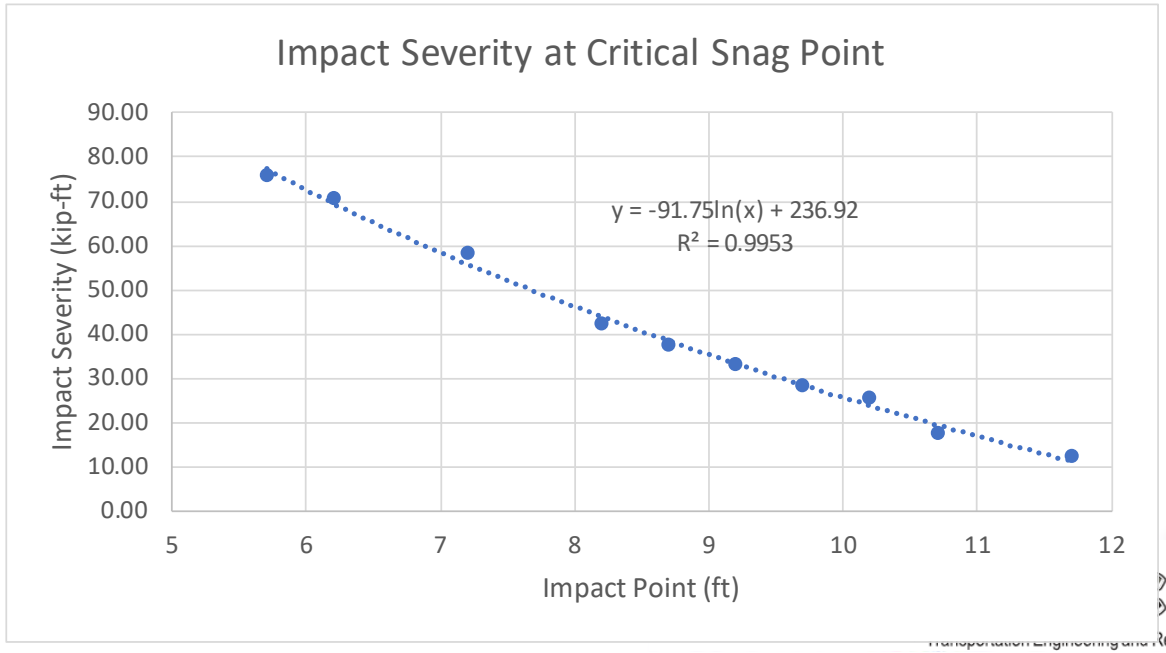
Vehicle Accelerations and Impact Severity at Time of Critical Snag Point

	Impact Severity at Critical Snag Point						
IP	≈Time	Mass	Speed		Angle	IS	
(ft)	(sec)	(kg)	(km/hr)	(m/s)	(deg)	KN-m	Kip-ft
5.7 ft	0.06	2270	87.62	24.3390836	23.02	102.82	75.83
6.2 ft	0.065	2270	86.98	24.1613044	22.34	95.73	70.60
7.2 ft	0.075	2270	84.08	23.3557424	20.93	79.01	58.27
8.2 ft	0.09	2270	81.11	22.5307358	18.4	57.41	42.34
8.7 ft	0.095	2270	79.68	22.1335104	17.57	50.67	37.37
9.2 ft	0.1	2270	79.90	22.194622	16.45	44.83	33.07
9.7 ft	0.107	2270	78.85	21.902953	15.43	38.54	28.43
10.2 ft	0.11	2270	78.69	21.8585082	14.59	34.41	25.38
10.7 ft	0.12	2270	77.96	21.6557288	12.22	23.85	17.59
11.7 ft	0.135	2270	76.96	21.3779488	10.33	16.68	12.30





Weighting CIP Criteria

Equal Weight for Pocketing and IS

Impact Point	Pocketing			IS			Vehicle Forward Speed			Vehicle Transverse Speed			Composite	
	Actual	Weight	Normalized	Actual	Weight	Normalized	Actual	Weight	Normalized	Actual	Weight	Normalized	(a*b*c)	(a+b+c)
5.7	1.732	1	0.42	75.83	1	1.00	87.62	0	1.00	9.52	0	1.00		**1.42**
6.2	2.541	1	0.62	70.6	1	0.93	86.98	0	0.99	9.18	0	0.96		**1.55**
7.2	2.787	1	0.68	58.27	1	0.77	84.08	0	0.96	8.34	0	0.88		**1.45**
8.2	3.436	1	0.84	42.34	1	0.56	81.11	0	0.93	7.11	0	0.75		**1.40**
8.7	3.72	1	0.91	37.37	1	0.49	79.68	0	0.91	6.68	0	0.70		**1.40**
9.2	4.09	1	1.00	33.07	1	0.44	79.9	0	0.91	6.29	0	0.66		**1.44**
9.7	3.724	1	0.91	28.43	1	0.37	78.85	0	0.90	5.83	0	0.61		**1.29**
10.2	4.042	1	0.99	25.38	1	0.33	78.69	0	0.90	5.51	0	0.58		**1.32**
10.7	3.836	1	0.94	17.59	1	0.23	77.96	0	0.89	4.58	0	0.48		**1.17**
11.7	3.653	1	0.89	12.3	1	0.16	76.96	0	0.88	3.83	0	0.40		**1.06**

Higher Weight for Pocketing

Impact Point	Pocketing			IS			Vehicle Forward Speed			Vehicle Transverse Speed			Composite	
	Actual	Weight	Normalized	Actual	Weight	Normalized	Actual	Weight	Normalized	Actual	Weight	Normalized	(a*b*c)	(a+b+c)
5.7	1.732	2	0.42	75.83	1	1.00	87.62	0	1.00	9.52	0	1.00		**1.85**
6.2	2.541	2	0.62	70.6	1	0.93	86.98	0	0.99	9.18	0	0.96		**2.17**
7.2	2.787	2	0.68	58.27	1	0.77	84.08	0	0.96	8.34	0	0.88		**2.13**
8.2	3.436	2	0.84	42.34	1	0.56	81.11	0	0.93	7.11	0	0.75		**2.24**
8.7	3.72	2	0.91	37.37	1	0.49	79.68	0	0.91	6.68	0	0.70		**2.31**
9.2	4.09	2	1.00	33.07	1	0.44	79.9	0	0.91	6.29	0	0.66		**2.44**
9.7	3.724	2	0.91	28.43	1	0.37	78.85	0	0.90	5.83	0	0.61		**2.20**
10.2	4.042	2	0.99	25.38	1	0.33	78.69	0	0.90	5.51	0	0.58		**2.31**
10.7	3.836	2	0.94	17.59	1	0.23	77.96	0	0.89	4.58	0	0.48		**2.11**
11.7	3.653	2	0.89	12.3	1	0.16	76.96	0	0.88	3.83	0	0.40		**1.95**

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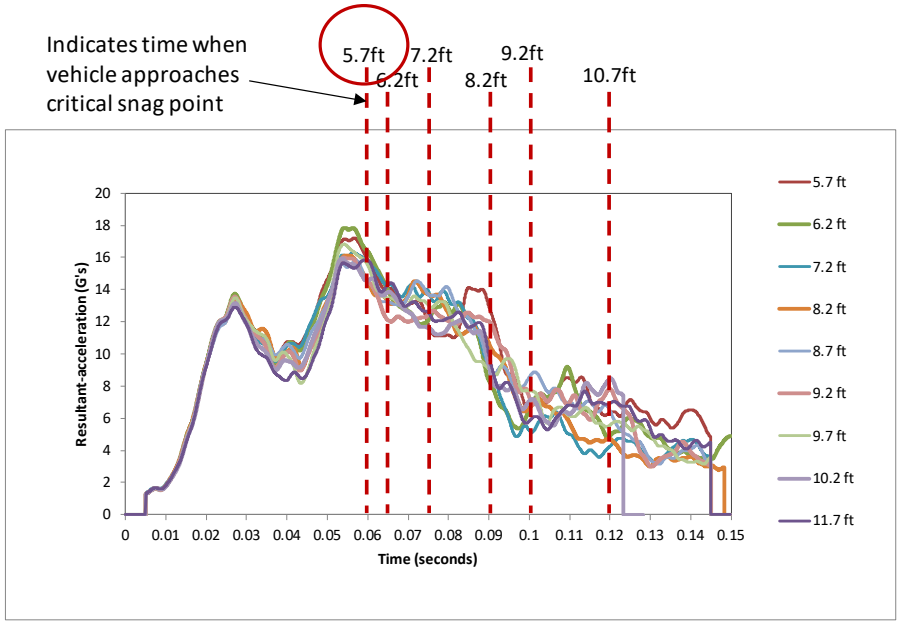
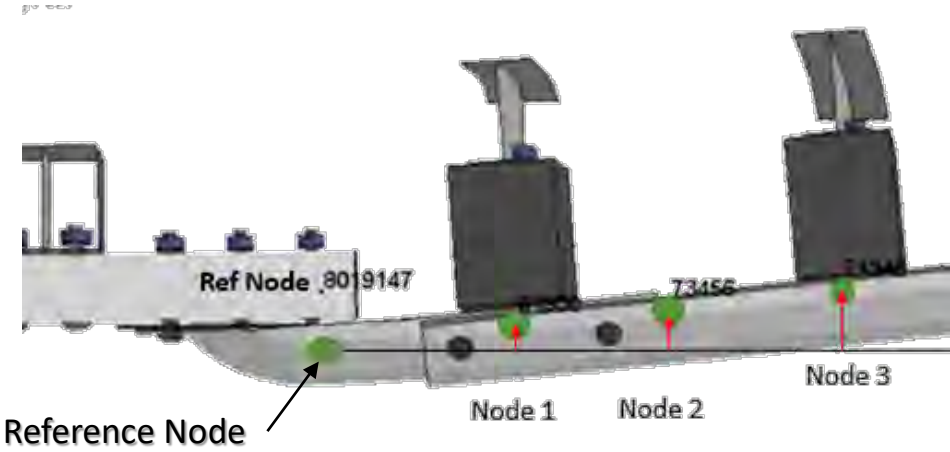
Summary for Test 4-21 CIP Evaluation

- Given the soil stiffness as modeled, the analysis results indicate:
  - A **very low potential for snags** on the end of the transition tube rails and
  - The **curb sufficiently shields the posts** from contact/snag from vehicle tires.
- Considering snag on the ends of the transition rail tubes:
  - **IP 7.2 ft** resulted in largest displacement of rail (at Node 1) approaching end of transition tube rails
  - **IP 6.2 ft** resulted in the highest accelerations and 2nd largest displacement of rail approaching end of rail tube
  - **IP 5.7 ft** resulted in the highest accelerations occurring at time of potential snag on end of transition rails.
- Considering pocketing
  - **IP 9.2 ft** resulted in the greatest relative deflection (at Nodes 1, 2, 3 and 4)





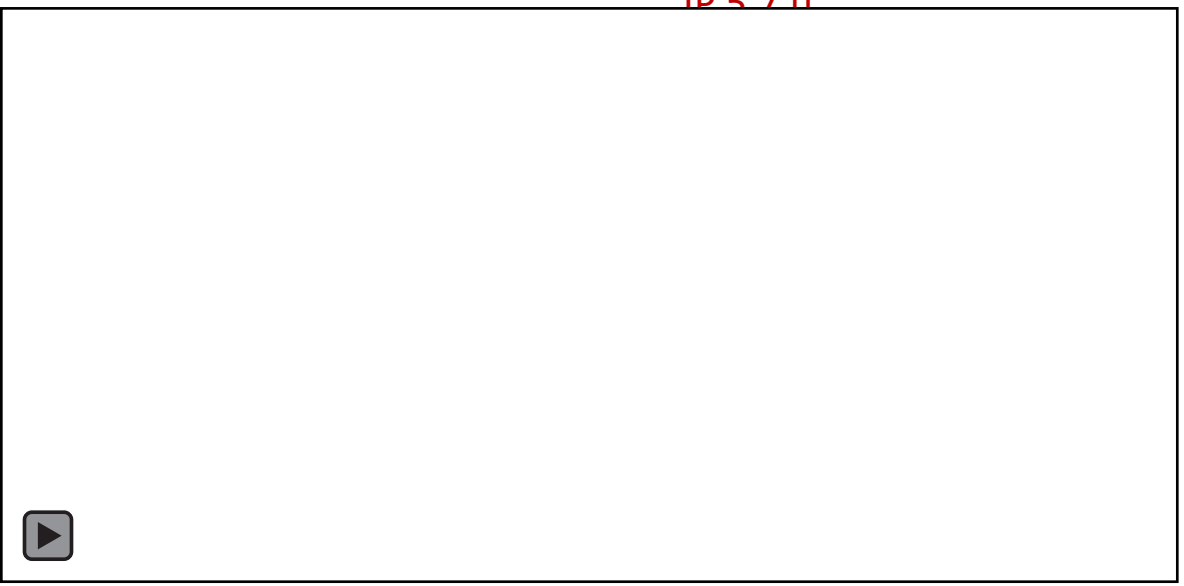
CIP used for Transitions in Previous Testing

NCHRP Report 350	[Alberson06] Test 401181-1: **5.1 ft** (1.55 m)
MASH Thrie-Beam to Rigid Concrete Abutment	[Rosenbaugh18] Test AGTB-1: **6.7 ft** (2.044m)
	[Plaxico18] MassDOT AGT: **5.5 ft** (1.68 m)
MASH Rigid Barrier	[MASH16] RIGID Barrier: **4.3 ft** (1.3 m)

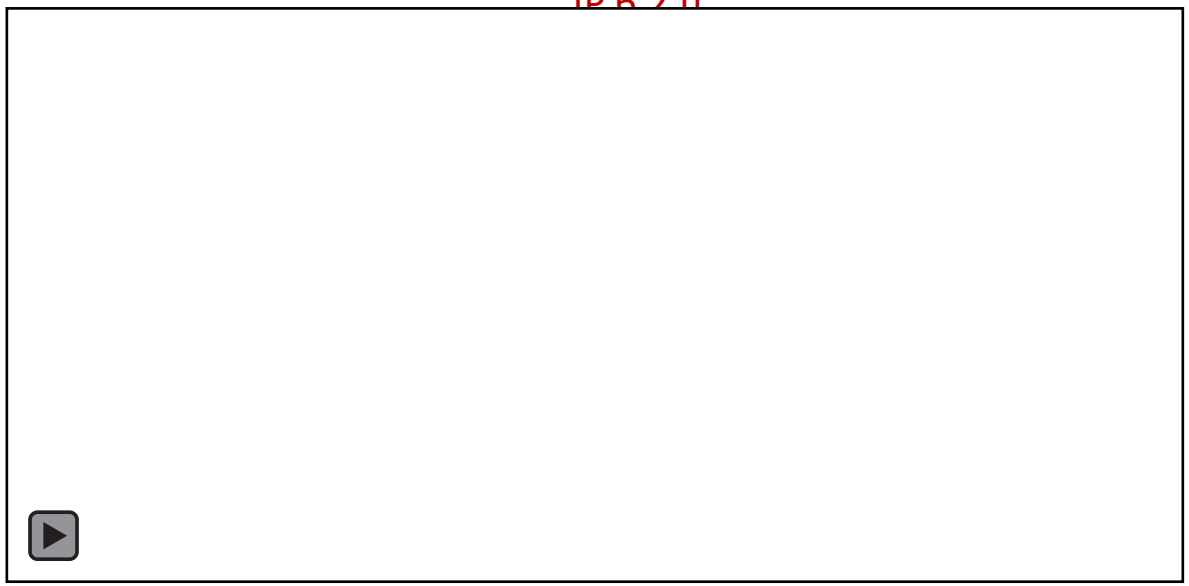
Conclusions for Test 4-21 CIP Evaluation

- Critical Impact Points for Test 4-21
  1. Primary CIP
     - 6.2 ft: Best overall compromise considering both pocketing and impact severity at time of snag.
  2. Secondary CIP: Was evaluated for the 2-Bar transition system
     - IP 9.2 ft: Greatest relative deflection (pocketing) of rail at approach to snag point.

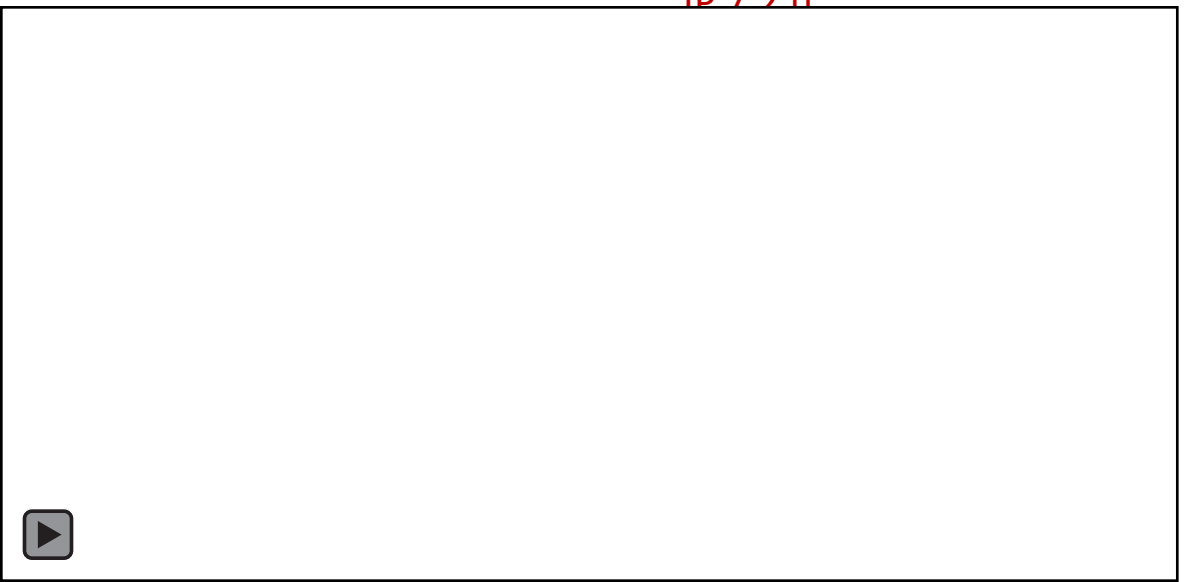
IP 5.7 ft



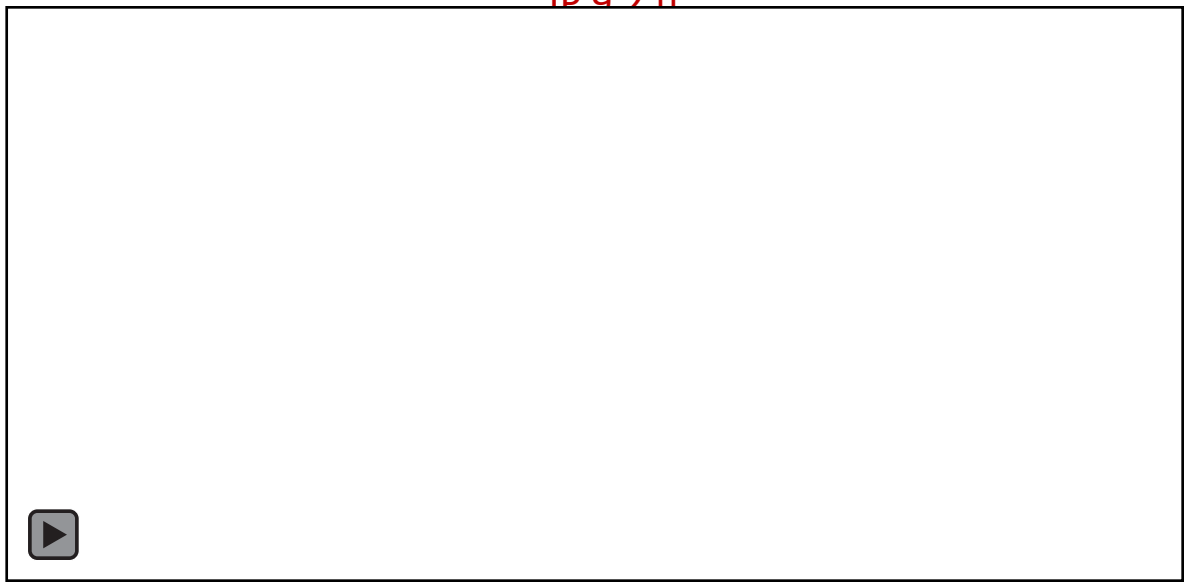
IP 6.2 ft



IP 7.2 ft



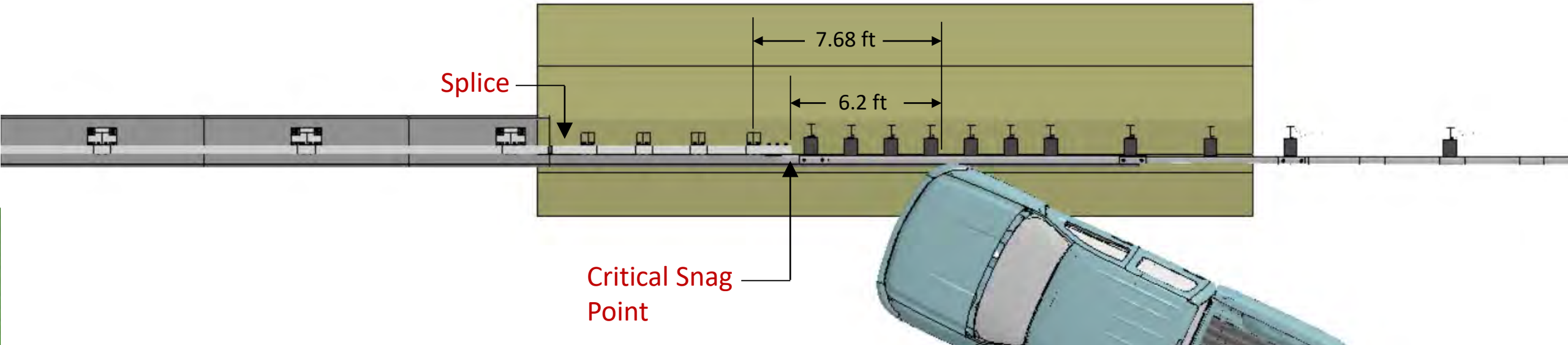
IP 9.2 ft



MASH Test 4-21 Simulation on the 3-Bar Trans

- Impact Conditions
  - Impact Speed = 62.1 mph (100 km/hr)
  - Impact Angle = 25 degrees
  - Impact Point = 6.2 ft upstream from end of tube-rail

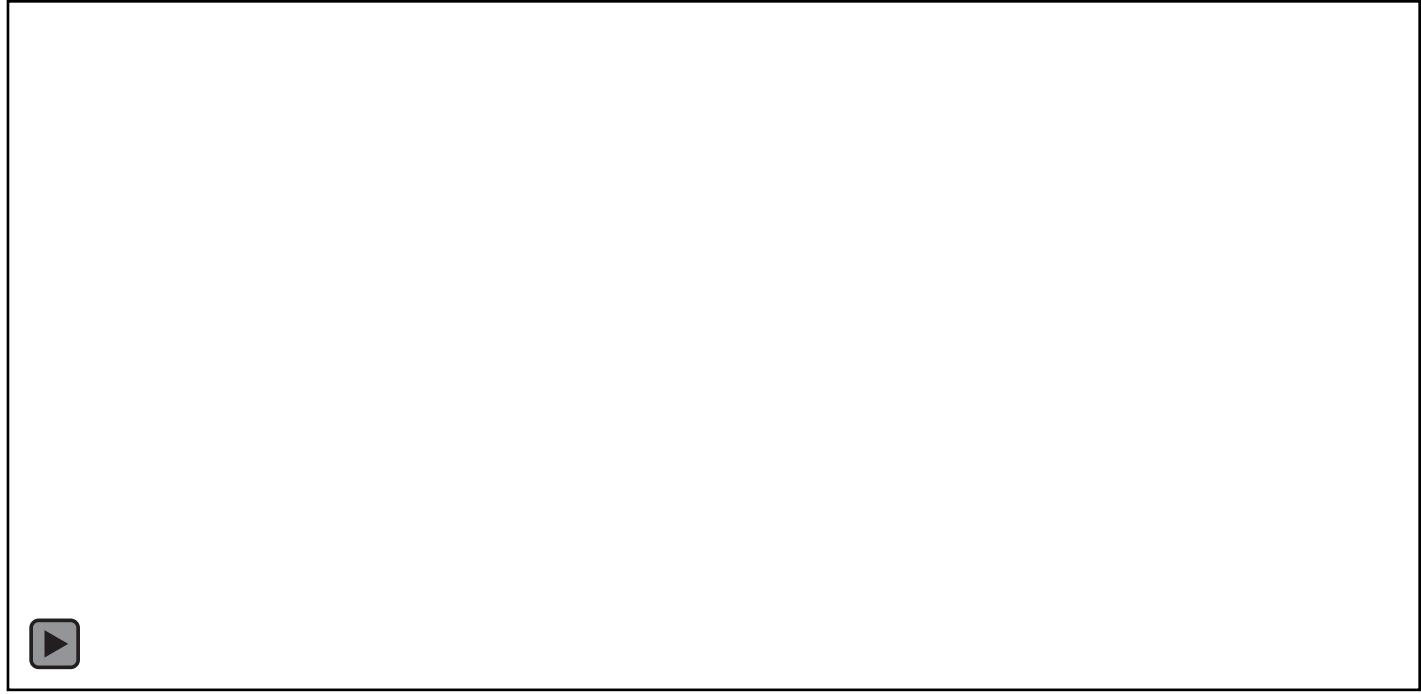
- Vehicle Model
  - SilveradoC_V3a_V180201_TireRS_35psi.k
  - Vehicle Mass = 2,268 kg (5,001 lb)

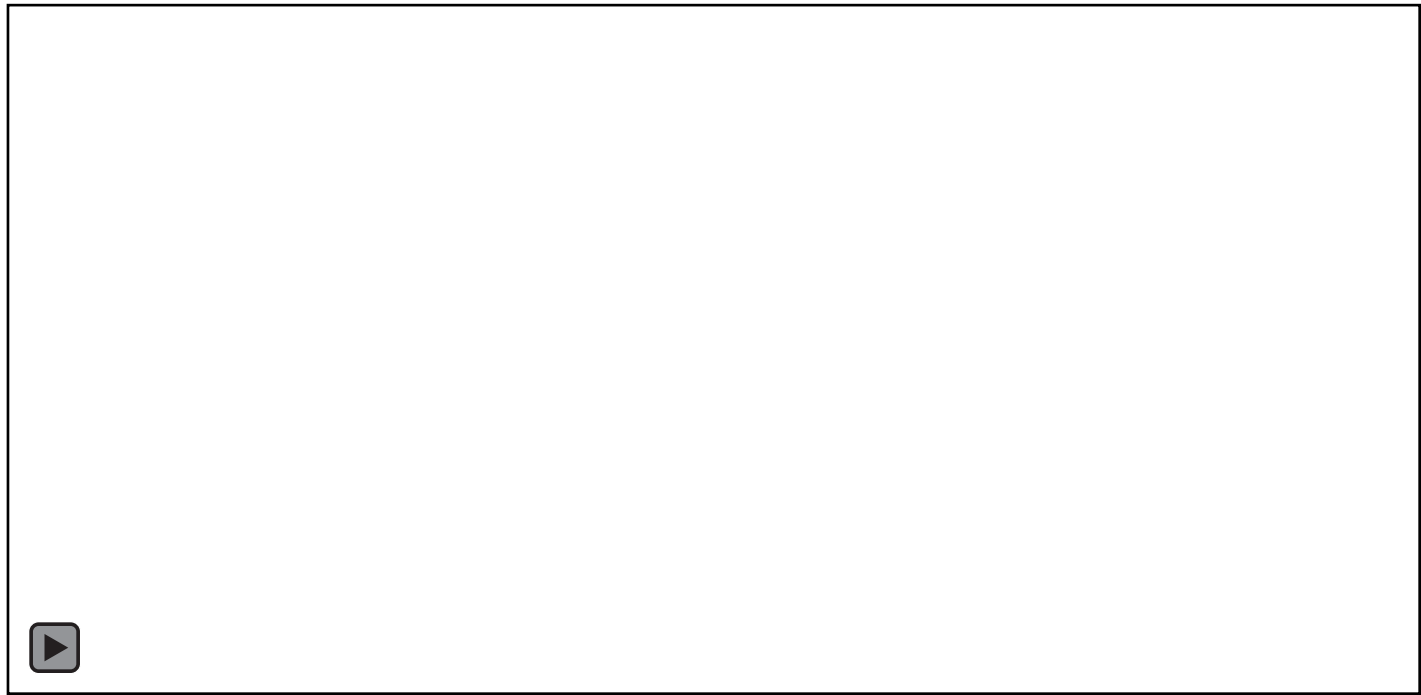


Movies

Movies

Movies





Movies

TRAP – Summary Table

Occupant Risk Factors		MASH T4-11 Test 4-21
Occupant Impact Velocity (ft/s)	x-direction	17.7
	y-direction	24.6
	at time	at 0.0925 seconds on right side of interior
THIV (ft/s)		30.5 at 0.0925 seconds on right side of interior
Ridedown Acceleration (g's)	x-direction	-5.2 (0.1082 - 0.1182 seconds)
	y-direction	-15.1 (0.1973 - 0.2073 seconds)
PHD (g's)		15.2 (0.1973 - 0.2073 seconds)
ASI		1.33 (0.0417 - 0.0917 seconds)
Max 50-ms moving avg. acc. (g's)	x-direction	-7.7 (0.0367 - 0.0867 seconds)
	y-direction	-10.6 (0.0419 - 0.0919 seconds)
	z-direction	2.9 (0.2506 - 0.3006 seconds)
Maximum Angular Disp. (deg)	Roll	-8.1 (0.4977 seconds)
	Pitch	-3.7 (0.5602 seconds)
	Yaw	-29.1 (0.6542 seconds)

MASH Criteria

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

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

< 75 deg ✓

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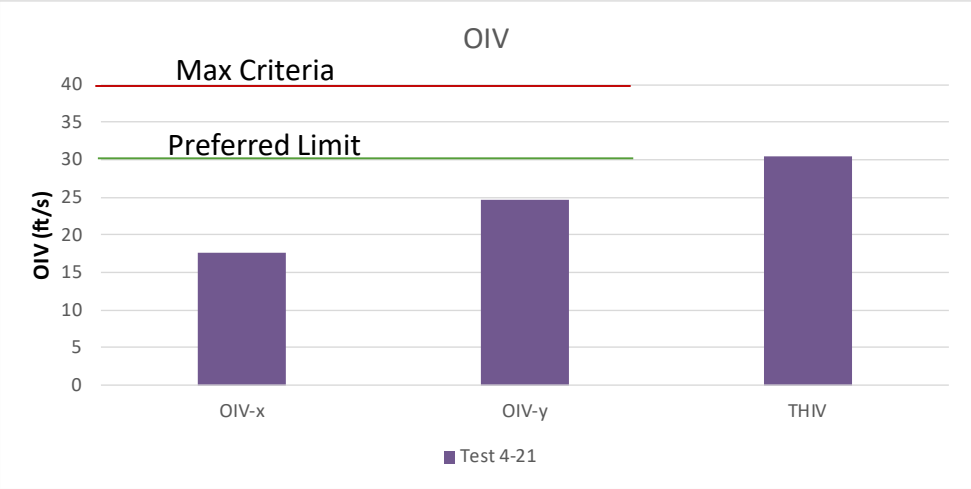
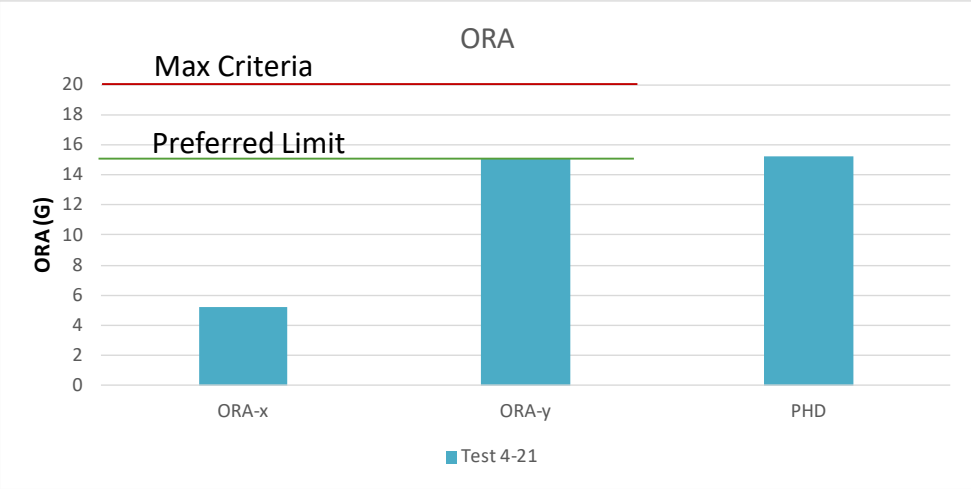
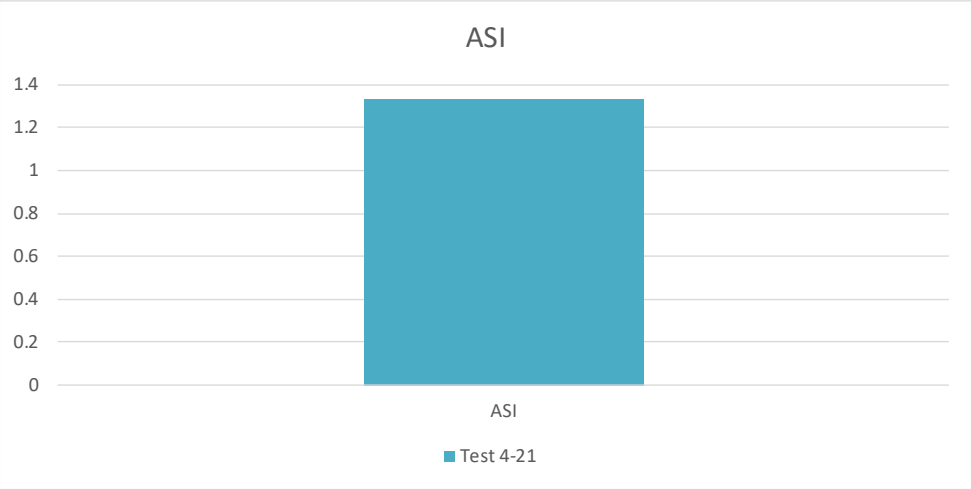
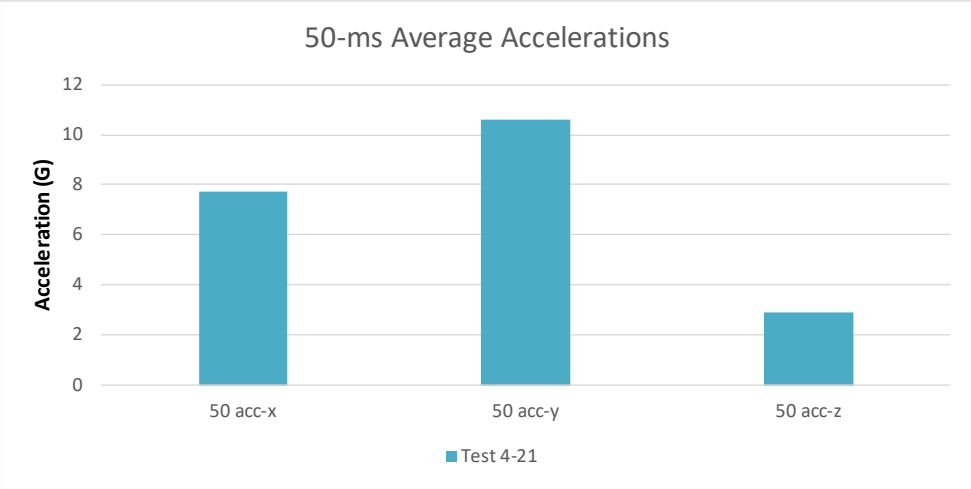
TRAP









