Development of MASH Computer Simulated Steel Bridge Rail and Transition Details

Task 8: Transition for 2-Bar BR MASH TL3

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

Chuck A. Plaxico

Archie Ray

Roadsafe LLC

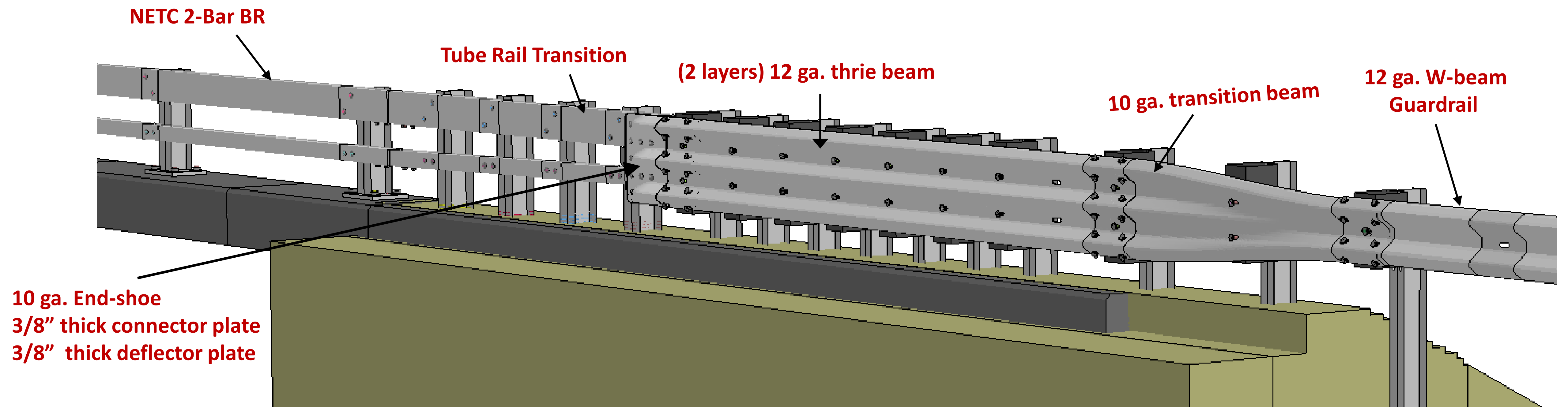
July 18, 2019

Task 8 – MASH TL-3 Evaluation of NETC 2-Bar Transition

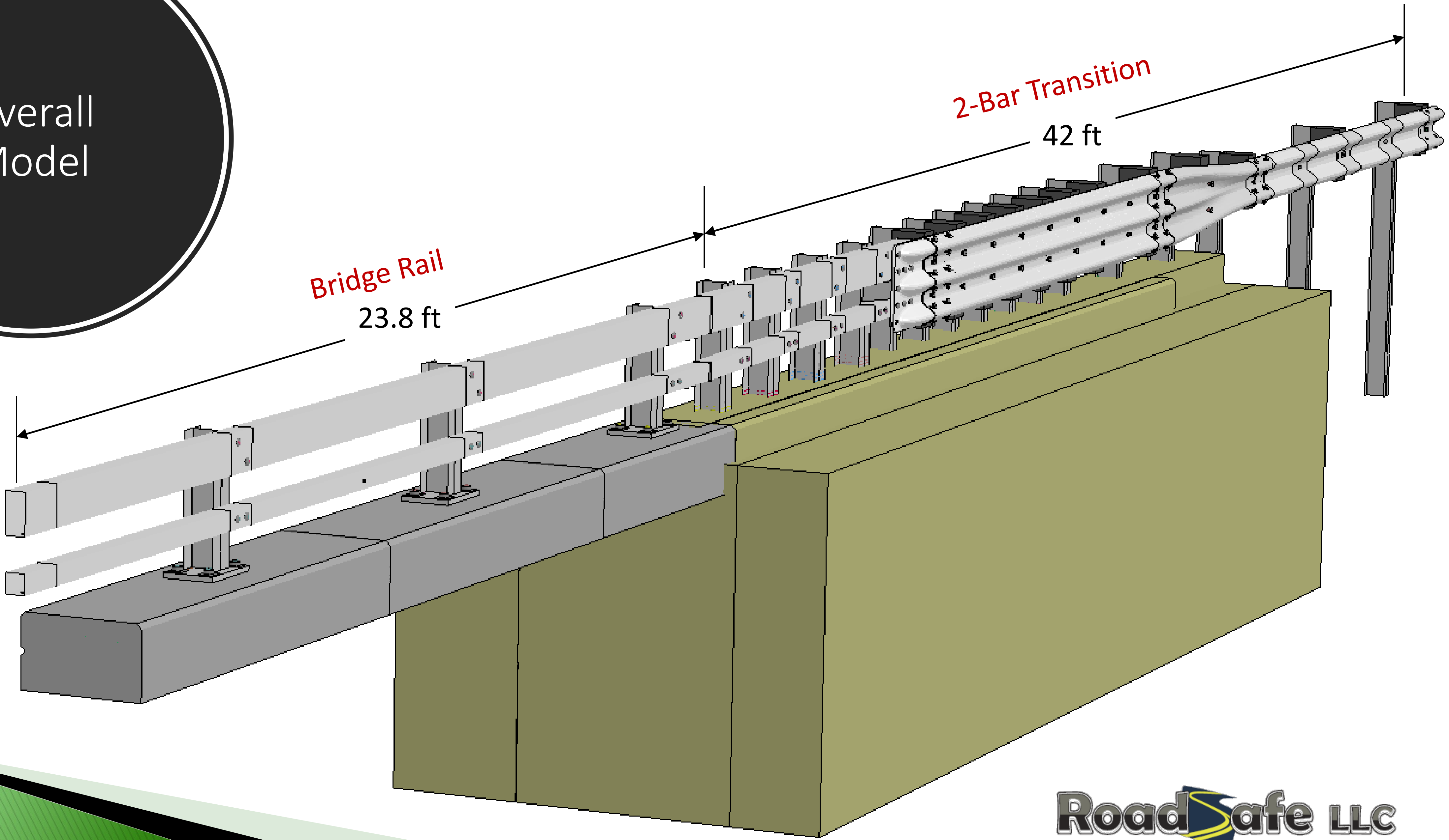
- The baseline finite element model of the NETC 2-Bar transition system was developed in Task 2b
- For the MASH evaluation of the 2-Bar transition, the baseline model was updated to reflect the current design standard for the 2-Bar system (per NHDOT design) and to include the general model improvements presented in Task 4 for the NETC 3-Bar transition.

<u>Primary Model Modifications for Development of 2-Bar System:</u>

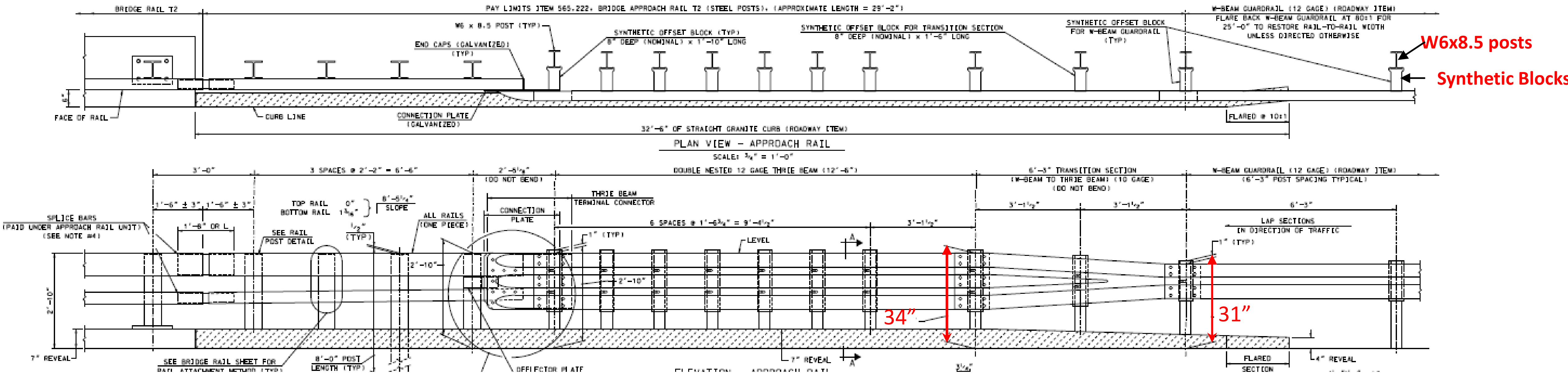
- Replacing 6x8” wood posts with W6x8.5 steel posts
- Increasing w-beam rail height from 27” to 31”
- Increasing Thrie-beam rail height from 32” to 34”
- Extending the continuum soil model to include all posts in the thrie-beam region.
- Including NETC 2-Bar bridge rail model



Overall Model



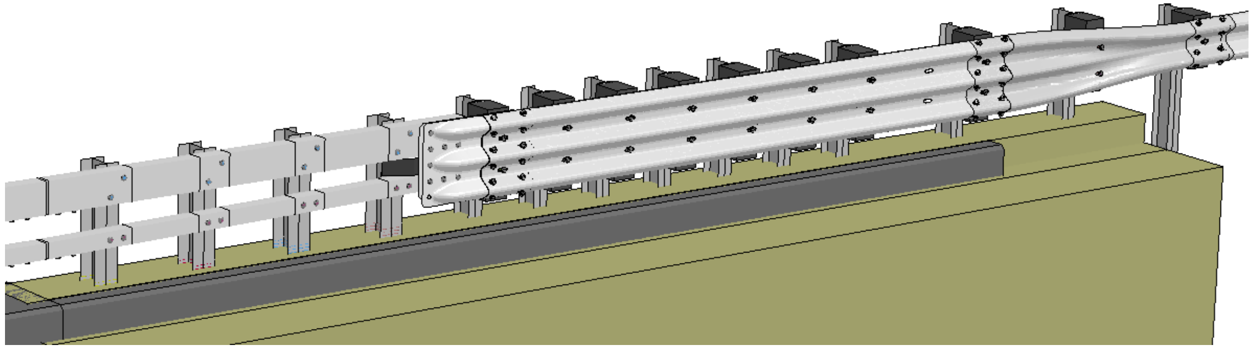
RoadSafe LLC
Transportation Engineering and Research



T2 Steel Bridge Approach Rail

NETC 2-Bar Transition

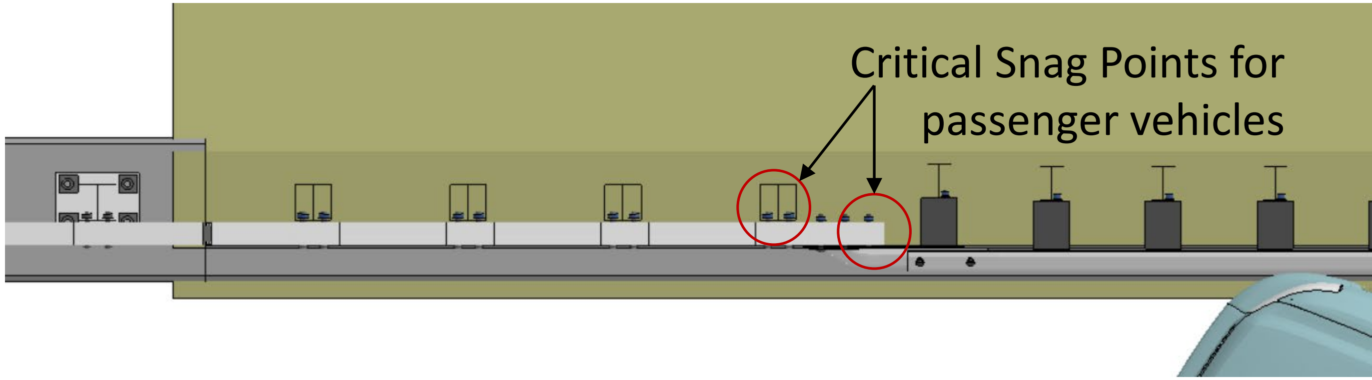
The transition system for the 2-Bar bridge rail was modeled based on the detailed drawing from NHDOT



RoadSafe LLC
Transportation Engineering and Research

Determining Critical Impact Point

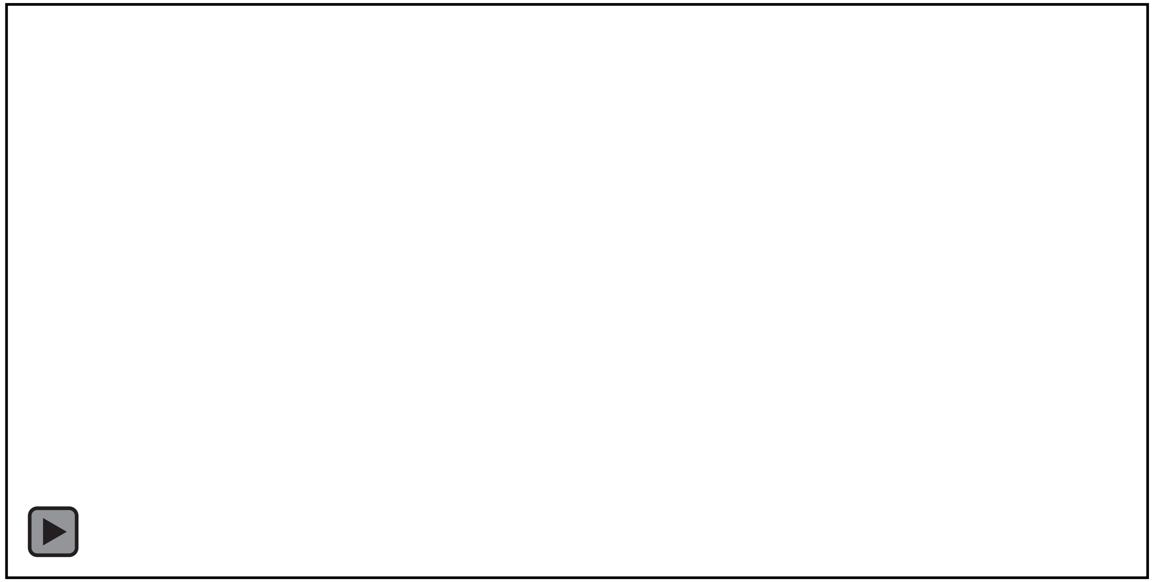
- Test 4-20 (small Car) and
- Test 4-21 (pickup):
  - Maximize potential for snag on end of transition tube railing
  - Maximize potential for snag on first post of tube rail transition
  - Maximize occupant risk metrics



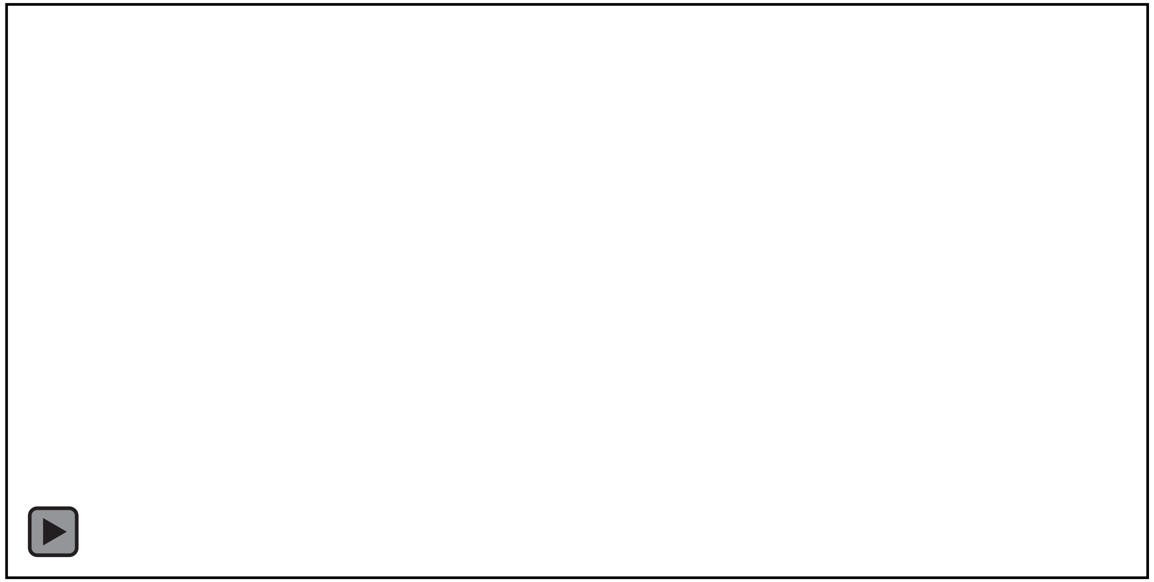
Determination of CIP for Test 4-20

- CIP was determined using FEA with respect to:
  - Maximizing potential for snag at the first post of the tube-rail transition section, and
  - OIV and ORA since these metrics are used directly in crashworthy assessments in MASH
- Analysis Cases (5 cases):
  - Impact points 5.0 ft, 5.5 ft, 6.0 ft, 6.5 ft, and 7.0 ft from the centerline of the first post in the tubular rail section.
  - 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 concrete abutment.
- The following slides present video of cases 5.0 – 6.5 ft. The 7.0-ft case (not shown) was very similar to Case 6.5-ft.

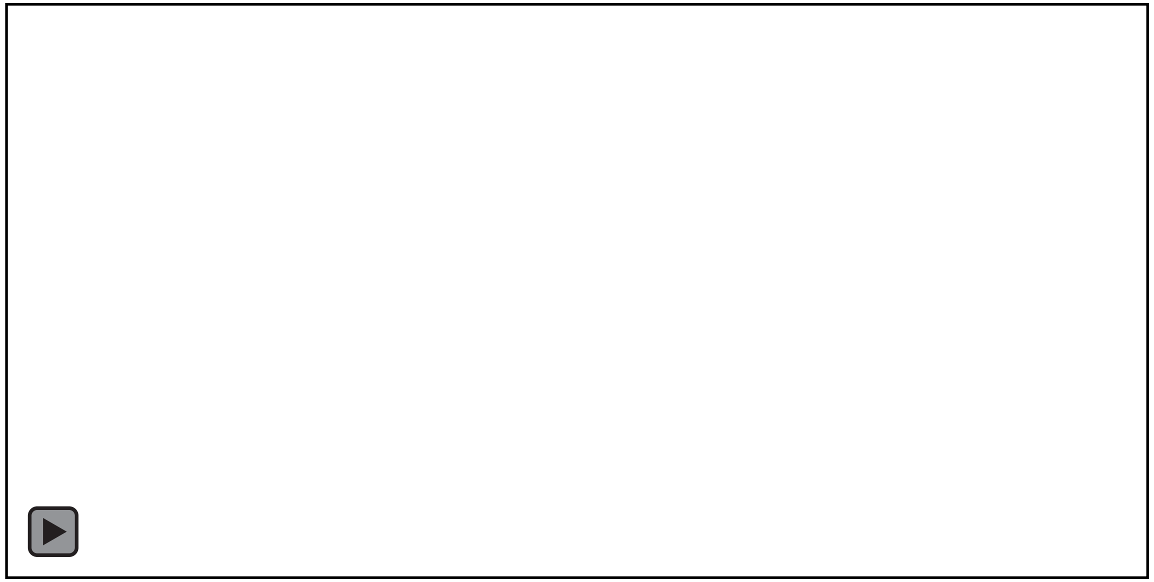
IP 5.0 ft



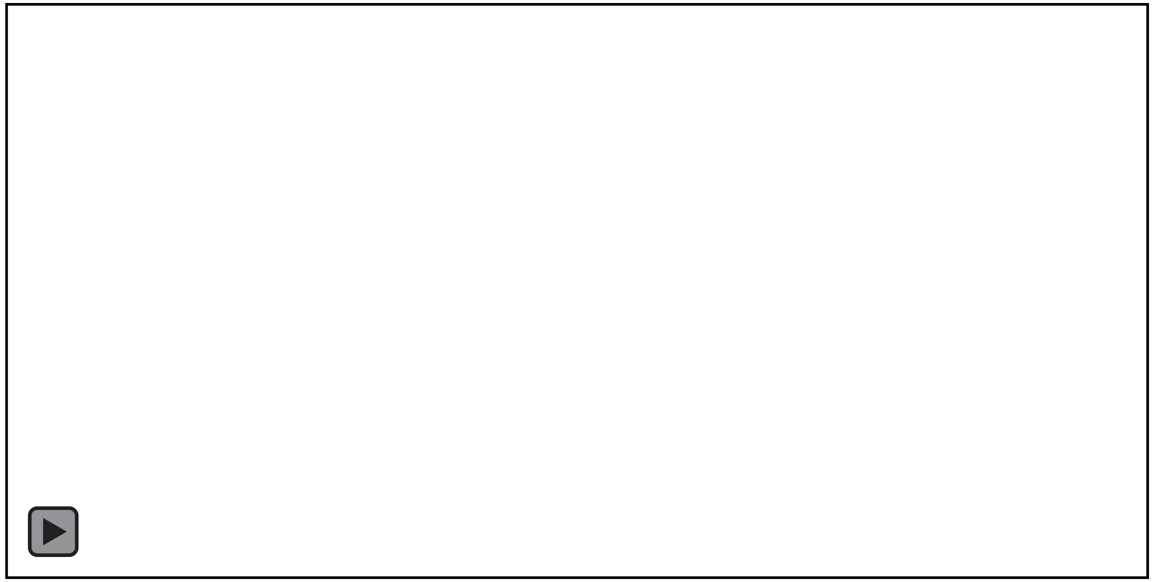
IP 5.5 ft



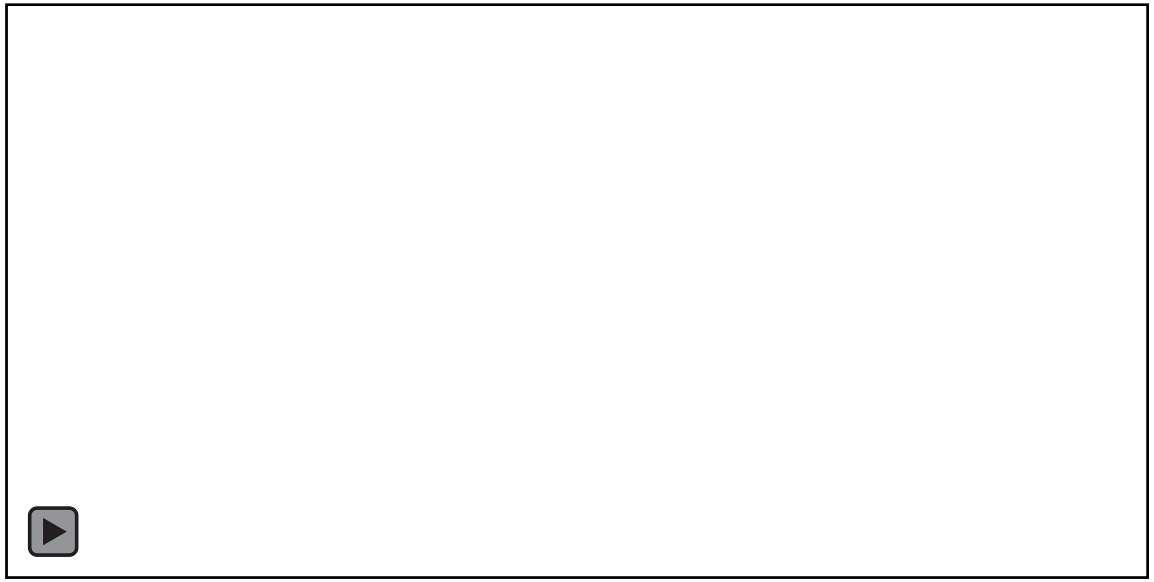
IP 6.0 ft



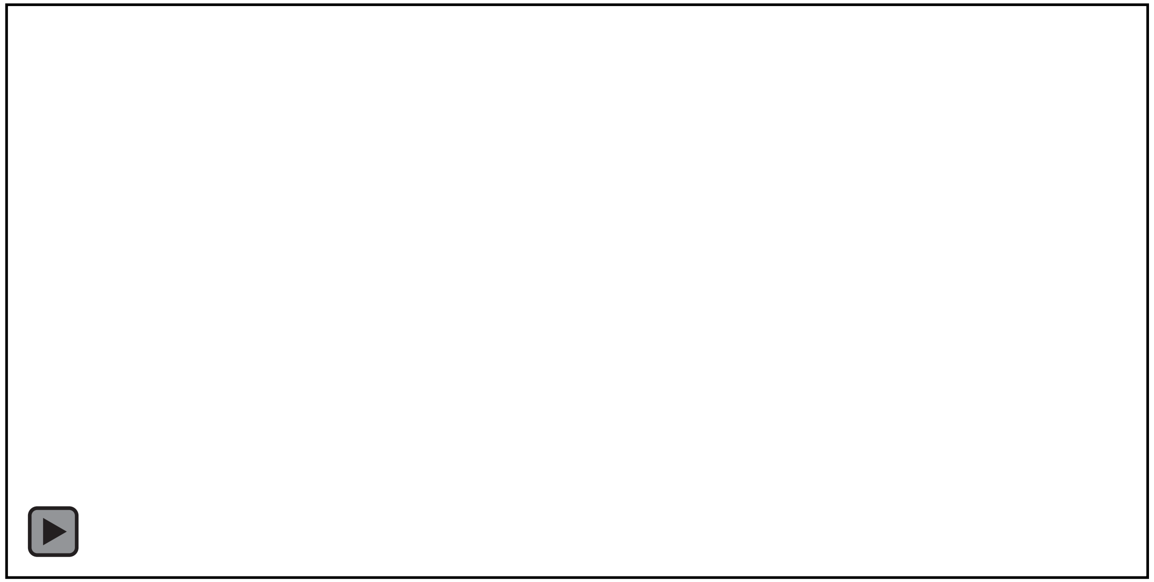
IP 6.5 ft



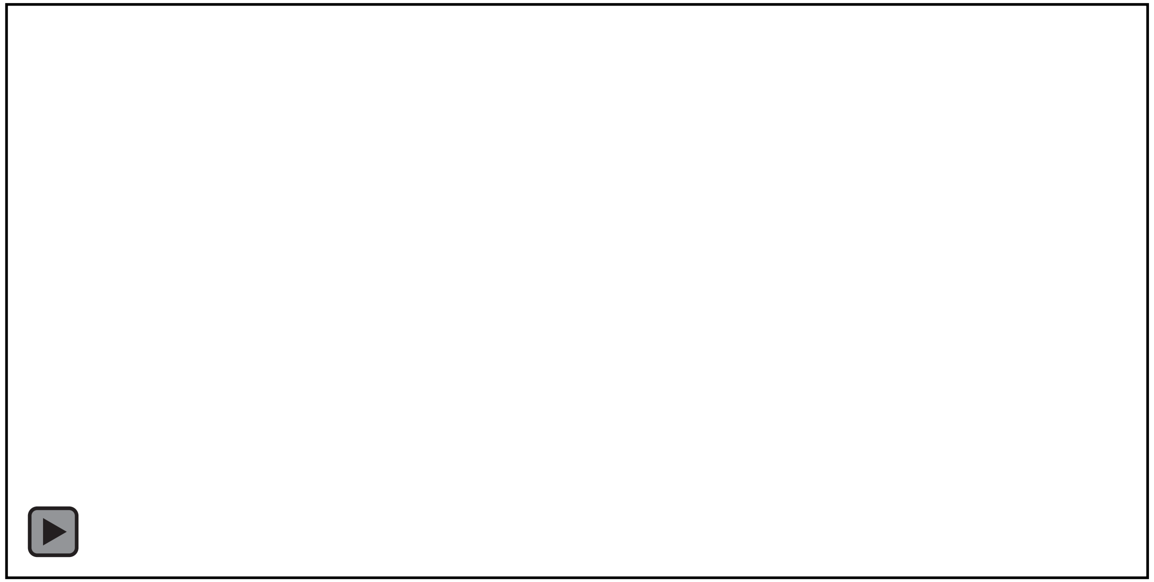
IP 5.0 ft



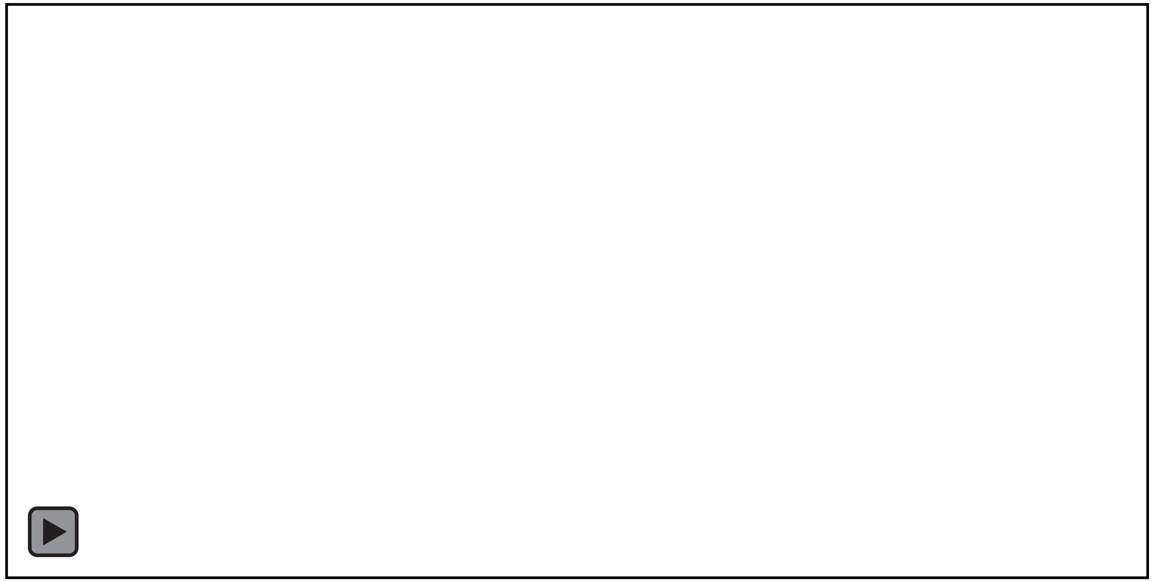
IP 5.5 ft



IP 6.0 ft



IP 6.5 ft



IP 5.0 ft

IP 5.5 ft

IP 6.0 ft

IP 6.5 ft

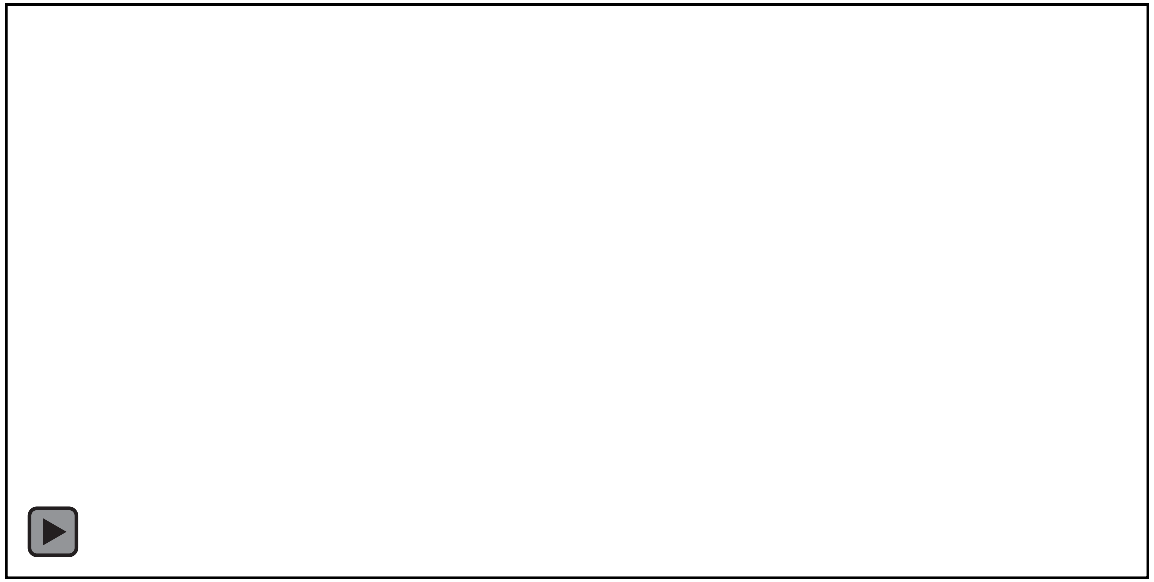
IP 5.0 ft

IP 5.5 ft

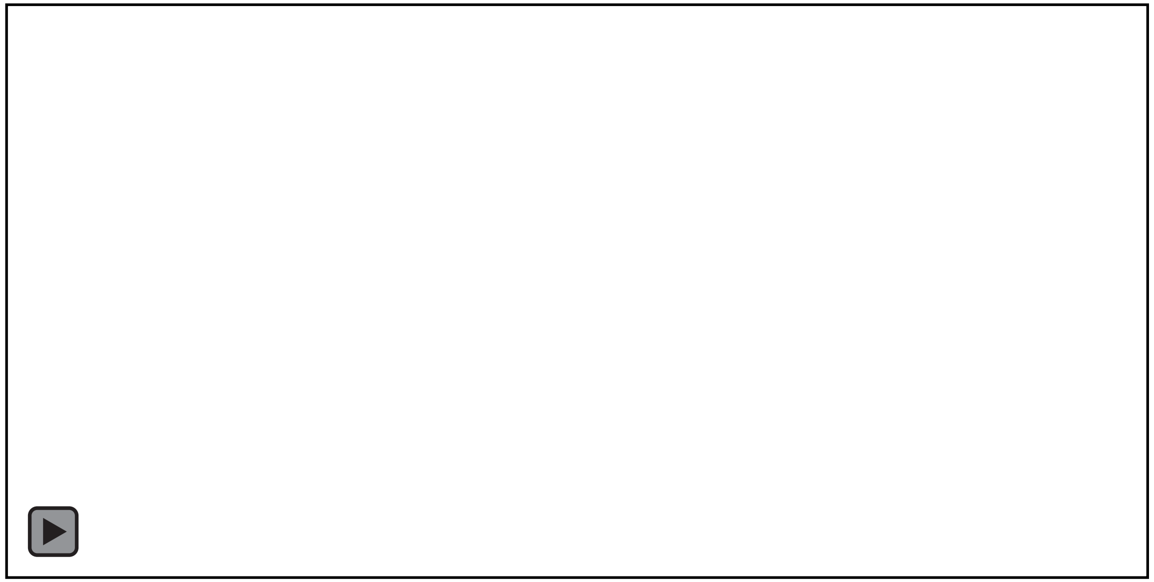
IP 6.0 ft

IP 6.5 ft

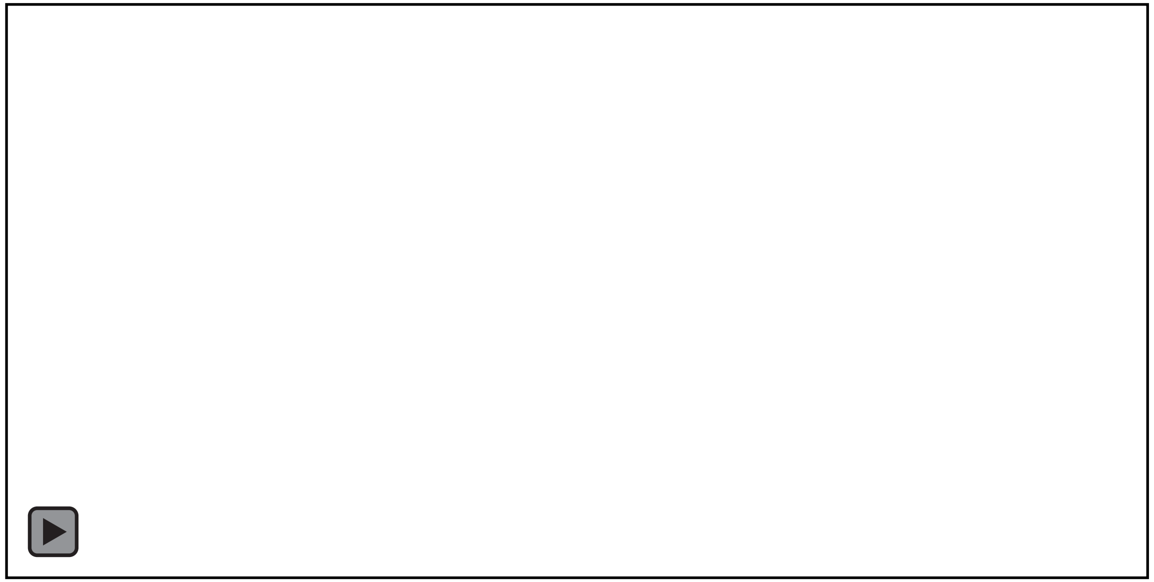
IP 5.0 ft



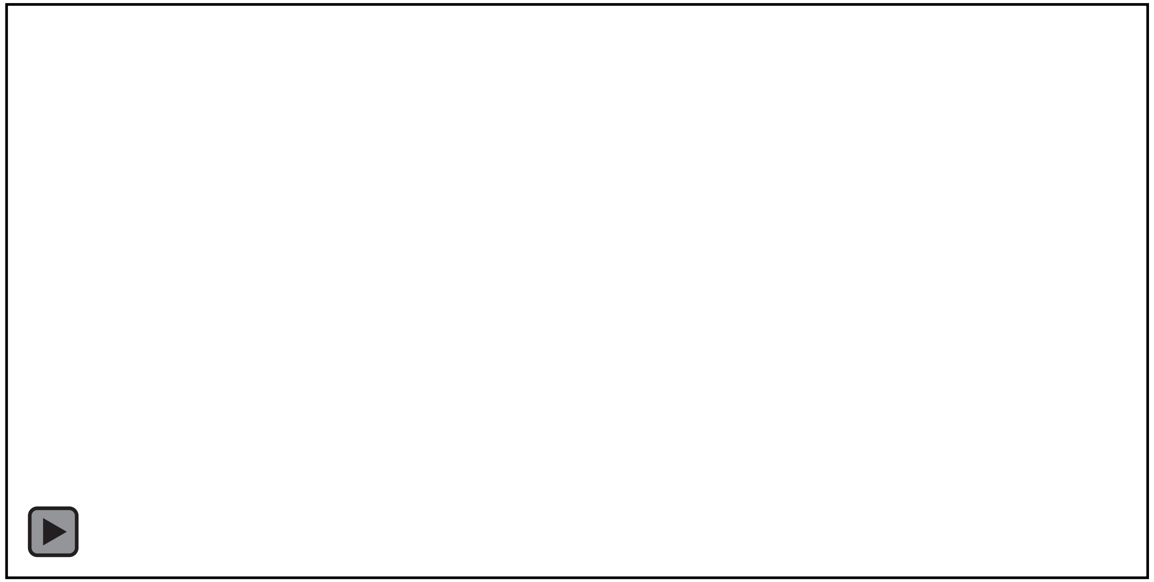
IP 5.5 ft



IP 6.0 ft



IP 6.5 ft



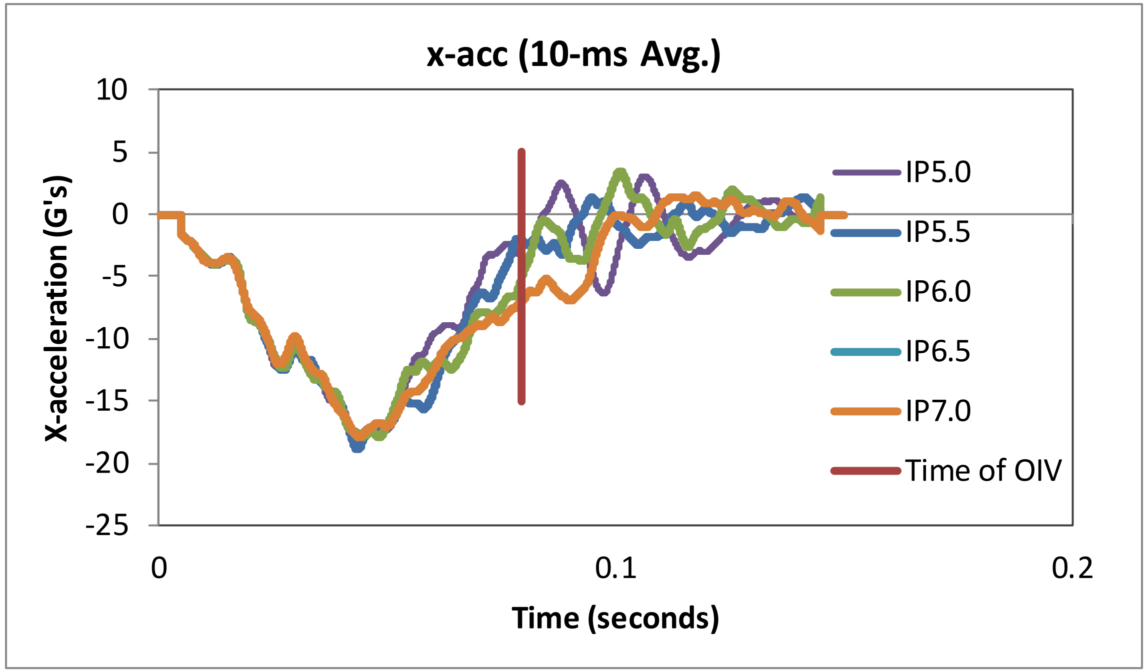
IP 5.0 ft

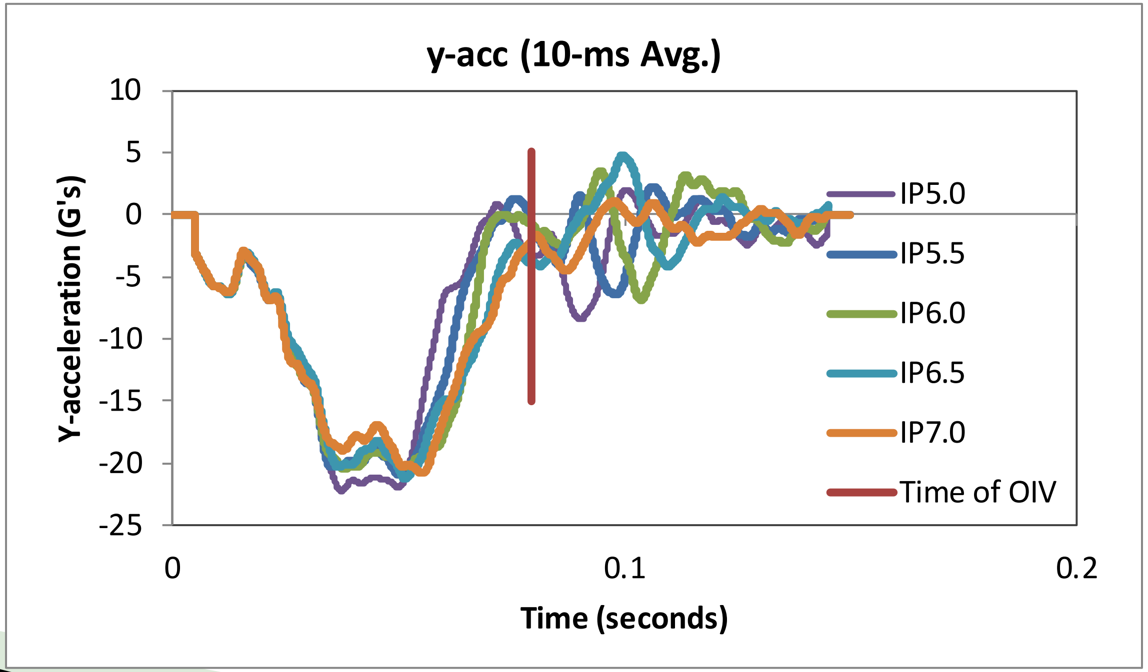
IP 5.5 ft

IP 6.0 ft

IP 6.5 ft

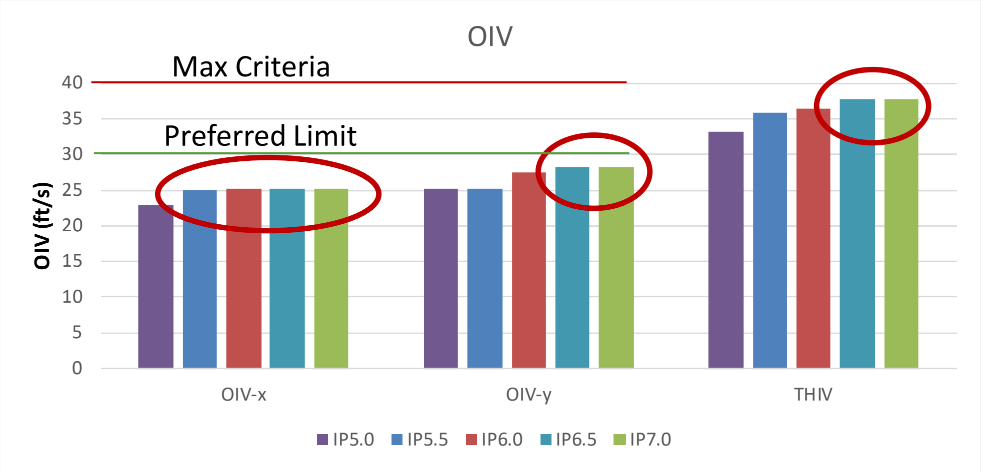
Acceleration-time Histories

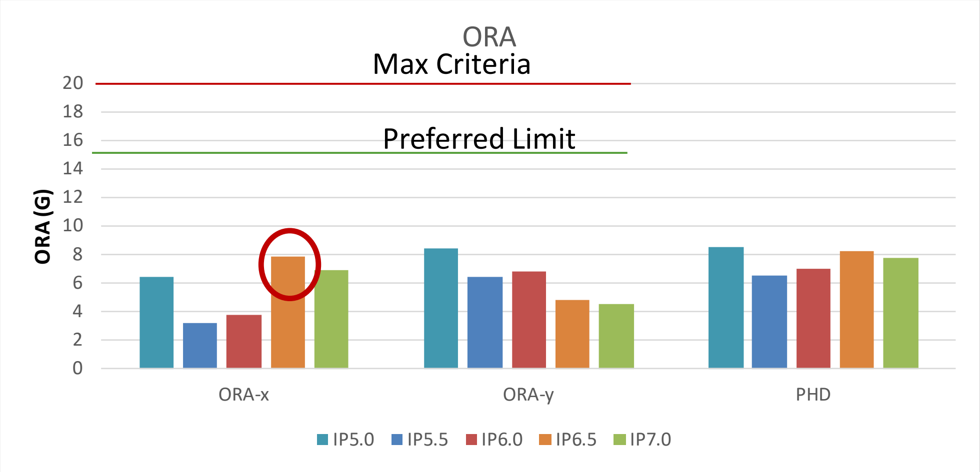


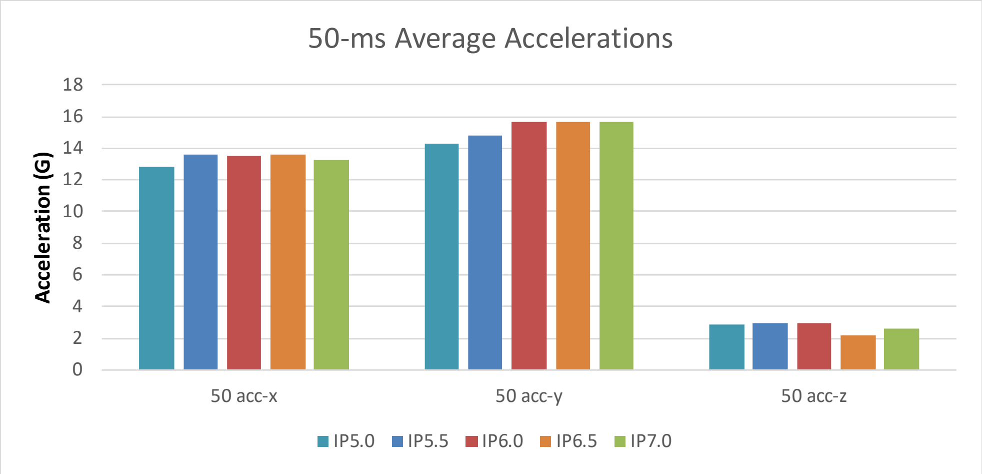


RoadSafe LLC
Transportation Engineering and Research

TRAP Results







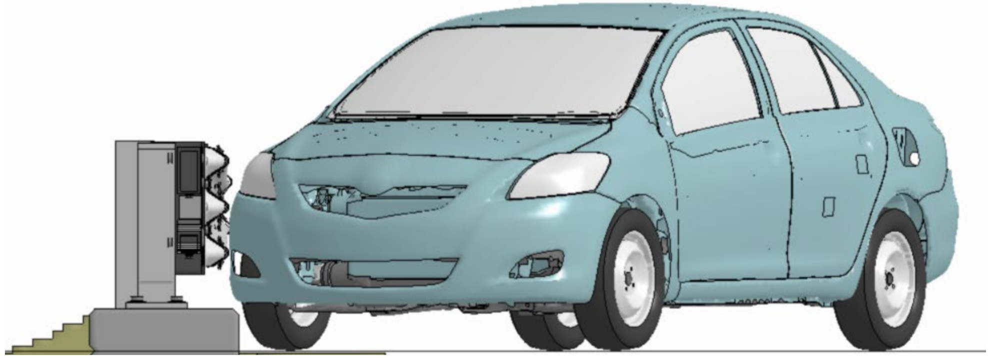
RoadSafe LLC
Transportation Engineering and Research

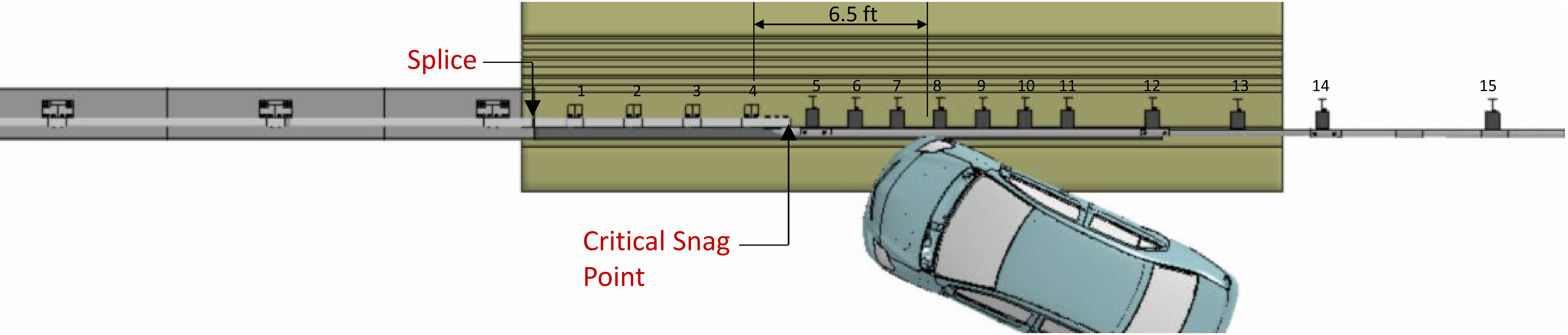
Summary on CIP Calculations

- From visual inspection of the analysis videos, the results at each impact point were very similar and the potential for wheel snag on a transition post was low.
- OIV:
  - **All cases were below recommended limits**
  - Case IP6.5 and IP7.0 yielded the highest values
- ORA:
  - **All cases were *well below* recommended limits**
  - **IP6.5 ft** resulted in highest ORA-x, and **IP5.0** resulted in highest ORA-y
  - These two cases also resulted in approximately the same PHD (e.g., pseudo resultant acceleration)
- For the small car, this system is essentially the same as the NETC 3-Bar transition.
  - In that case, the CIP was selected as 5.5 ft
- The **CIP** for the 2-Bar system was selected as **IP6.5ft** to maximize OIV (which was close to preferred limit).