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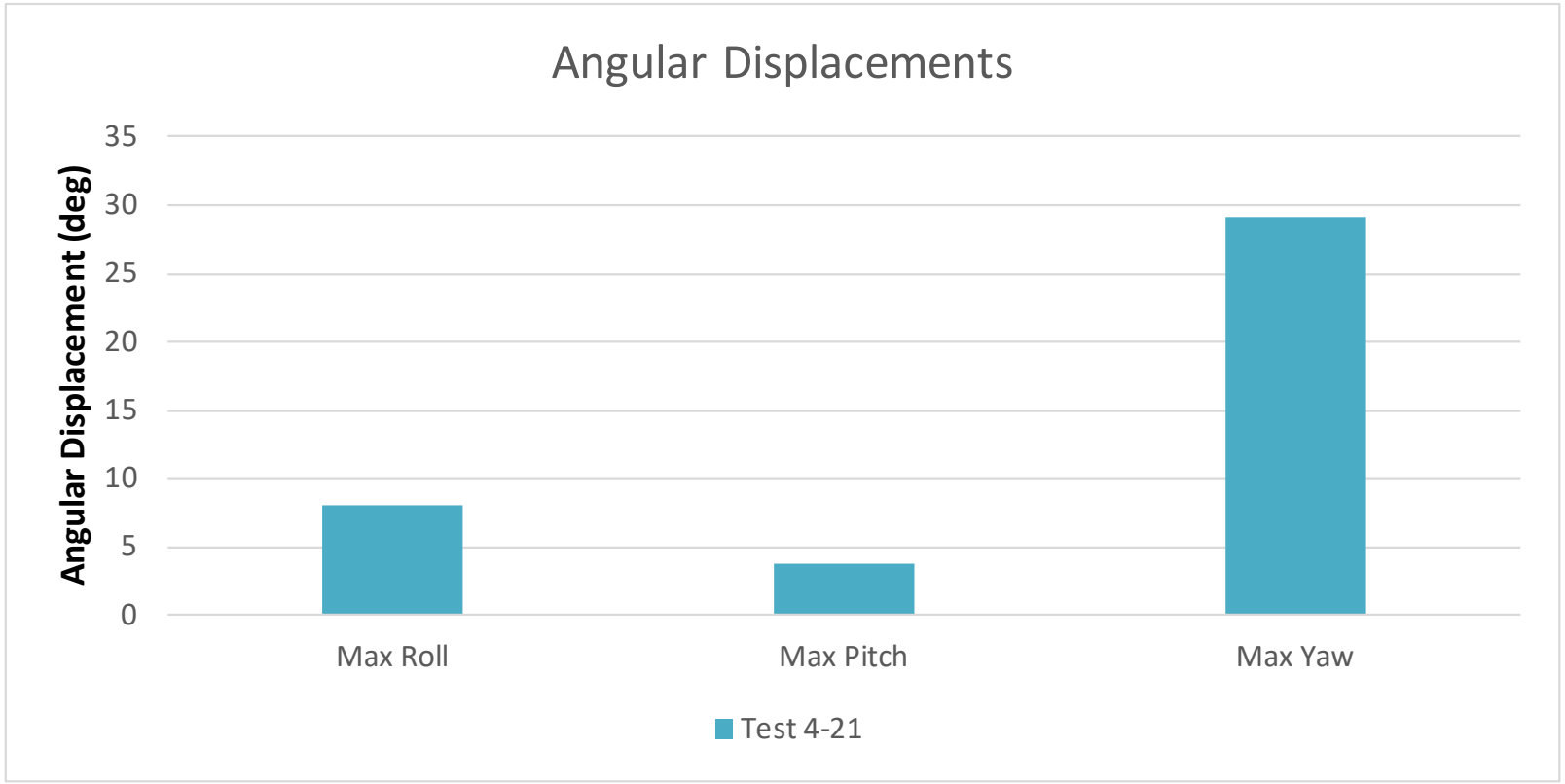
TRAP



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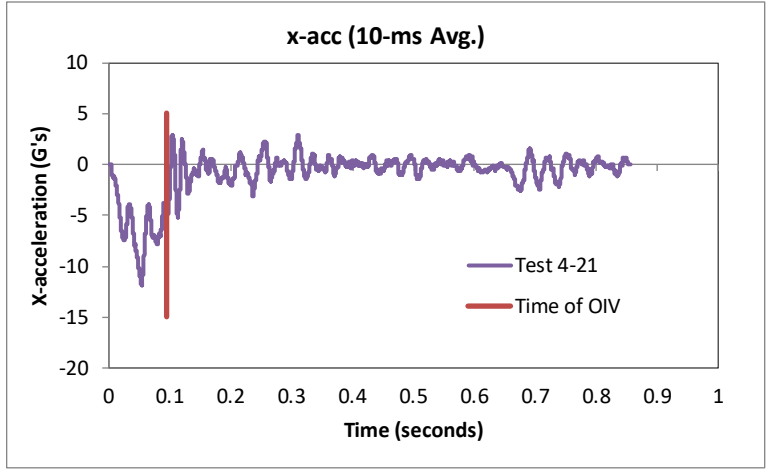
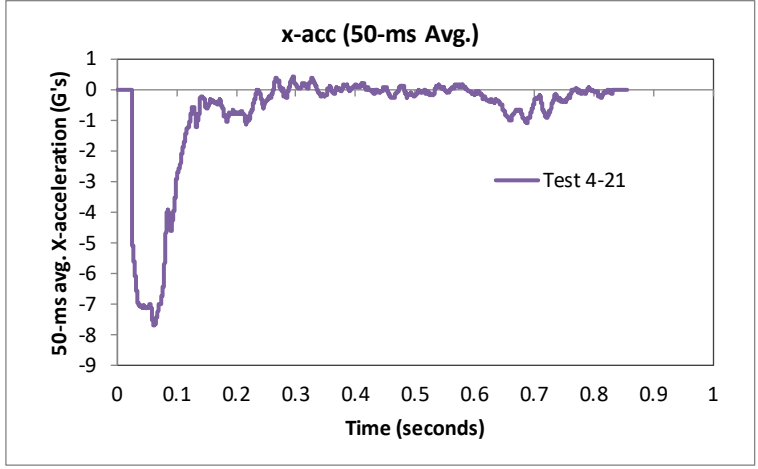
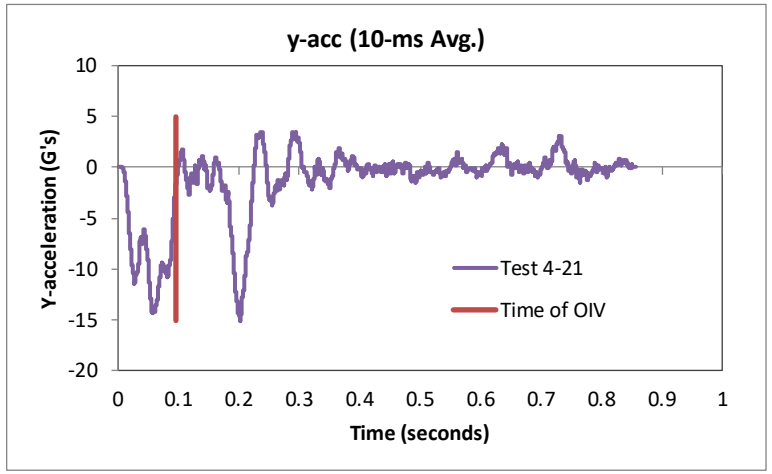
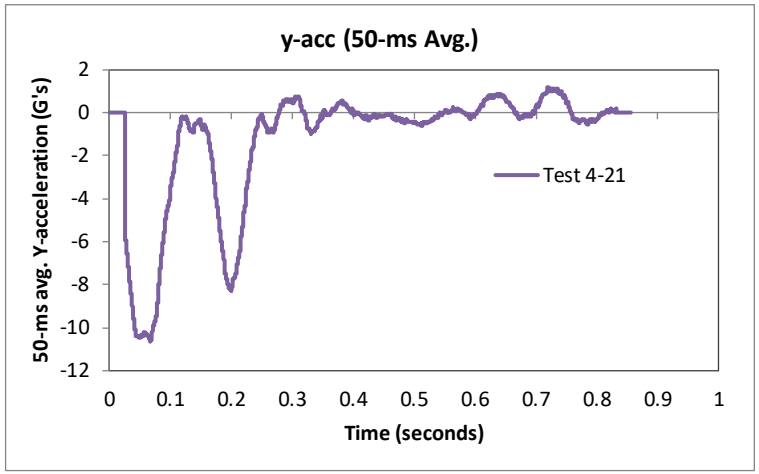
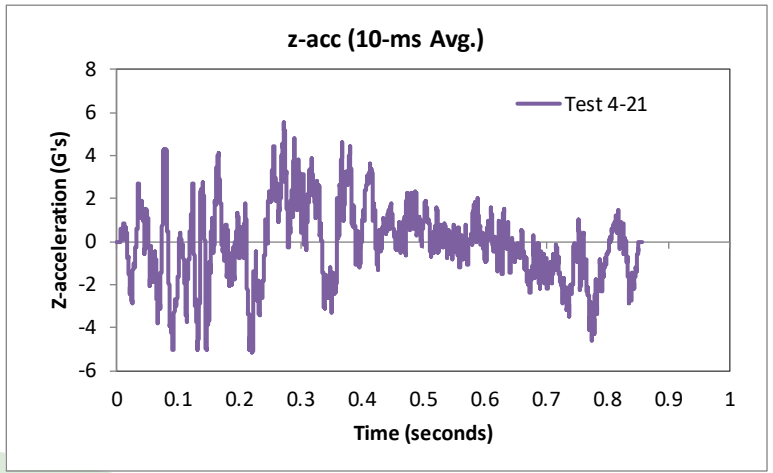
Acceleration Plots

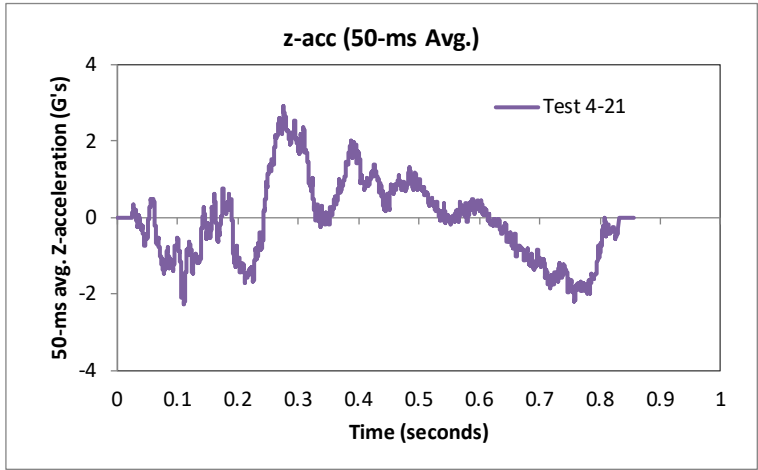




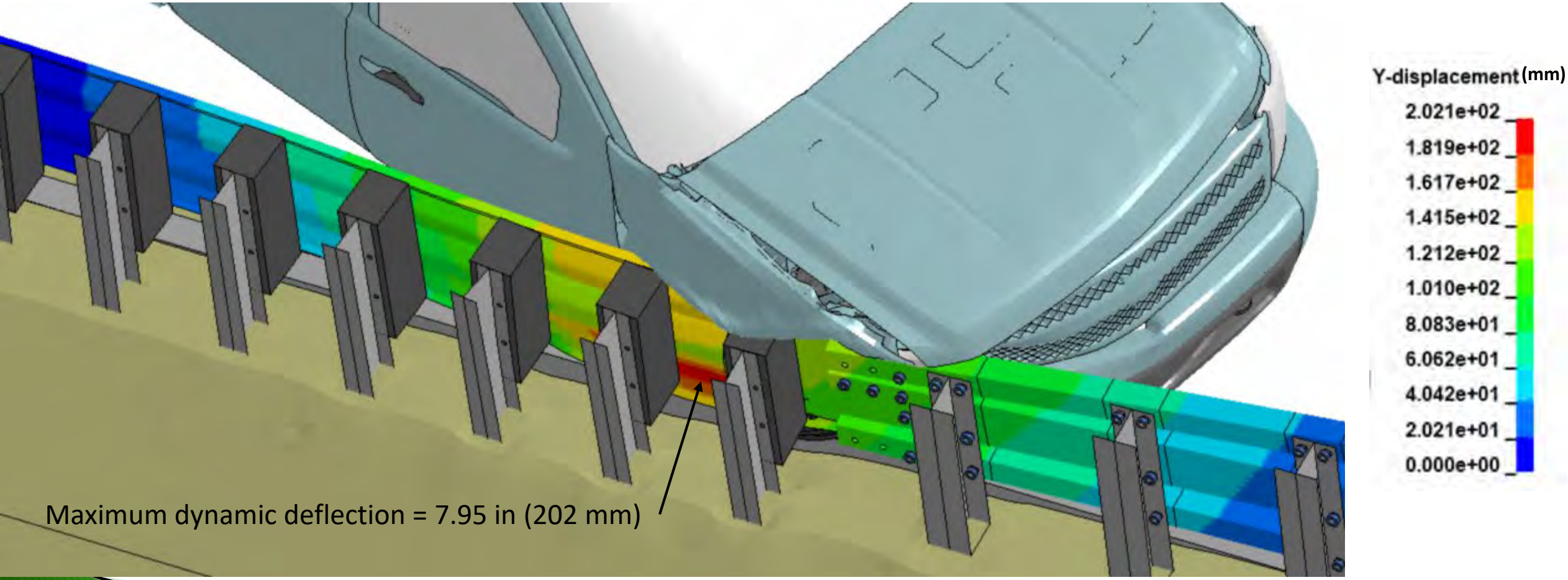








Lateral Dynamic Deflection



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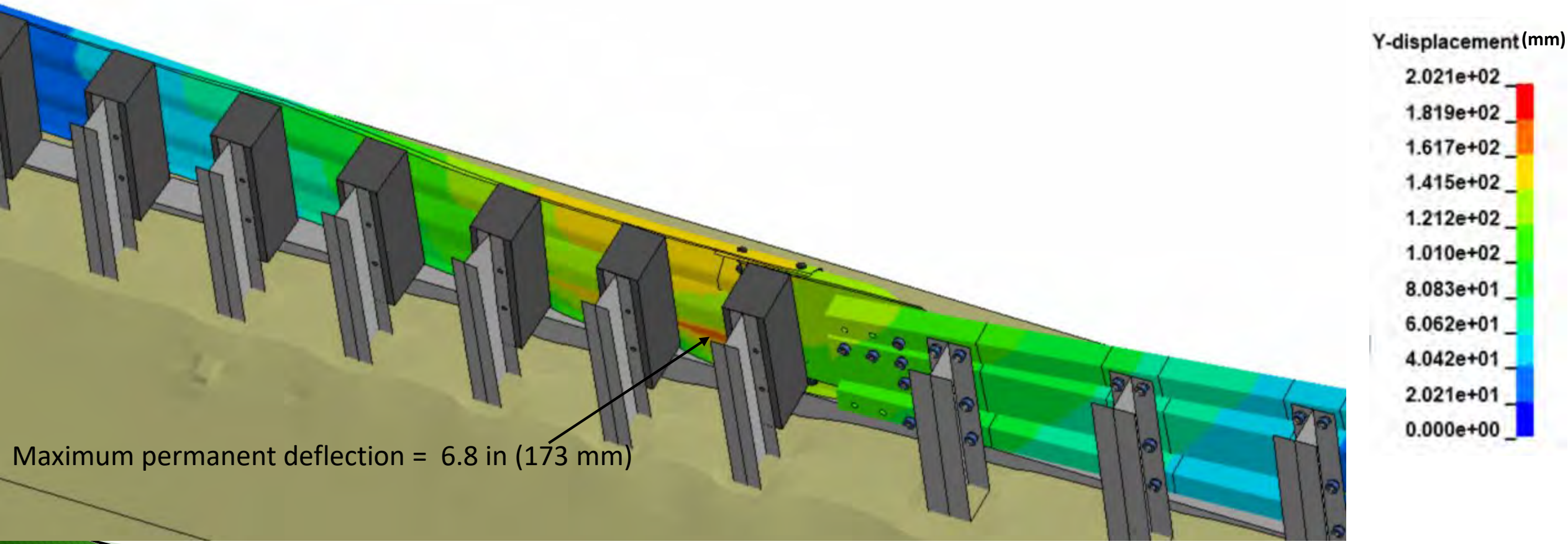
Lateral Permanent Deflection



Maximum permanent deflection = 6.8 in (173 mm)

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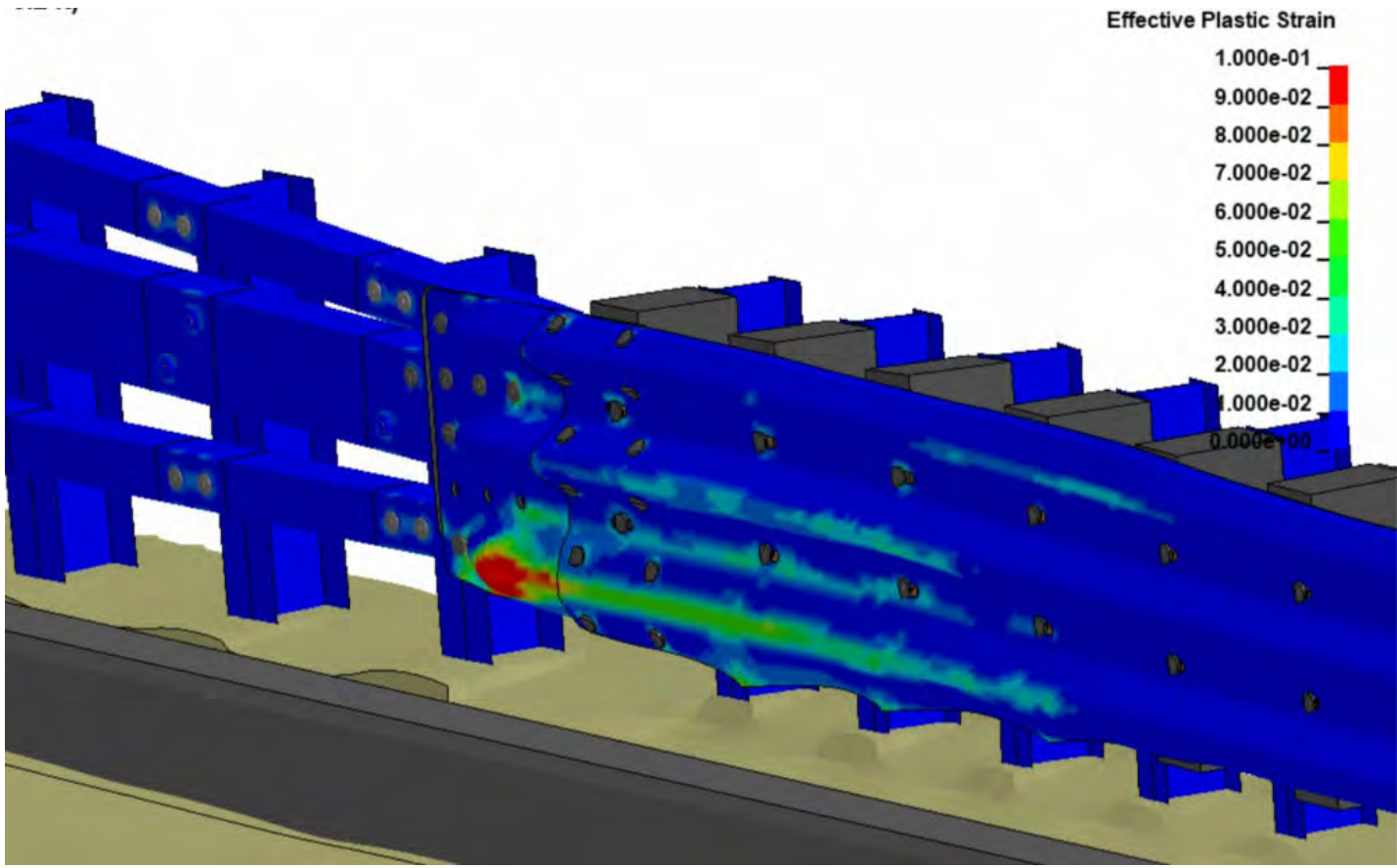
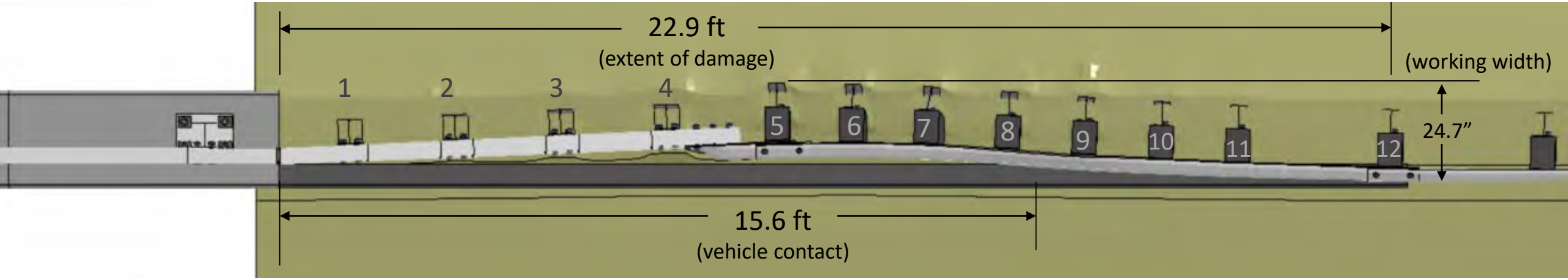
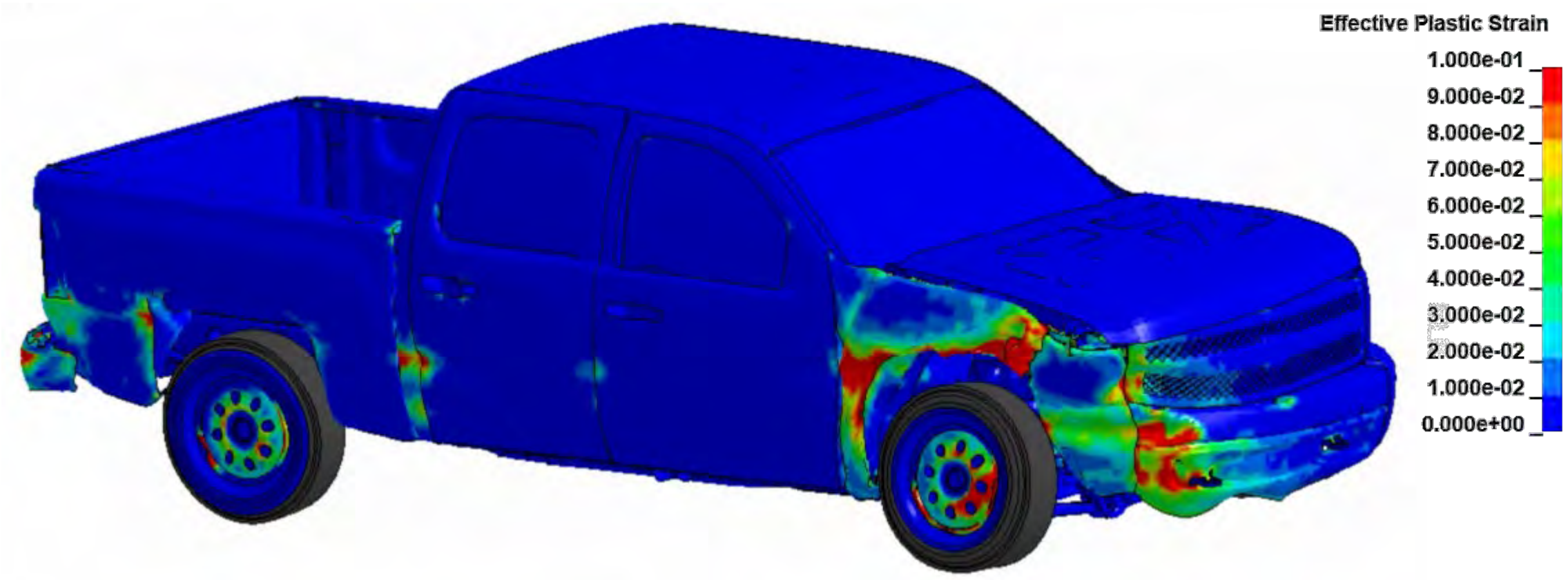
Barrier Damage

- Primary plastic deformations of the rail elements were limited to the thrie-beam and thrie-beam terminal connector. The highest strains were on the terminal connector element.
- Total length of system deformed was 22.9 ft extending from the first post of the thrie-beam to the start of the bridge rail.
- The vehicle was in contact with the system for approximately 15.6 ft.
- The maximum working width = 24.7 in
  - Measured as maximum dynamic lateral position of Post 5 (top-back of post) relative to the initial face of the barrier.





Effective Plastic Strain for Pickup Test



The most severe damages were to the front bumper, the front fender, the upper control arm of front suspension, front and rear wheels, rear edge of rear door, front edge of truck bed, rear quarter panel of truck bed and rear bumper.

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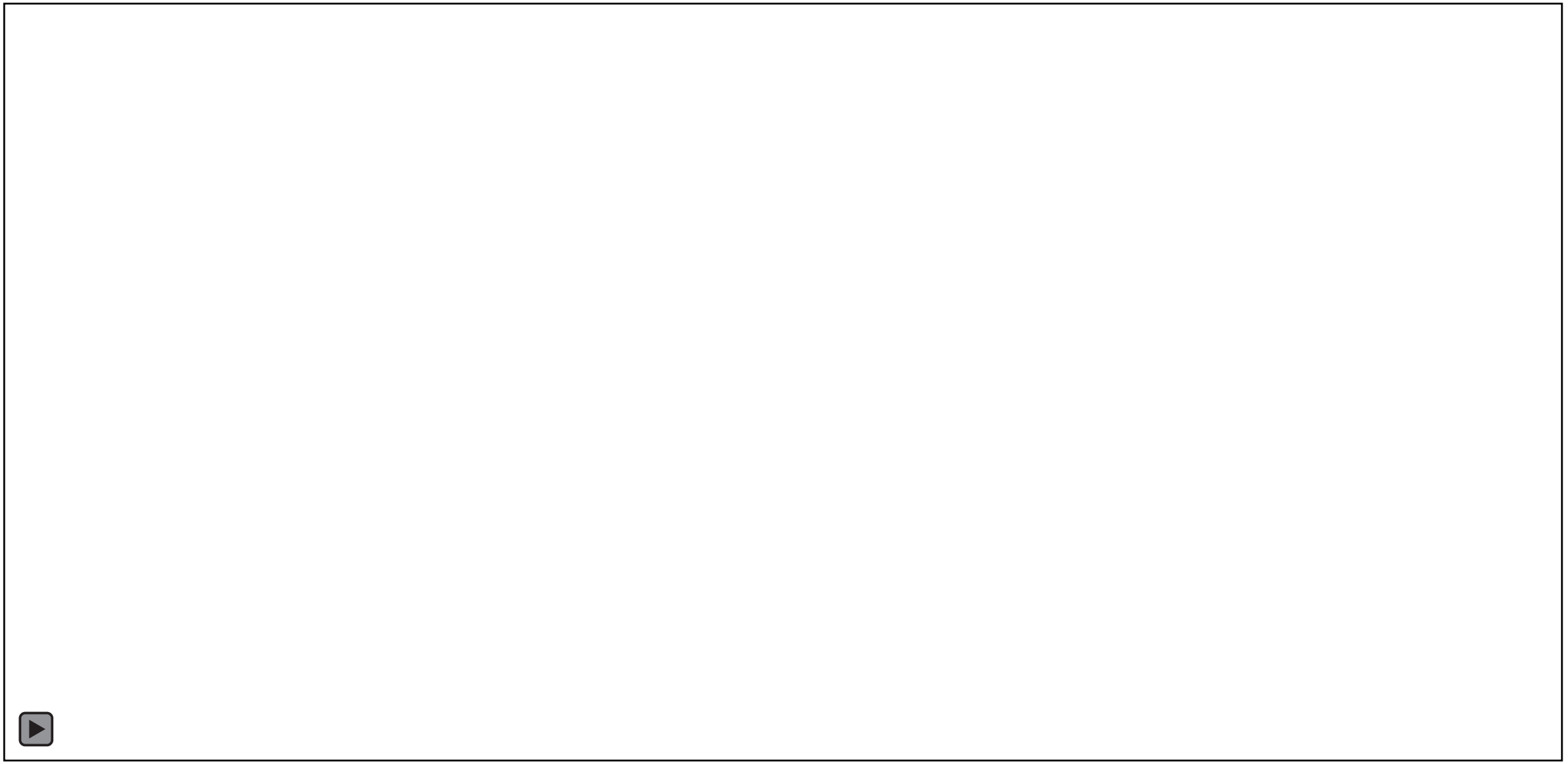
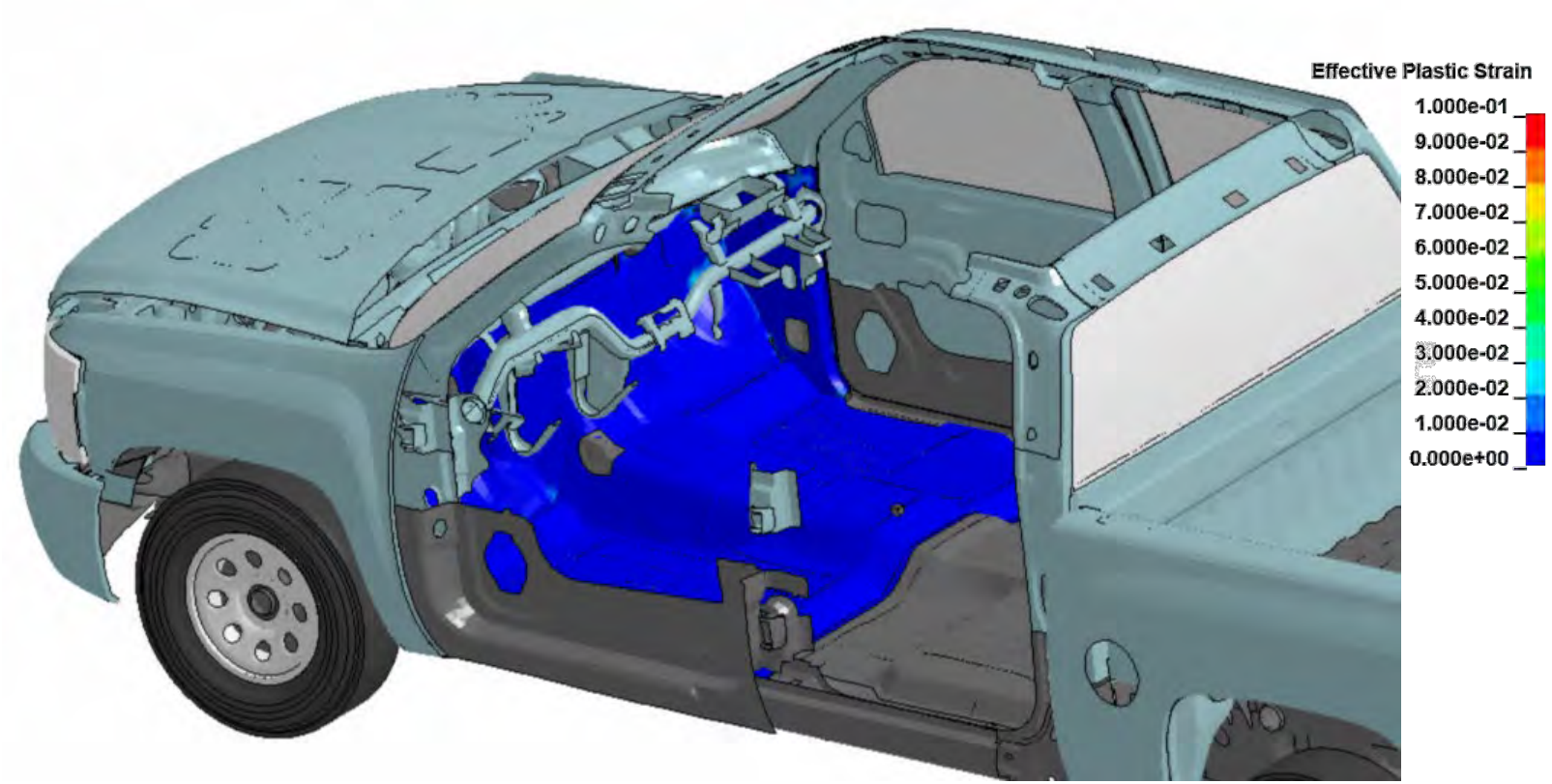
Occupant Compartment Intrusion



Occupant Compartment Intrusion (OCI)



OCI was negligible

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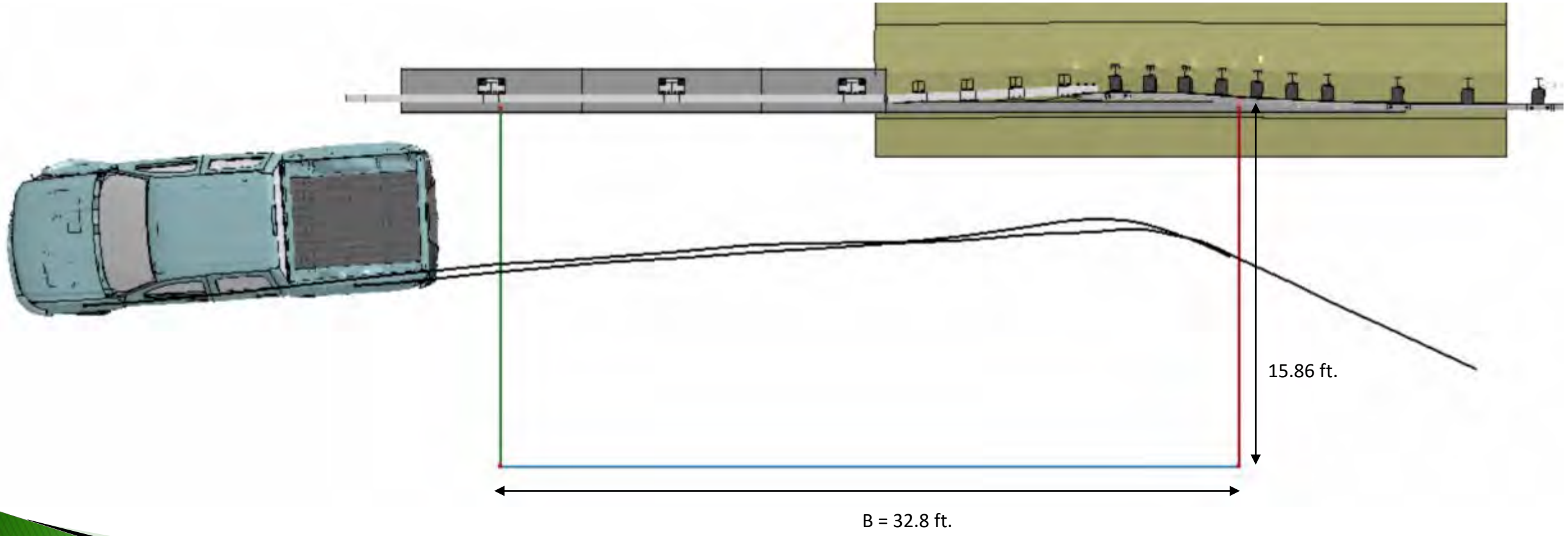
Exit Box – 3-Bar Trans – Test 4-21

The driver-side front tire wheel track was used to determine the beginning location of the exit box. From MASH pg. 97: "All wheel tracks of the vehicle should not cross the parallel line within the distance B."