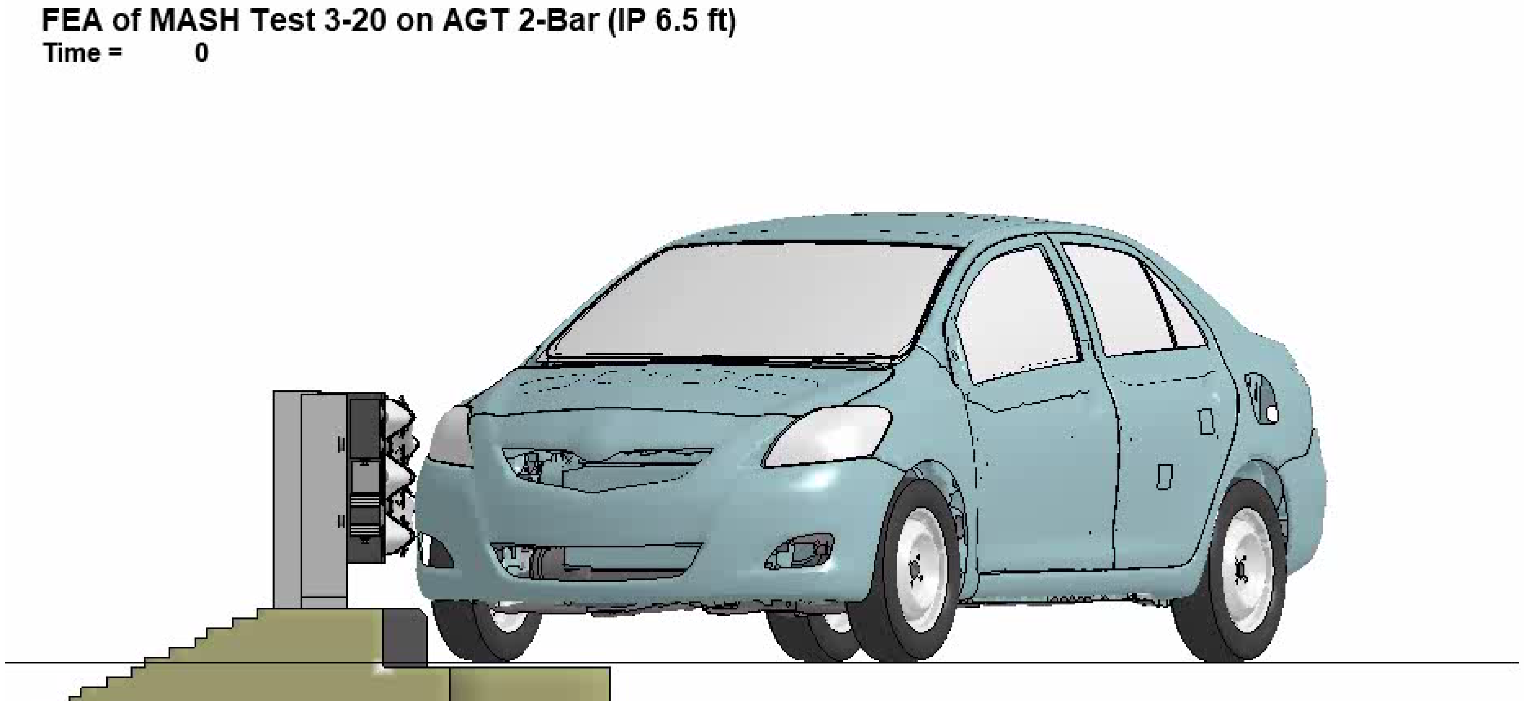
MASH Test 4-20 Simulation on the 2-Bar Transition

- Impact Conditions
  - Impact Speed = 62.1 mph (100 km/hr)
  - Impact Angle = 25 degrees
  - Impact Point = 6.5 ft upstream from critical Post
- Vehicle Model
  - YarisC_V1l_R160407.k
  - Vehicle Mass = 1,177 kg (2,595 lb)



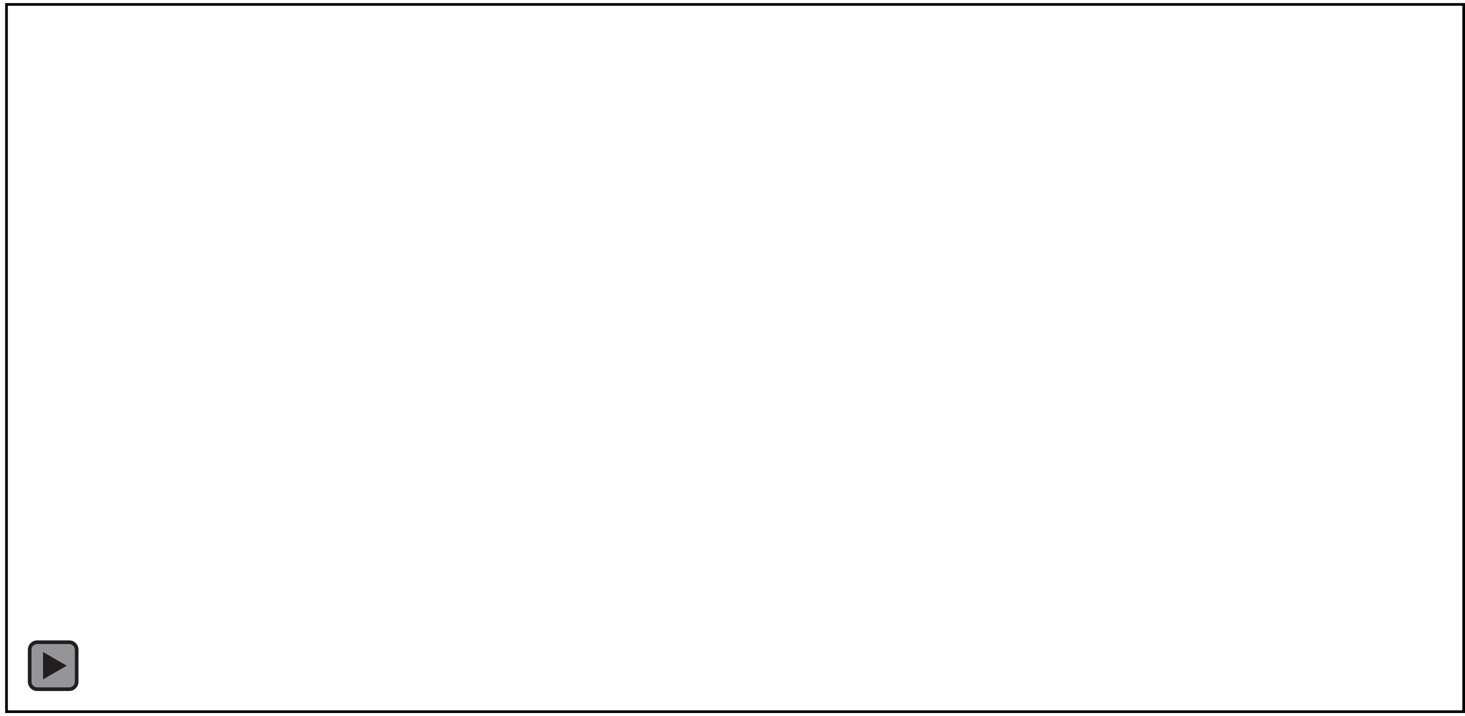


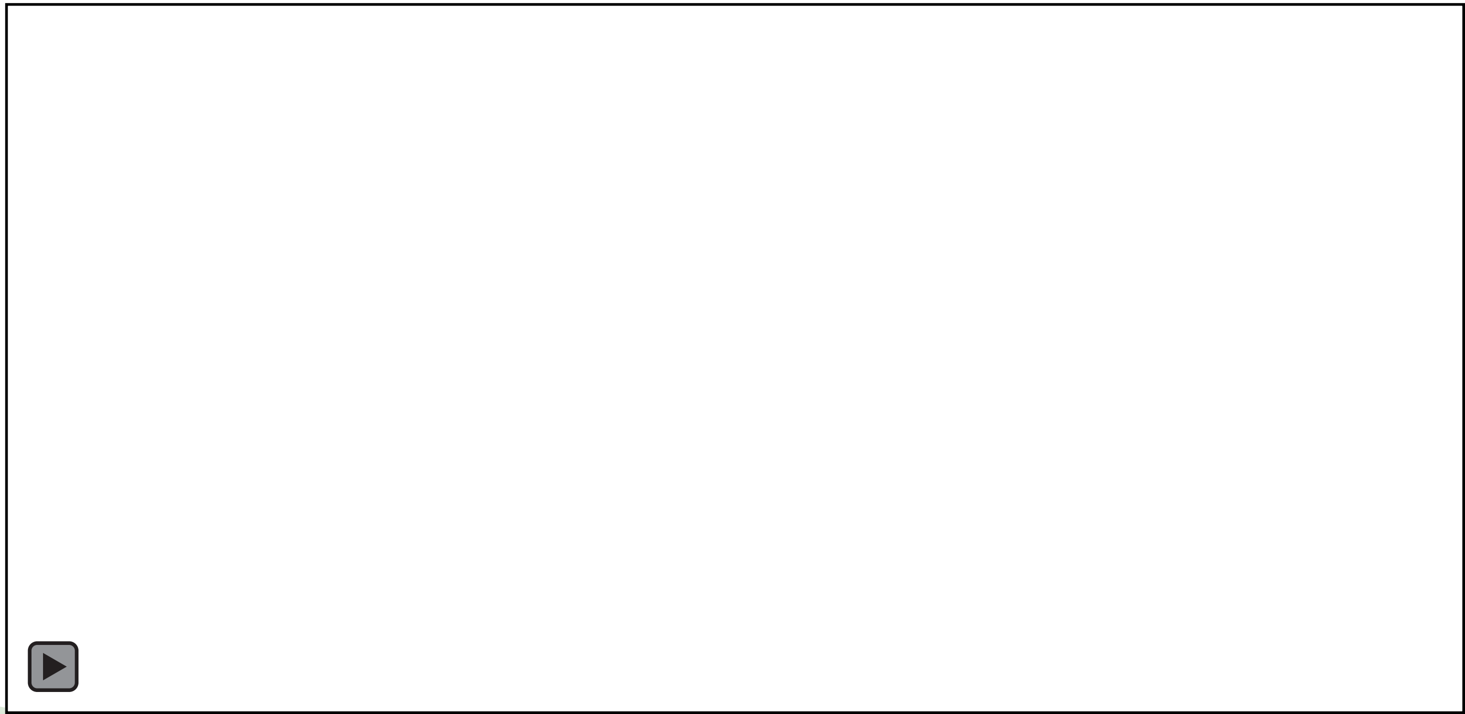
Movies



RoadSafe LLC
Transportation Engineering and Research

Movies





Movies

Occupant Risk Metrics

Occupant Risk Factors		MASH Test 4-20
Occupant Impact Velocity (ft/s)	x-direction	25.3
	y-direction	28.2
	at time	at 0.0765 seconds on right side of interior
THIV (ft/s)		37.7
		at 0.0765 seconds on right side of interior
Ridedown Acceleration (g's)	x-direction	-7.9 (0.0824 - 0.0924 seconds)
	y-direction	4.8 (0.0946 - 0.1046 seconds)
PHD (g's)		8.2 (0.0822 - 0.0922 seconds)
ASI		2.08 (0.0211 - 0.0711 seconds)
Max 50-ms moving avg. acc. (g's)	x-direction	-13.6 (0.0216 - 0.0716 seconds)
	y-direction	-15.7 (0.0209 - 0.0709 seconds)
	z-direction	-2.9 (0.5346 - 0.5846 seconds)
Maximum Angular Disp. (deg)	Roll	-6.7 (0.2664 seconds)
	Pitch	-3.6 (0.4934 seconds)
	Yaw	-32.6 (0.3077 seconds)

MASH Criteria

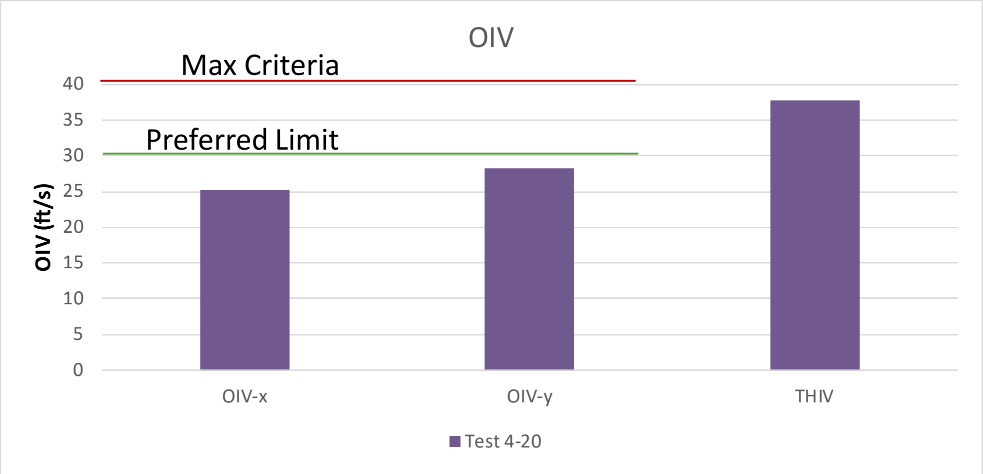
< 30 ft/s (preferred) ✓
< 40 ft/s (limit)

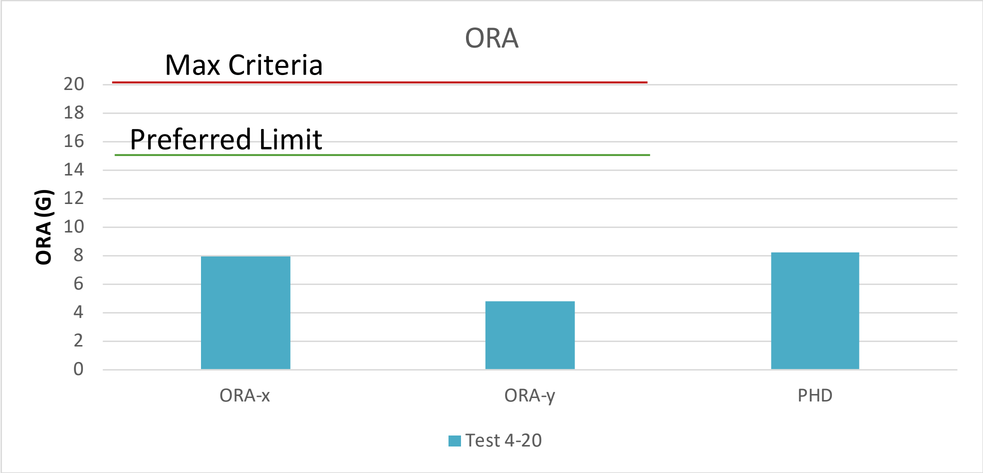
< 15 G (preferred) ✓
< 20.49 G (limit)

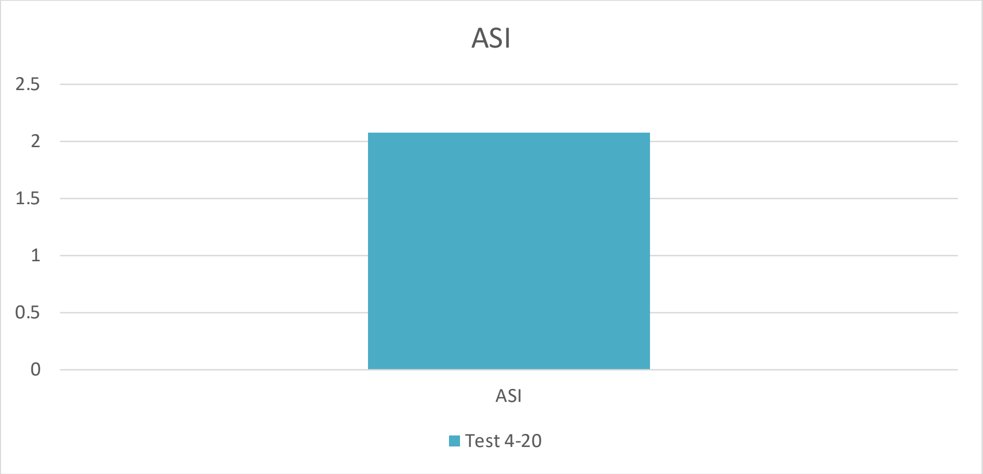
< 75 deg ✓

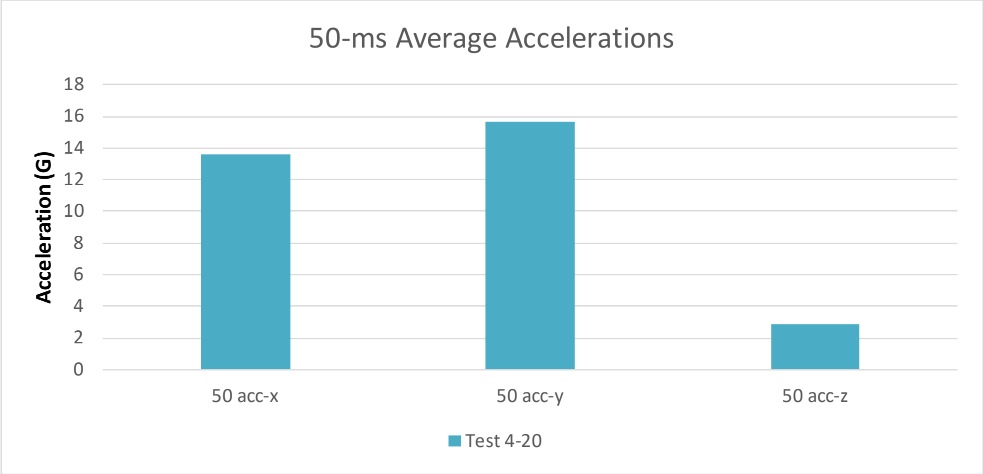
RoadSafe LLC
Transportation Engineering and Research

Occupant Risk Metrics

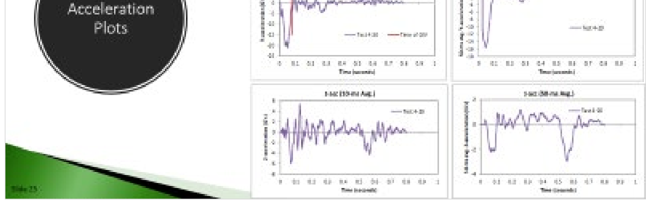




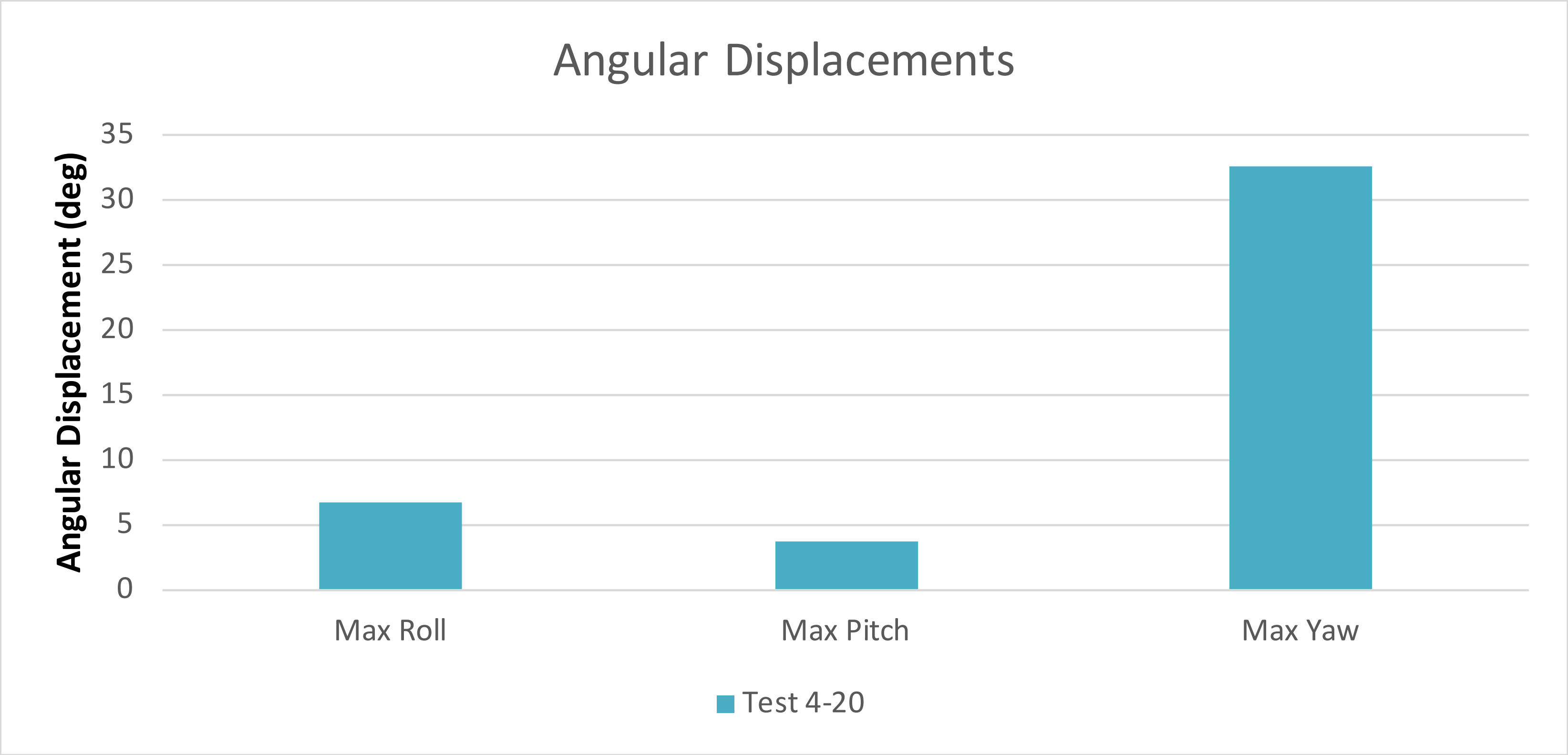




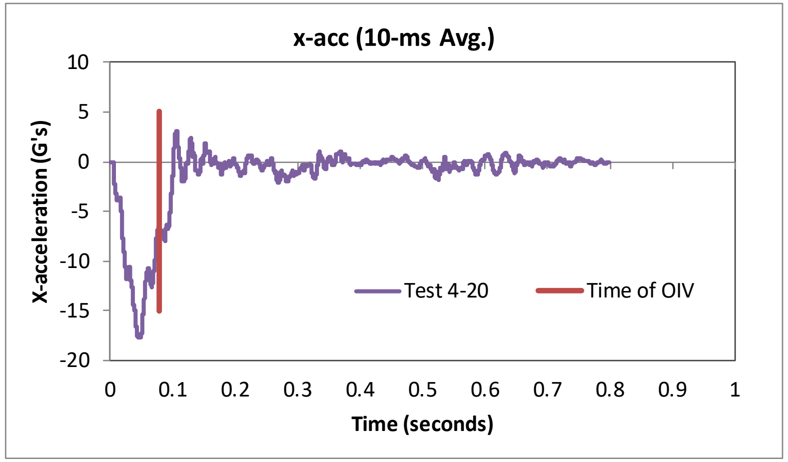
RoadSafe LLC
Transportation Engineering and Research