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Conclusions on Test 4-21 on the 3-Bar Transition

- The barrier successfully contained and redirected the 2270P vehicle.
- The vehicle remained upright and stable through impact and redirection, with relatively low angular displacements
  - Max Roll = **8.1 degrees** and Max Pitch = **3.7 degrees**.
- The OIV was within preferred limits and the maximum ORA was within critical limits specified in MASH.
  - OIV_x = **17.7 ft/s** and OIV_y = **24.6 ft/s**
  - ORA_x = **5.2 G** and ORA_y = **15.1 G**
- The occupant compartment deformation was negligible for this impact case.
- The vehicle also **remained well within the "exit box"** limits and showed no sign of entering back into travel lanes at aggressive angle.
- Barrier damage was moderate and barrier deflections were considered low to moderate.
- The greatest deformation of the barrier occurred at the thrie-beam terminal connector and was:
  - Max Dynamic = **7.95 inches**; Max Permanent = **6.8 inches**

Conclusions on Test 4-21 on the 3-Bar Transition

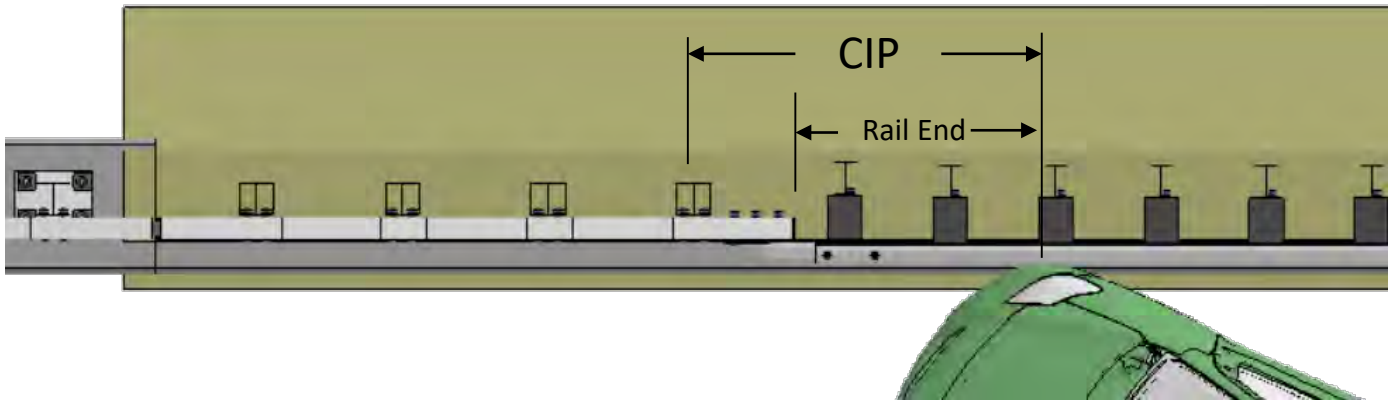
Evaluation Factors		Evaluation Criteria	Results
Structural Adequacy	A	Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is 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

Determination of CIP for Test 4-20

- CIP was determined using FEA based with respect to maximizing potential for wheel snag on the first post of the tube-rail section of the transition.
- Analysis cases evaluated (Note: CIP for rigid barrier = 3.61 ft)

IP	Relative to Post (ft)	Relative to Rail End (ft)
IP3.6	*3.61	2.13
IP4.0	4.0	2.52
IP4.5	4.5	3.02
IP5.0	5.1	*3.61
IP5.5	5.47	4.0
IP6.0	5.98	4.5

**CIP for rigid barriers*



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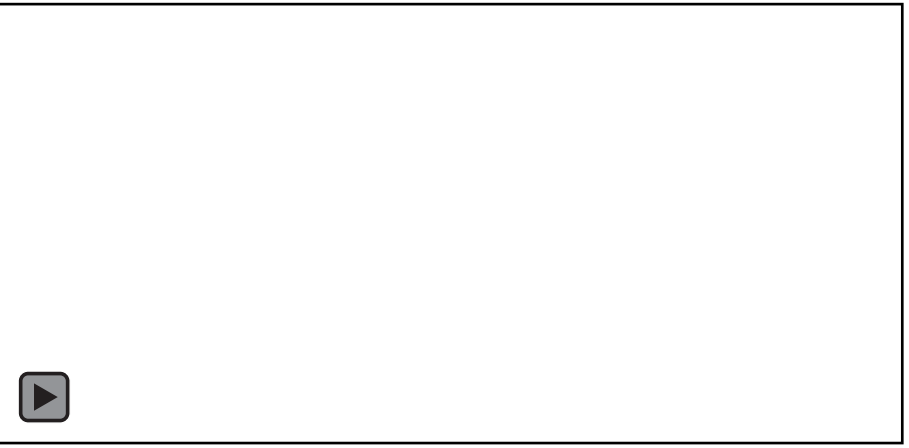
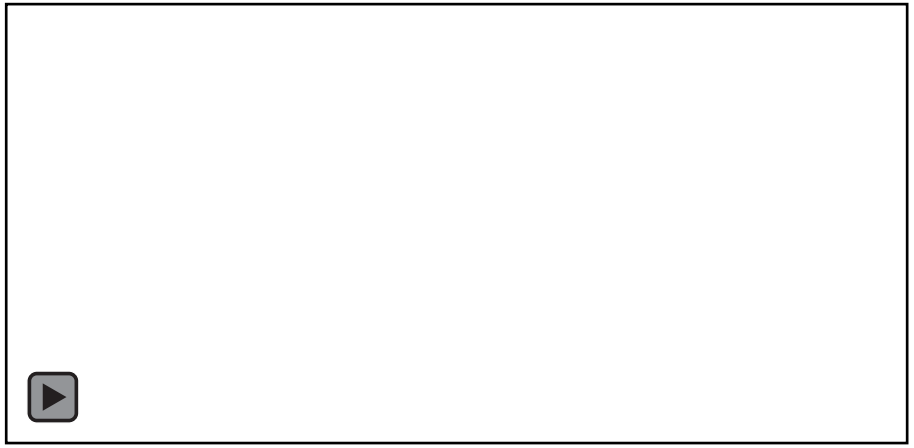
CIP Analysis Cases

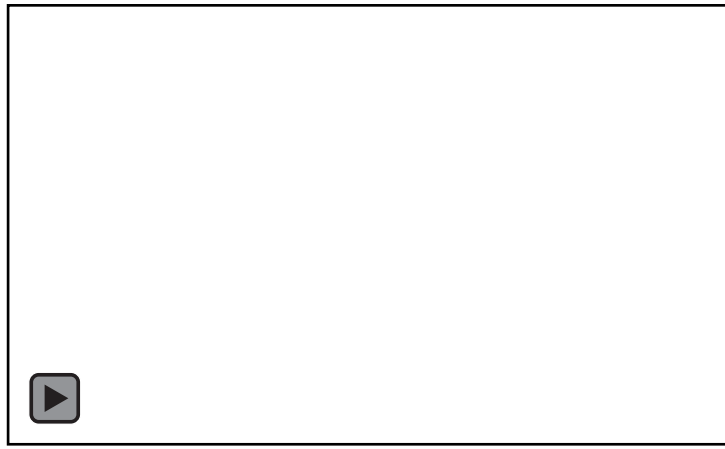
IP 3.6 ft



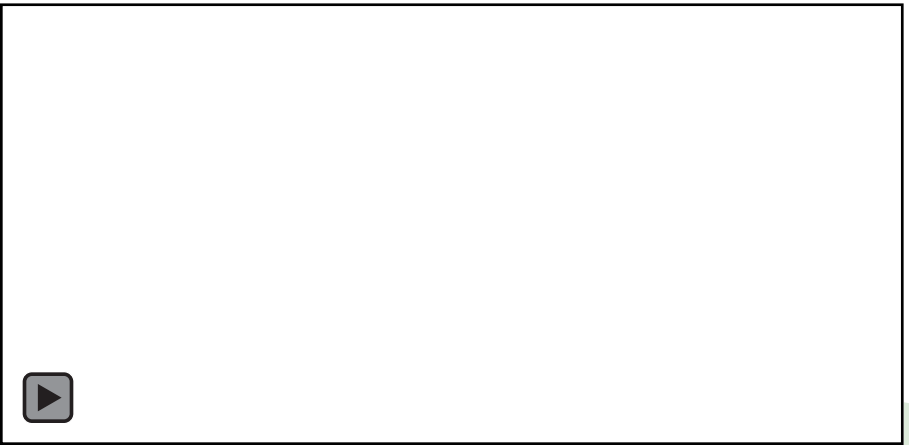
IP 4.0 ft



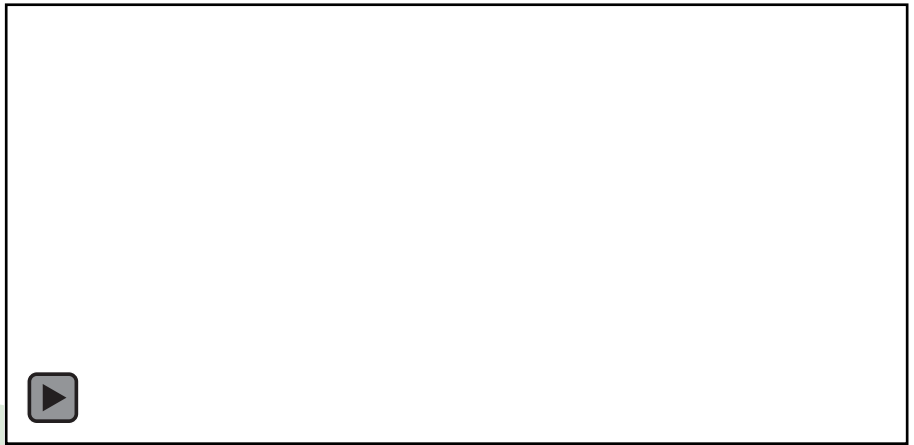
IP 4.5 ft



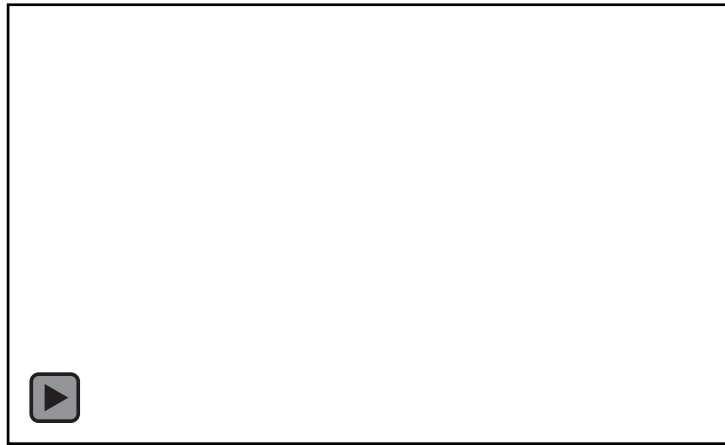
IP 5.0 ft



IP 5.5 ft

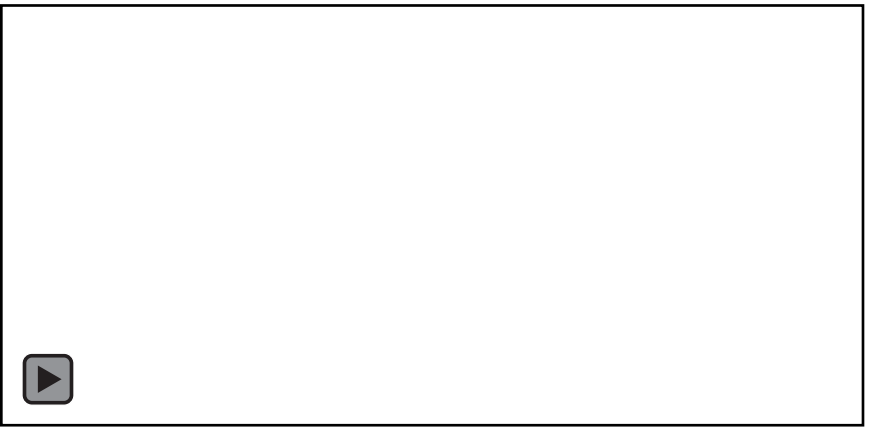


IP 6.0 ft

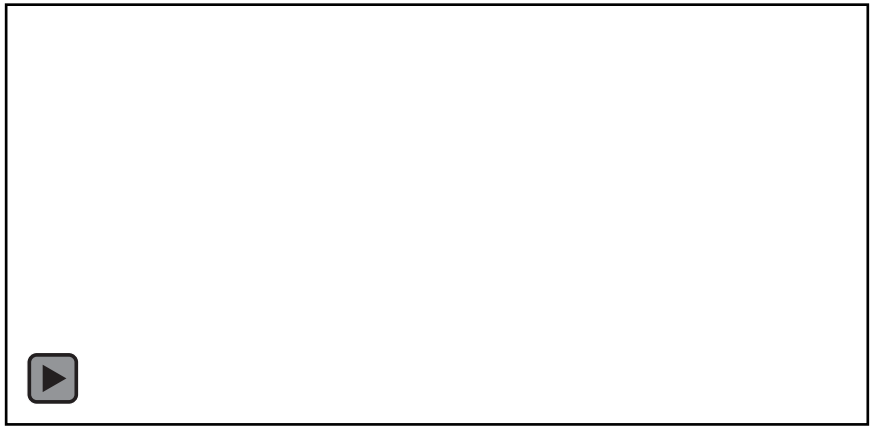


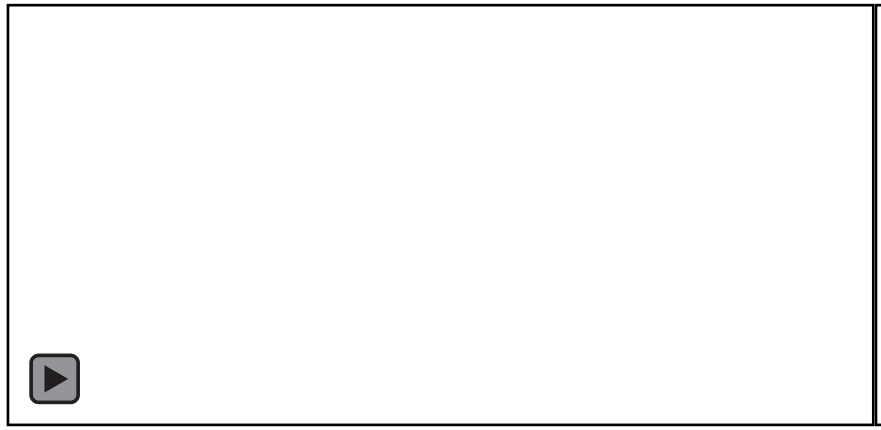
CIP Analysis Cases Movies

IP 5.0 ft

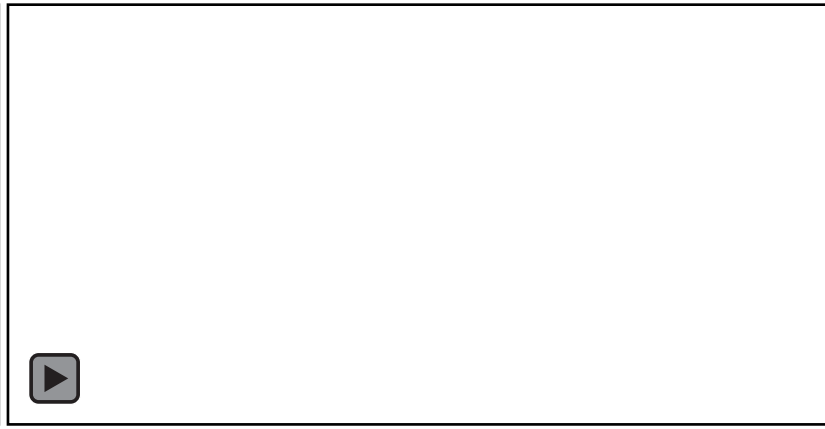


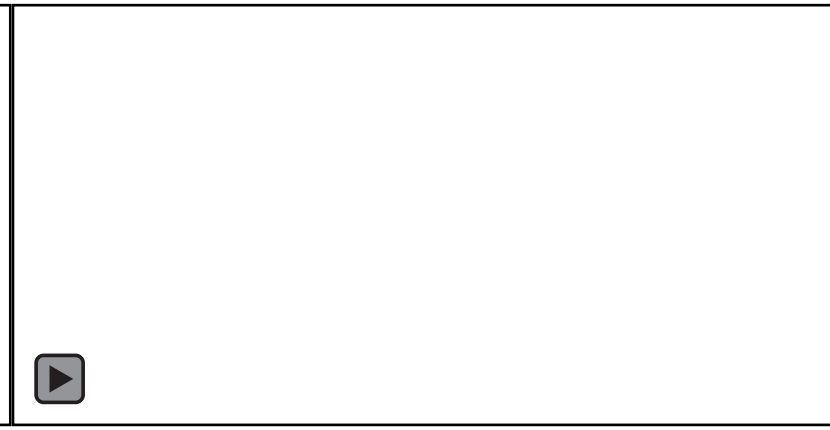
IP 5.5 ft





IP 6.0 ft





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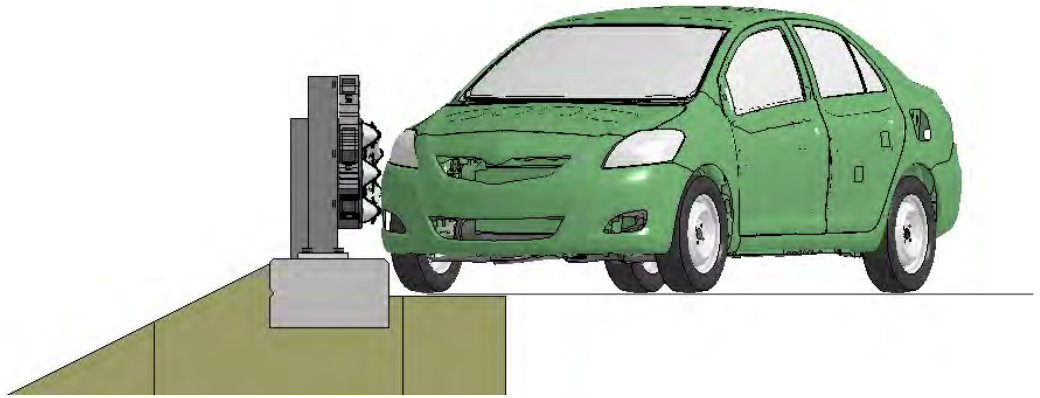
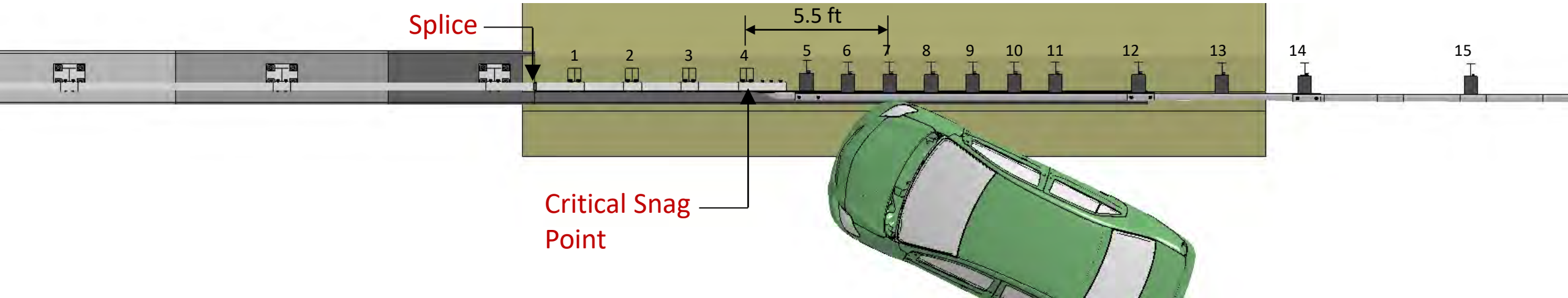
MASH Test 4-20 Simulation on the NETC 3-Bar

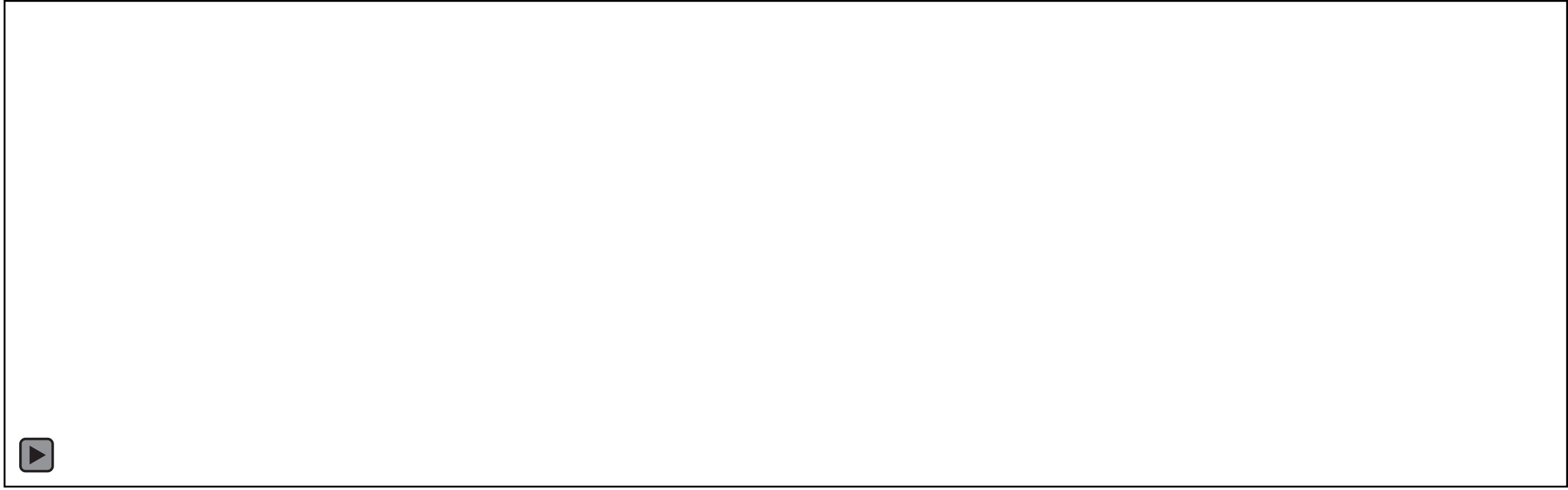
- Impact Conditions
  - Impact Speed = 62.1 mph (100 km/hr)
  - Impact Angle = 25 degrees
  - Impact Point = 5.5 ft upstream from critical Post

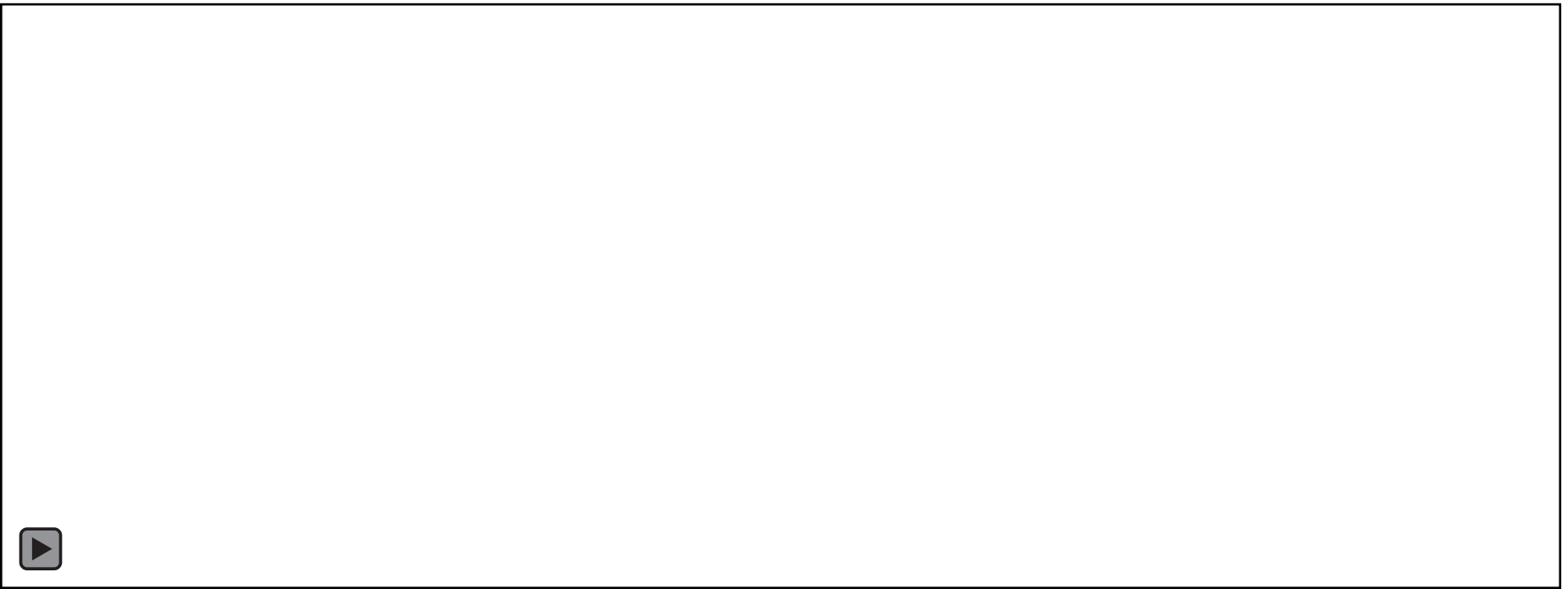
- Vehicle Model
  - YarisC_V1l_R160407.k
  - Vehicle Mass = 1,177 kg (2,595 lb)