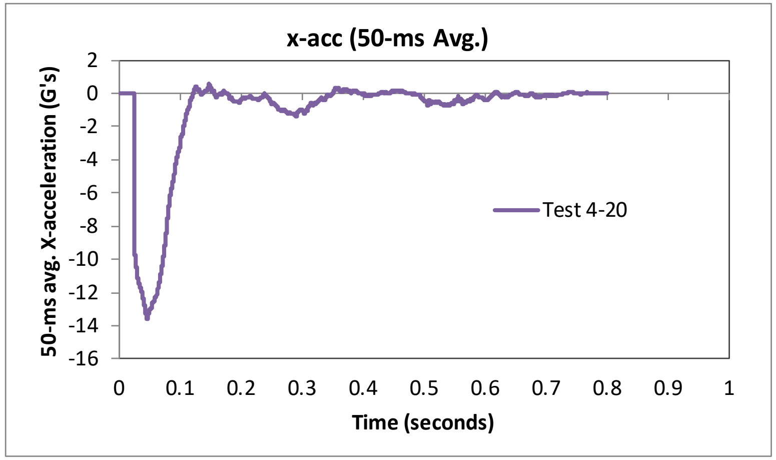


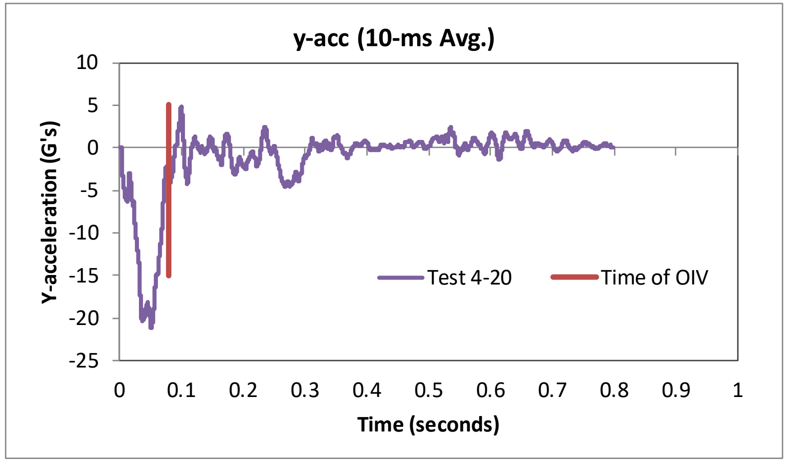
gular Displacements

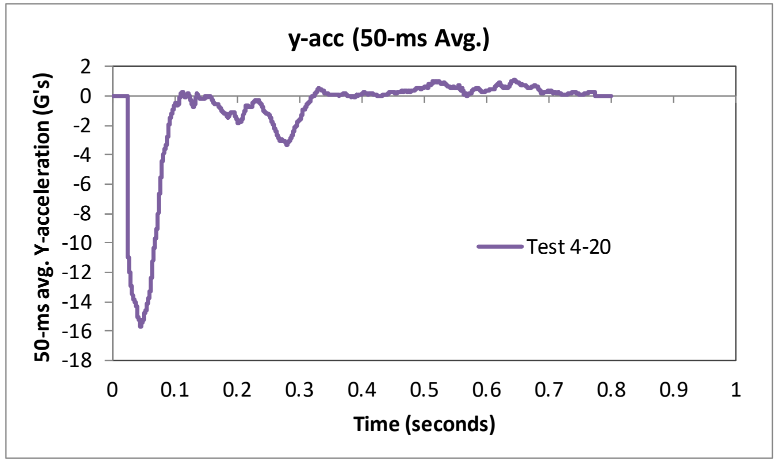


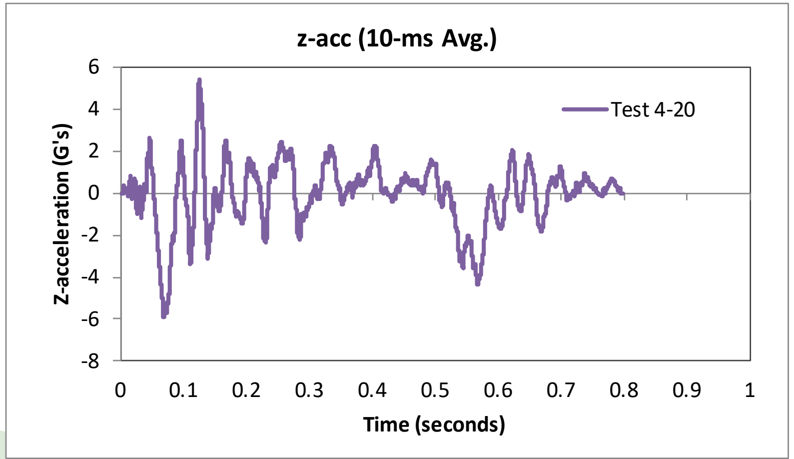
Acceleration Plots

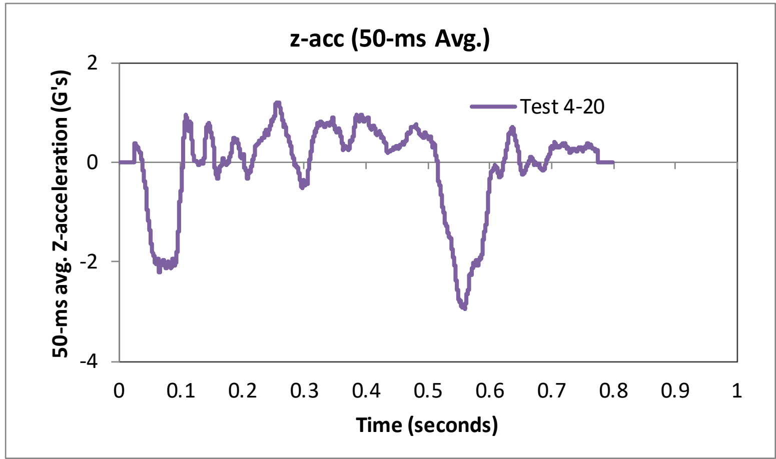




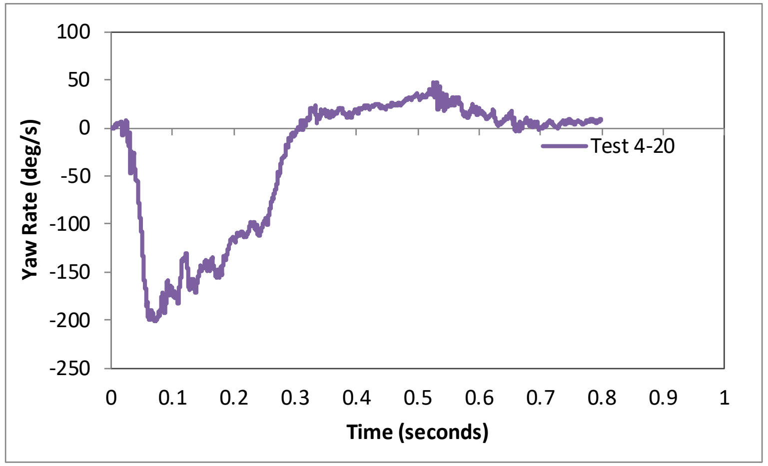


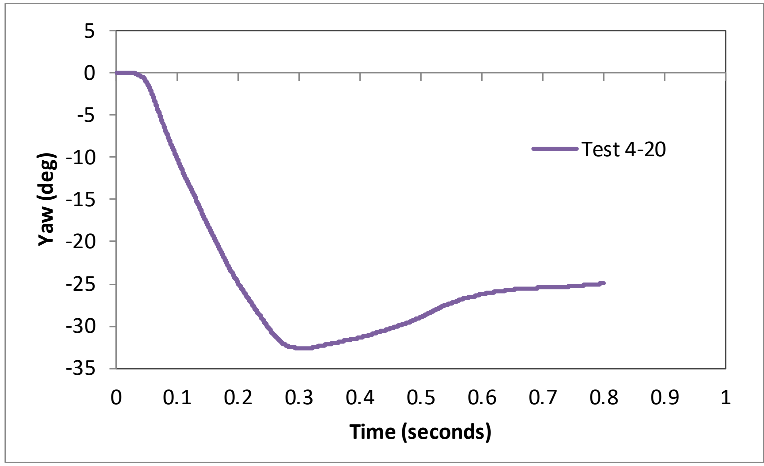


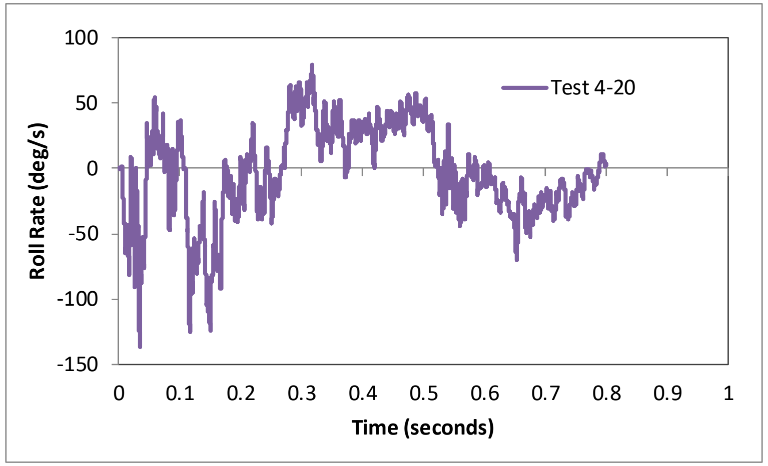


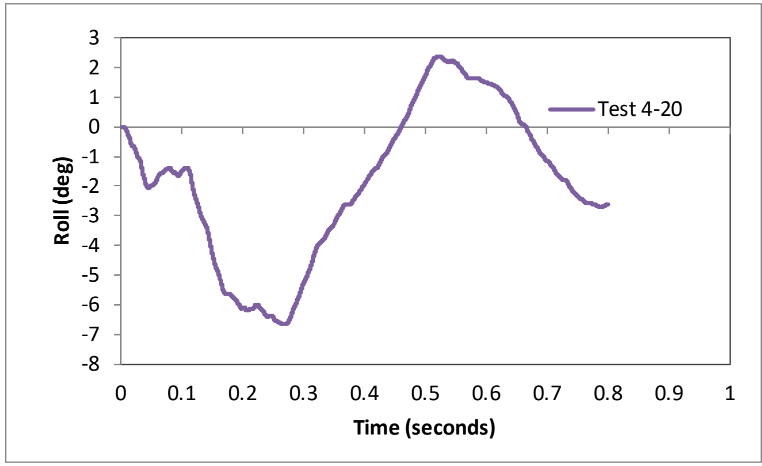


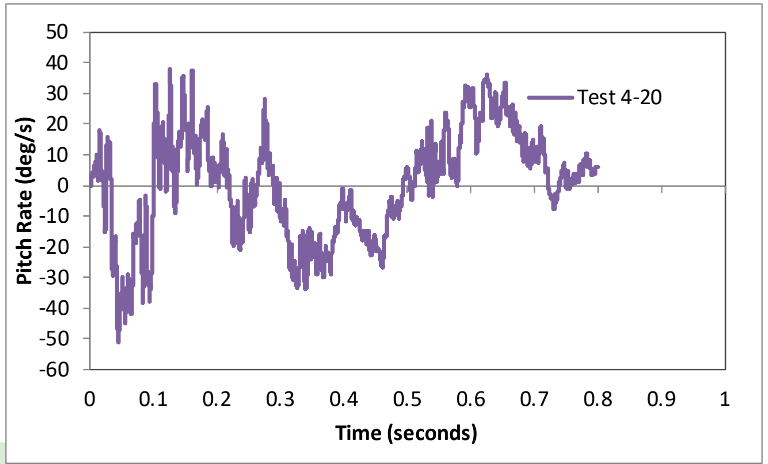
Angular Rate and Displacement Plots

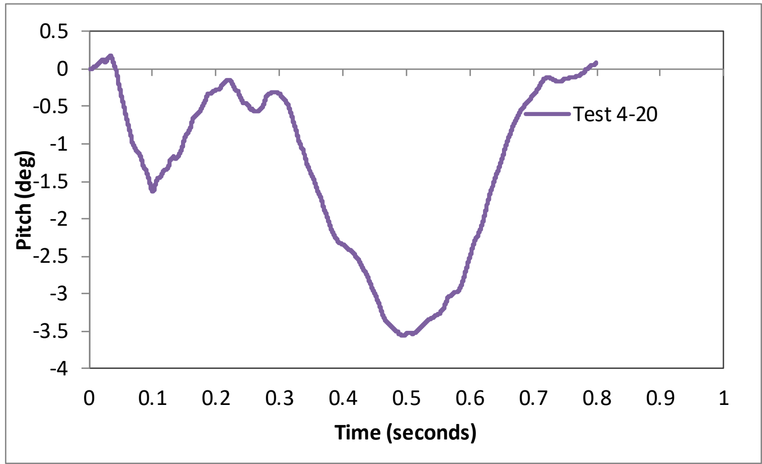






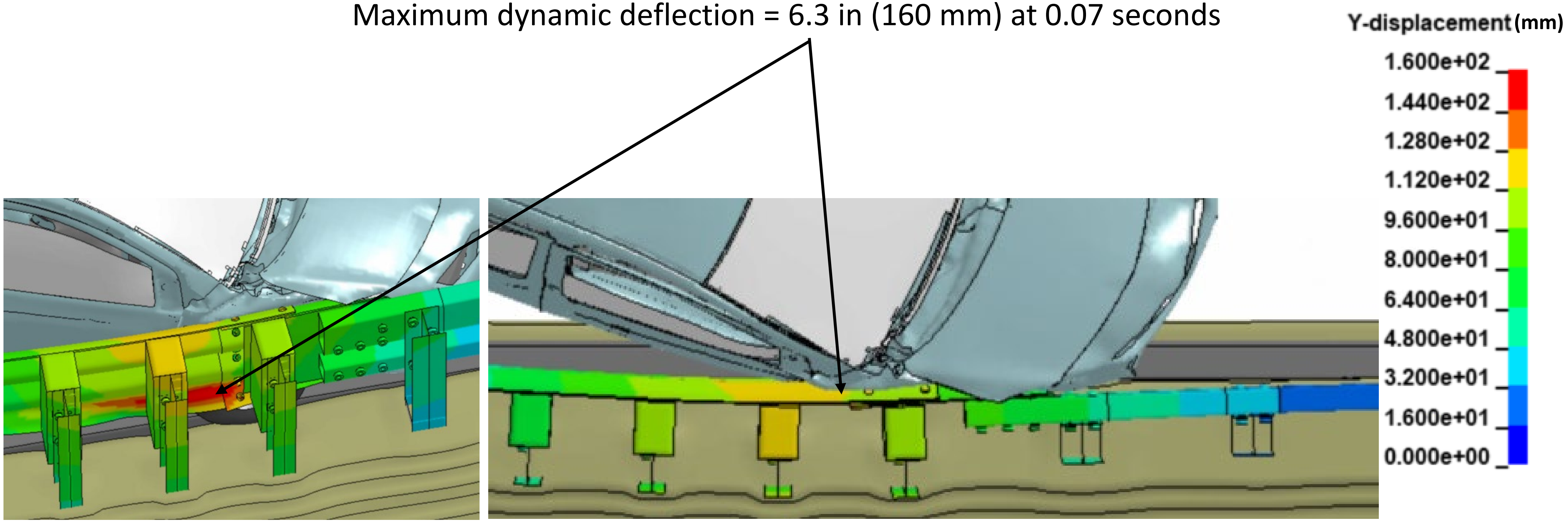






Lateral Dynamic Deflection

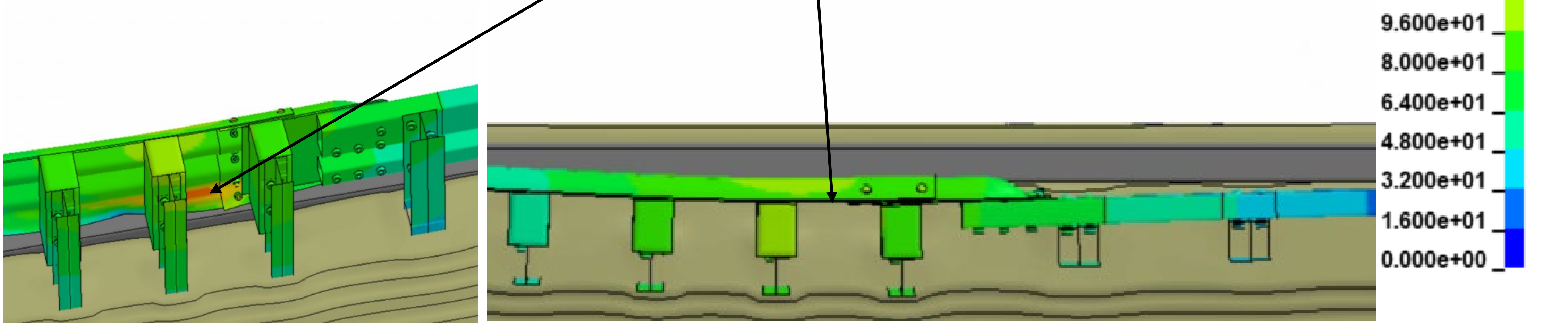
Maximum dynamic deflection = 6.3 in (160 mm) at 0.07 seconds



RoadSafe LLC
Transportation Engineering and Research

Lateral Permanent Deflection

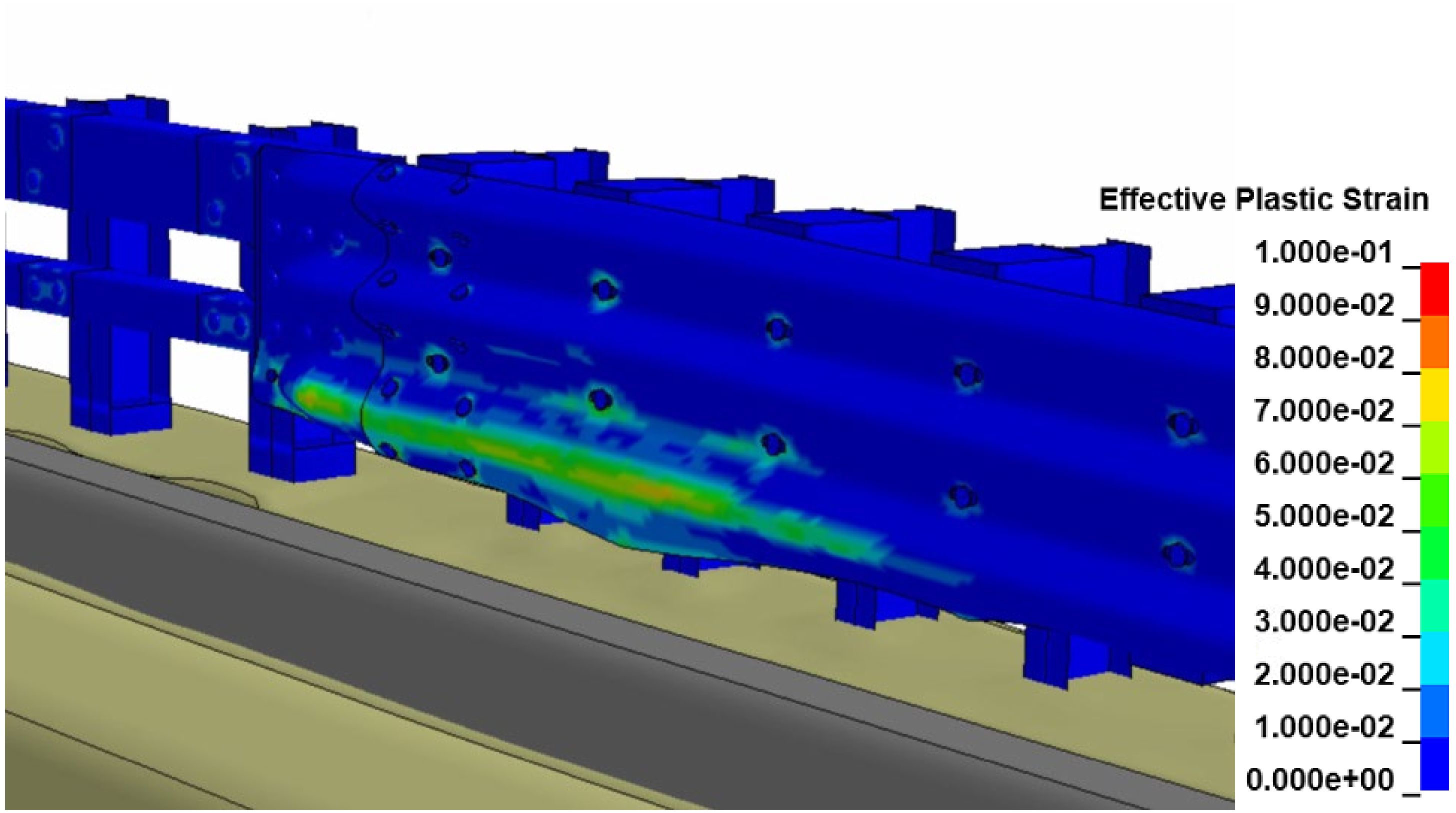
Maximum permanent deflection = 5.2 in (133 mm)

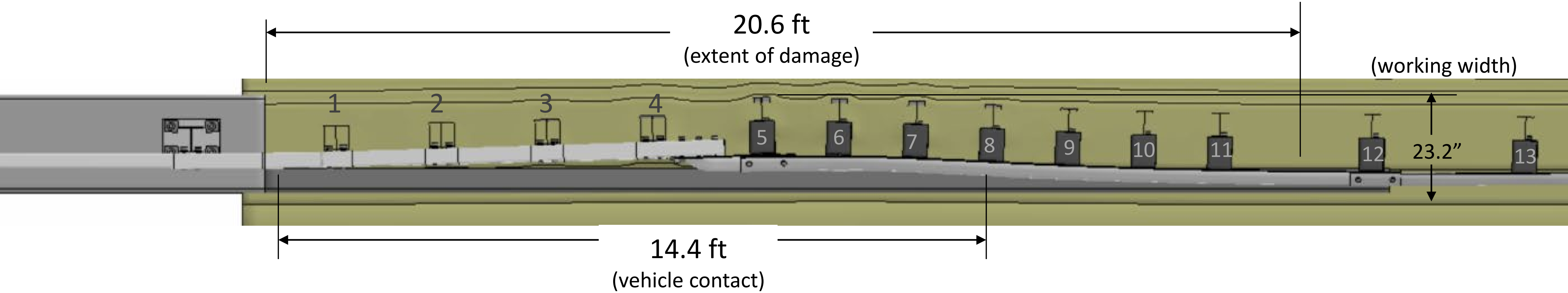


RoadSafe LLC
Transportation Engineering and Research

Barrier Damage

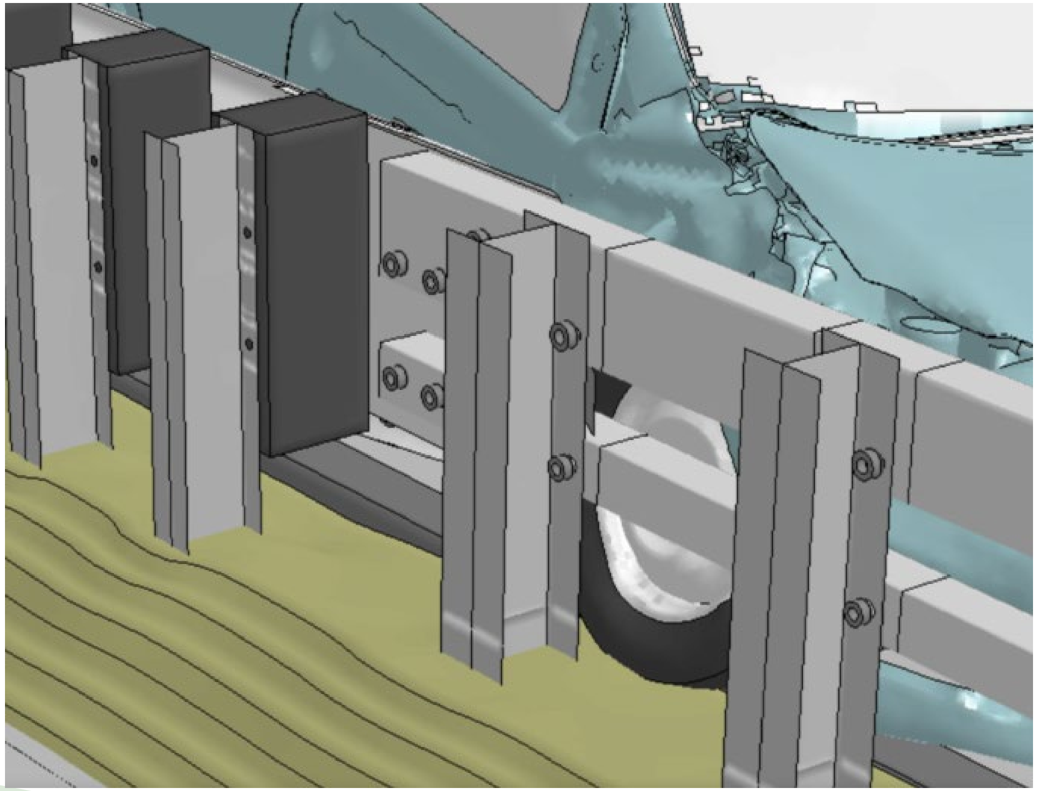
- Primary plastic deformations of the rail elements were limited to the lower corrugation of the thrie-beam and thrie-beam terminal connector.
- Total length of system deformed was approximately 20.6 ft starting between Posts 11 and 12 end extending to the beginning of the bridge rail.
- The vehicle was in contact with the system for approximately 14.4 ft.
- The maximum working width = 23.2 in
  - Measured as maximum dynamic lateral position of Post 5 (top-back of post) relative to the initial face of the barrier.

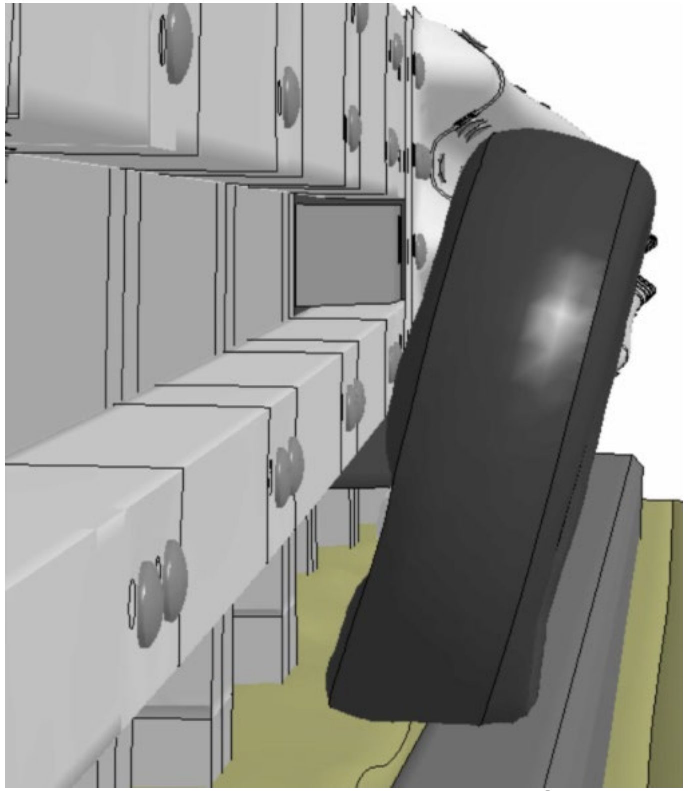




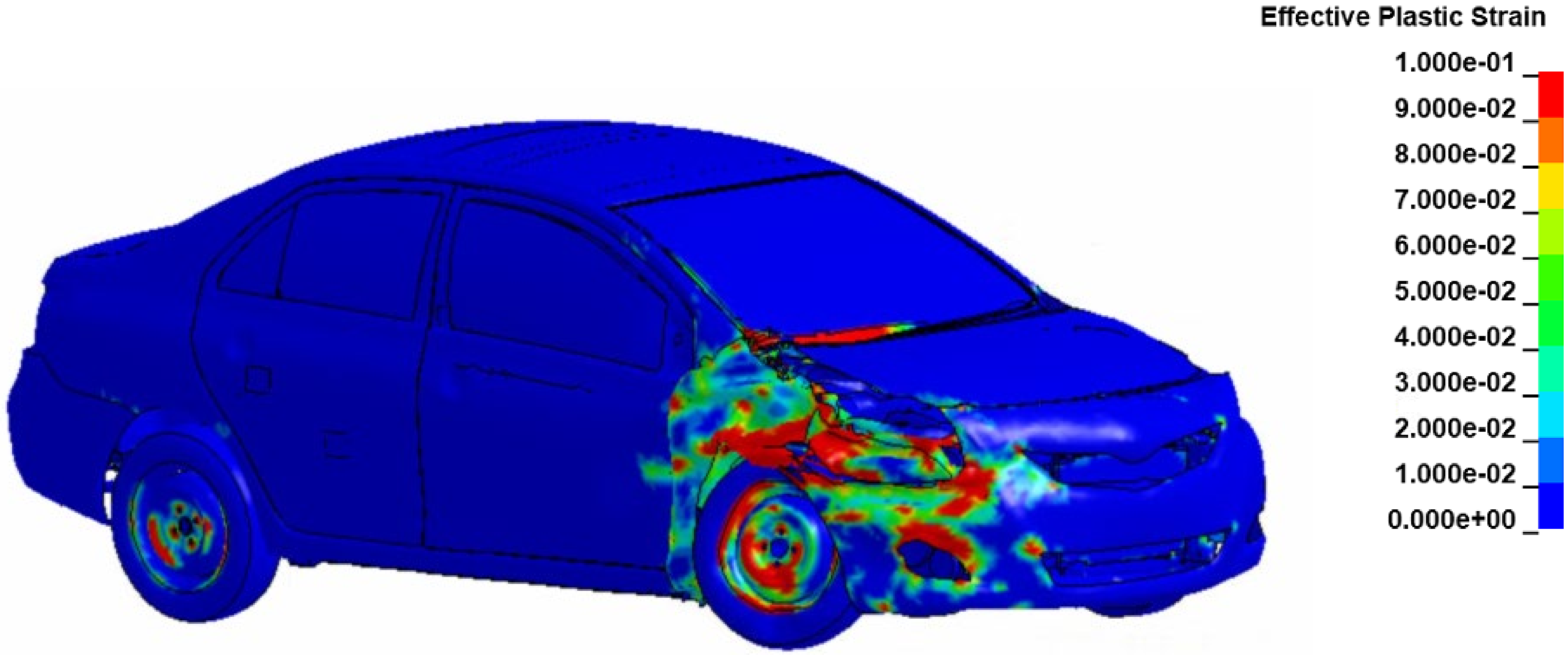
Assessment of Potential Vehicle Contact with Post

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





Effective Plastic Strain for Small Car Test

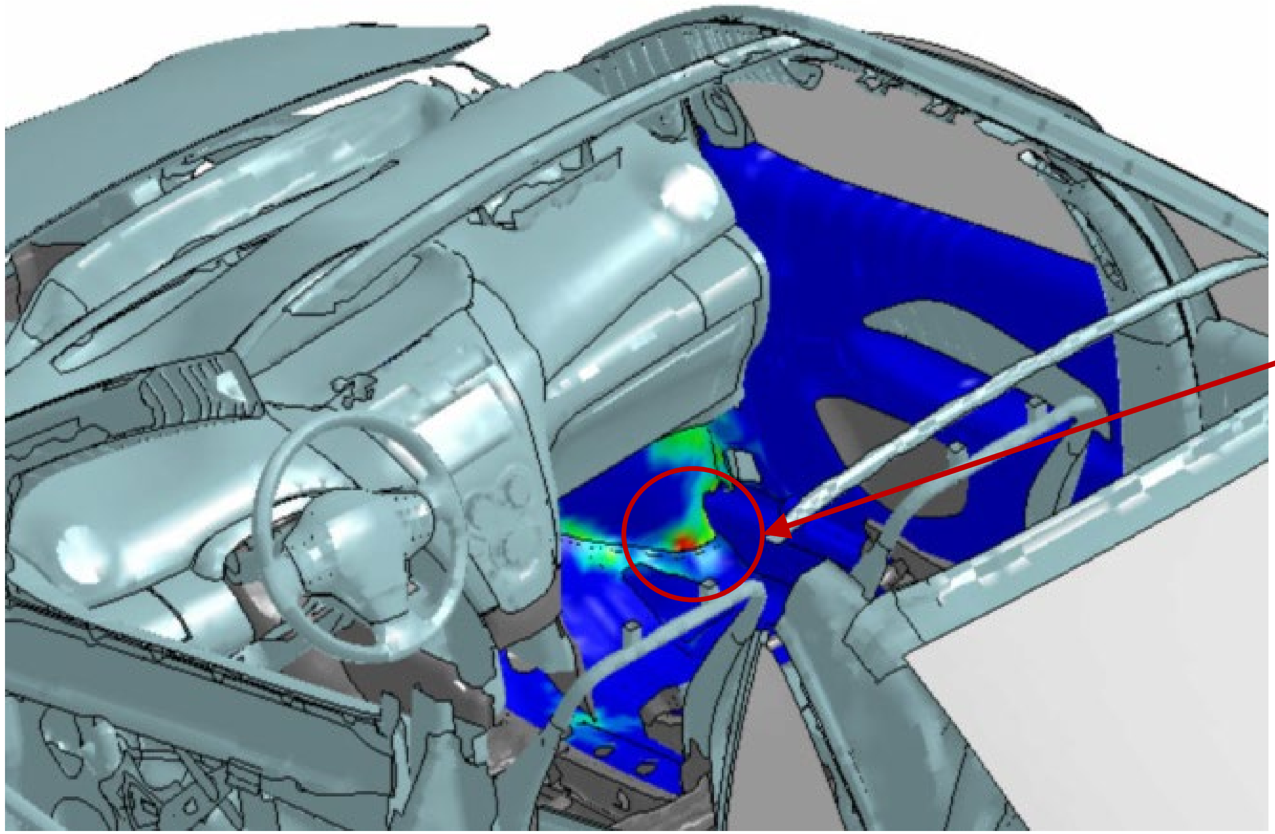


The most severe damages were to the front fender, the upper and lower control arm of front suspension, front wheel, lower-impact-side edge of windshield (cracking), with light damage to the rear wheel of the vehicle.

RoadSafe LLC
Transportation Engineering and Research

Occupant Compartment Intrusion (OCI) Video

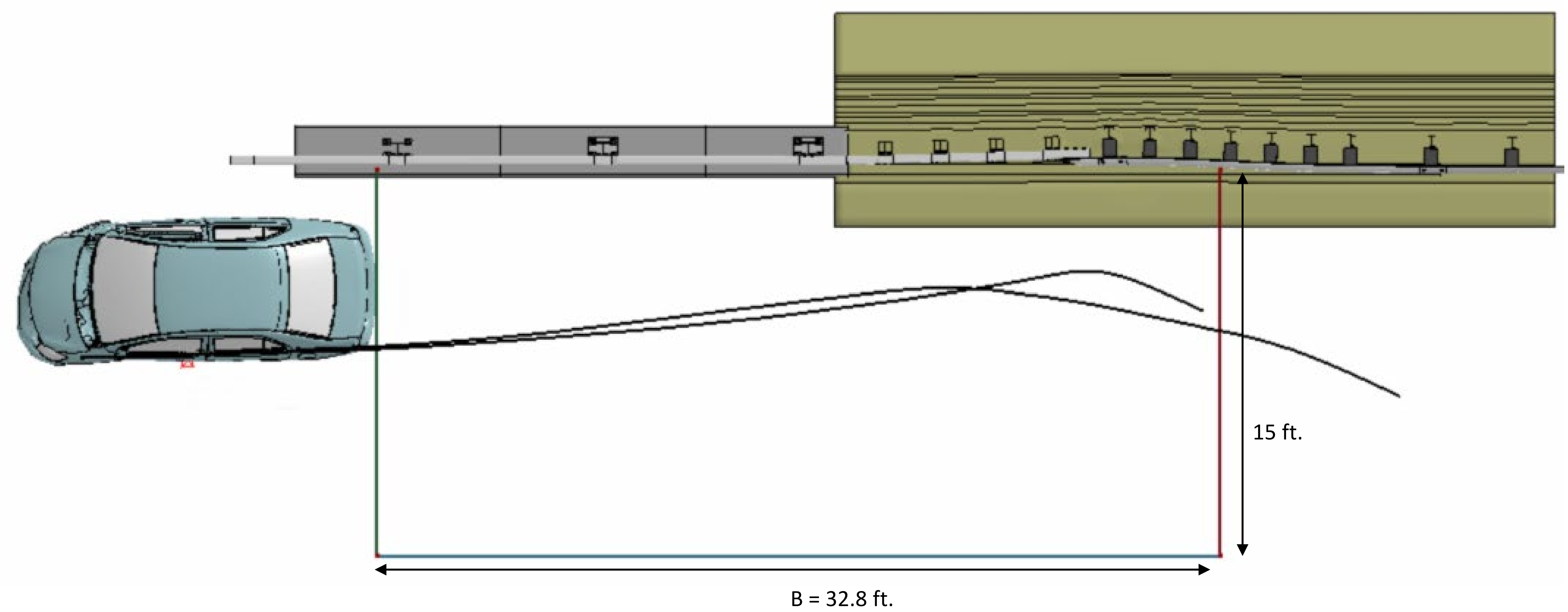
Occupant Compartment Intrusion (OCI)



Maximum OCI was ≈ 1.4 inches (36 mm) and occurred at the right-front toe-pan at the wheel well. *Maximum allowable is 9".*

Exit Box – 2-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.”



Conclusions Regarding Test 4-20 on the 2-Bar Transition

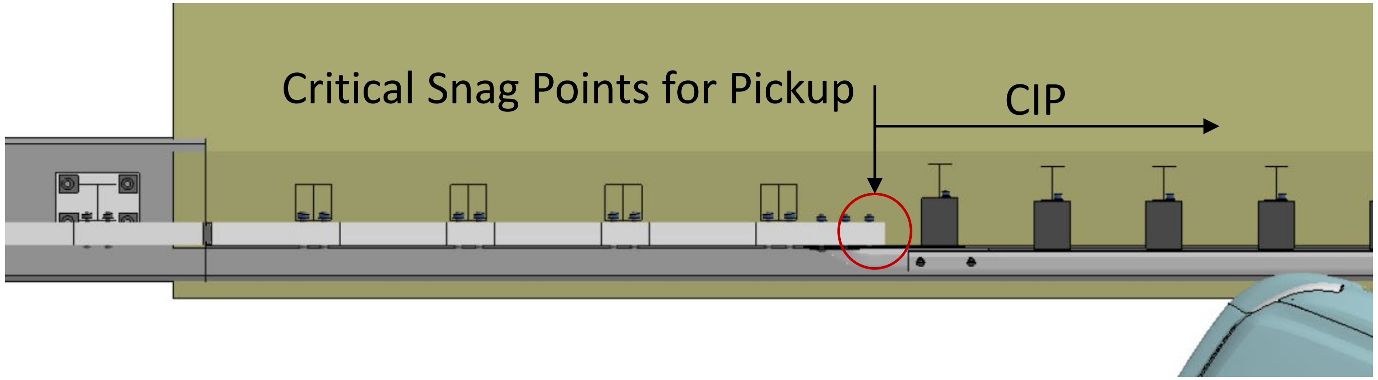
- The barrier successfully contained and redirected the 1100P vehicle.
- The vehicle remained upright and stable through impact and redirection, with relatively low angular displacements
  - Max Roll = **6.7 degrees** and Max Pitch = **3.6 degrees**.
- The OIV and ORA were within preferred limits specified in MASH.
  - OIV_x = **25.3 ft/s** and OIV_y = **28.2 ft/s**
  - ORA_x = **7.9 G** and ORA_y = **4.8 G** (*values dependent on time of occupant impact, particularly for the x-dir.*)
- The maximum **occupant compartment deformation** was **1.4 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 on the thrie-beam between Posts 5 and 6:
  - Max Dynamic = **6.3 inches**; Max Permanent = **5.2 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 4-21

- CIP was determined using FEA based on maximizing potential for snag on the end of transition tube railing.
  - Pocketing
    - Maximum relative deflection between thrie-beam and tube rail end.
  - 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)
  - OIV and ORA since these metrics are used directly in crashworthy assessments in MASH
  - Impact severity and kinetic energy at time of impact with critical snag point



- Analysis Cases (7 cases):
  - Impact points 6.0, 6.5, 7.0, 7.5 , 8.0, 8.5 and 9.0 feet from the end of the tube rail section.
  - These analyses were conducted for 0.25 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 tube railing.
  - This was sufficient time for determining both maximum OIV and ORA for the impact event.