Movies





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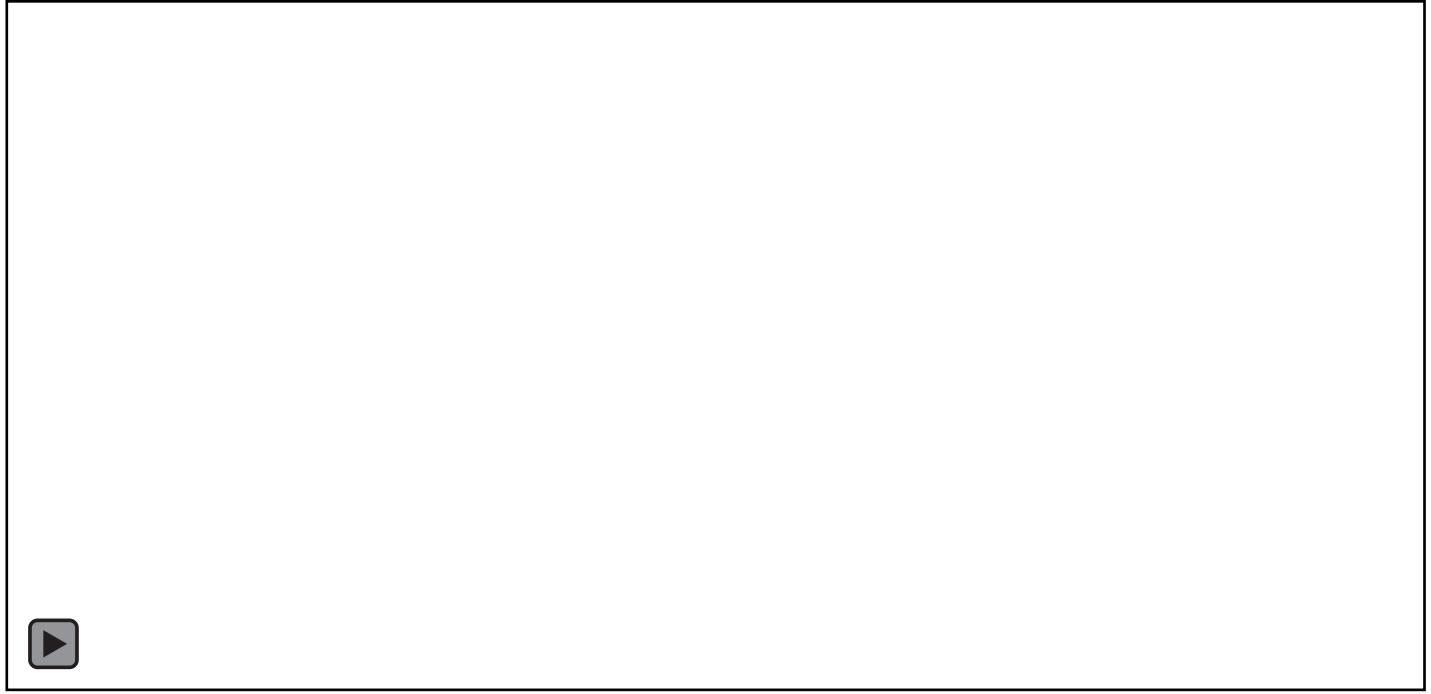
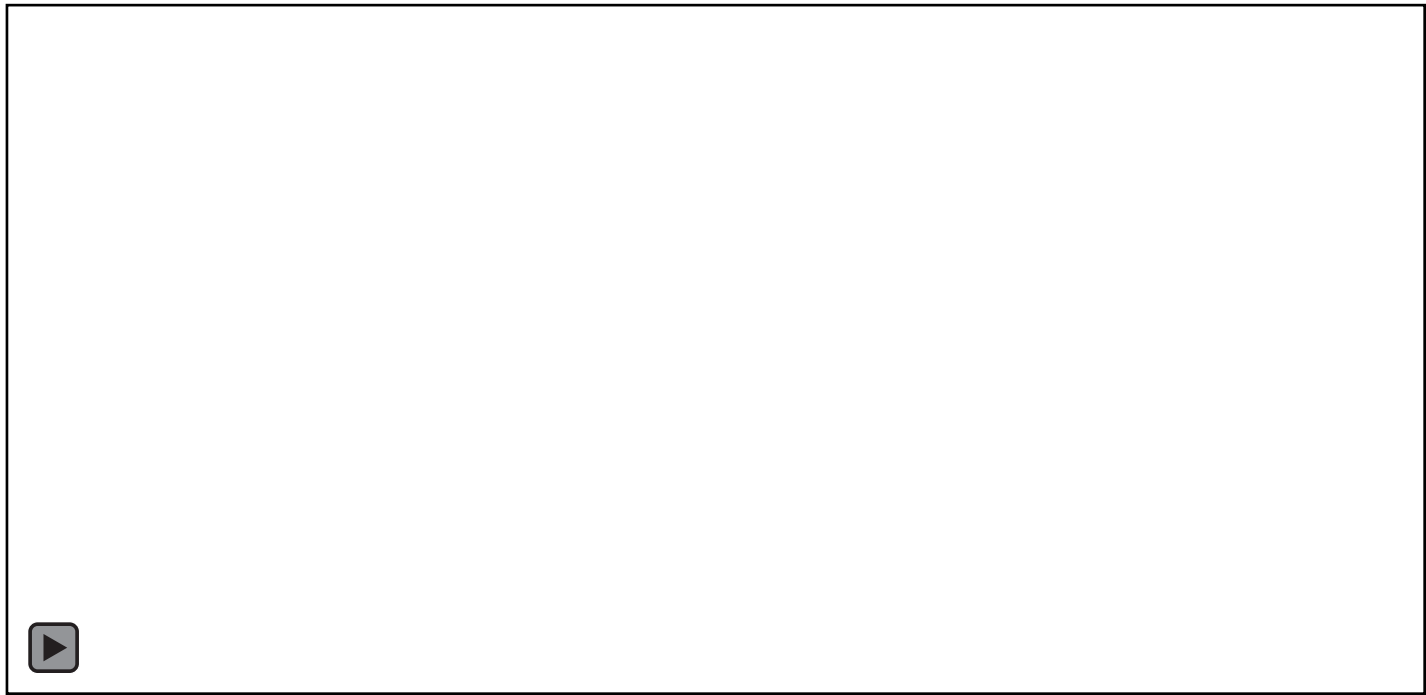
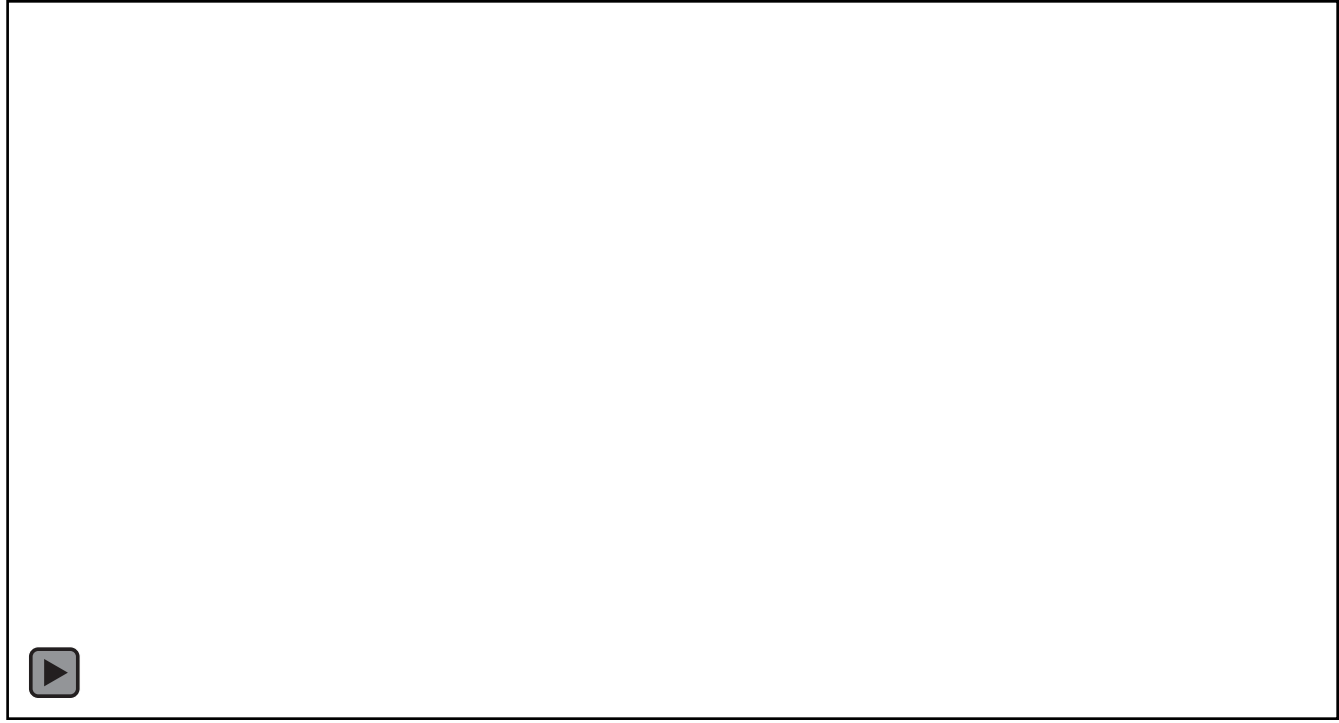
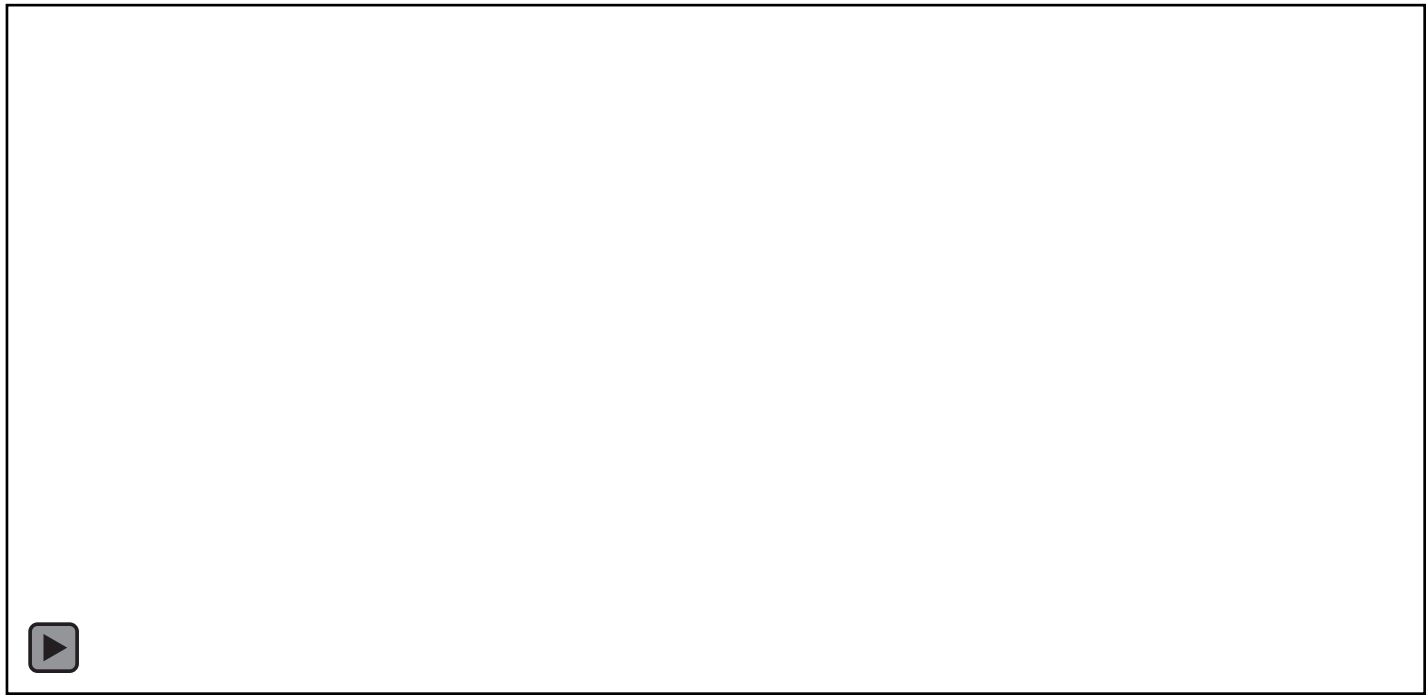
Movies



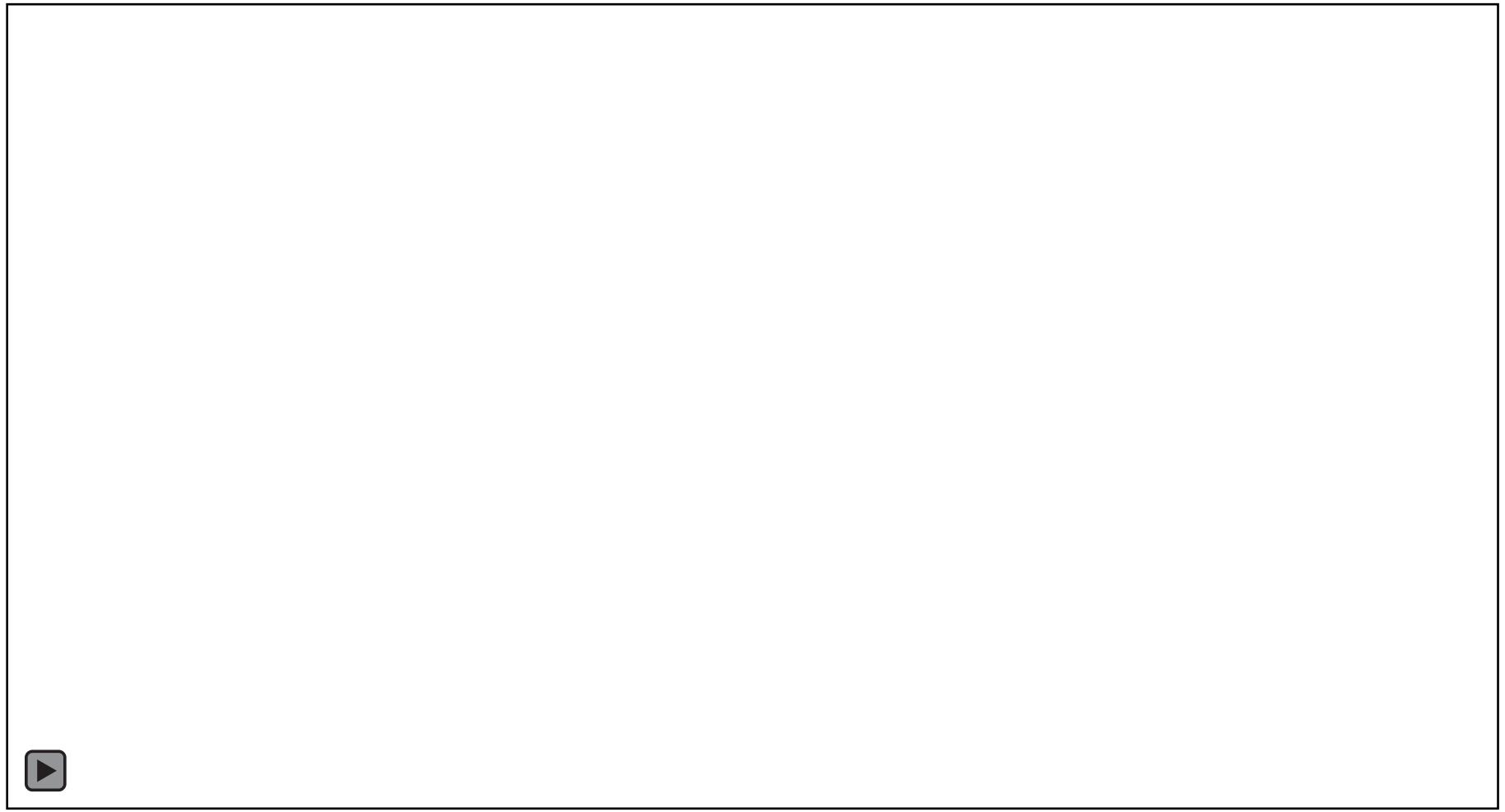


Movies





Movies



TRAP – Summary Table

Occupant Risk Factors		MASH T4-10 Test 4-20
Occupant Impact Velocity (ft/s)	x-direction	24.3
	y-direction	25.9
	at time	at 0.0761 seconds on right side of interior
THIV (ft/s)		35.1 at 0.0761 seconds on right side of interior
Ridedown Acceleration (g's)	x-direction	-4.2 (0.0976 - 0.1076 seconds)
	y-direction	-7.4 (0.2218 - 0.2318 seconds)
PHD (g's)		7.5 (0.2218 - 0.2318 seconds)
ASI		1.99 (0.0151 - 0.0651 seconds)
Max 50-ms moving avg. acc. (g's)	x-direction	-13 (0.0219 - 0.0719 seconds)
	y-direction	-15.1 (0.0148 - 0.0648 seconds)
	z-direction	-3.5 (0.5417 - 0.5917 seconds)
Maximum Angular Disp. (deg)	Roll	-6.2 (0.2565 seconds)
	Pitch	-3.9 (0.4753 seconds)
	Yaw	-29.4 (0.2632 seconds)

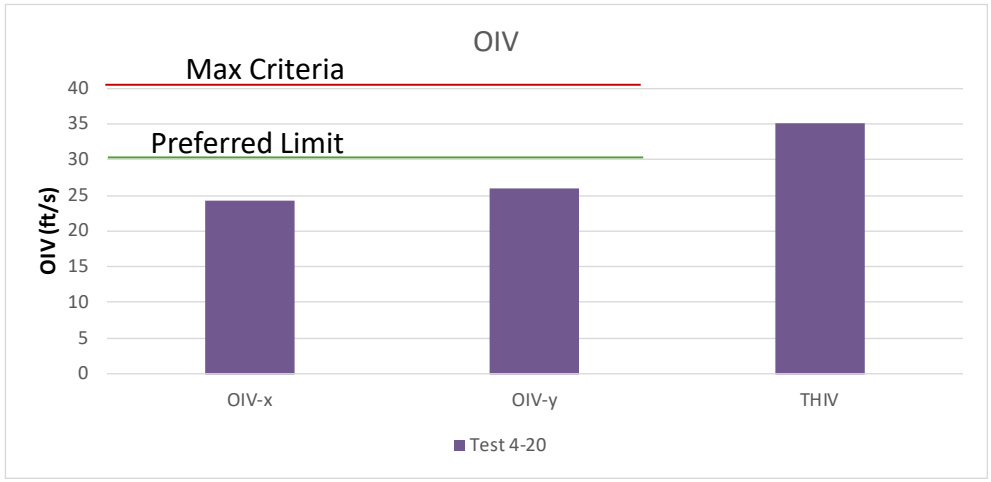
MASH Criteria

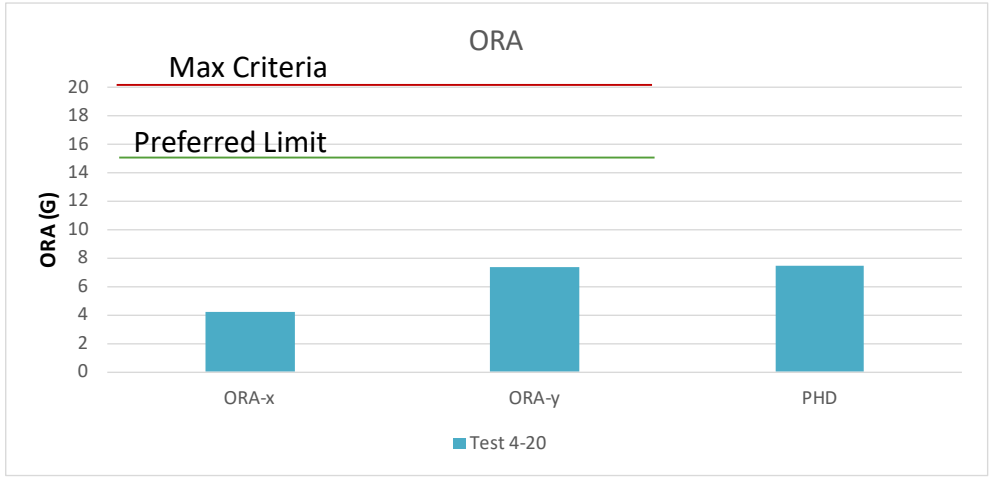
< 30 ft/s (preferred) ✓
< 40 ft/s (limit)

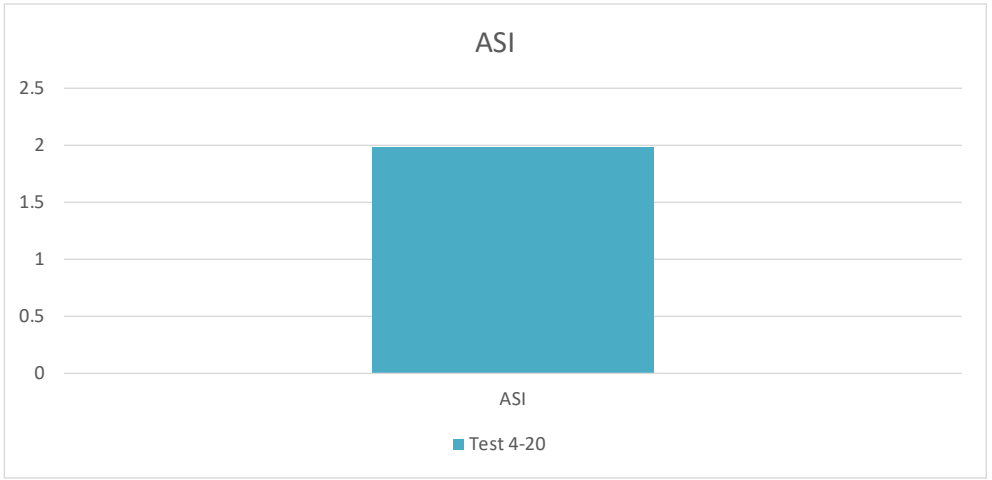
< 15 G (preferred) ✓
< 20.49 G (limit)

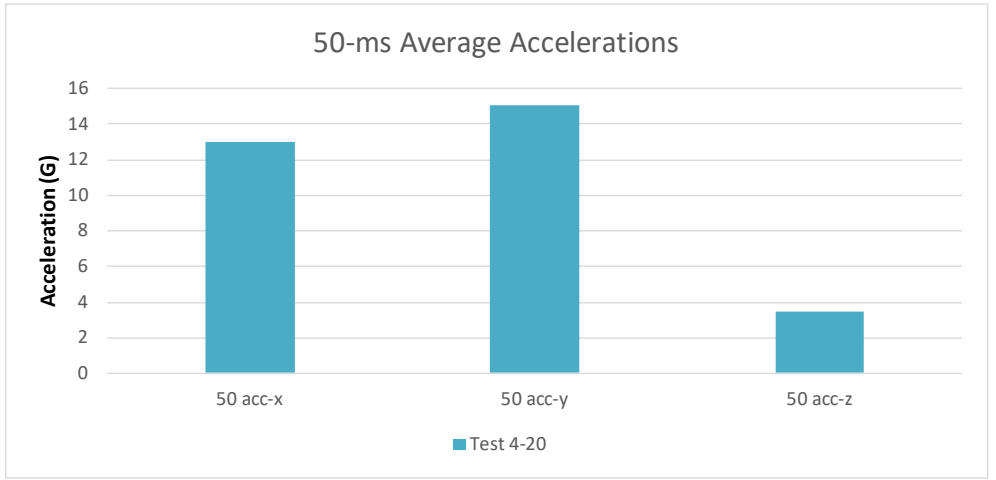
< 75 deg ✓

TRAP









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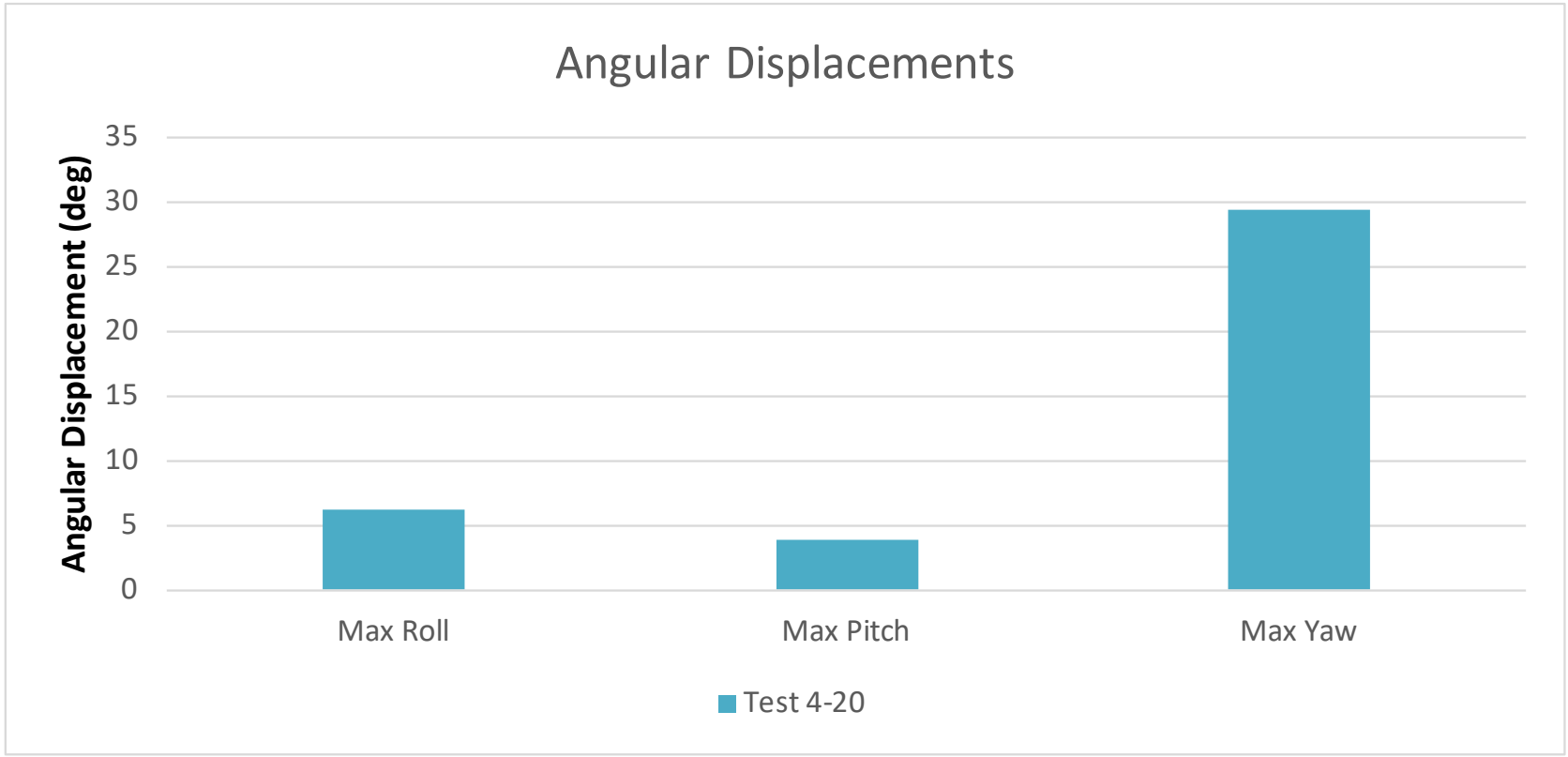
TRAP



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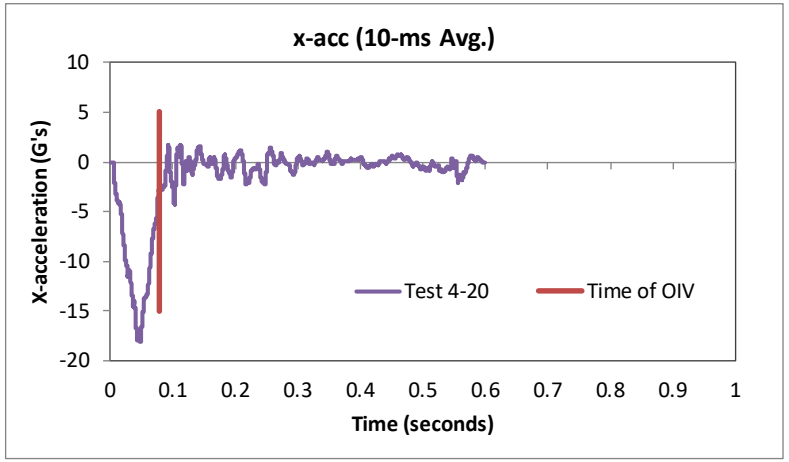
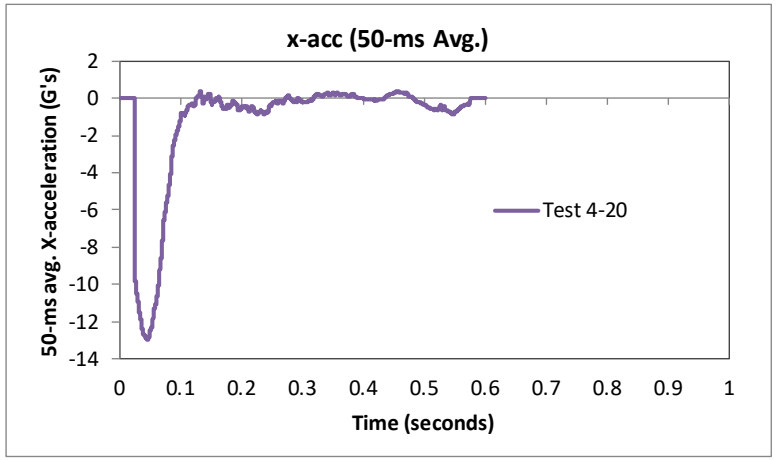
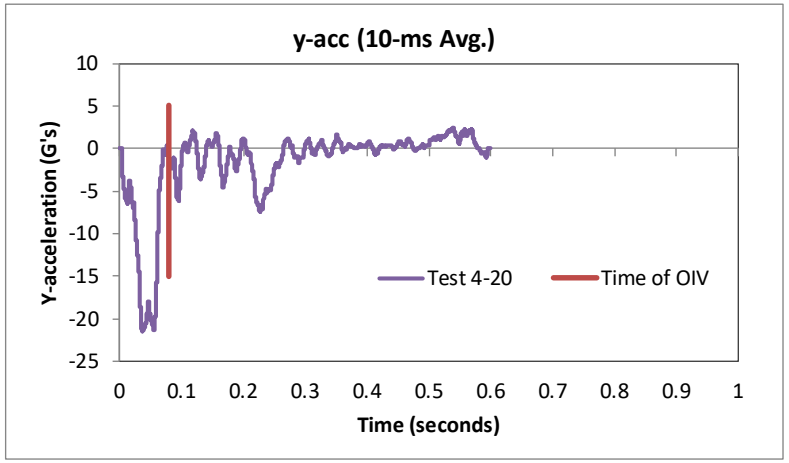
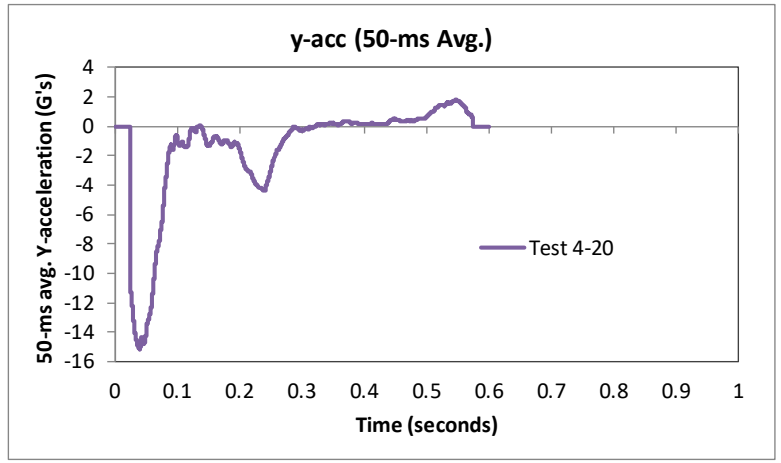
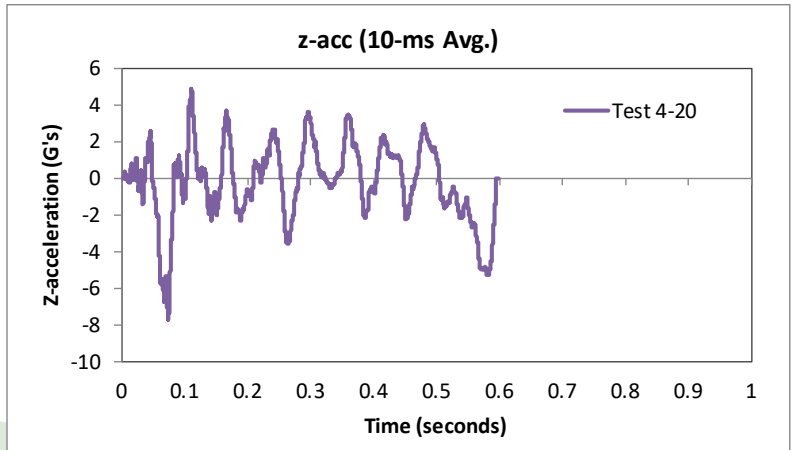
Acceleration Plots