IP 6.0 ft

IP 6.5 ft

IP 7.0 ft

IP 7.5 ft

IP 8.0 ft

IP 8.5 ft

IP 9.0 ft

IP 9.5 ft

RoadSafe LLC
Transportation Engineering and Research

IP 6.0 ft

IP 6.5 ft

IP 7.0 ft

IP 7.5 ft

IP 8.0 ft

IP 8.5 ft

IP 9.0 ft

IP 9.5 ft

IP 6.0 ft

IP 6.5 ft

IP 7.0 ft

IP 7.5 ft

IP 8.0 ft

IP 8.5 ft

IP 9.0 ft

IP 9.5 ft

IP 6.0 ft

IP 6.5 ft

IP 7.0 ft

IP 7.5 ft

IP 8.0 ft

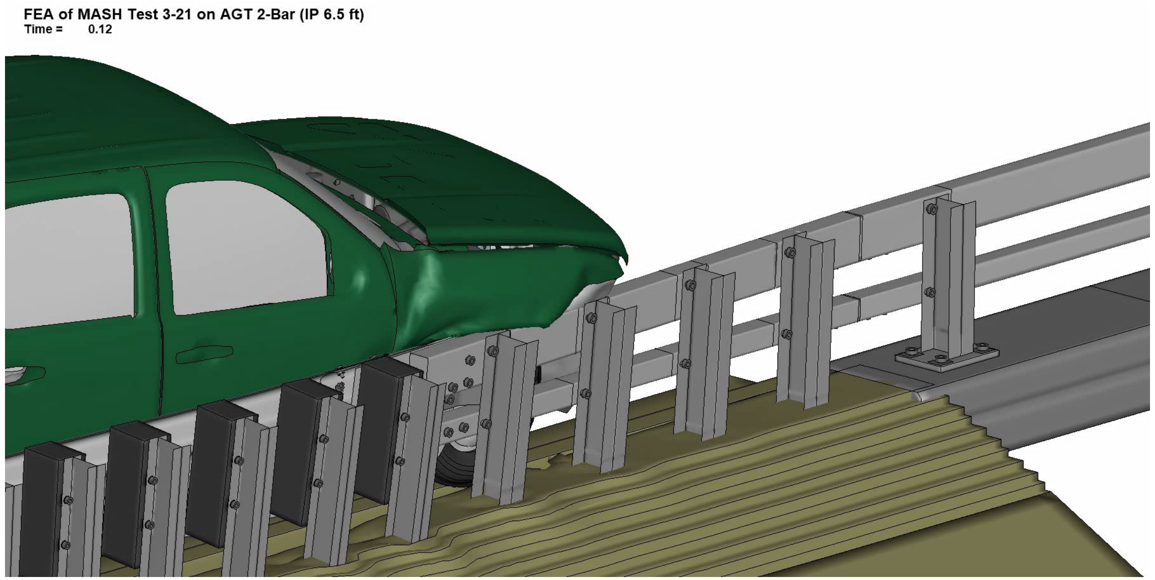
IP 8.5 ft

IP 9.0 ft

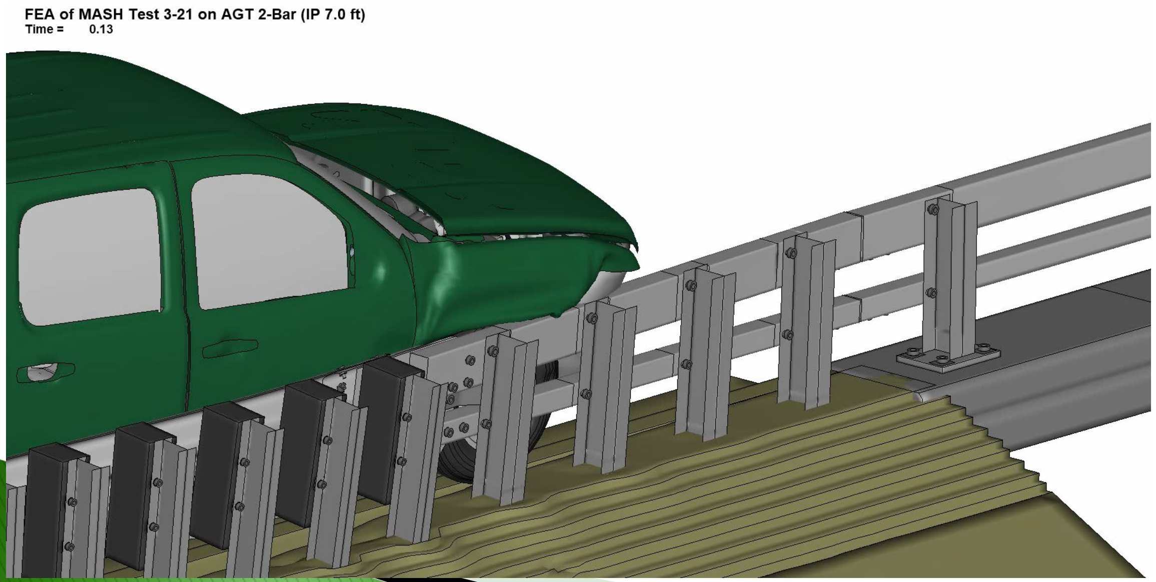
IP 9.5 ft

IP 6.0 ft

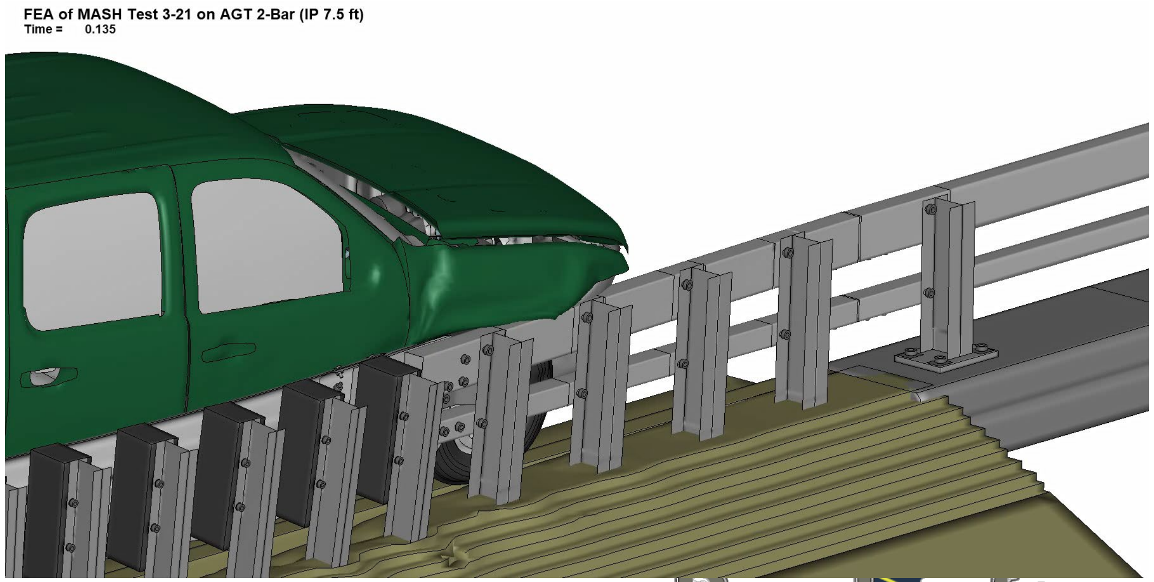
IP 6.5 ft



IP 7.0 ft



IP 7.5 ft



IP 8.0 ft

IP 8.5 ft

IP 9.0 ft

IP 9.5 ft

IP 6.0 ft

IP 6.5 ft

IP 7.0 ft

IP 7.5 ft

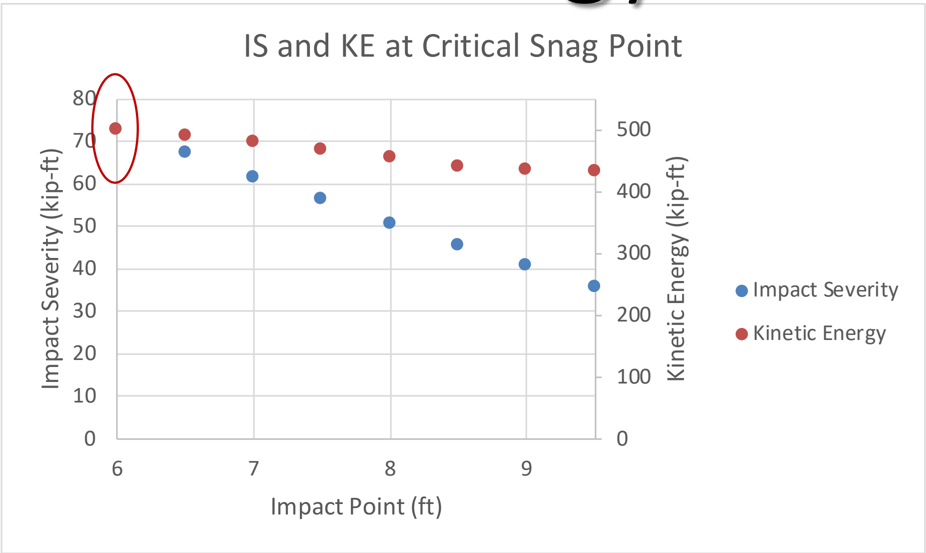
IP 8.0 ft

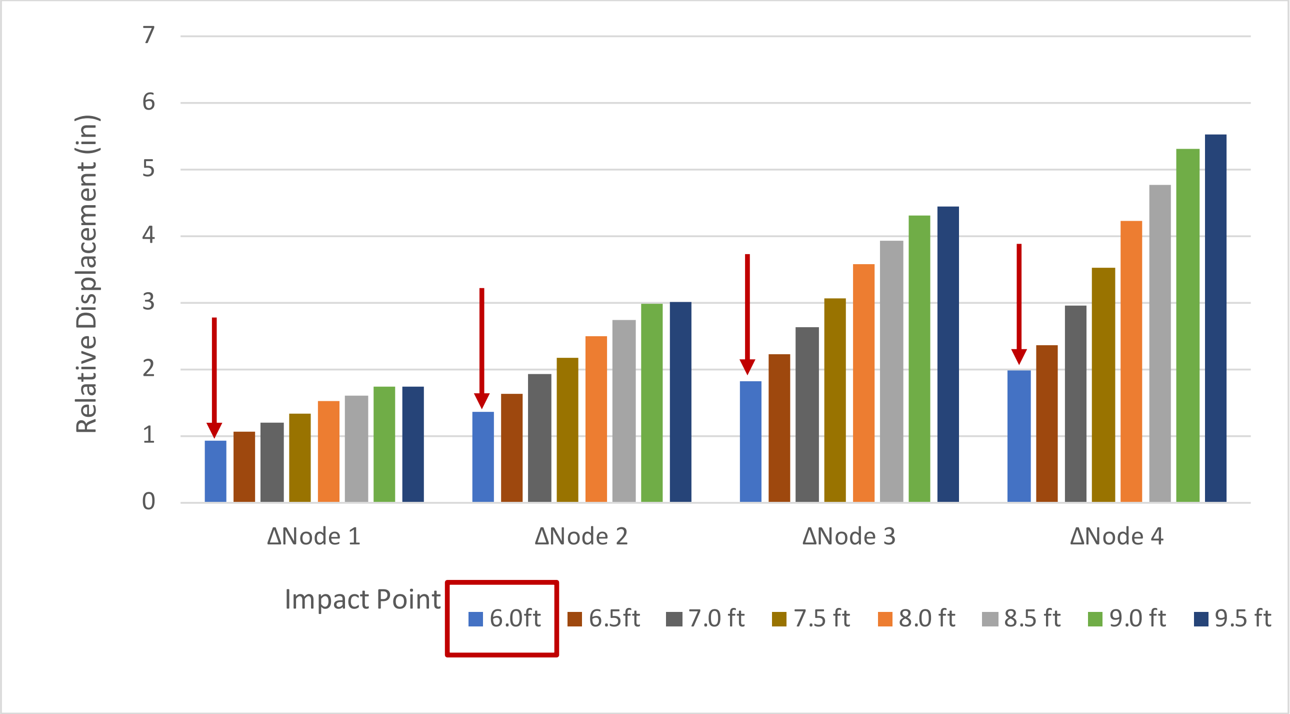
IP 8.5 ft

IP 9.0 ft

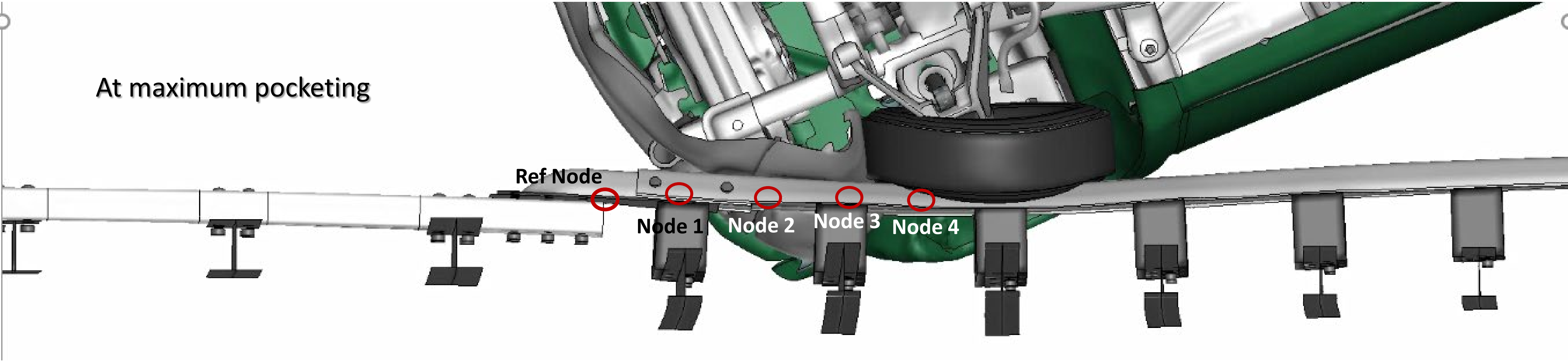
IP 9.5 ft

Pocketing, IS and Kinetic Energy

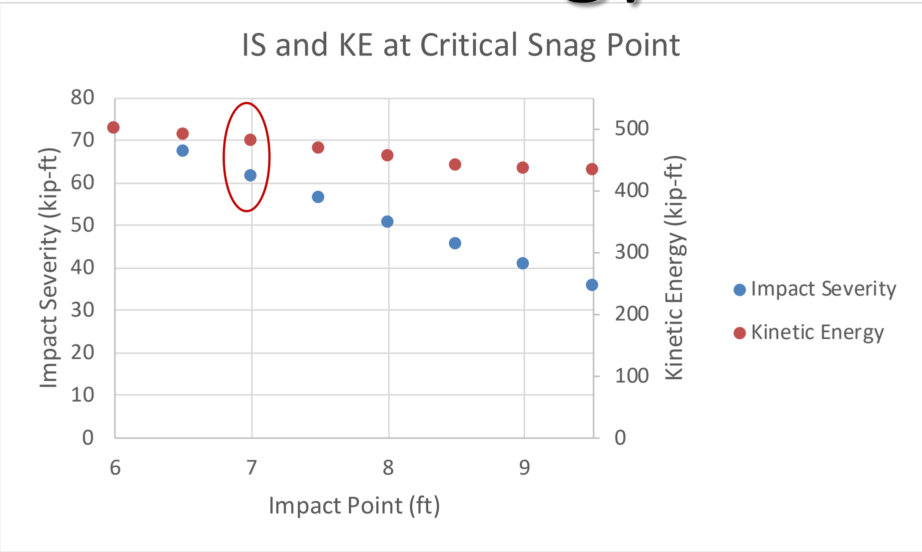


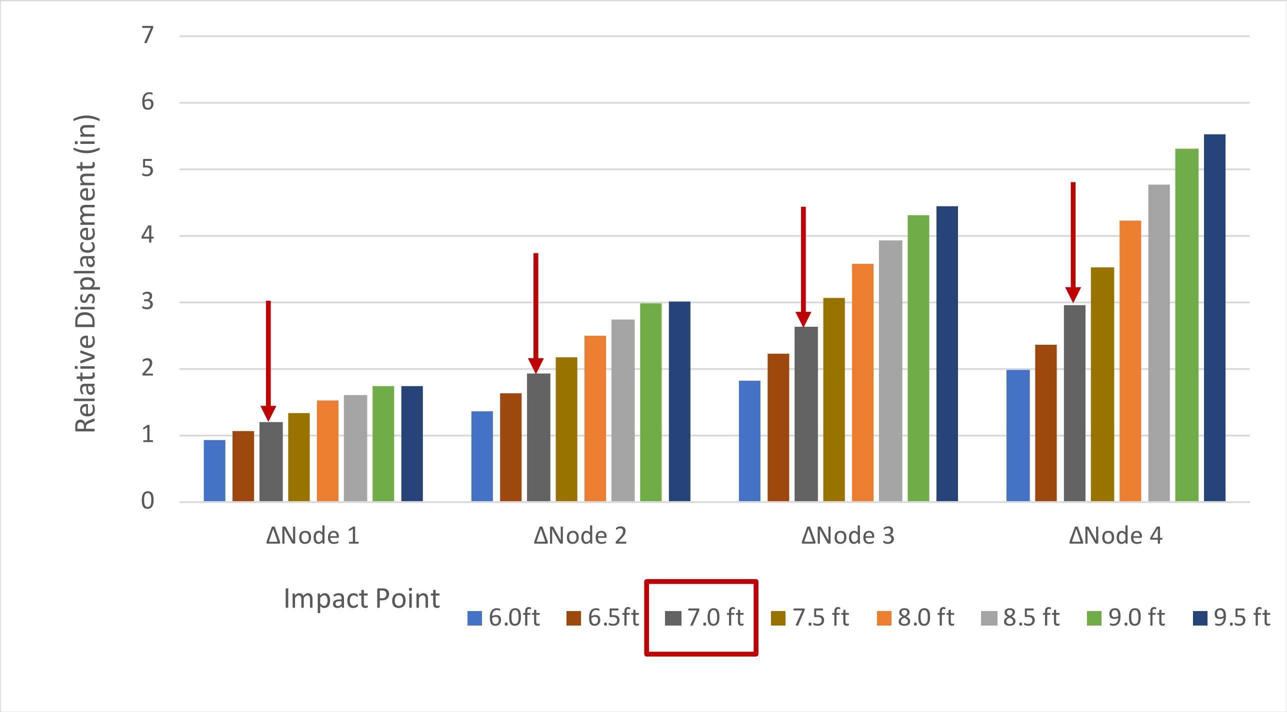


At maximum pocketing

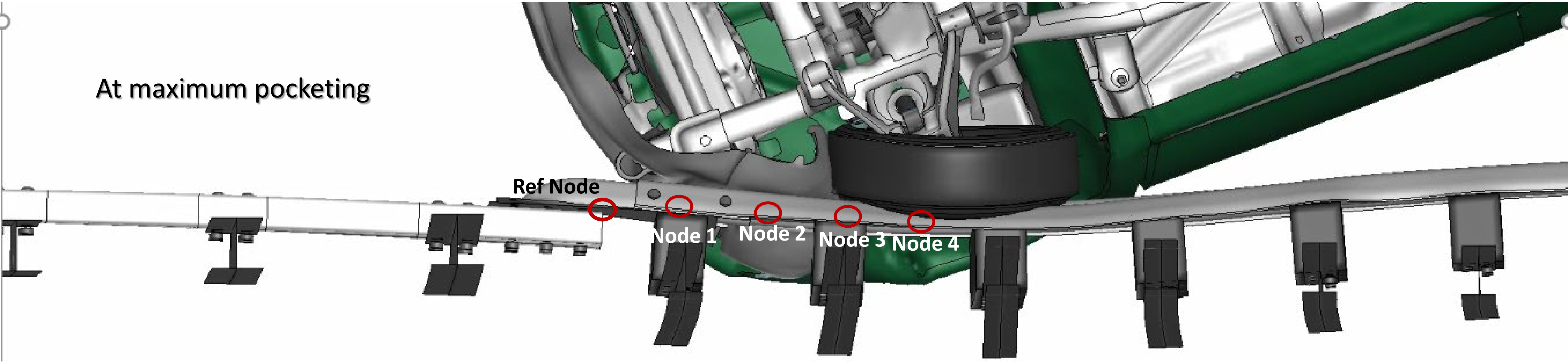


Pocketing, IS and Kinetic Energy

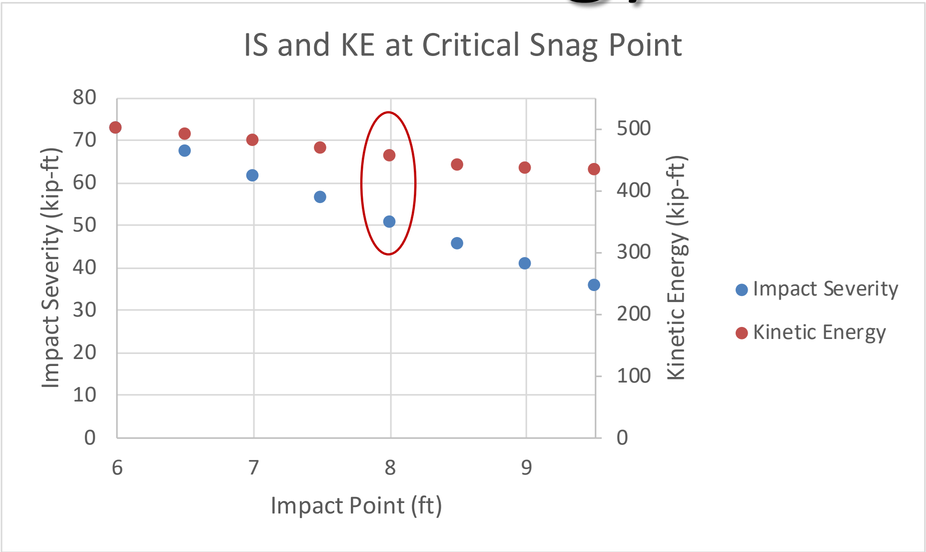


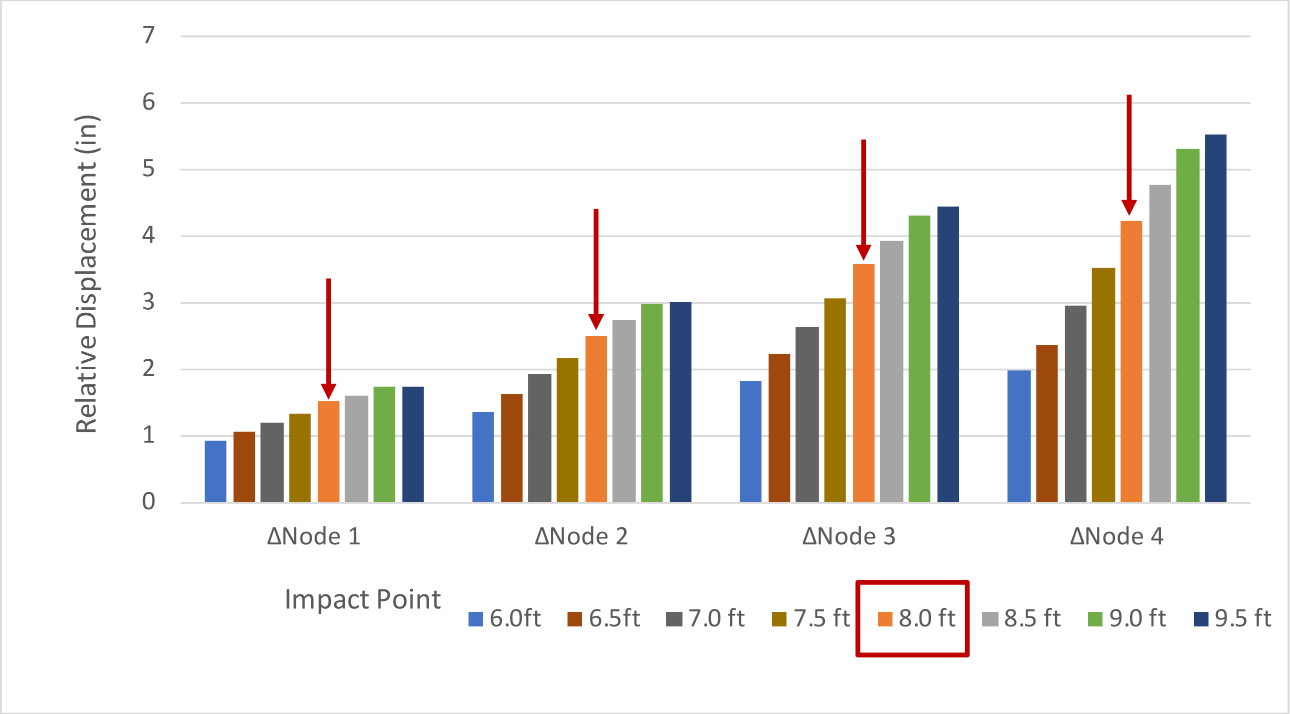


At maximum pocketing

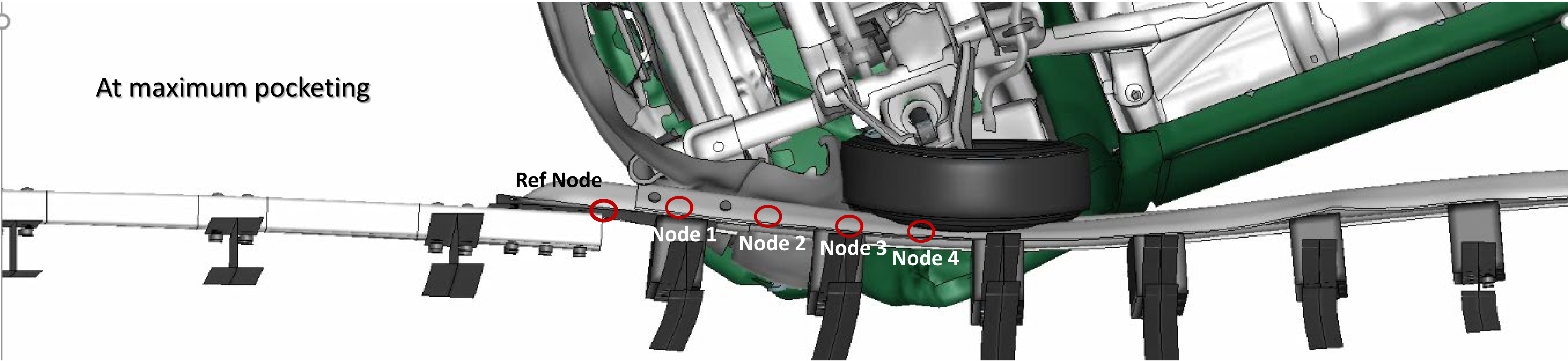


Pocketing, IS and Kinetic Energy

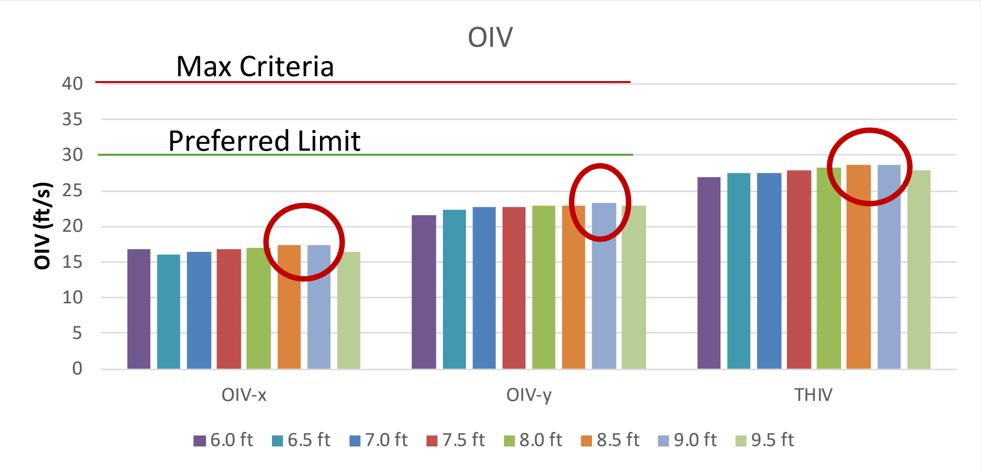


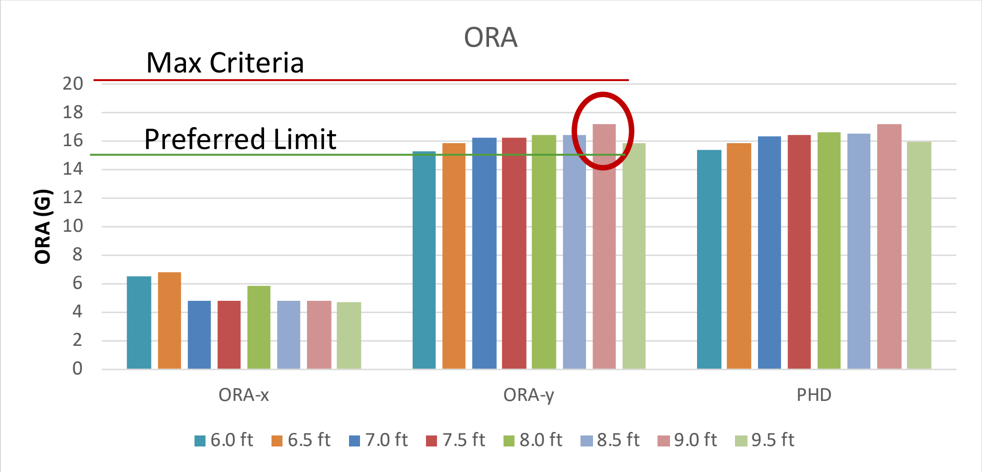


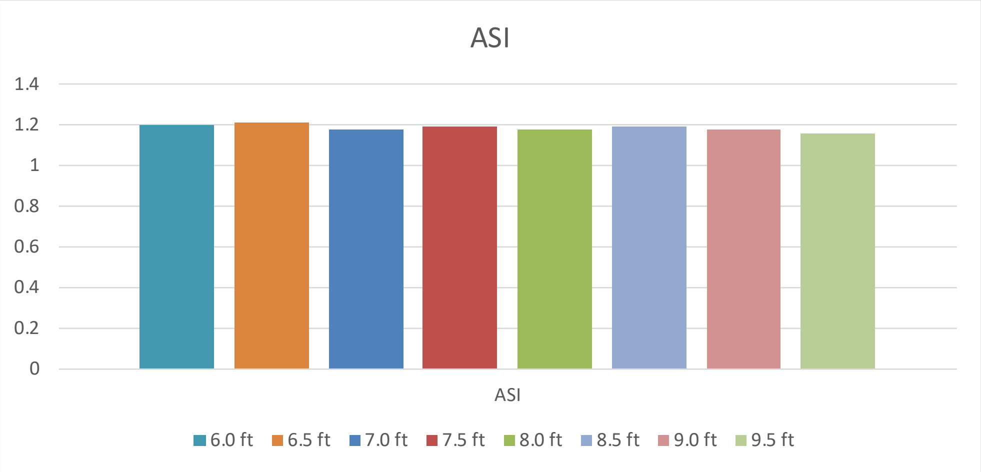
At maximum pocketing

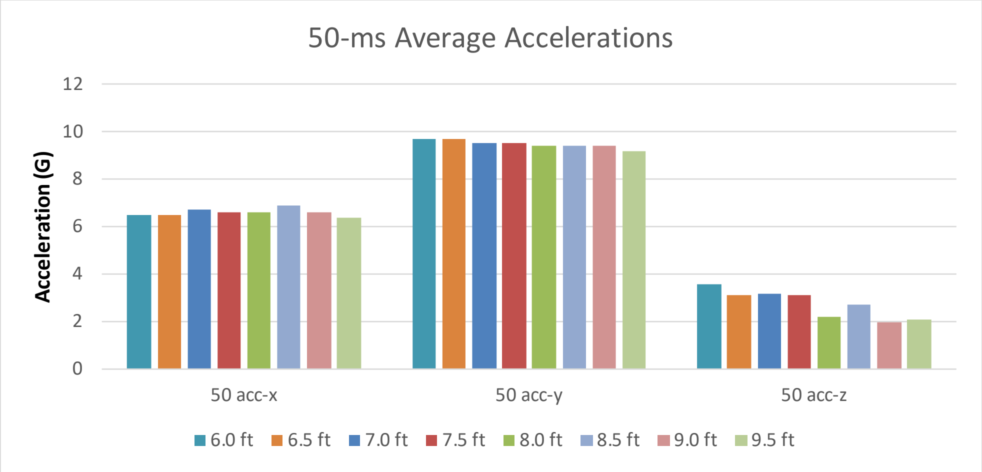


TRAP Results









RoadSafe LLC
Transportation Engineering and Research

Summary on CIP Calculations

- The results indicated:
  - 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 pocketing
  - **IP 9.0 ft and 10 ft** resulted in the greatest relative deflection
- OIV:
  - **Essentially the same for all cases**; however,
    - highest lateral acceleration occurred for Cases **8.5 and 9 ft**
- ORA:
  - Highest longitudinal: **IP 6.5 ft**
  - Highest lateral: **IP 9.0 ft**
- Additional comparisons were made for the 3-Bar transition case, which are not repeated here but are considered relevant to this 2-Bar system.

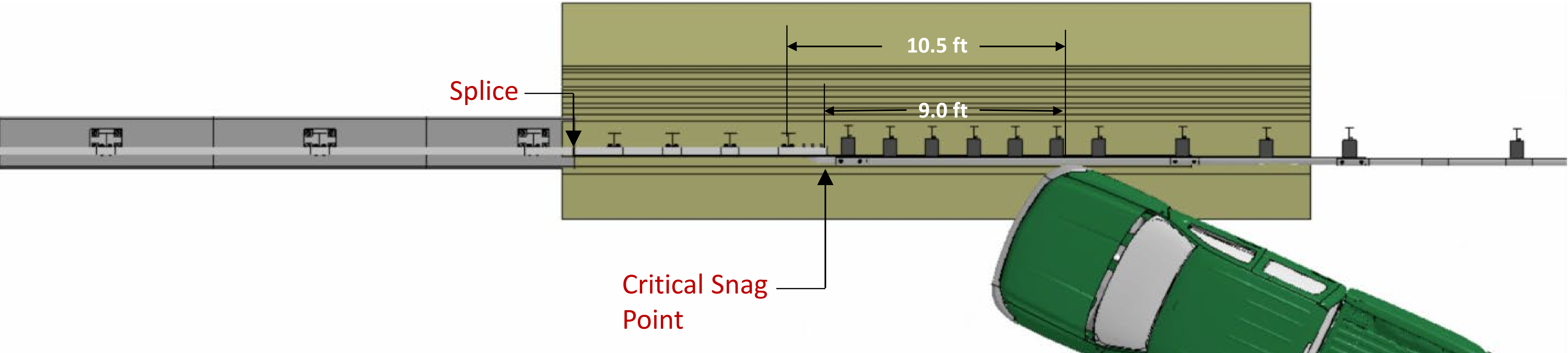
RoadSafe LLC
Transportation Engineering and Research

Conclusions on CIP Selection

- Given that this system is very similar to the 3-Bar transition evaluated in Task 4, the results are essentially identical to that system.
- Any differences correspond to the fact that the CIP for the 3-Bar was based on results up to 0.15 seconds of the impact; whereas, for the 2-Bar system the analysis was extended to 0.25 seconds to include the tail-slap of the pickup into the barrier.
- **The CIP for the 2-Bar system was determined to be 9.0 ft.**
  - This was also considered as a secondary CIP for the 3-Bar system, but that analysis case was not run-out for the full impact event (e.g., 1.0 second).
  - It is assumed that the results for the 2-Bar at impact point = 9.0 ft would also pertain to the 3-Bar system.

MASH Test 4-21 Simulation on the 2-Bar Trans

- Impact Conditions
  - Impact Speed = 62.1 mph (100 km/hr)
  - Impact Angle = 25 degrees
  - Impact Point = 9 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

TRAP – Summary Table

Occupant Risk Factors		MASH Test 4-21
Occupant Impact Velocity (ft/s)	x-direction	17.4
	y-direction	23.3
	at time	at 0.0973 seconds on right side of interior
THIV (ft/s)		28.5 at 0.0973 seconds on right side of interior
Ridedown Acceleration (g's)	x-direction	-4.8 (0.1112 - 0.1212 seconds)
	y-direction	-17.2 (0.1919 - 0.2019 seconds)
PHD (g's)		17.2 (0.1919 - 0.2019 seconds)
ASI		1.18 (0.0484 - 0.0984 seconds)
Max 50-ms moving avg. acc. (g's)	x-direction	-6.6 (0.0377 - 0.0877 seconds)
	y-direction	-9.4 (0.0485 - 0.0985 seconds)
	z-direction	4.1 (0.2373 - 0.2873 seconds)
Maximum Angular Disp. (deg)	Roll	9.3 (0.4070 seconds)
	Pitch	-5.5 (0.4992 seconds)
	Yaw	-32.8 (0.4083 seconds)

MASH Criteria

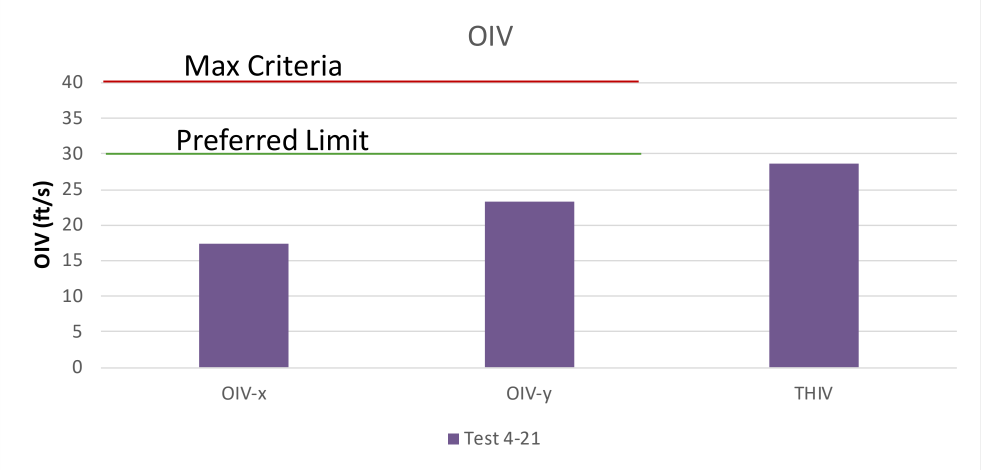
< 30 ft/s (preferred) ✓
< 40 ft/s (limit)

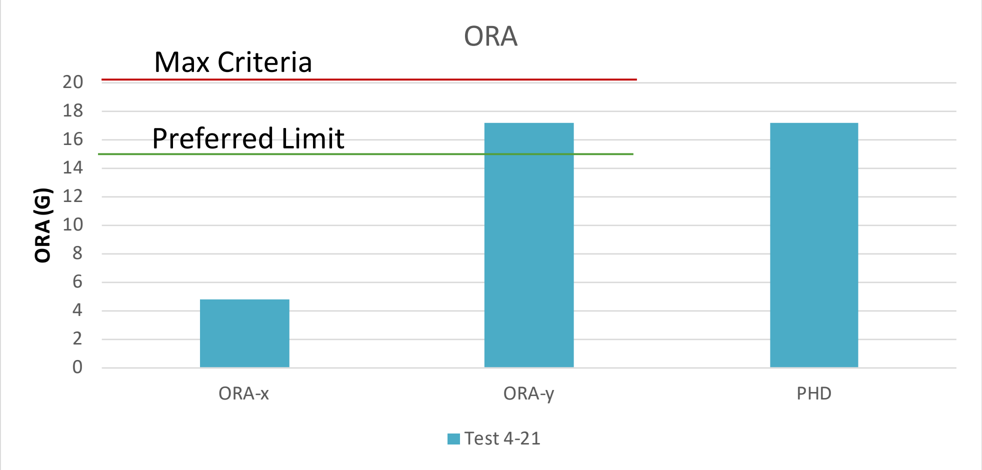
> 15 G (preferred)
< 20.49 G (limit) ✓

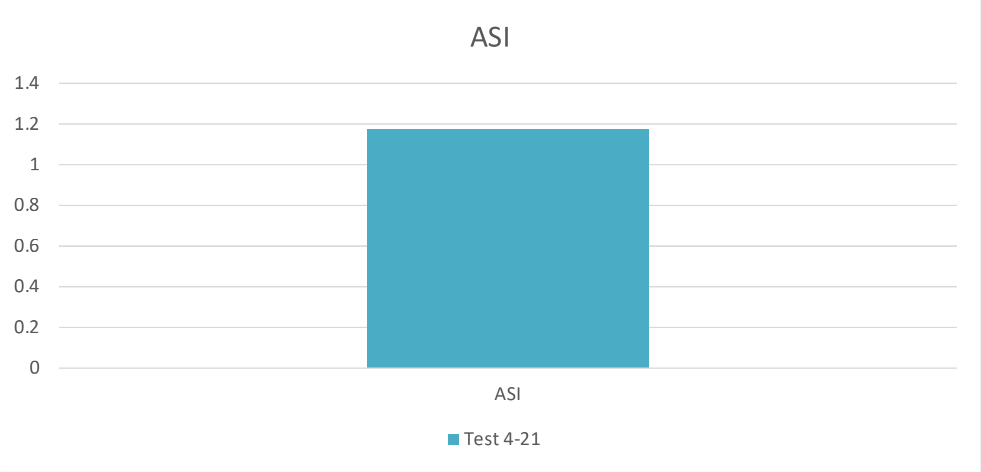
< 75 deg ✓

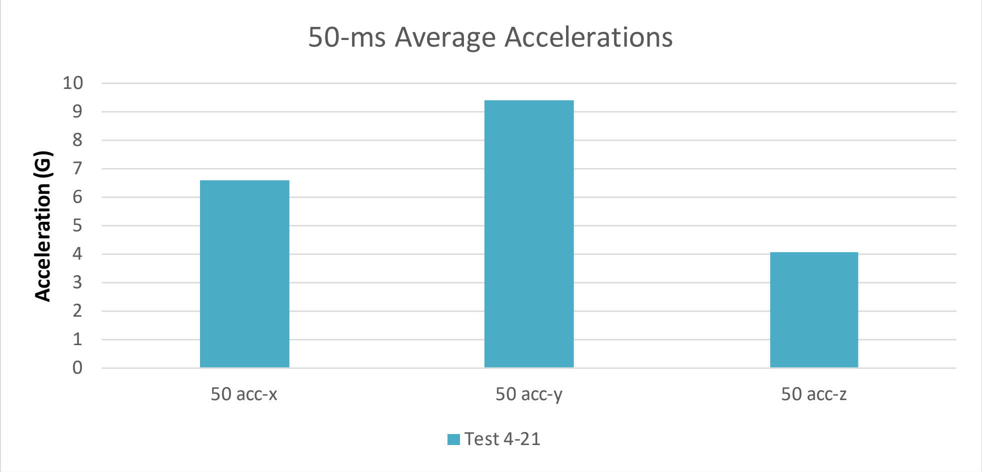
RoadSafe LLC
Transportation Engineering and Research

TRAP

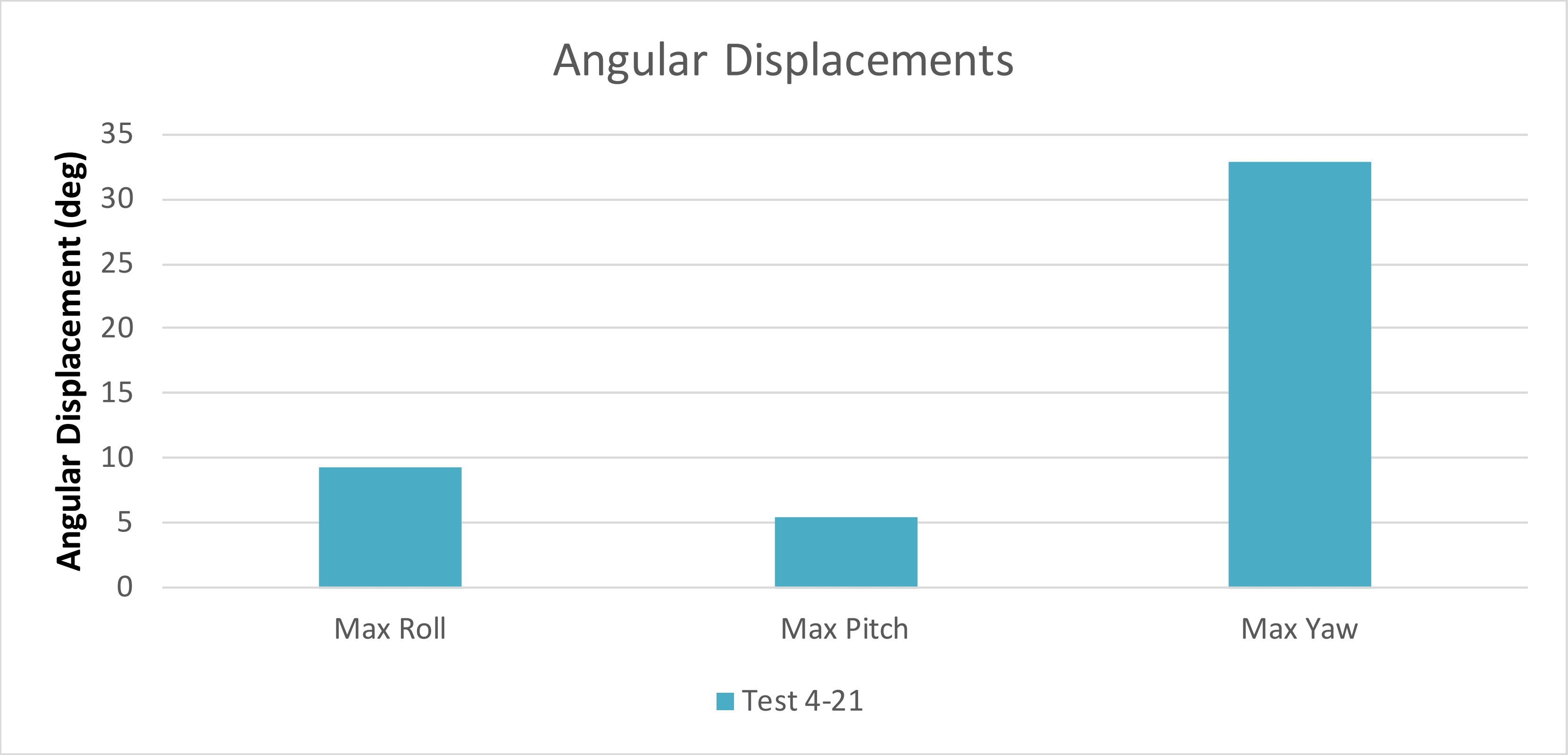

OIV
Max Criteria
Preferred Limit
OIV (ft/s)
40
35
30
25
20
15
10
5
0
OIV-x
OIV-y
THIV
Test 4-21


ORA
Max Criteria
Preferred Limit
ORA (G)
20
18
16
14
12
10
8
6
4
2
0
ORA-x
ORA-y
PHD
Test 4-21

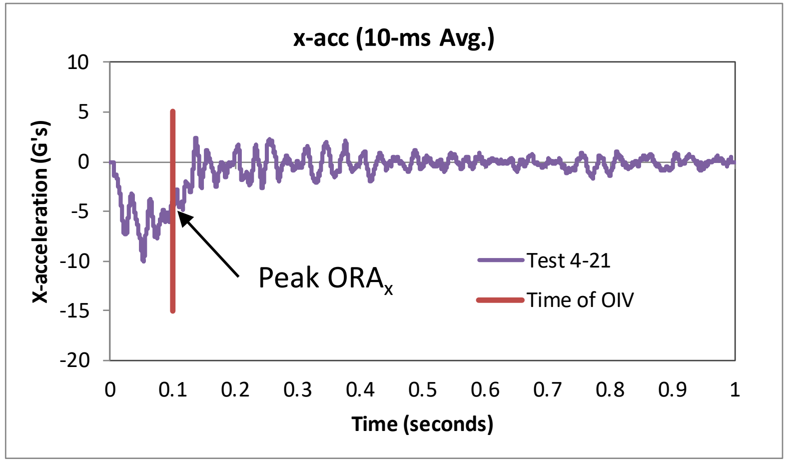

ASI
1.4
1.2
1
0.8
0.6
0.4
0.2
0
ASI
Test 4-21

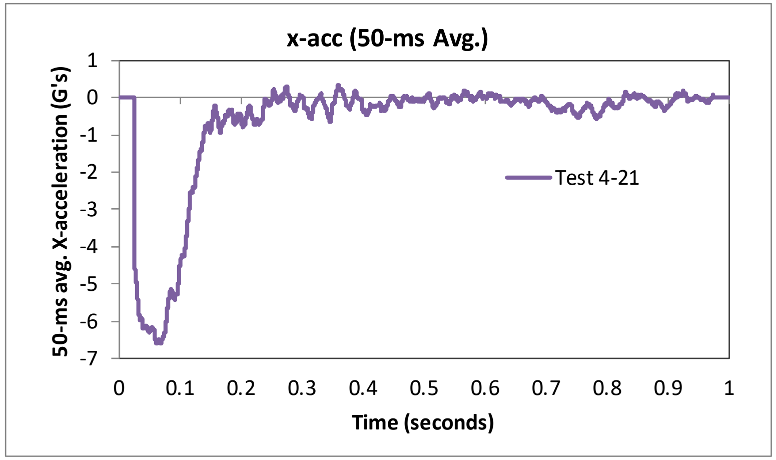

50-ms Average Accelerations
Acceleration (G)
10
9
8
7
6
5
4
3
2
1
0
50 acc-x
50 acc-y
50 acc-z
Test 4-21

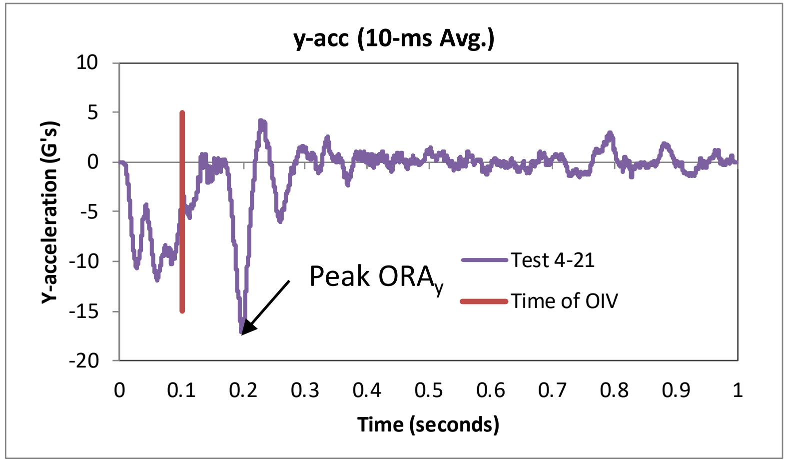
TRAP

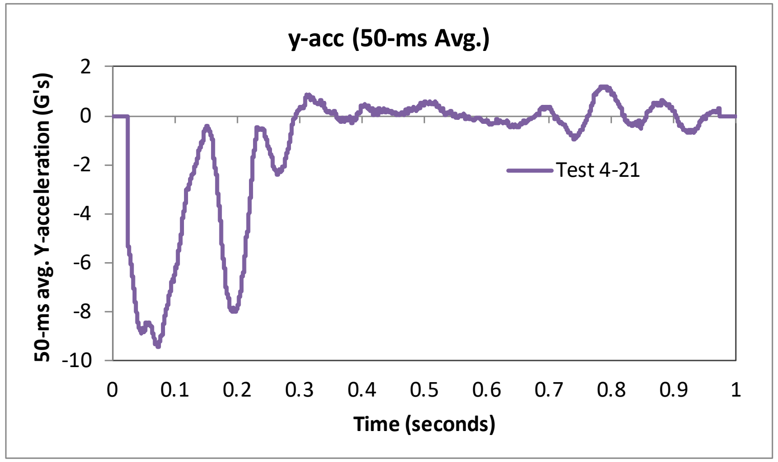

Angular Displacements
Angular Displacement (deg)
35
30
25
20
15
10
5
0
Max Roll
Max Pitch
Max Yaw
Test 4-21