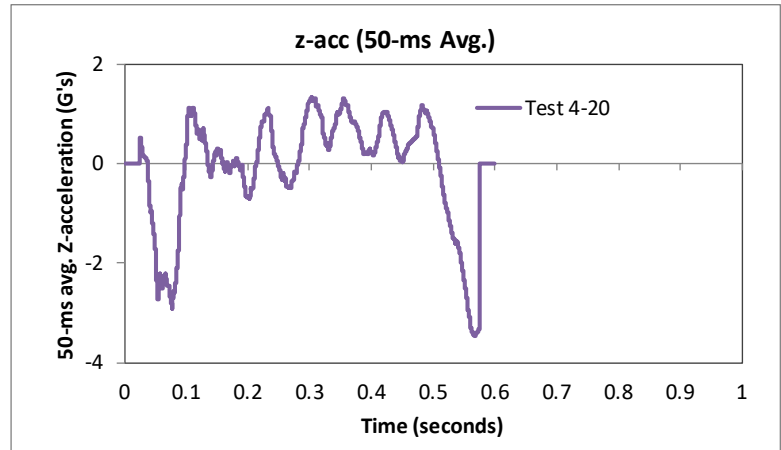




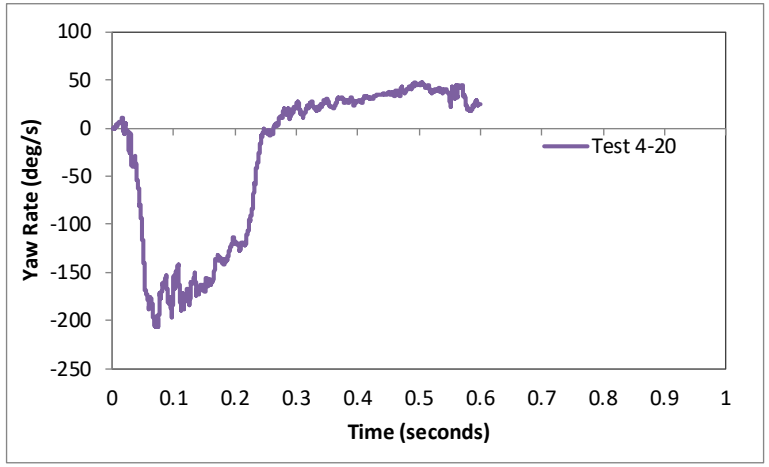


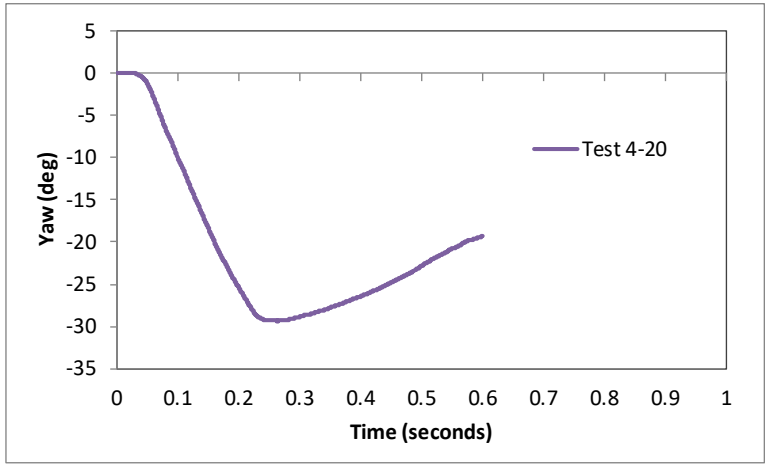


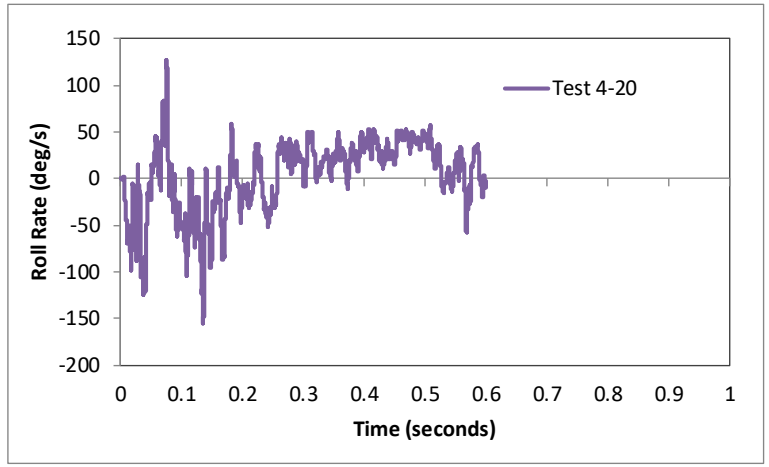


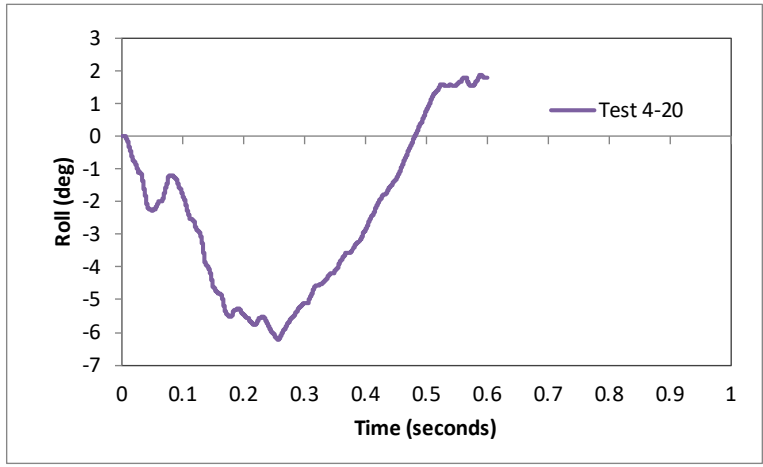


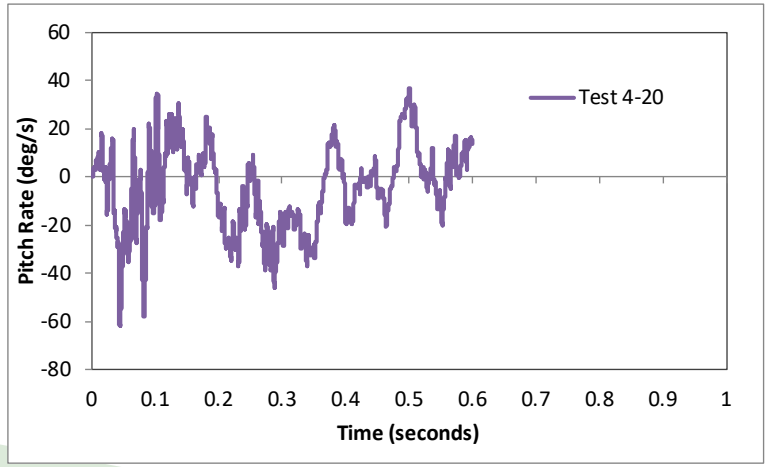
Angular Rate and Displacement Plots

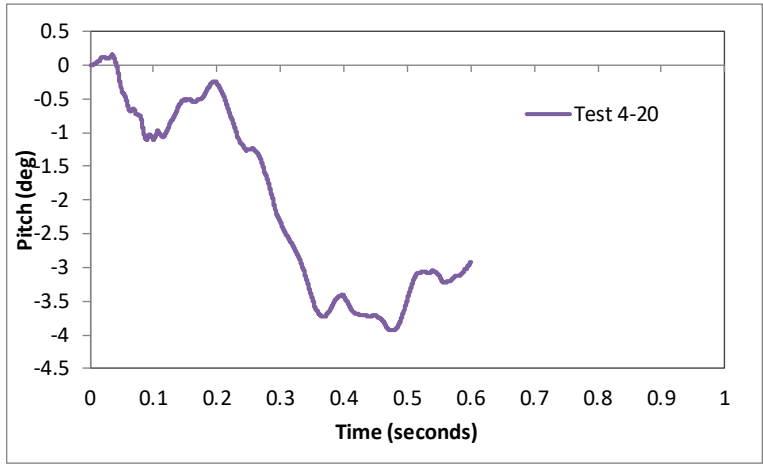






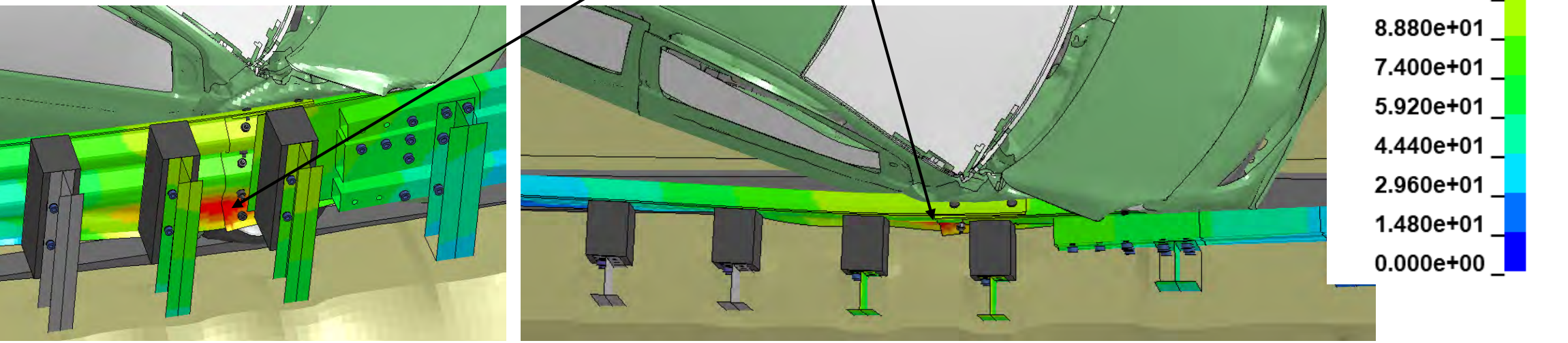






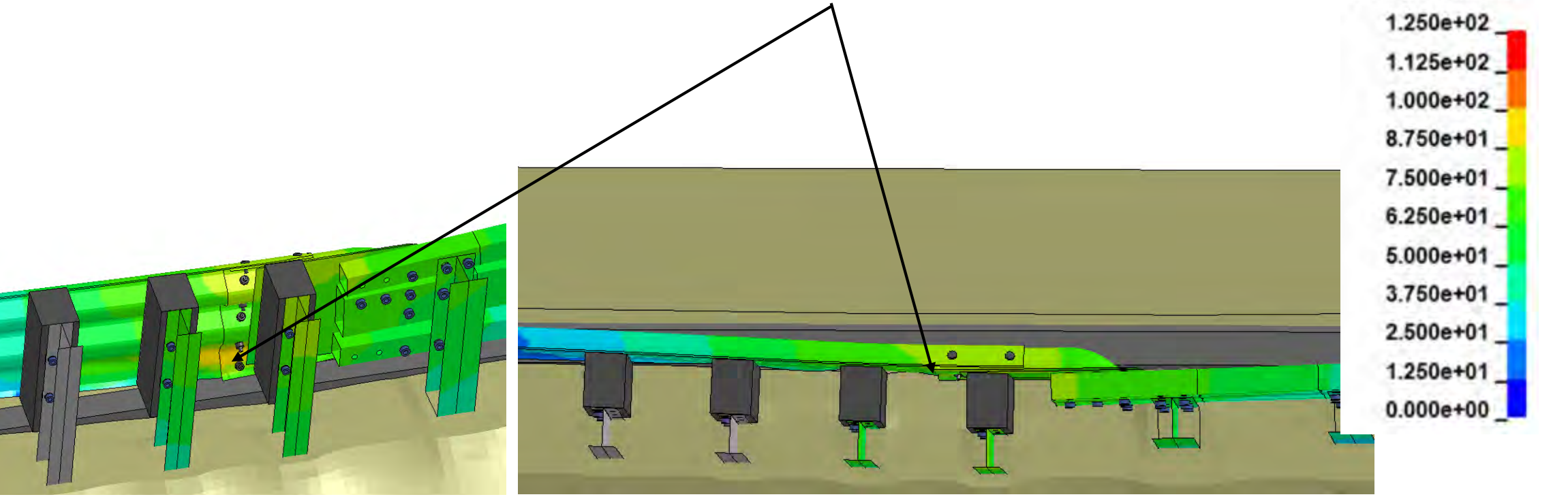
Lateral Dynamic Deflection

Maximum dynamic deflection = 5.8 in (148 mm) at 0.06 seconds



Lateral Permanent Deflection

Maximum permanent deflection = 4.65 in (118 mm)



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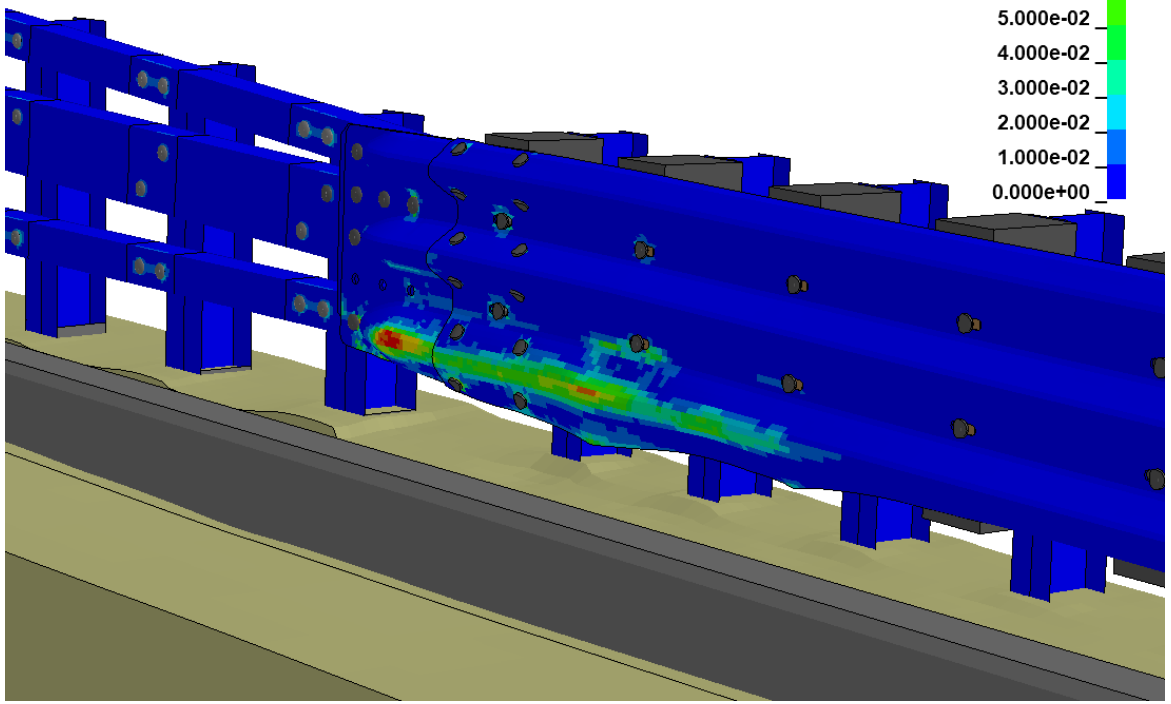
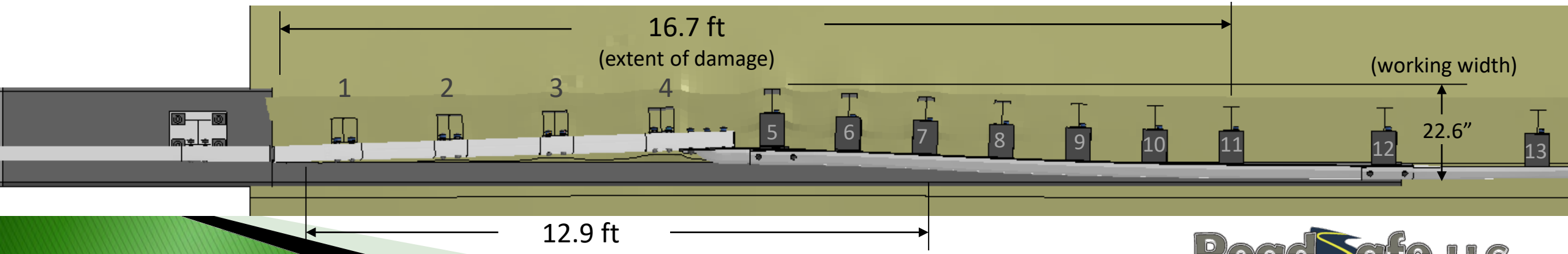
Barrier Damage

- Primary plastic deformations of the rail elements were limited to the thrie-beam and thrie-beam terminal connector. The highest strains were on the terminal connector element.
- Total length of system deformed was 16.7 ft extending from the first post of the thrie-beam to the start of the bridge rail.
- The vehicle was in contact with the system for approximately 12.9 ft.
- The maximum working width = 22.6 in
  - Measured as maximum dynamic lateral position of Post 5 (top-back of post) relative to the initial face of the barrier.





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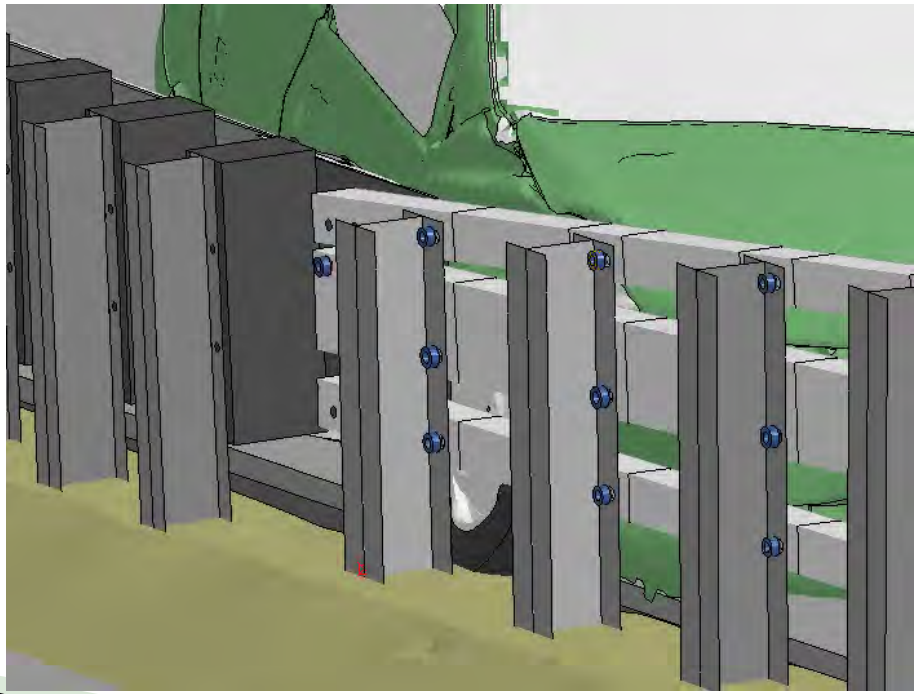
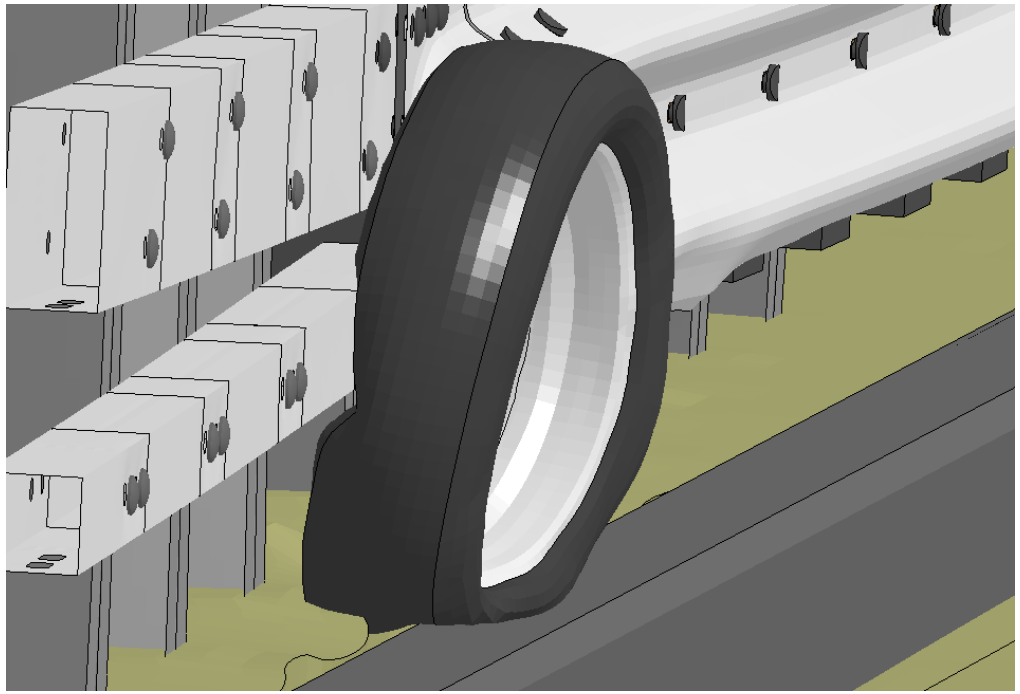
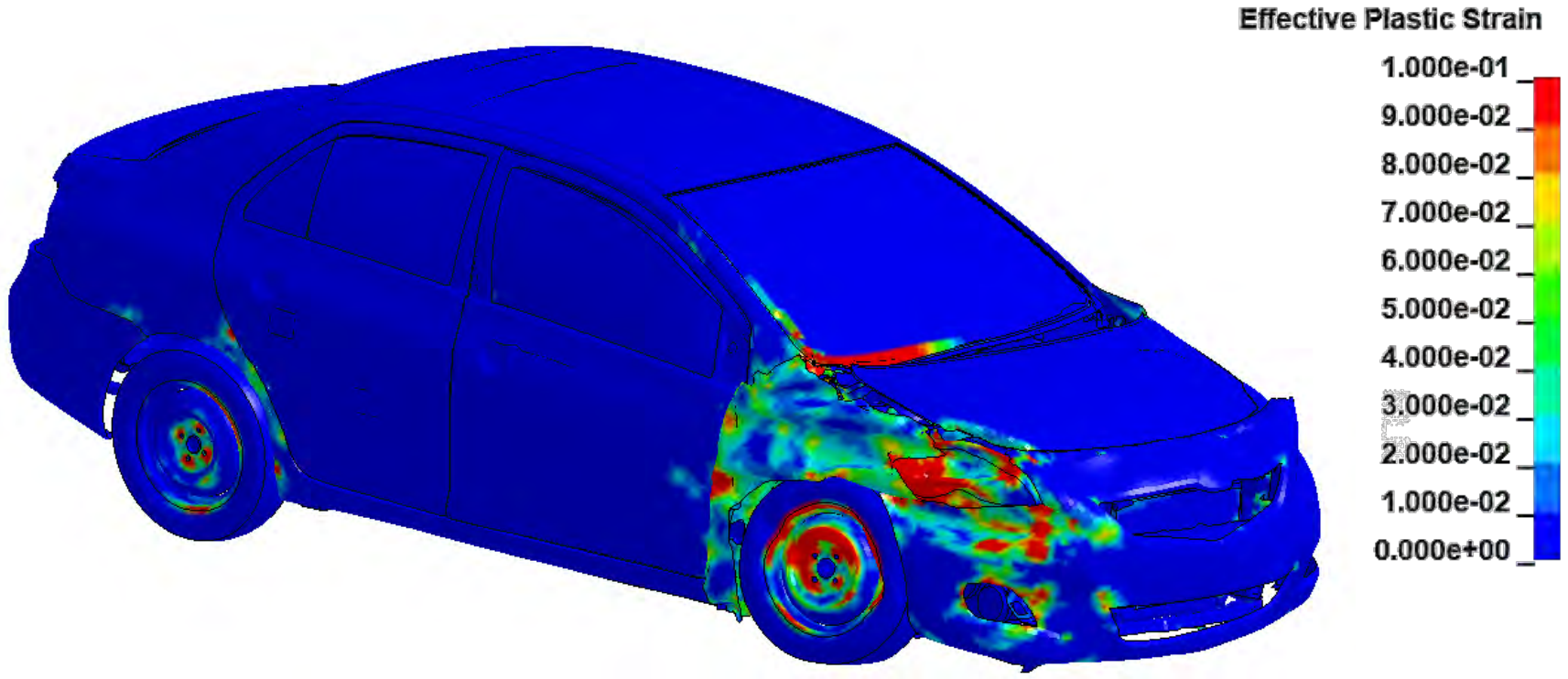
Assessment of Potential Vehicle Contact with Post

- The results of the analysis indicated that the tire would not contact the post during impact.





Effective Plastic Strain for Small Car Test



The most severe damages were to the front fender, the upper and lower control arm of front suspension, front wheel, lower-impact edge of windshield (cracking), with light damage to the rear quarter panel of the vehicle.

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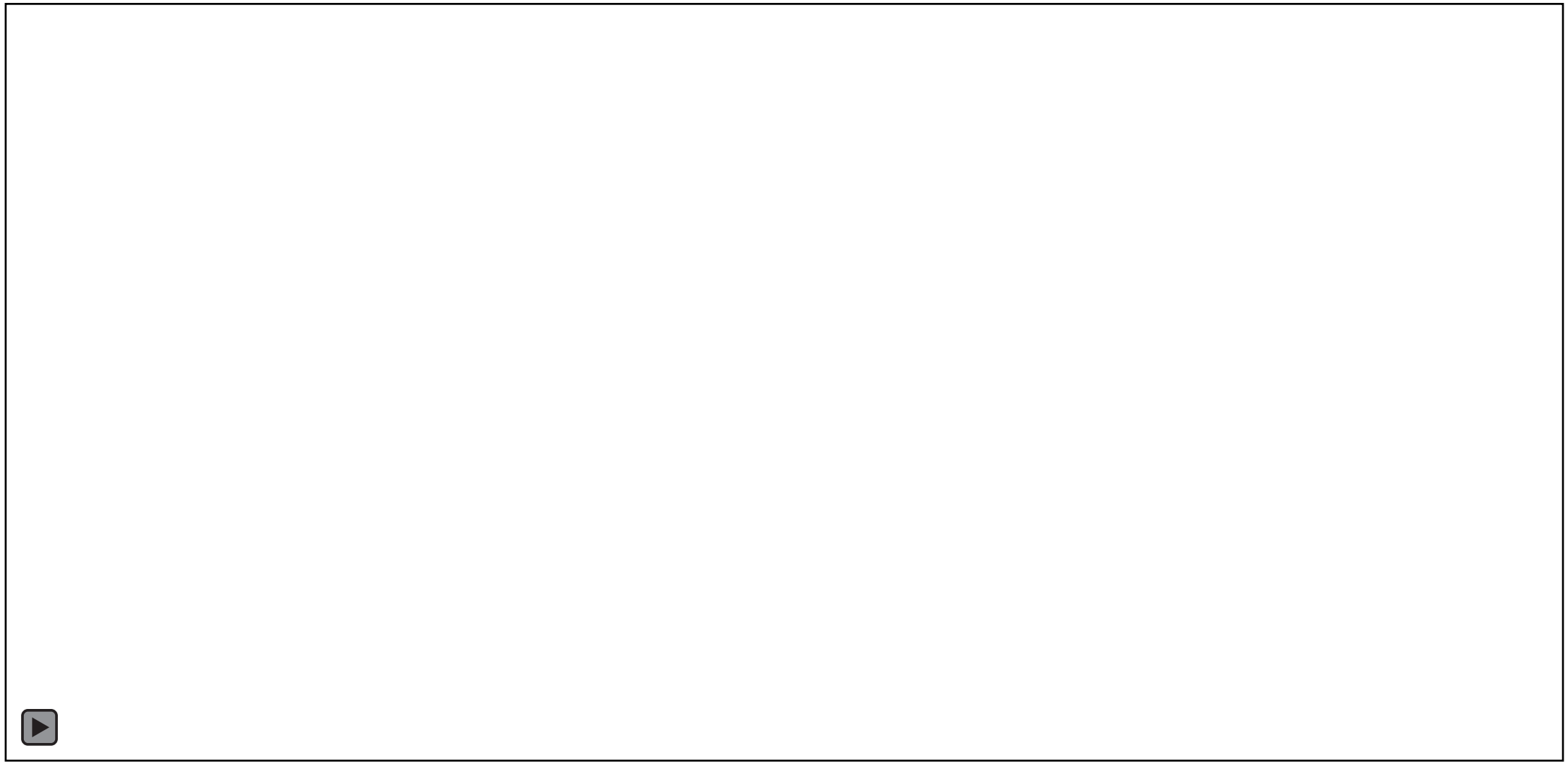
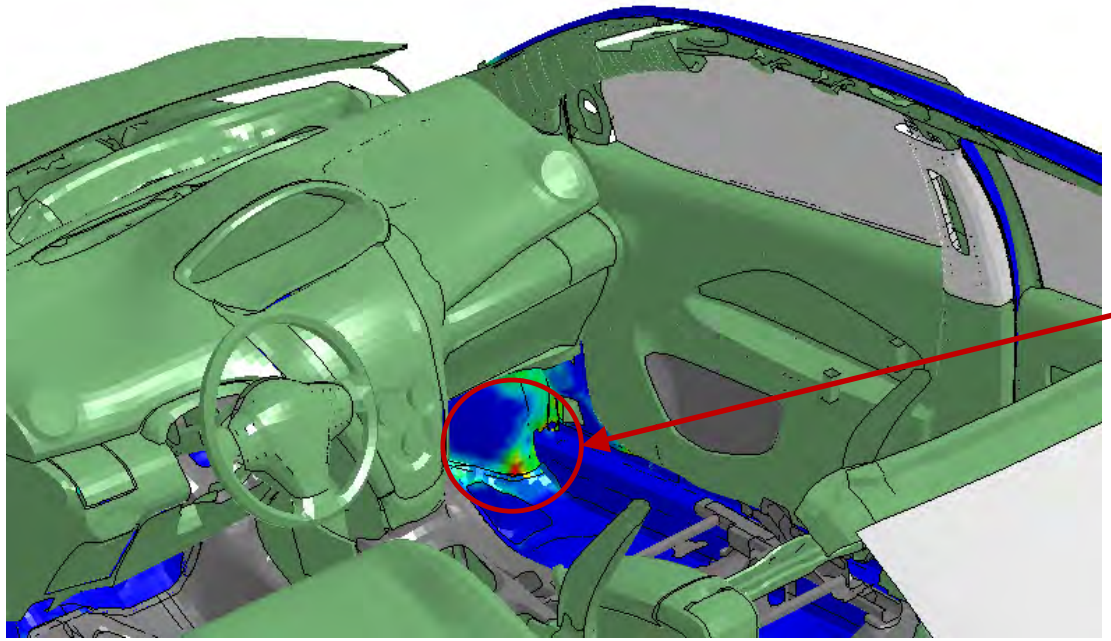
Occupant Compartment Intrusion (OCI) Video



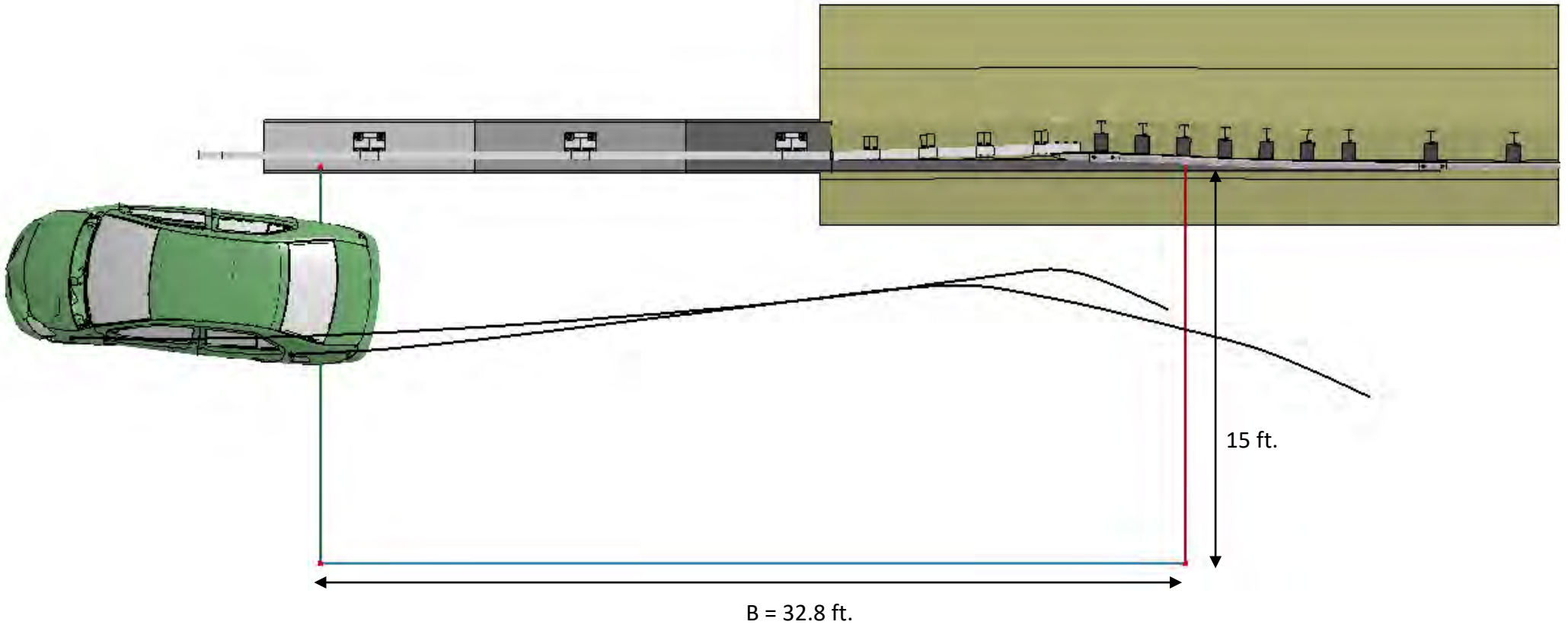
Occupant Compartment Intrusion (OCI)



Maximum OCI was < 1 **inch** and occurred at the right-front toe-pan at the wheel well. *Maximum allowable is 9".*

Exit Box – 3-Bar Trans – Test 4-20

The driver-side front tire wheel track was used to determine the beginning location of the exit box. From MASH pg. 97: "All wheel tracks of the vehicle should not cross the parallel line within the distance B."



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Conclusions Regarding Test 4-20 on the 3-Bar Transition

- The barrier successfully contained and redirected the 1100P vehicle.
- The vehicle remained upright and stable through impact and redirection, with relatively low angular displacements
  - Max Roll = **6.2 degrees** and Max Pitch = **3.9 degrees**.
- The OIV and ORA were within preferred limits specified in MASH.
  - OIV_x = **24.3 ft/s** and OIV_y = **25.9 ft/s**
  - ORA_x = **4.2 G** and ORA_y = **7.4 G** (*values dependent on time of occupant impact, particularly for the x-dir.*)
- The maximum **occupant compartment deformation** was less than **1 inch** and occurred at the lower right-front toe pan. This value is well within acceptable limit of 9 inches.
- The vehicle also **remained within the "exit box"** limits.
- Barrier damage was moderate and barrier deflections were considered low to moderate.
- The greatest deformation of the barrier occurred at the thrie-beam terminal connector and was:
  - Max Dynamic = **5.8 inches**; Max Permanent = **4.7 inches**

Conclusions on Test 4-20 on the 3-Bar Transition

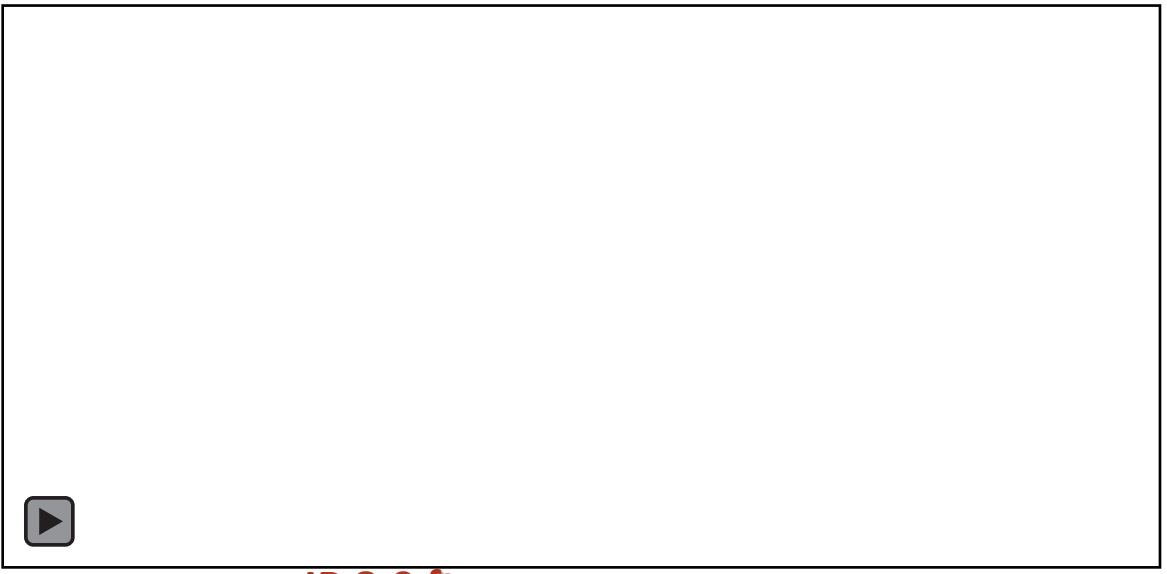
Evaluation Factors		Evaluation Criteria	Results
Structural Adequacy	A	Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is 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

Determination of CIP for Test 4-22

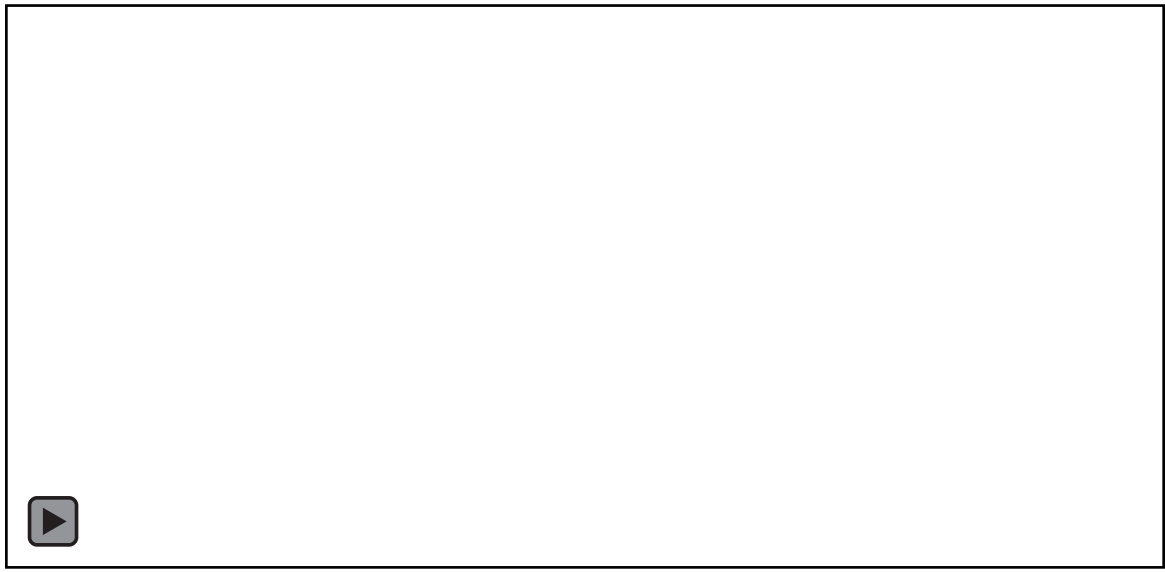
- CIP will be determined using FEA based with respect to maximizing potential for wheel snag on the first post of the tube-rail section of the transition.
- Analysis cases evaluated (Note: CIP for rigid barrier = 5 ft)
  - **IP = 5 ft** (CIP for Rigid Barrier)
  - **IP = 7.0 ft**
  - **IP = 8.0 ft**
  - **IP = 9.0 ft**

CIP Analysis Cases

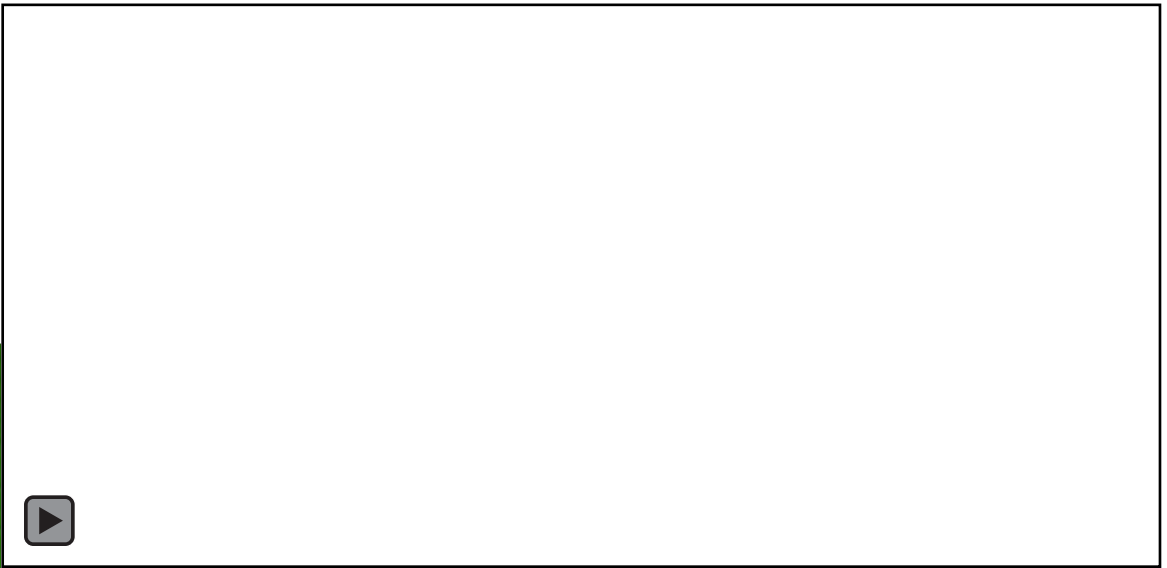
IP 5.0 ft



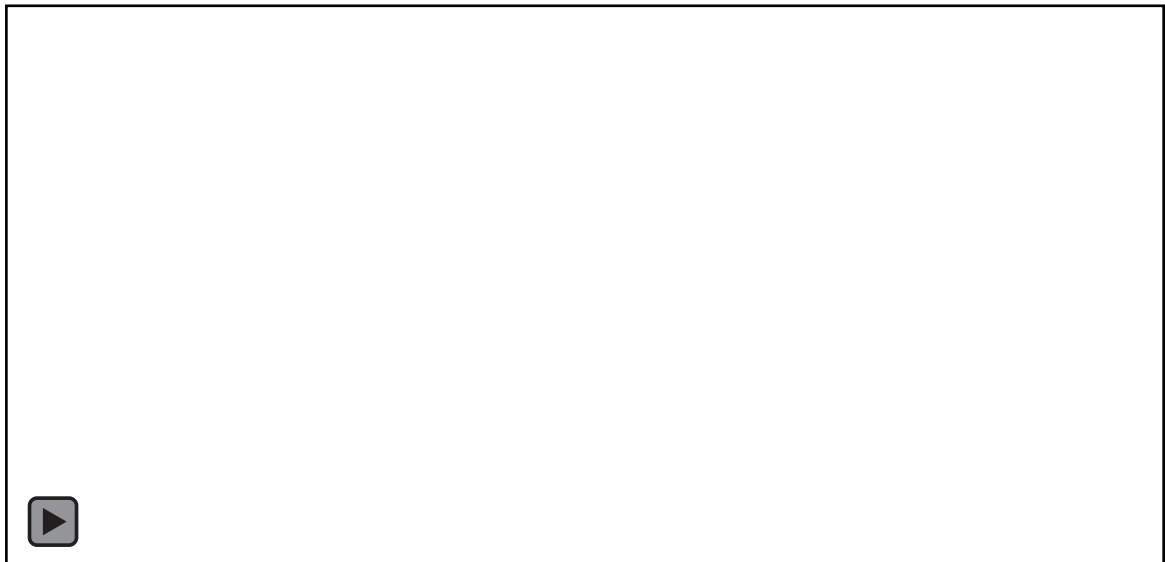
IP 7.0 ft



IP 8.0 ft

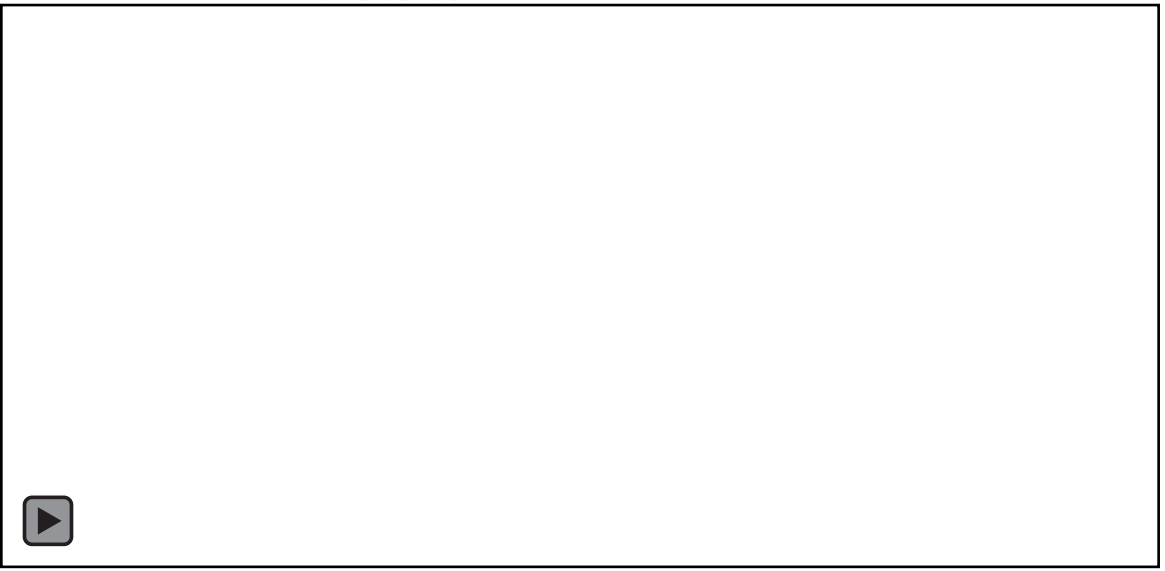


IP 9.0 ft

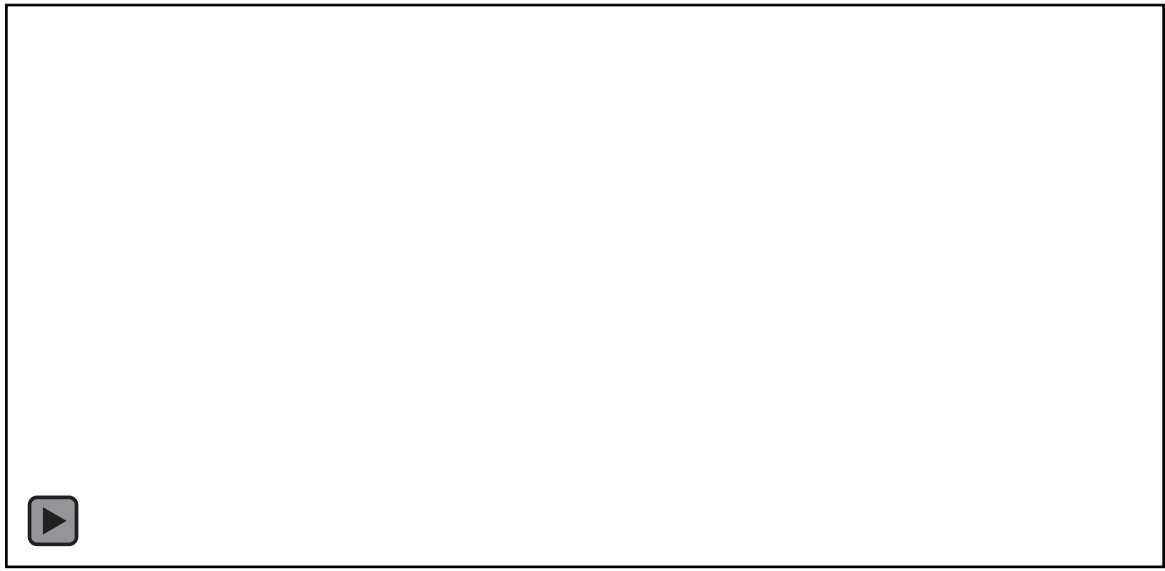


CIP Analysis Cases

IP 5.0 ft

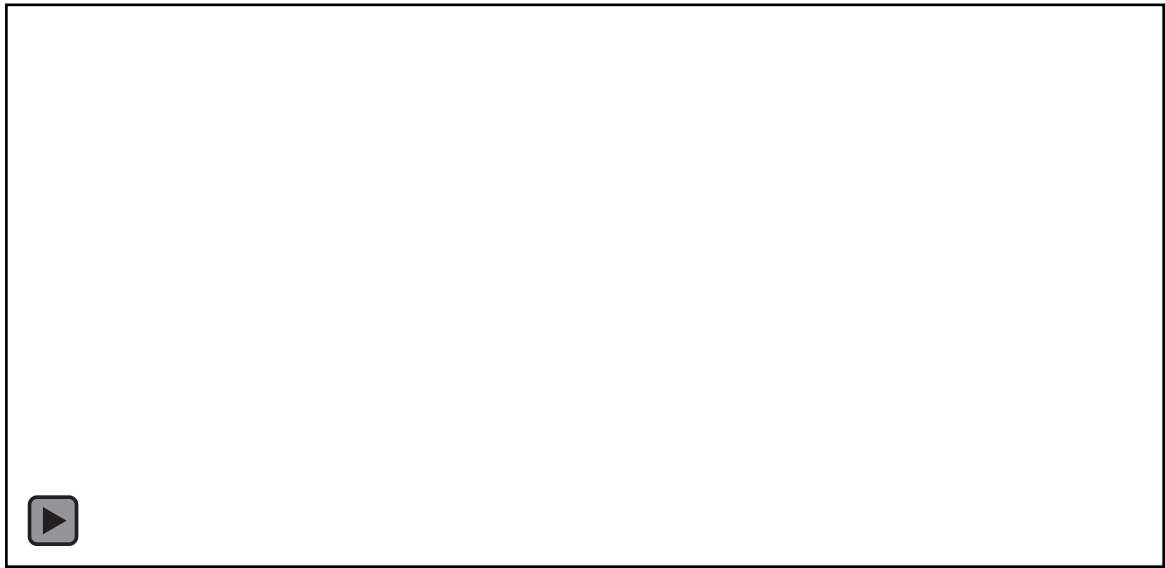


IP 7.0 ft



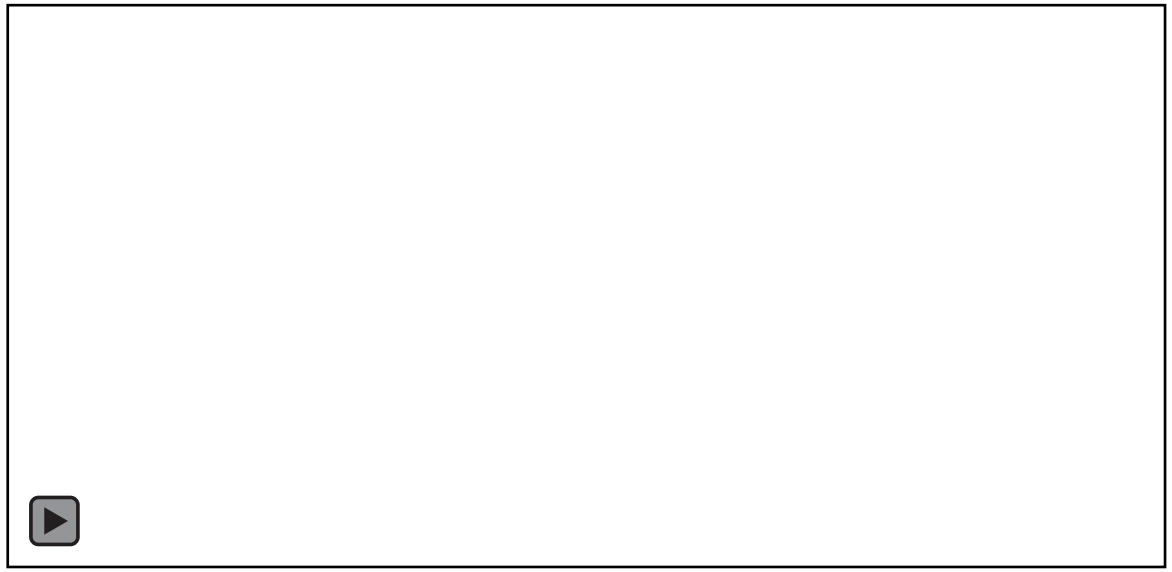
IP 8.0 ft

IP 9.0 ft

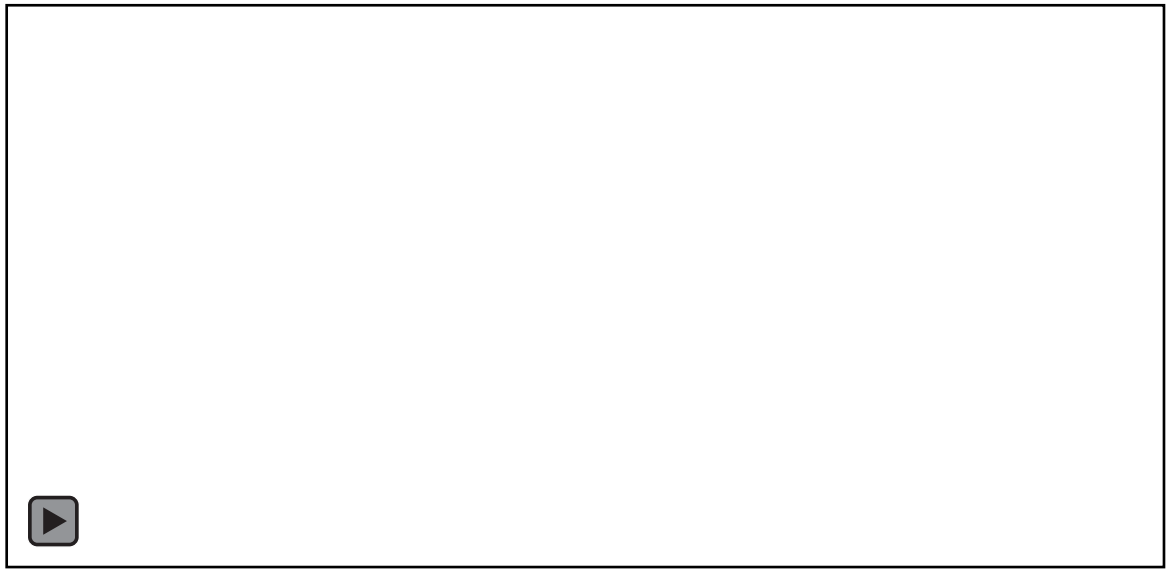


CIP Analysis Cases

IP 5.0 ft



IP 7.0 ft

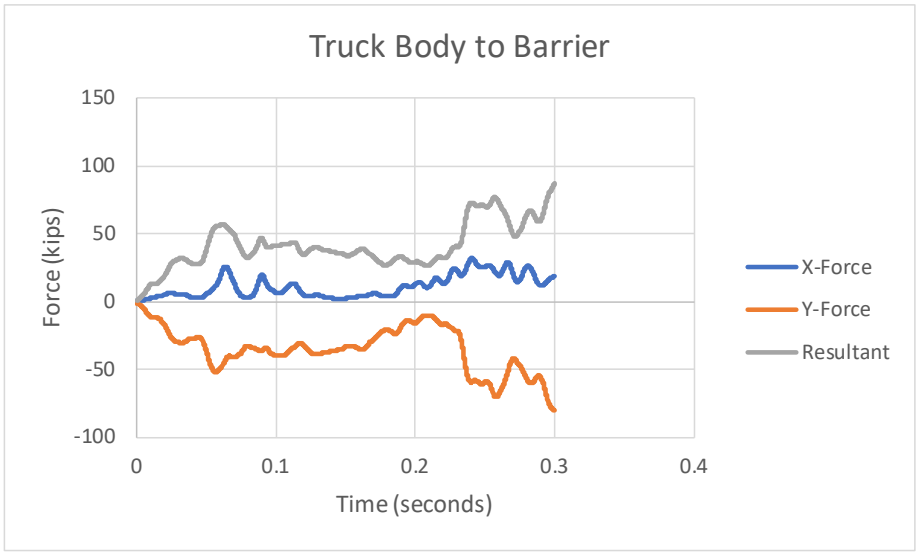


IP 8.0 ft

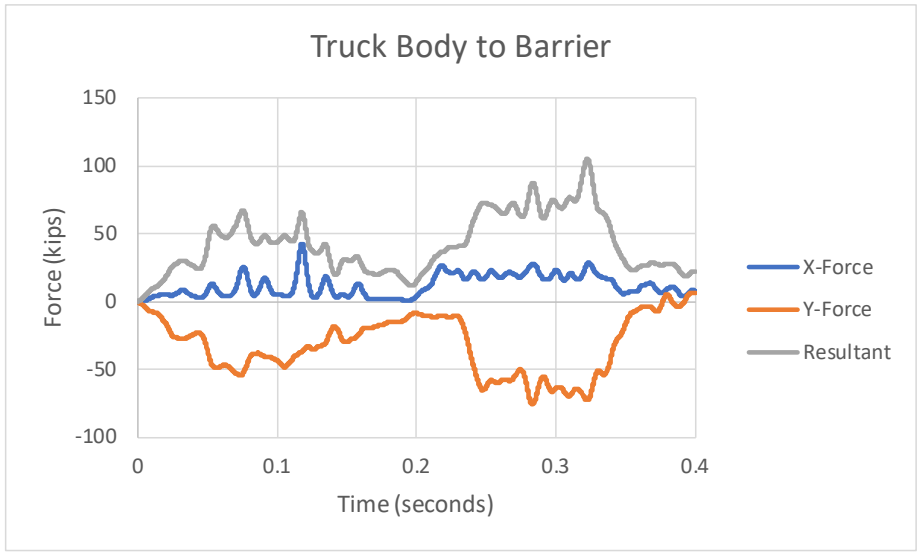
IP 9.0 ft

CIP Analysis Cases

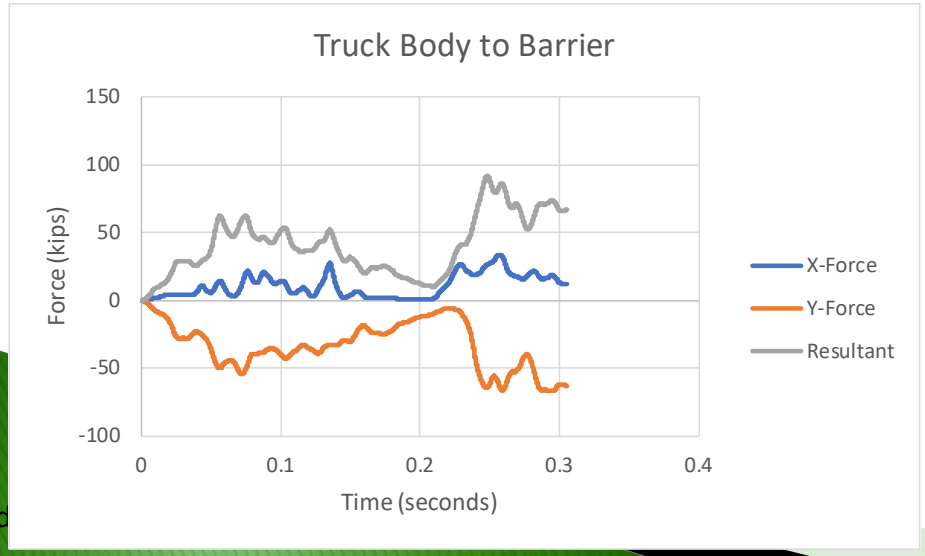
IP 5.0 ft



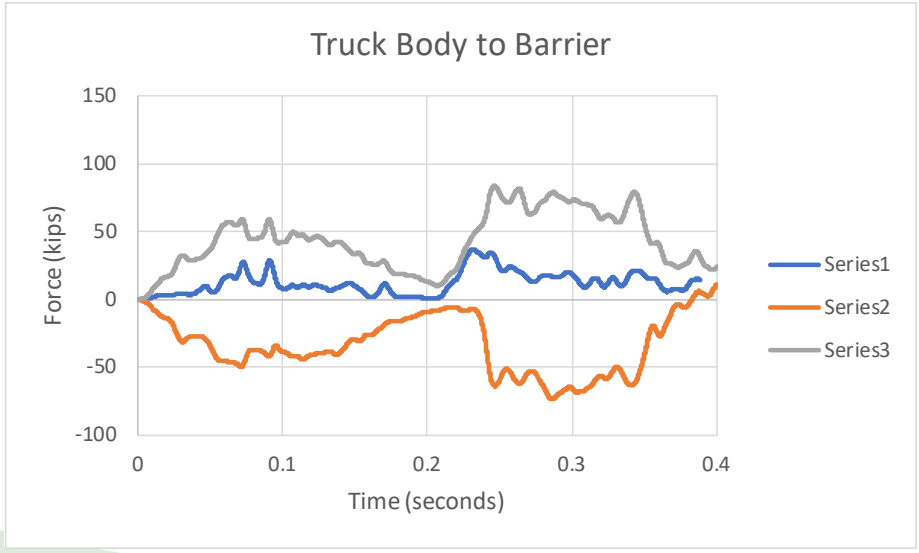
IP 7.0 ft



IP 8.0 ft



IP 9.0 ft



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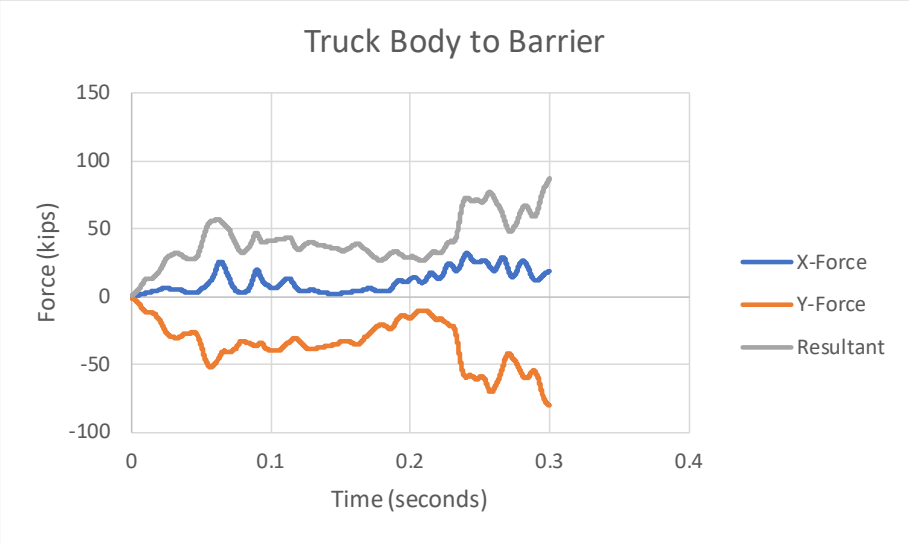
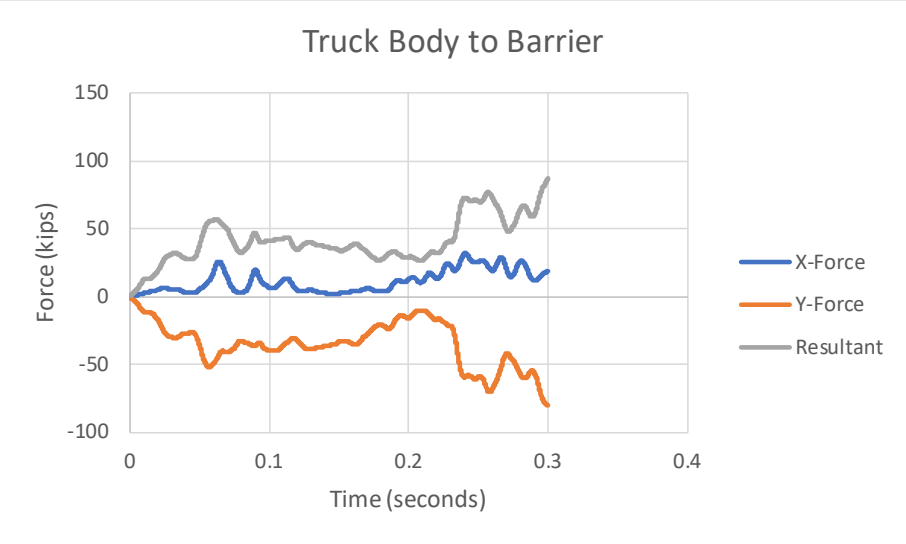
CIP Analysis Cases

IP 5.0 ft



Successive Overlay



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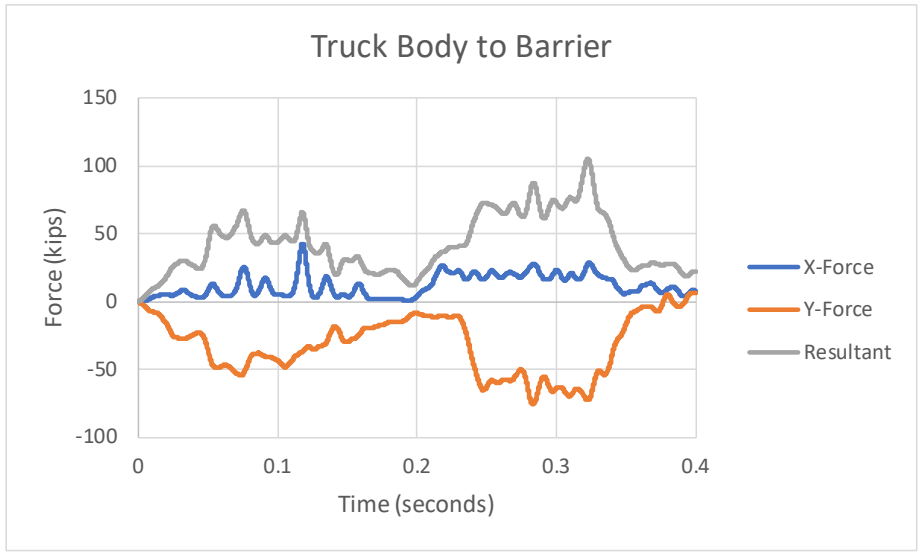
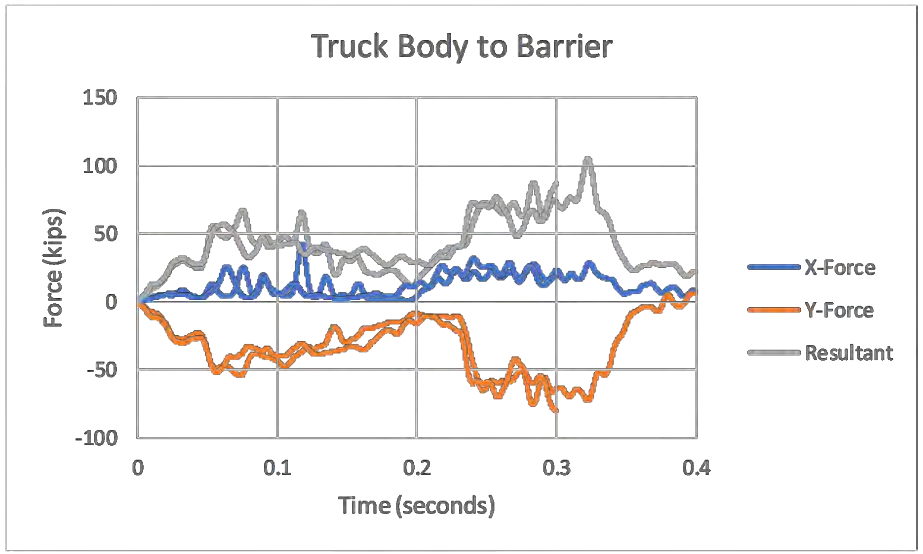
CIP Analysis Cases

IP 7.0 ft



Successive Overlay



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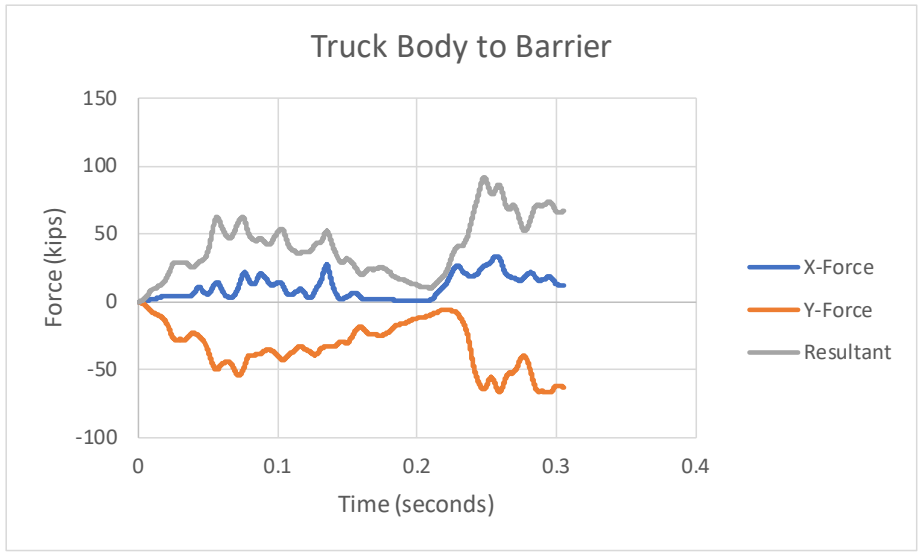
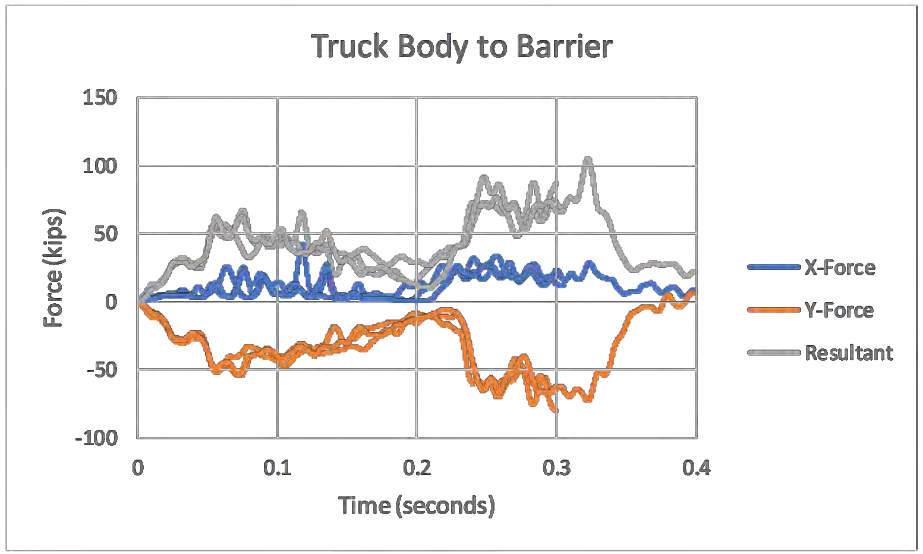
CIP Analysis Cases

IP 8.0 ft



Successive Overlay



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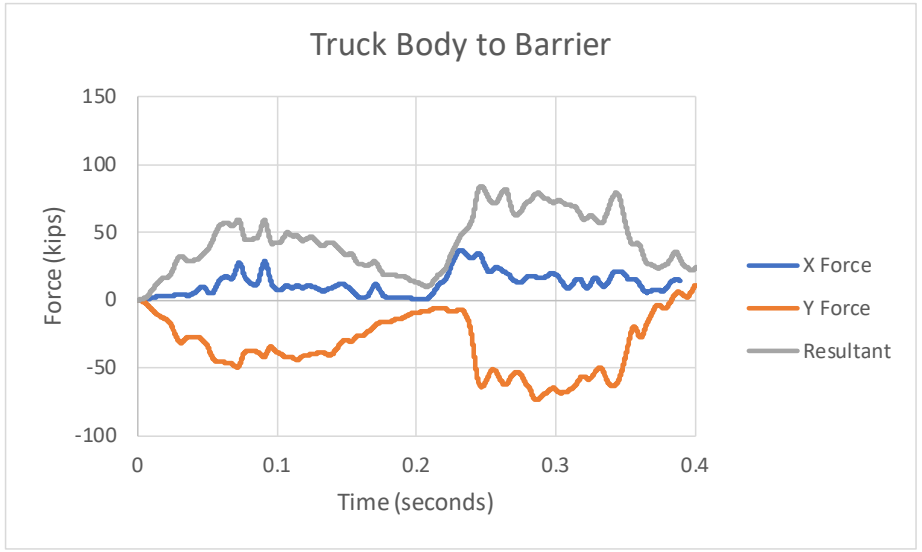
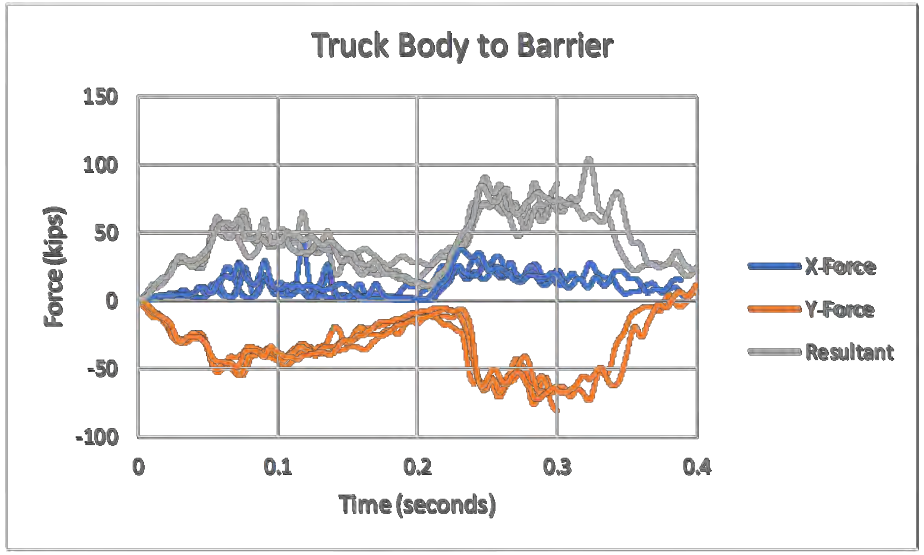
CIP Analysis Cases

IP 9.0 ft



Successive Overlay



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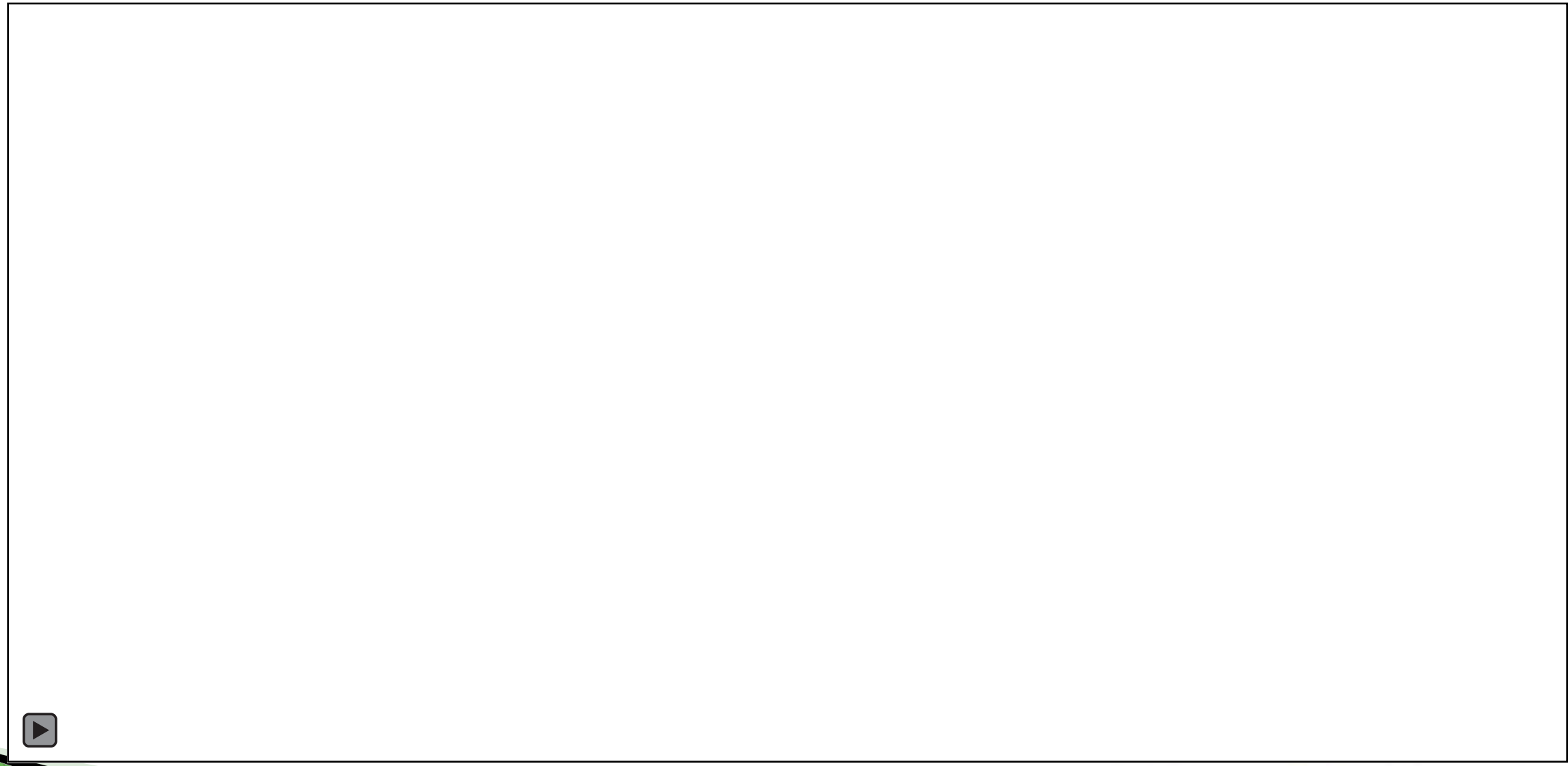
Underneath Cargo-Bed Viewpoint



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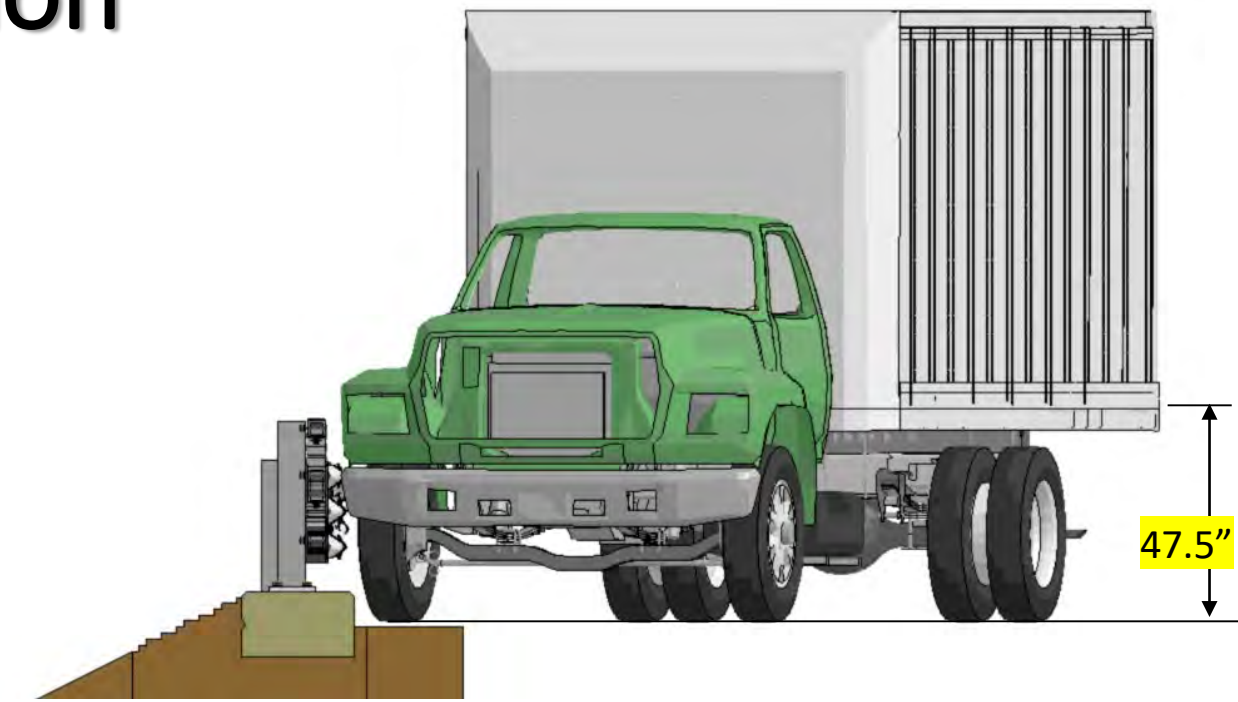
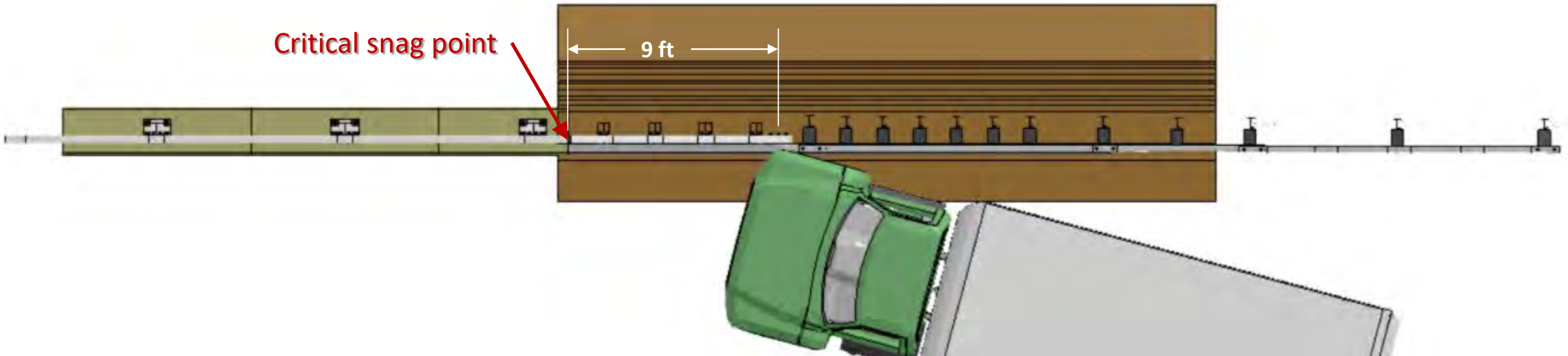
MASH Test 4-22 Simulation

- **Impact Conditions**
  - Mass = 22,061 lb
  - Impact Speed = 56 mph (90 km/hr)
  - Impact Angle = 15 degrees
  - Impact Point = 9 ft upstream of Bridge Rail tube ends
- **Vehicle Model**
  - F800_No-Box_181114_UboltF0p17.k
  - TruckBox_181114.k
  - F800-SuspenStress_FRONT_35N.k
  - F800-SuspenStress_REAR_60N.k
  - Vehicle Mass = 10,000 kg (22,046 lb)

Ford 800 Surrogate





Movies

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TRAP – Summary Table

Occupant Risk Factors		MASH Test 4-22
Occupant Impact Velocity (ft/s)	x-direction	2.3
	y-direction	-14.8
	at time	at 0.1553 seconds on left side of interior
THIV (ft/s)		15.1
		at 0.1553 seconds on left side of interior
Ridedown Acceleration (g's)	x-direction	-8.9 (0.3536 - 0.3636 seconds)
	y-direction	-5.5 (1.4779 - 1.4879 seconds)
PHD (g's)		9 (0.3536 - 0.3636 seconds)
ASI		0.69 (0.0757 - 0.1257 seconds)
Max 50-ms moving avg. acc. (g's)	x-direction	-2.9 (0.1877 - 0.2377 seconds)
	y-direction	5.9 (0.0750 - 0.1250 seconds)
	z-direction	-3.7 (0.0552 - 0.1052 seconds)
Maximum Angular Disp. (deg)	Roll	-26.3 (0.7569 seconds)
	Pitch	-11.9 (0.8730 seconds)
	Yaw	-35.3 (1.4987 seconds)

MASH Criteria

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

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

< 75 deg ✓

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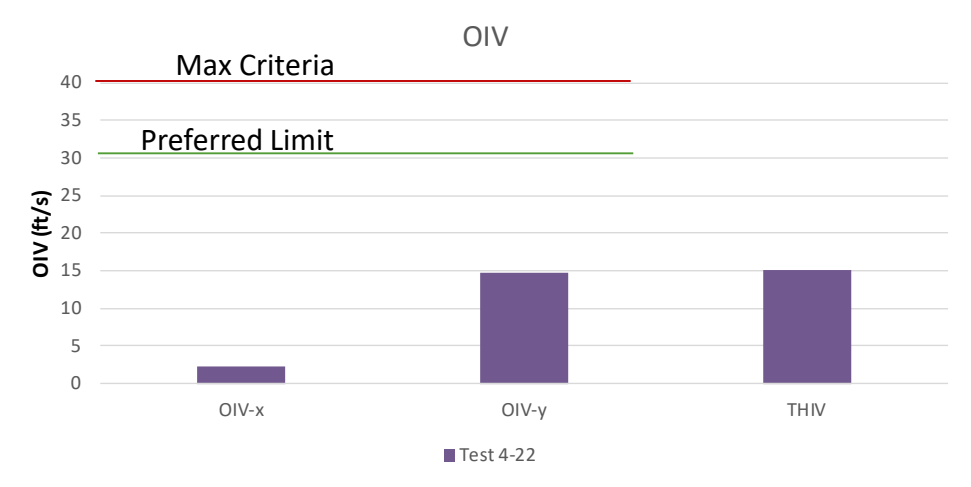
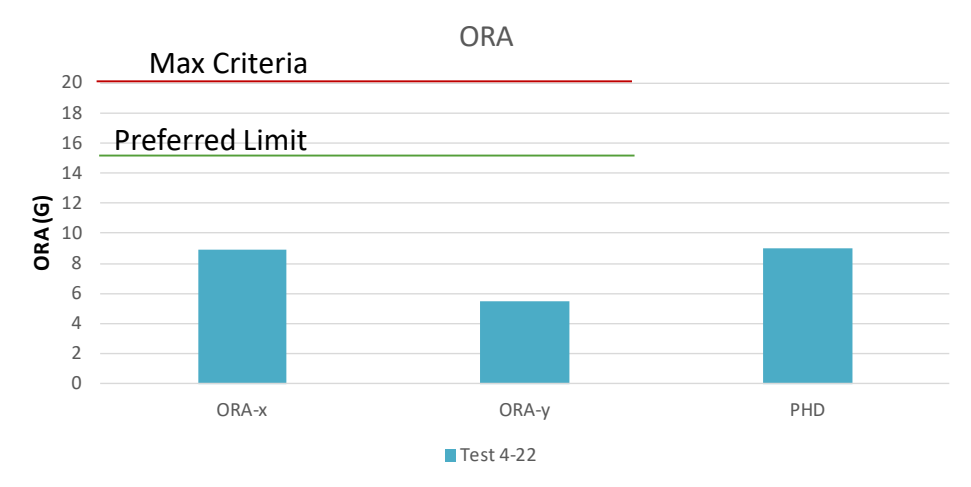
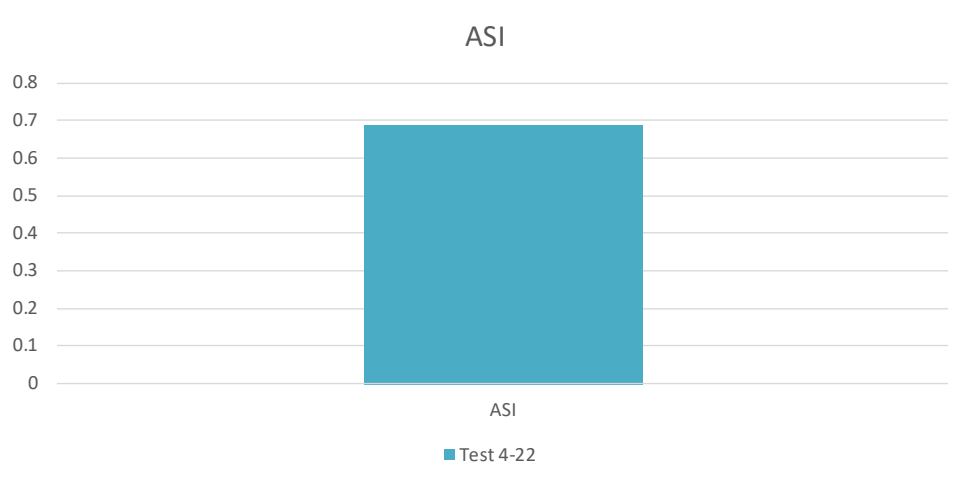
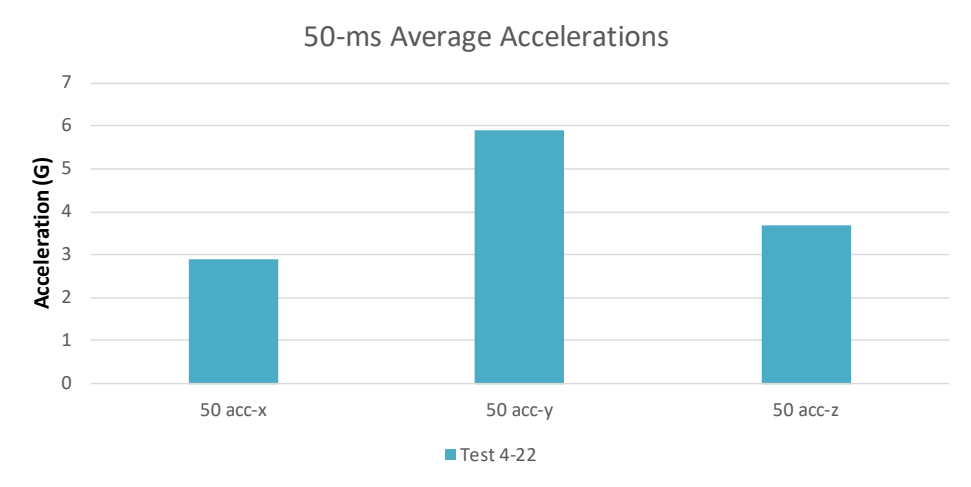
TRAP









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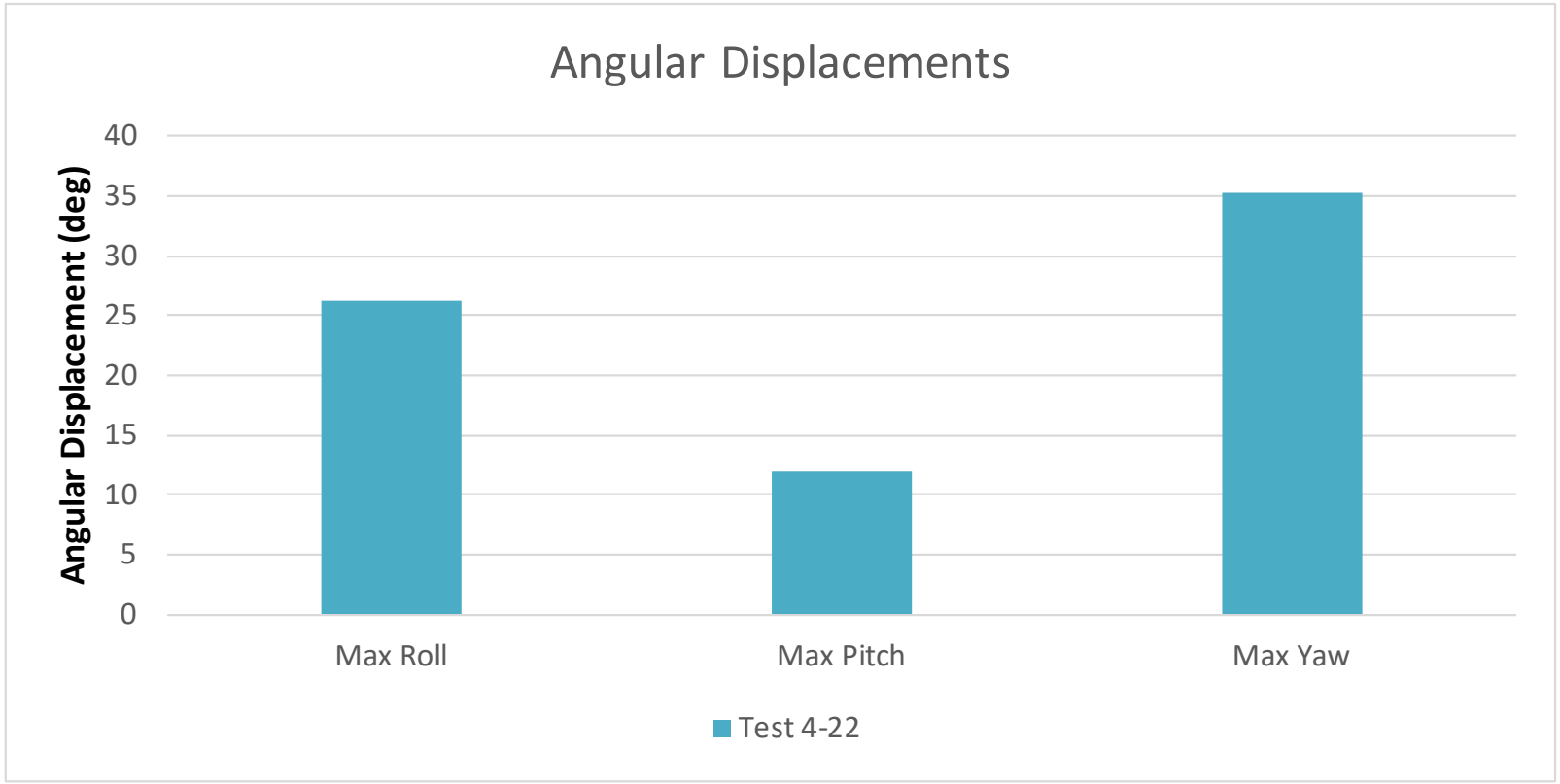
TRAP



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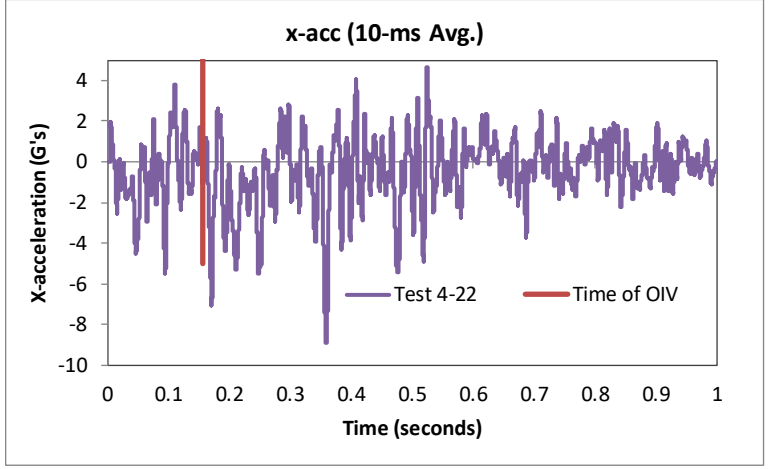
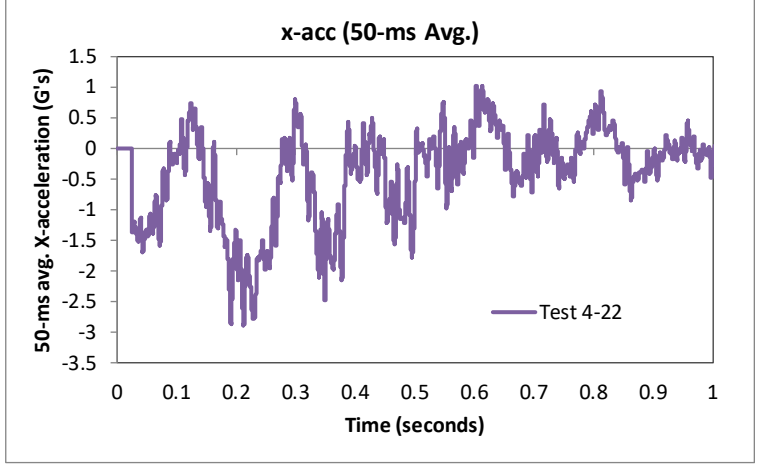
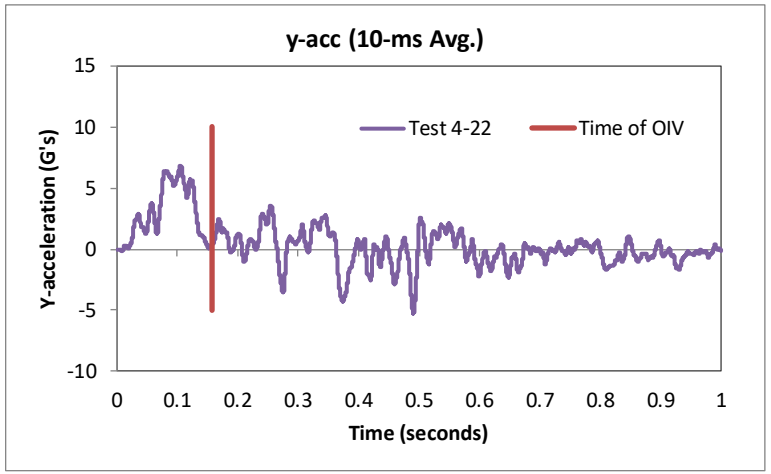
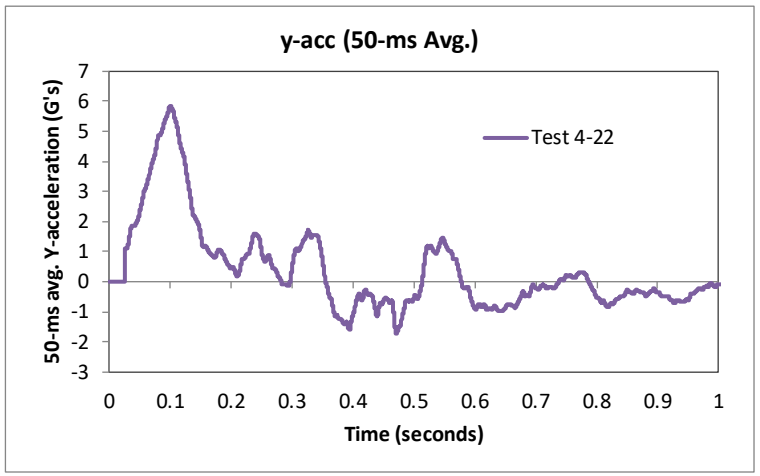
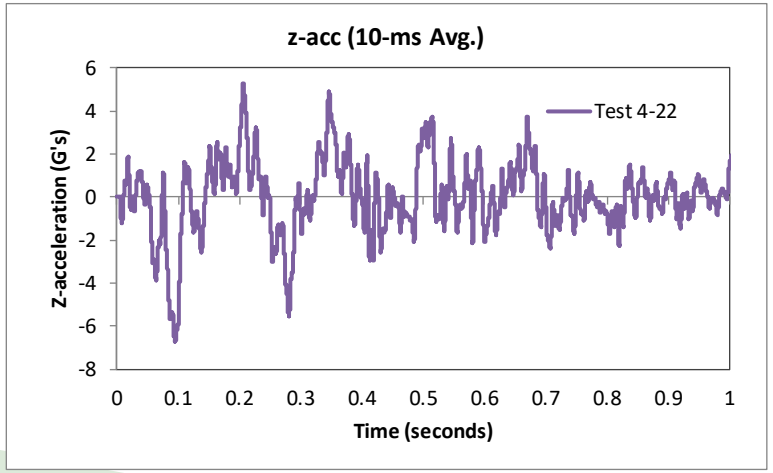
Acceleration Plots

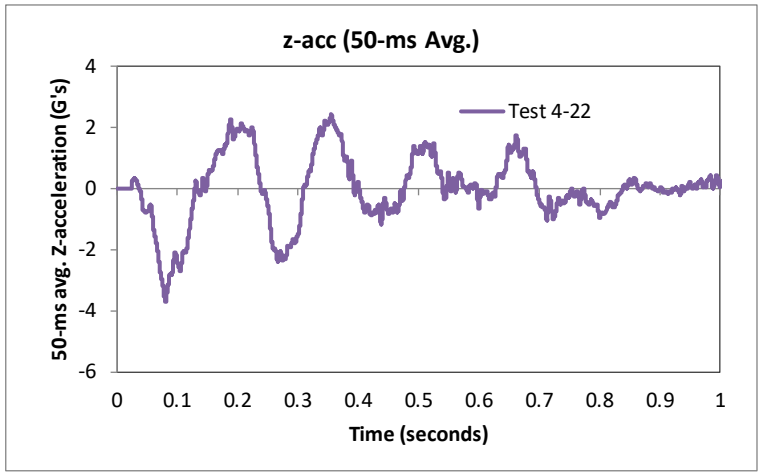




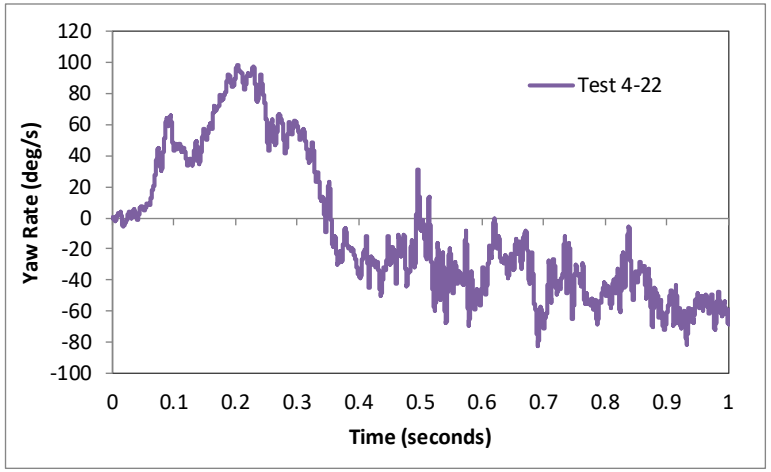


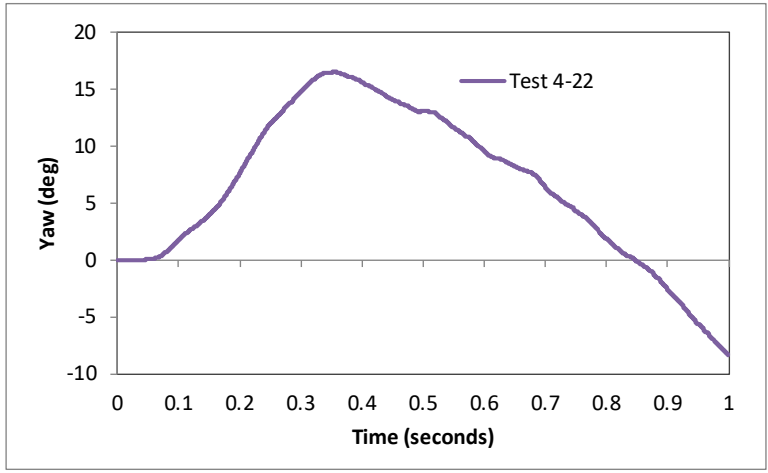


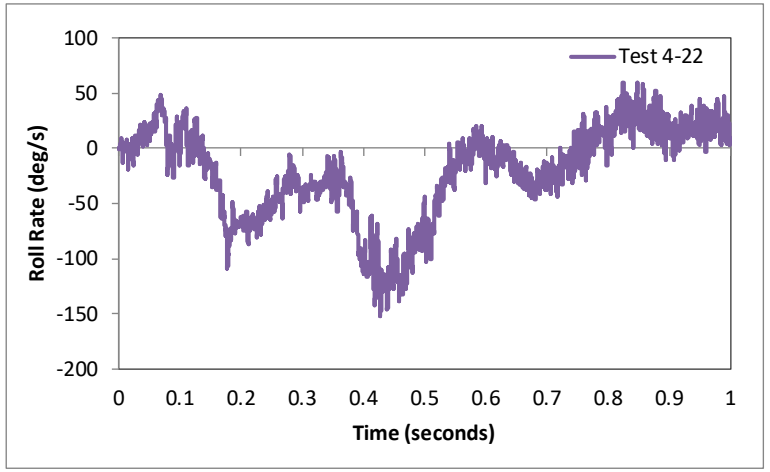


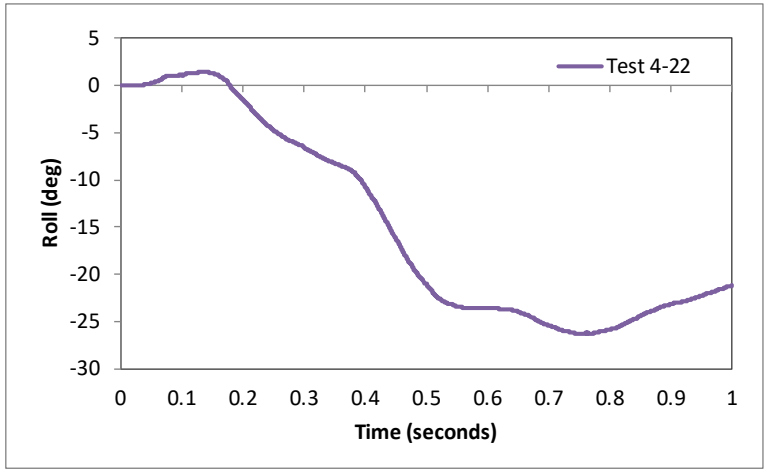


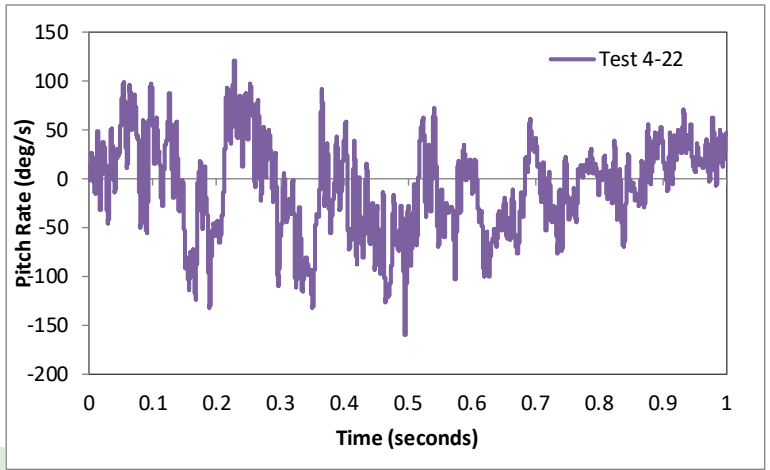
Angular Rate and Displacement Plots

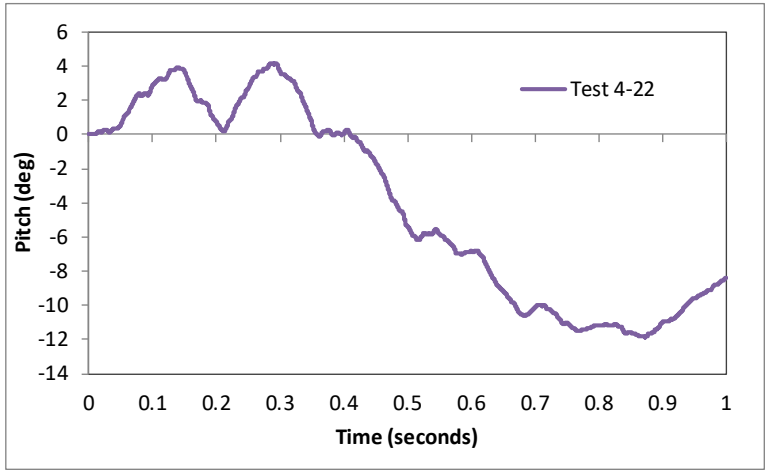




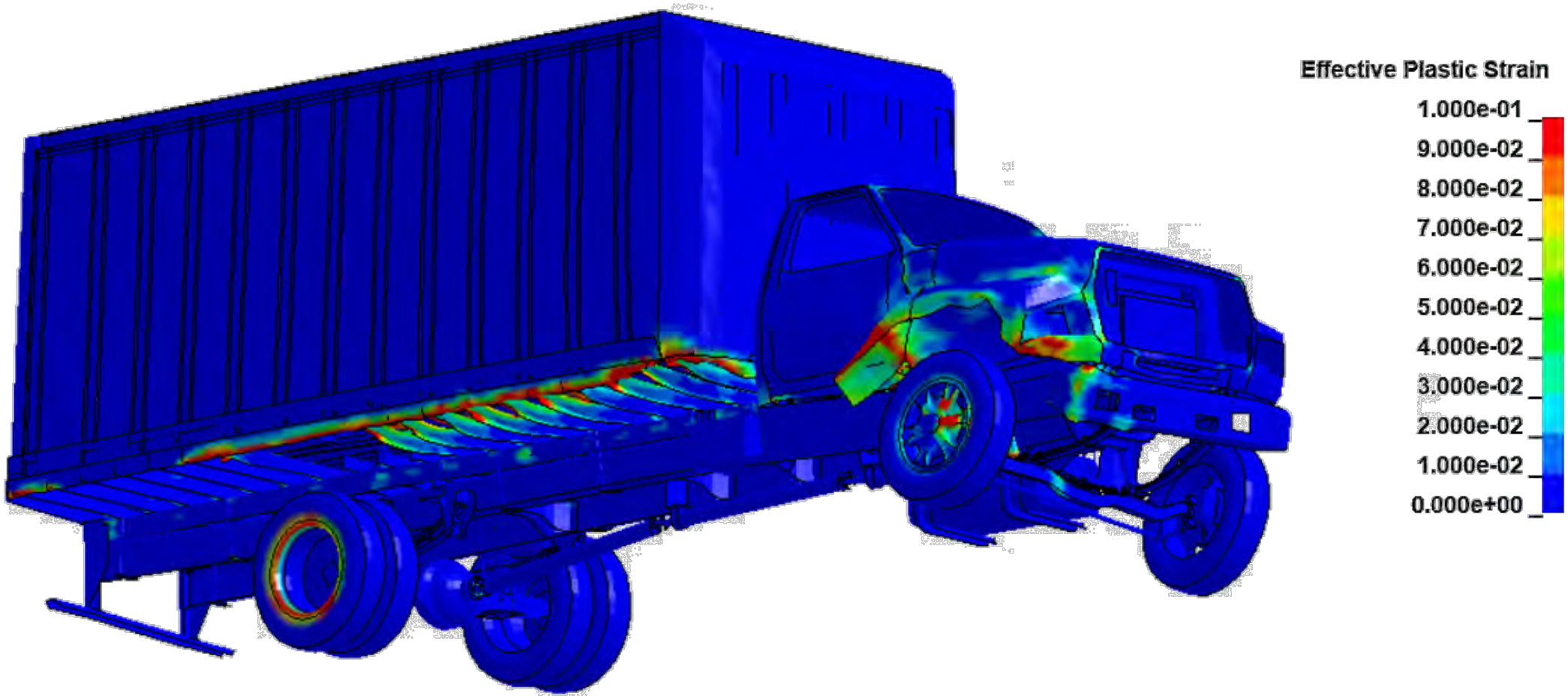








Effective Plastic Strain for SUT Tests



Truck Damages:
The front bumper, front fender, front-right suspension, front axle and wheel, and rear wheel.

Cargo-Box Damages:
Front-lower corner of box, lateral floor beams, main bed rail, wood flooring, and side rail.

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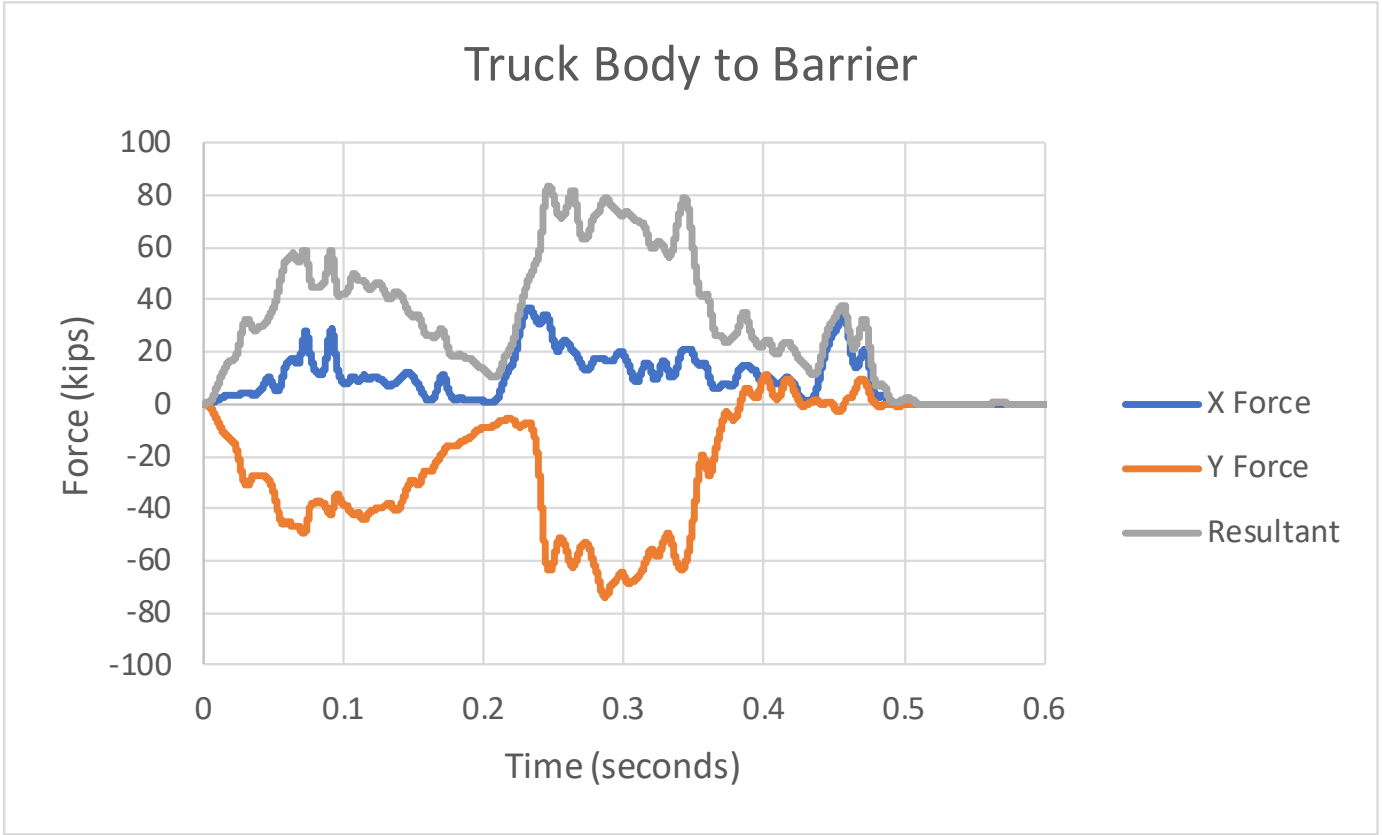
Impact Forces on Transition



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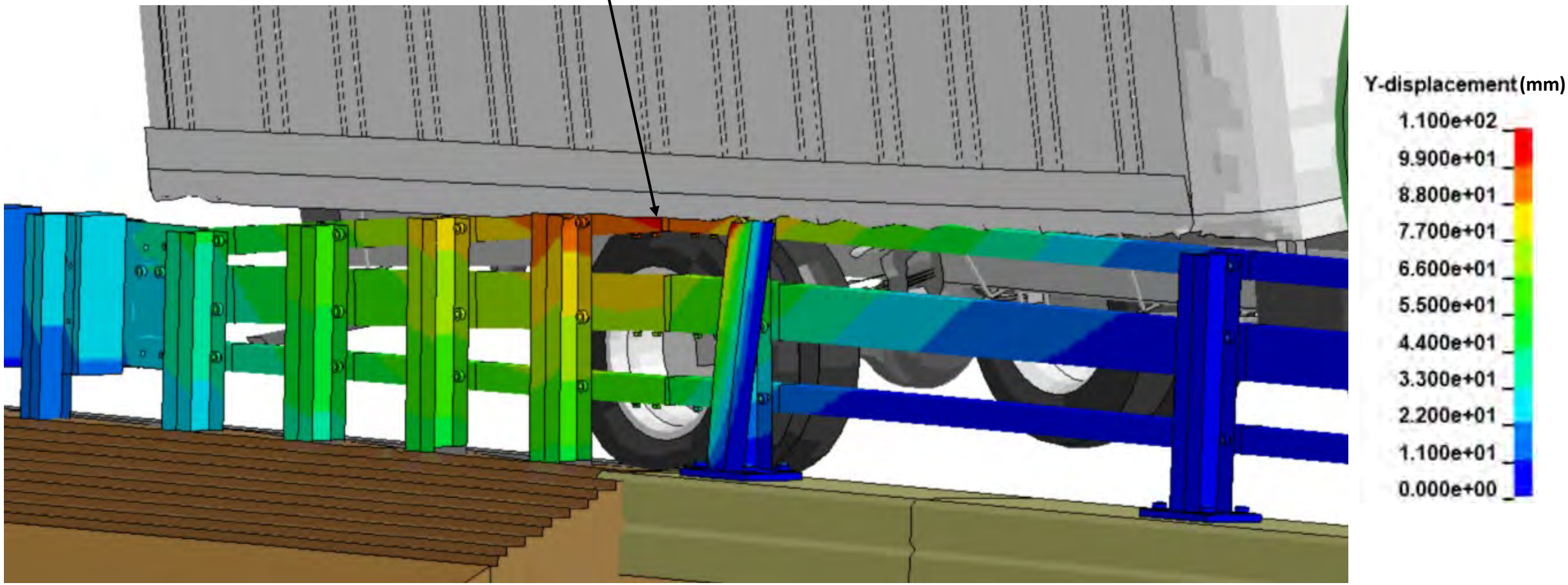
Lateral Dynamic Deflection

Maximum dynamic deflection = 4.29 in (109 mm)



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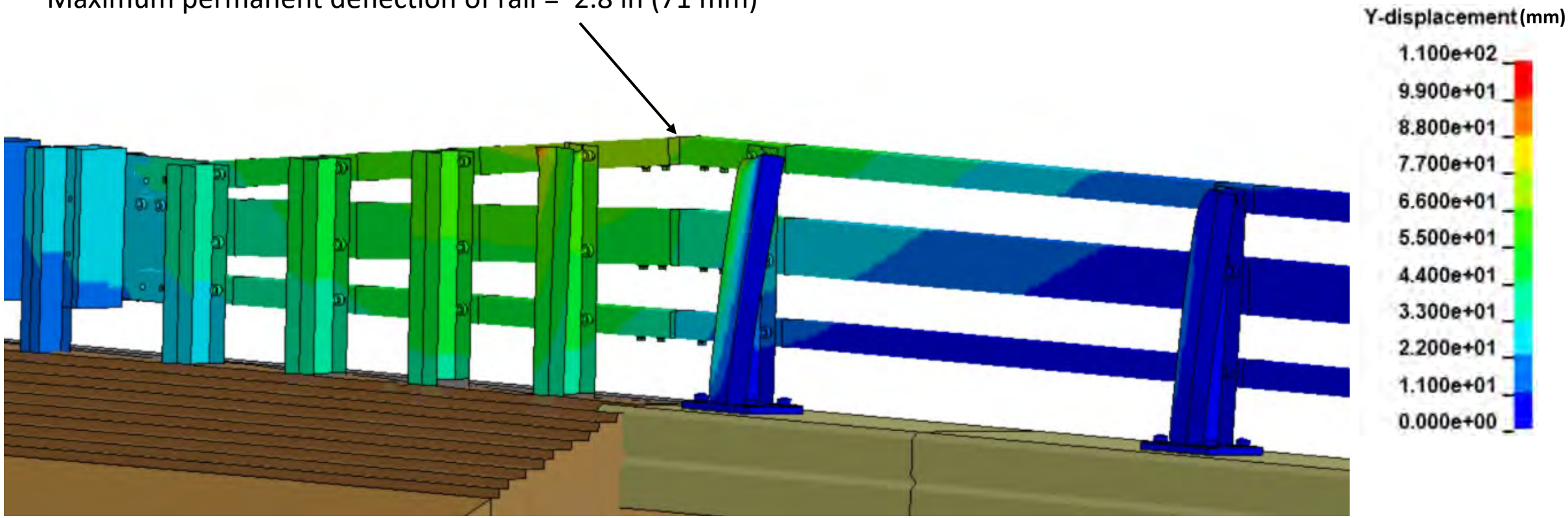
Lateral Permanent Deflection

Maximum permanent deflection of rail = 2.8 in (71 mm)



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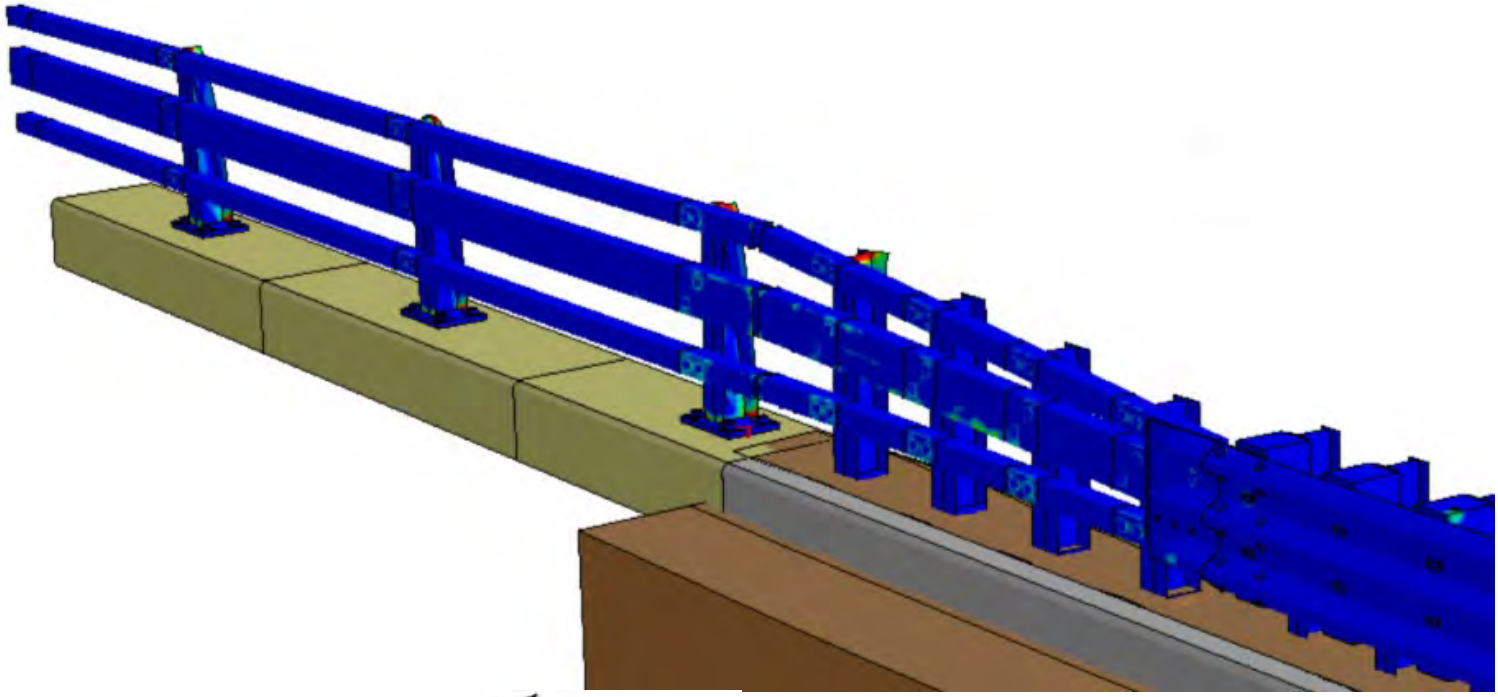
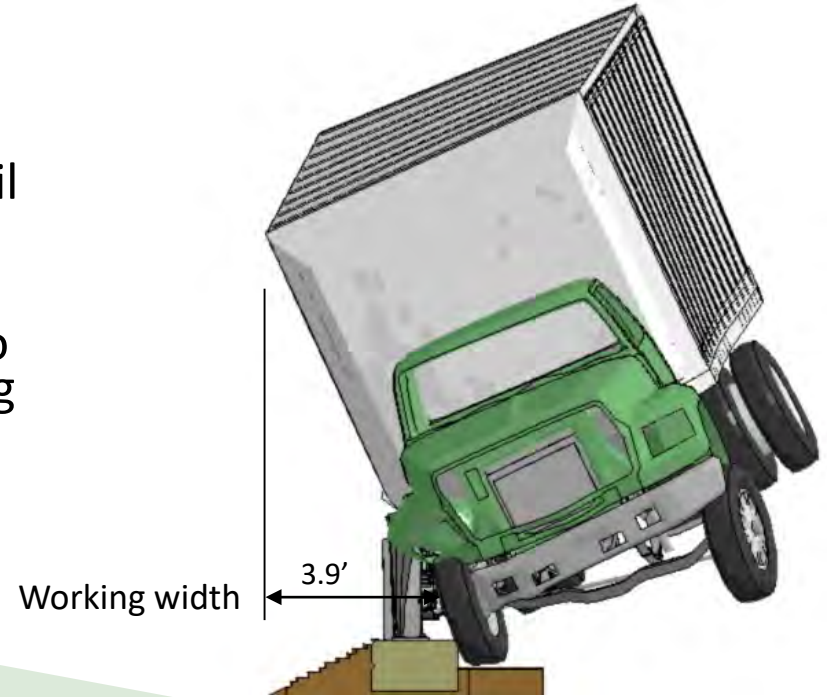
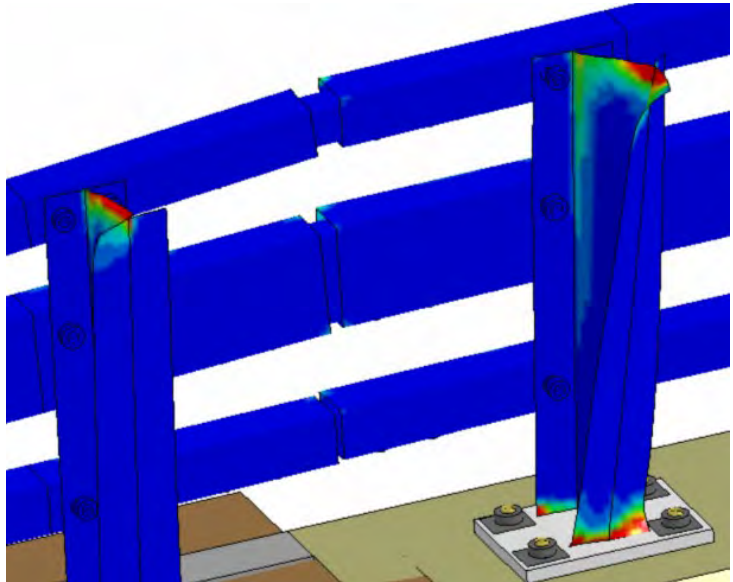
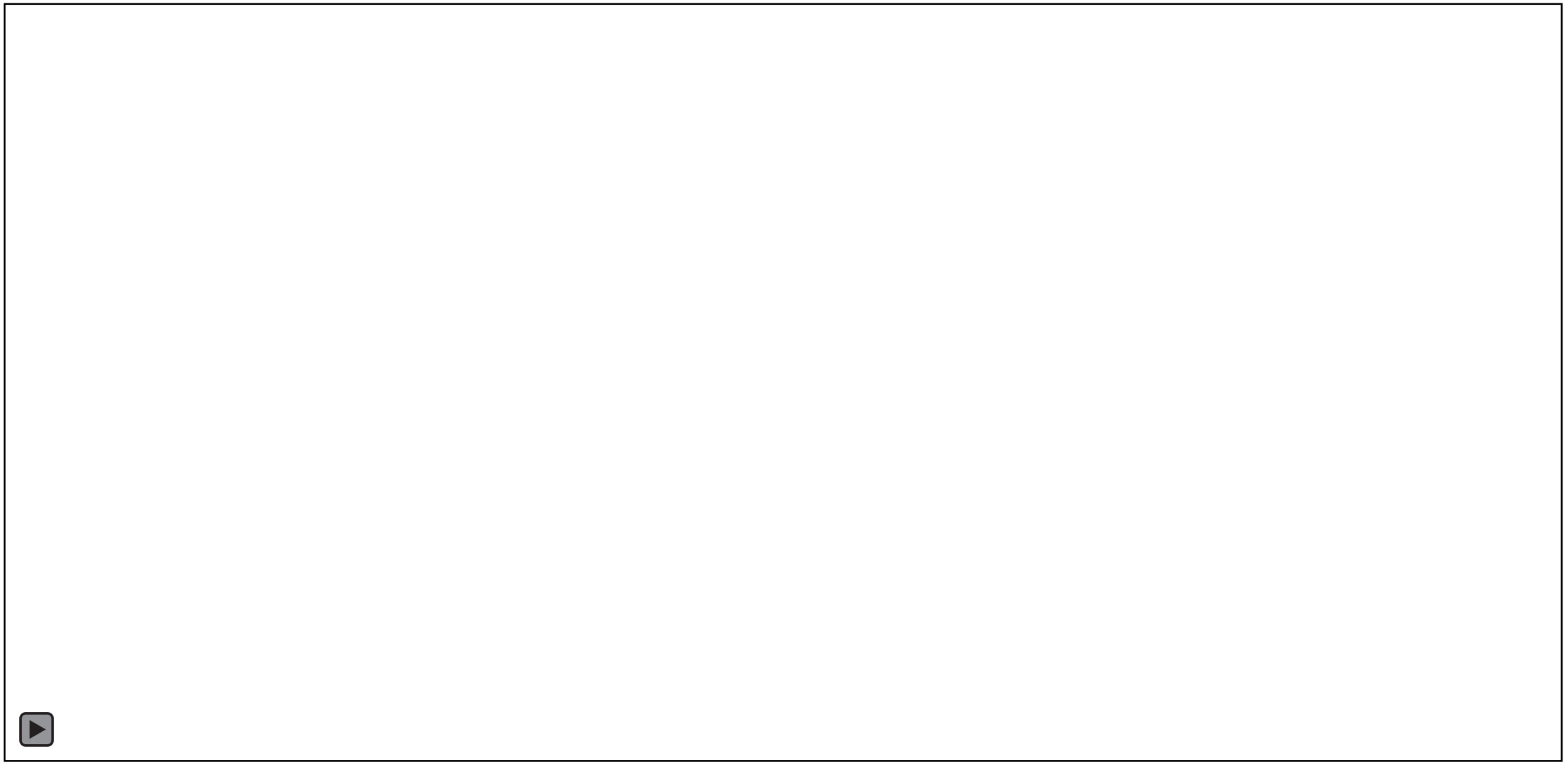
Barrier Damage

- Plastic deformations of the steel components were primarily to the top of Post 1 of the transition and to all three (3) bridge rail posts.
- There was some plastic deformation of the transition rail elements.
- The damage to the posts were due to the bottom of the cargo-box snagging on the top of the posts. This caused torque rotation and longitudinal deformation of the posts.
- The vehicle was in contact with the barrier from the point of contact until the truck box slid off the end of the bridge rail at 0.55 seconds.
- The maximum working width prior to exiting the barrier was 3.9 ft resulting from the top of the cargo box extending over the bridge rail.









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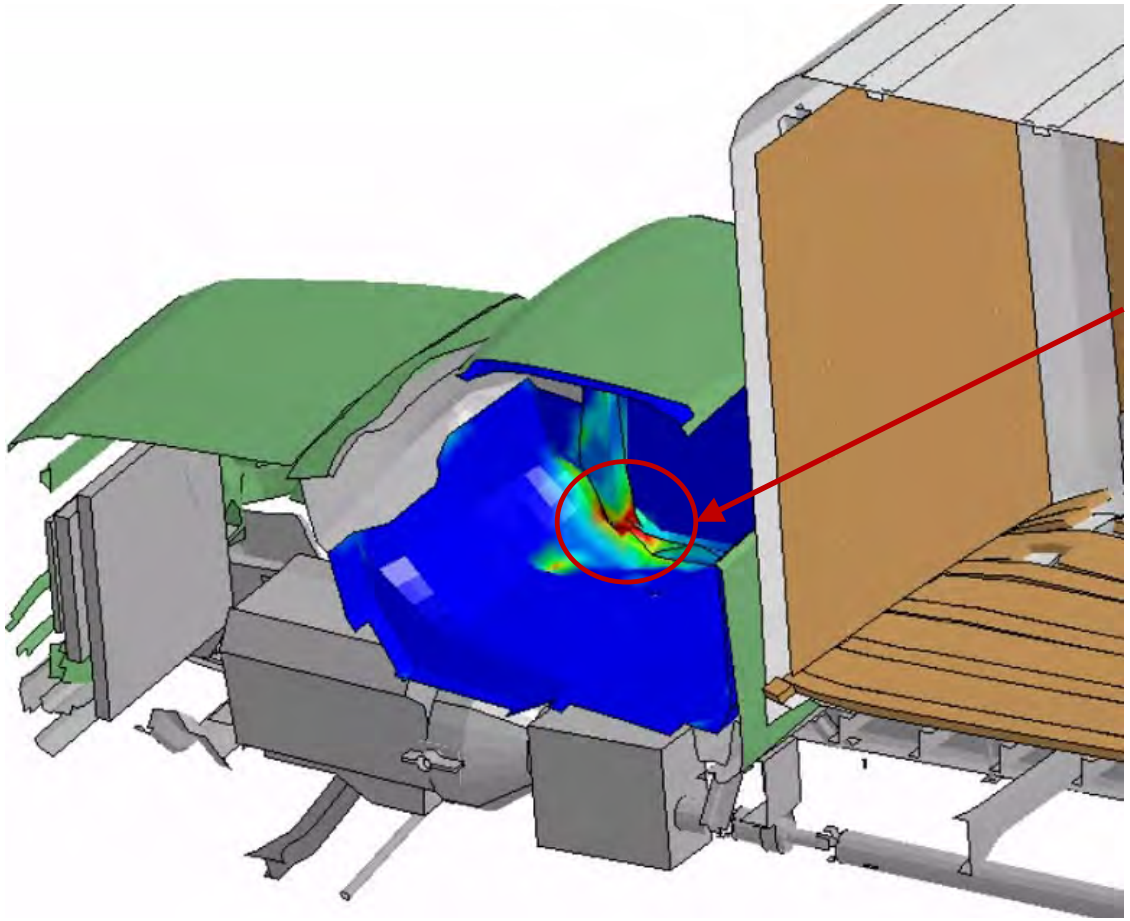
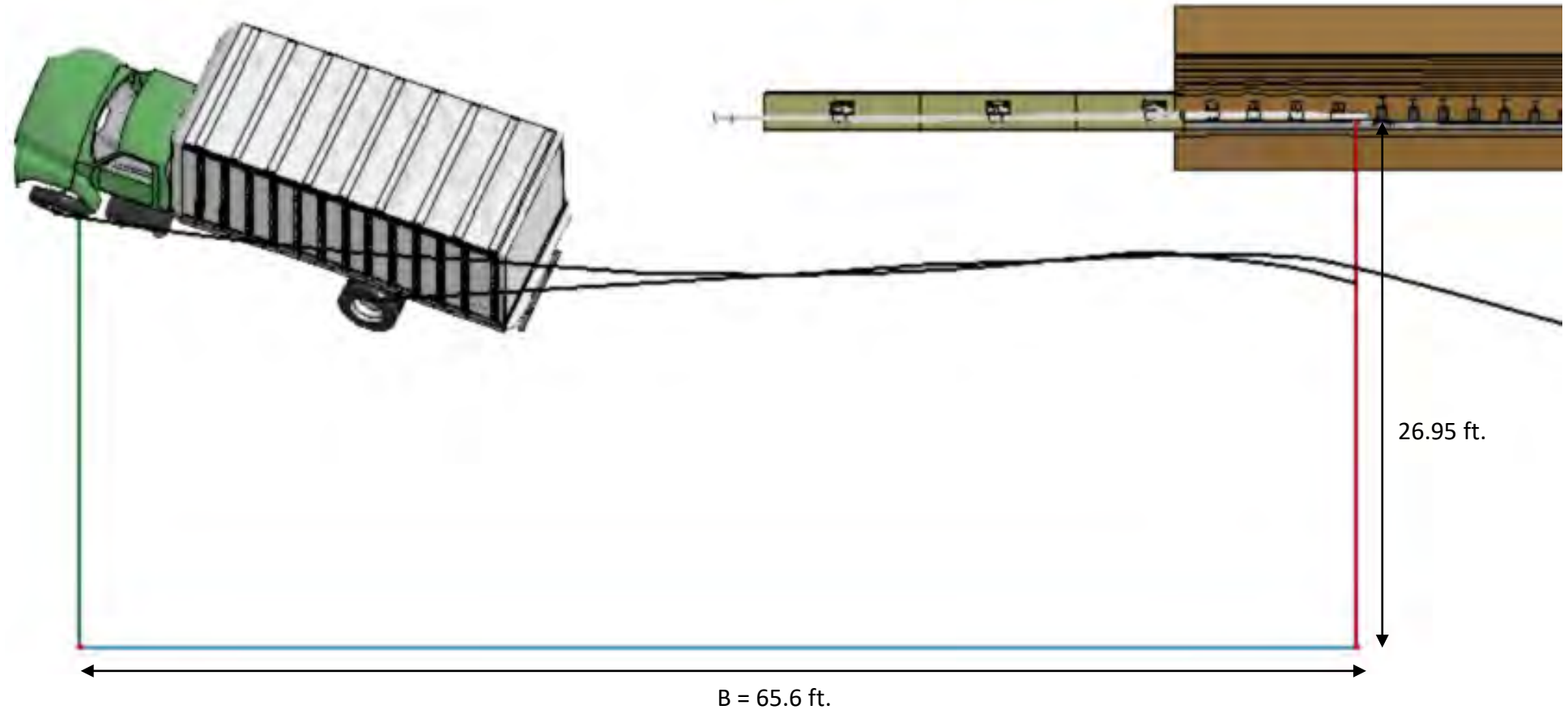
Occupant Compartment Intrusion (OCI)



Maximum OCI was ≈ 2.6 inch (66 mm) and occurred at the lower right-front corner of the toe-pan at wheel well.

Exit Box – Test 4-22

The driver-side front tire wheel track was used to determine the beginning location of the exit box. From MASH pg. 97: "All wheel tracks of the vehicle should not cross the parallel line within the distance B."



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Conclusions on Test 4-22 on the 3-Bar Trans

- The analysis showed that barrier adequately contained and redirected the 10,000S vehicle.
- Occupant compartment intrusion was moderate but well below critical limits.
- The **maximum roll angle** of the vehicle:
  - Cabin= **26.3 degrees**.
  - Cargo Box = **34 degrees**.
- The **maximum pitch angle** of the vehicle:
  - Cabin = **11.9 degrees**.
  - Cargo Box = **11.8 degrees**.
- The maximum **occupant compartment deformation** was **2.6 inches** and occurred at the lower right-front toe pan. This value is well within acceptable limit of 9 inches.
- The vehicle also **remained within the "exit box"** limits.
- The damage to the transition was low to moderate:
  - Soil displacement at 6 posts
  - Minimal plastic deformation of barrier components.
  - Maximum **dynamic deflection = 4.3 inches** at splice connection to bridge rail.
  - Maximum **permanent deflection = 2.8 inches** at splice connection.
- Damage to the bridge rail posts was significant due to the bottom of the cargo-box snagging on the tops of the posts.

Conclusions on Test 4-22 on the 3-Bar Trans

Evaluation Factors		Evaluation Criteria – MASH Test 4-12	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
	G	It is preferable, although not essential, that the vehicle remain upright during and after collision.	Undetermined

Conclusions for Overall Barrier Performance

- MASH Requirements:
  - Structural Adequacy: (PASS)
    - The barrier successfully contained and redirected the vehicle in all test cases.
    - There was low-to-moderate damage to the transition in all cases.
    - Test 4-22 resulted in the bottom of the cargo-bed contacting and snagging on the tops of the bridge rail posts and deforming those posts.
  - Occupant Risk (PASS)
    - Occupant compartment intrusion was well below allowable limits for all cases
    - OIV and ORA
      - Small Car : OIV and ORA were within preferred limits (*values highly dependent on time of occupant impact*); however, peak accelerations were below critical limits throughout the acceleration-time history.
      - Pickup: OIV was within preferred limits; ORA was within critical limits
  - Vehicle Trajectory (PASS)
    - Vehicle remained upright through impact and redirection.
    - Roll and Pitch for Tests 4-20 (small car) and 4-21 (pickup) were relatively low.
    - Roll and pitch for Test 4-22 (SUT) were relatively high. Final vehicle stability was undetermined at 1.5 seconds.