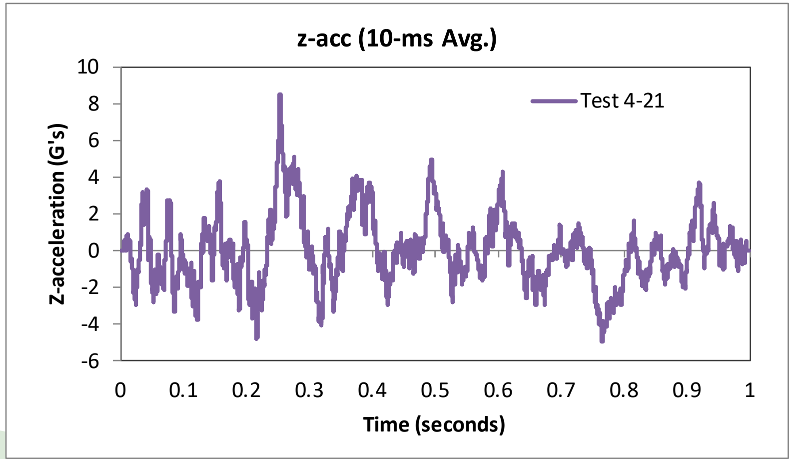
Acceleration Plots

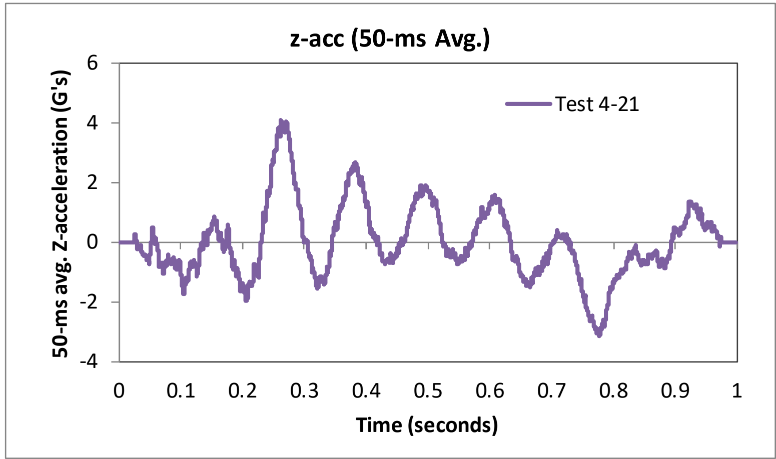




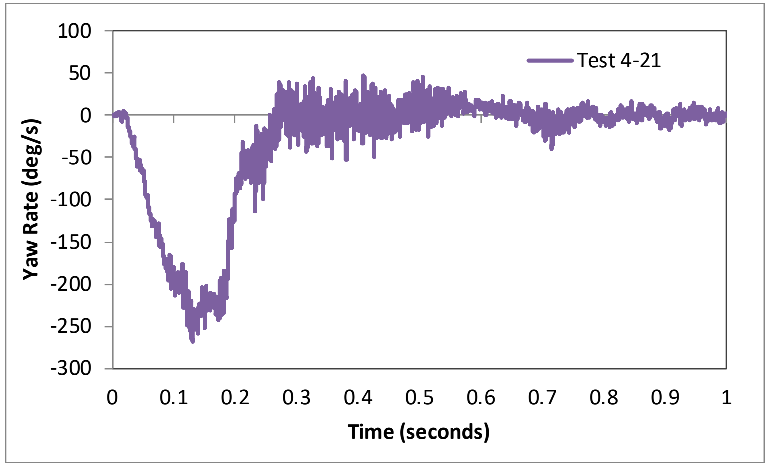


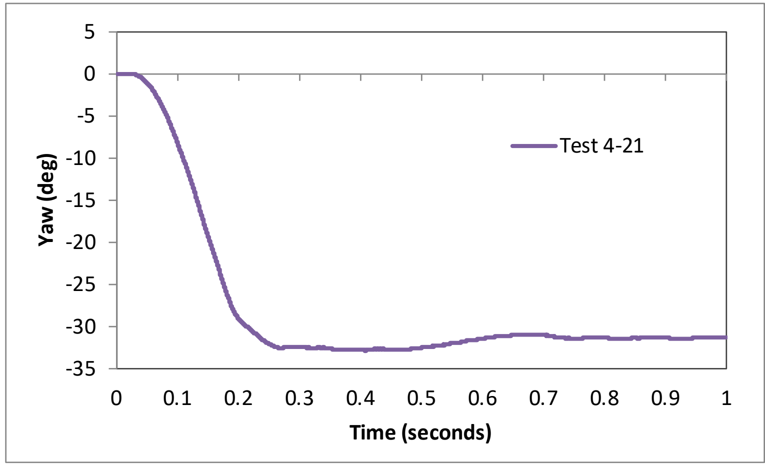


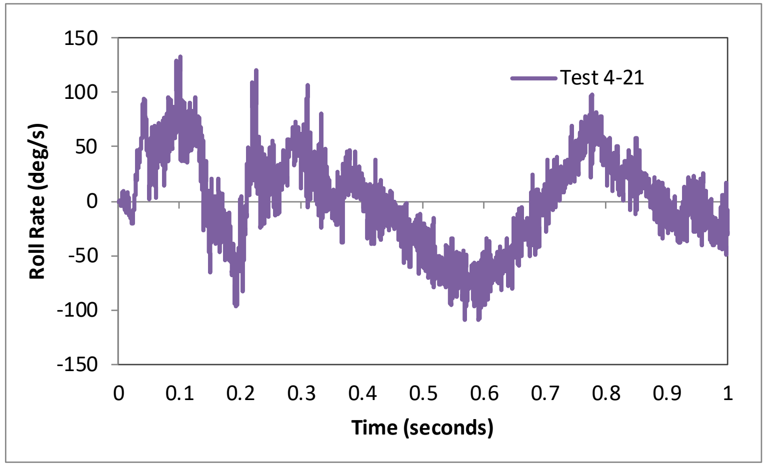


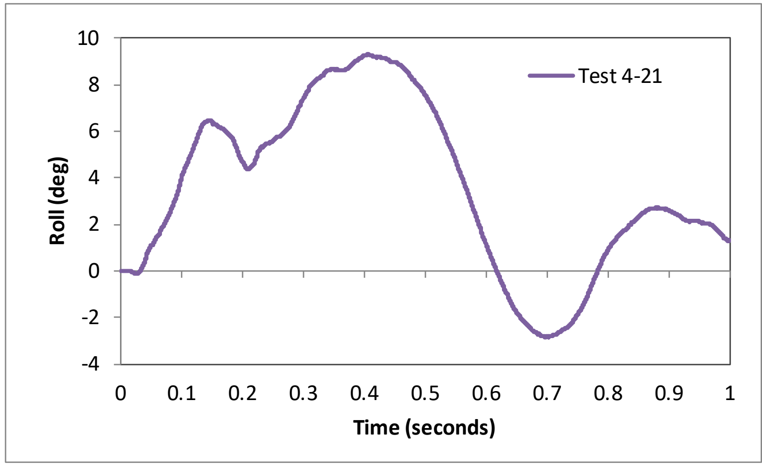


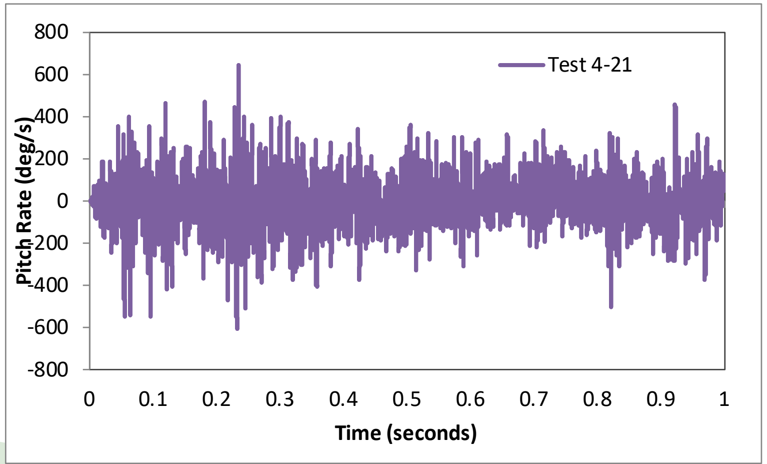
Angular Rate and Displacement Plots

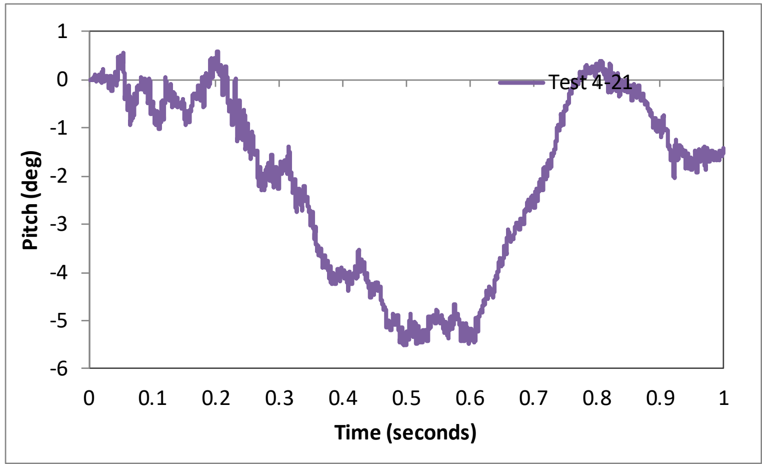


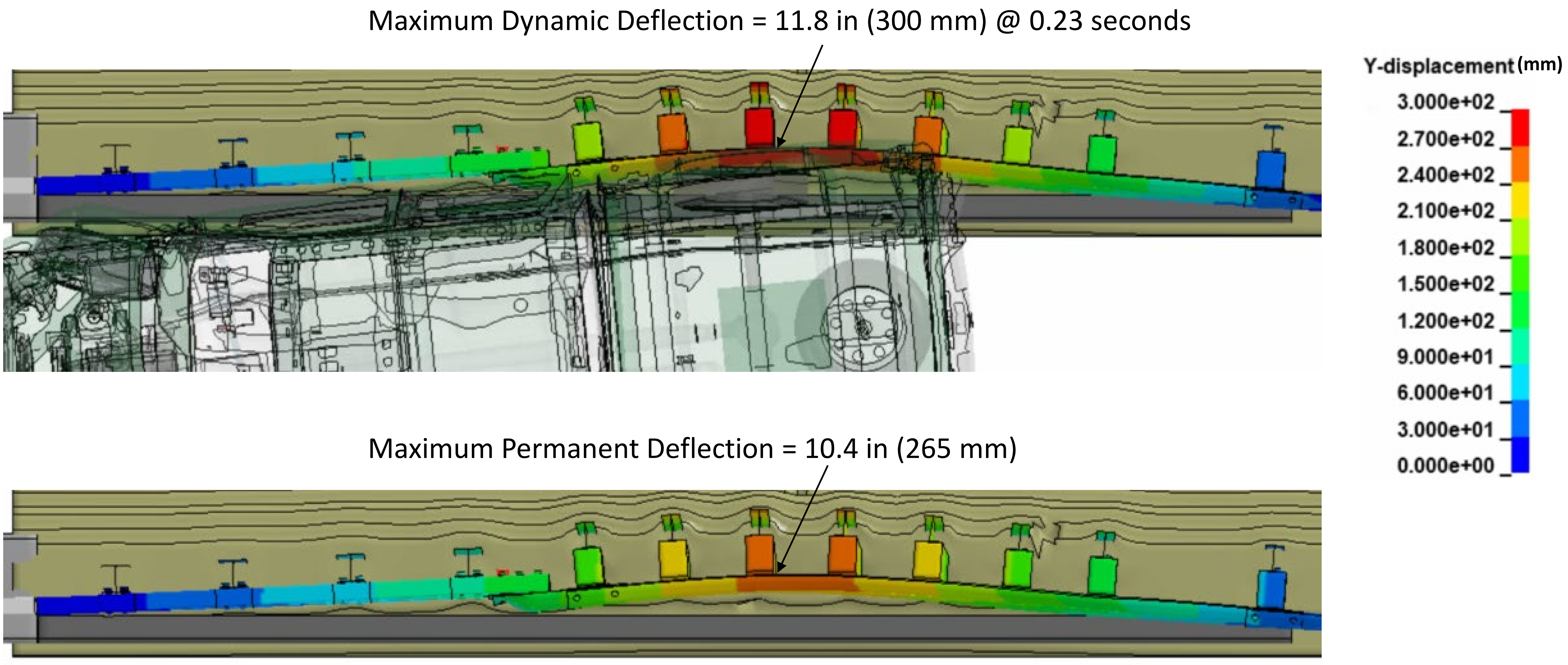






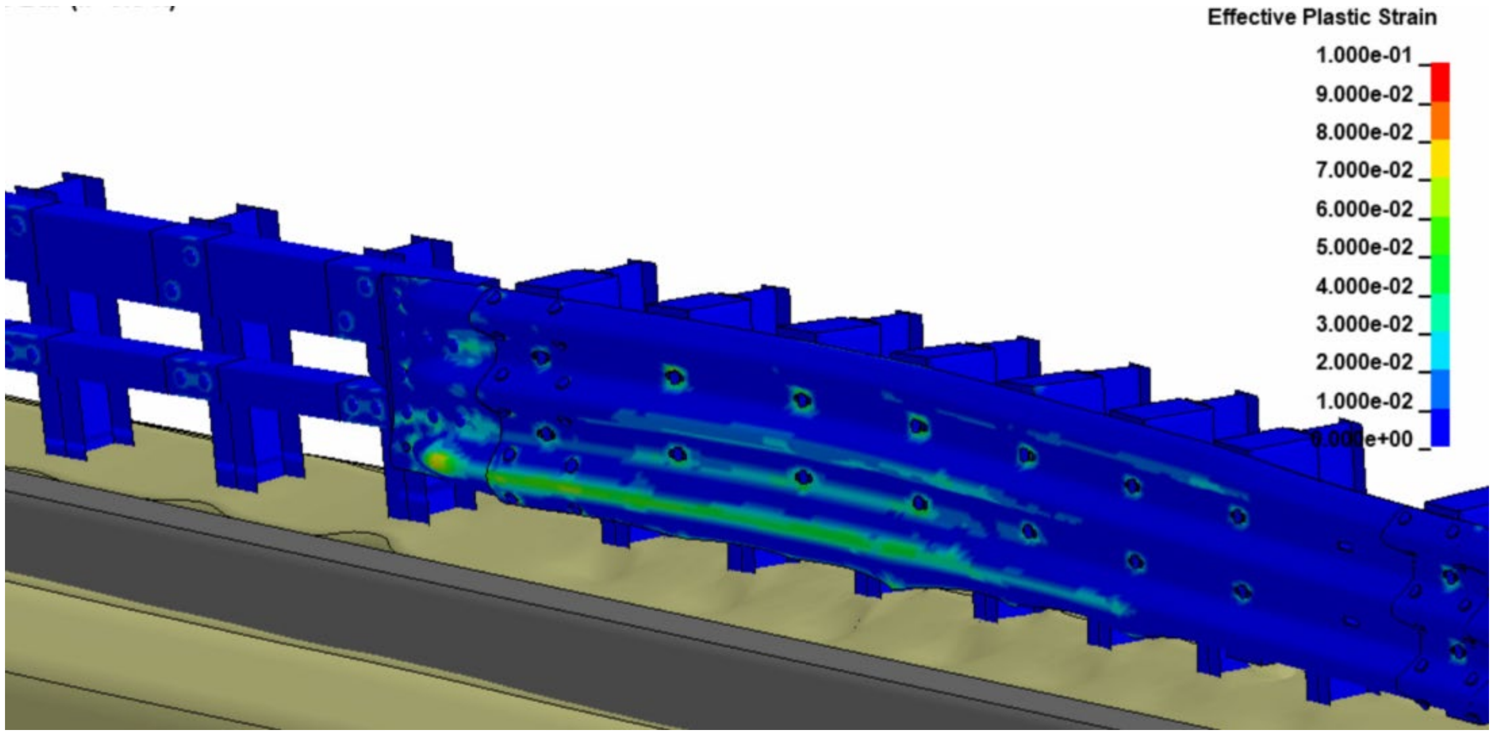


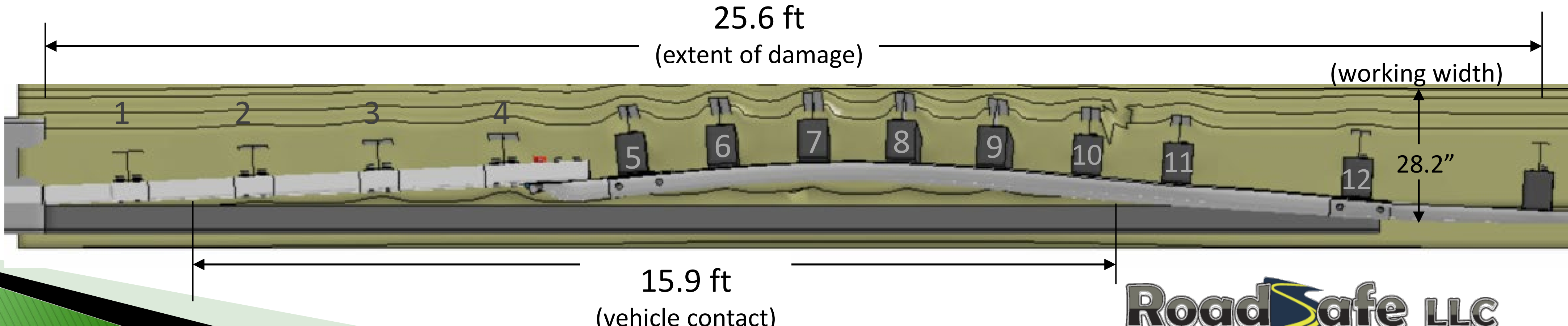



Maximum Dynamic Deflection = 11.8 in (300 mm) @ 0.23 seconds
Maximum Permanent Deflection = 10.4 in (265 mm)
Y-displacement (mm)
3.000e+02
2.700e+02
2.400e+02
2.100e+02
1.800e+02
1.500e+02
1.200e+02
9.000e+01
6.000e+01
3.000e+01
0.000e+00

Barrier Damage

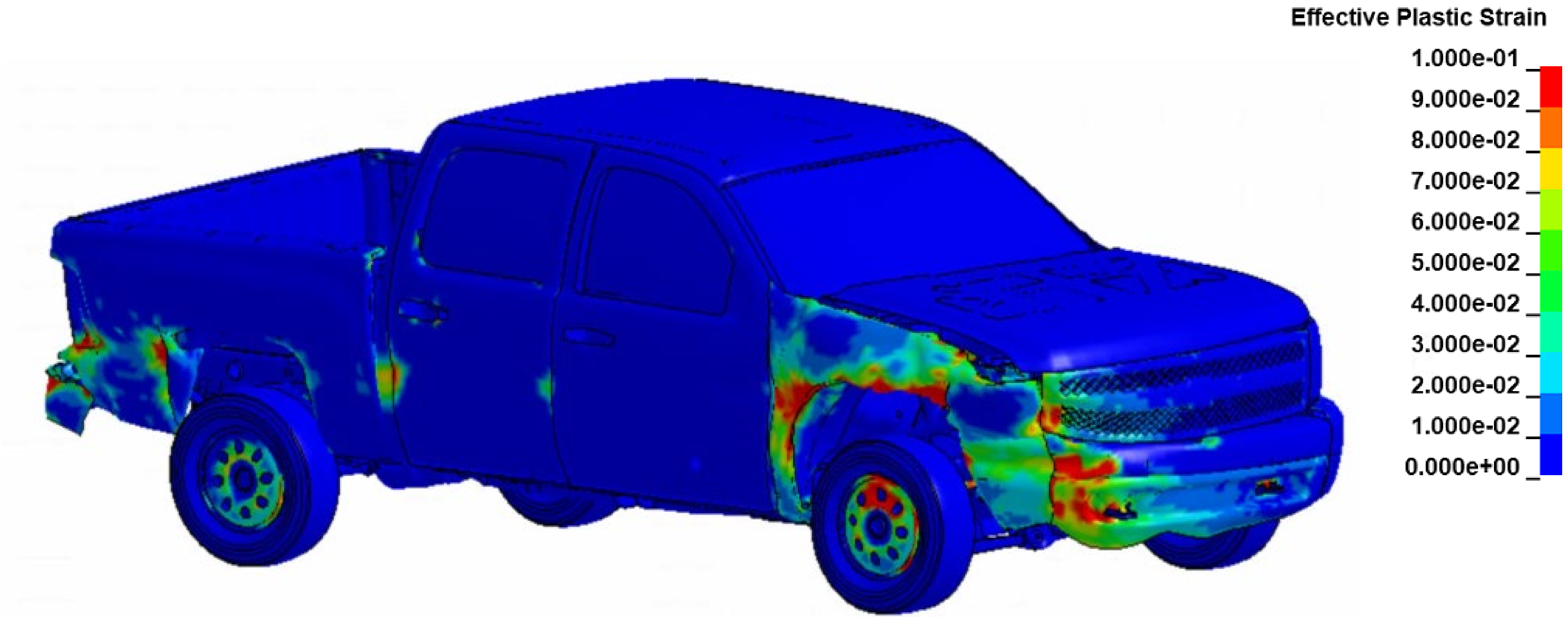
- Primary plastic deformations of the rail elements were limited to the thrie-beam and thrie-beam terminal connector. The highest strains were on the terminal connector element, but well below failure values.
- Total length of system deformed was approximately 25.6 ft extending from the Post 13 to the start of the bridge rail.
- The vehicle was in contact with the system for approximately 15.9 ft.
- The maximum working width = 28.2 in
    - Measured as maximum dynamic lateral position of Post 7 (top-back of post) relative to the initial face of the barrier.





RoadSafe LLC
Transportation Engineering and Research

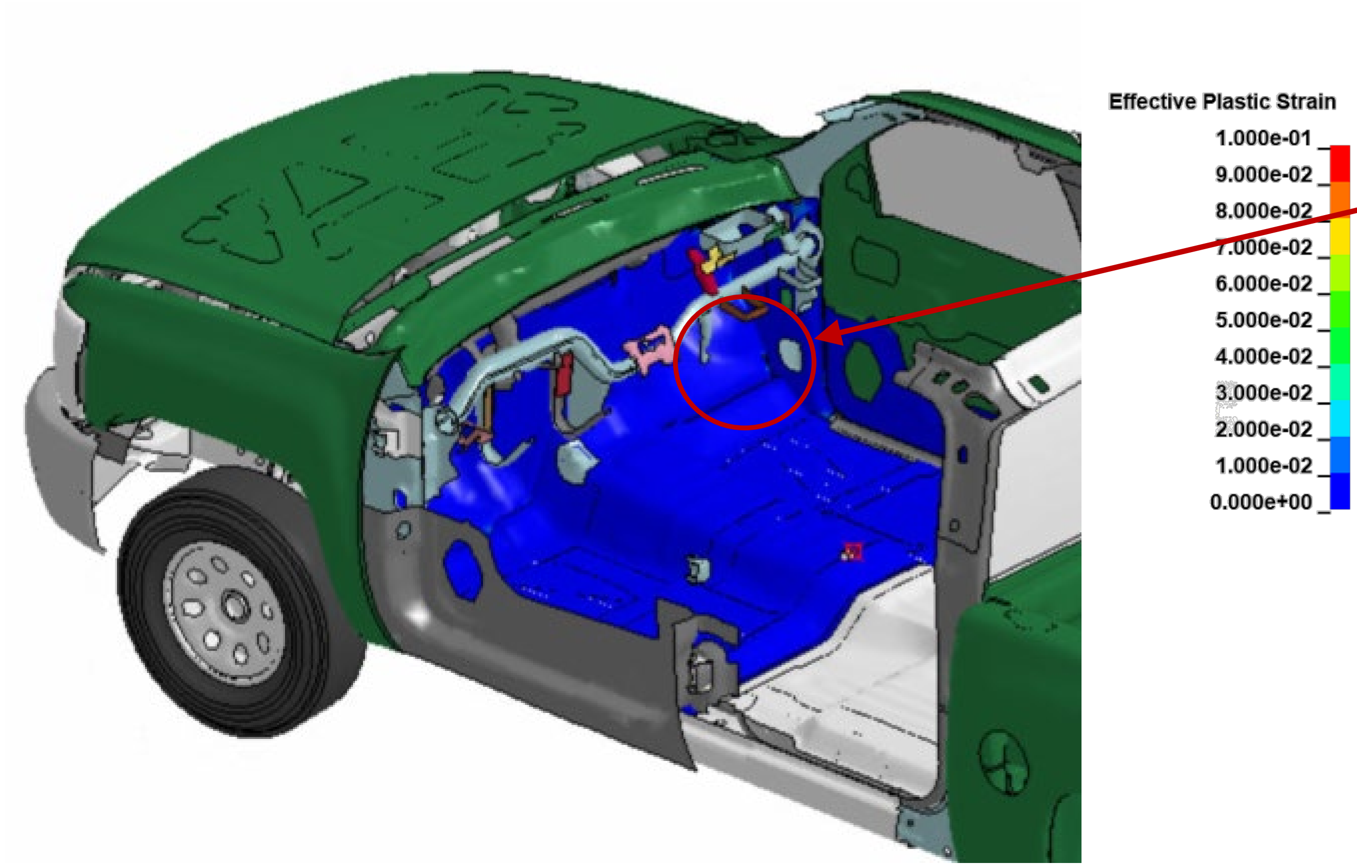
Effective Plastic Strain for Pickup Test



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.

Occupant Compartment Intrusion

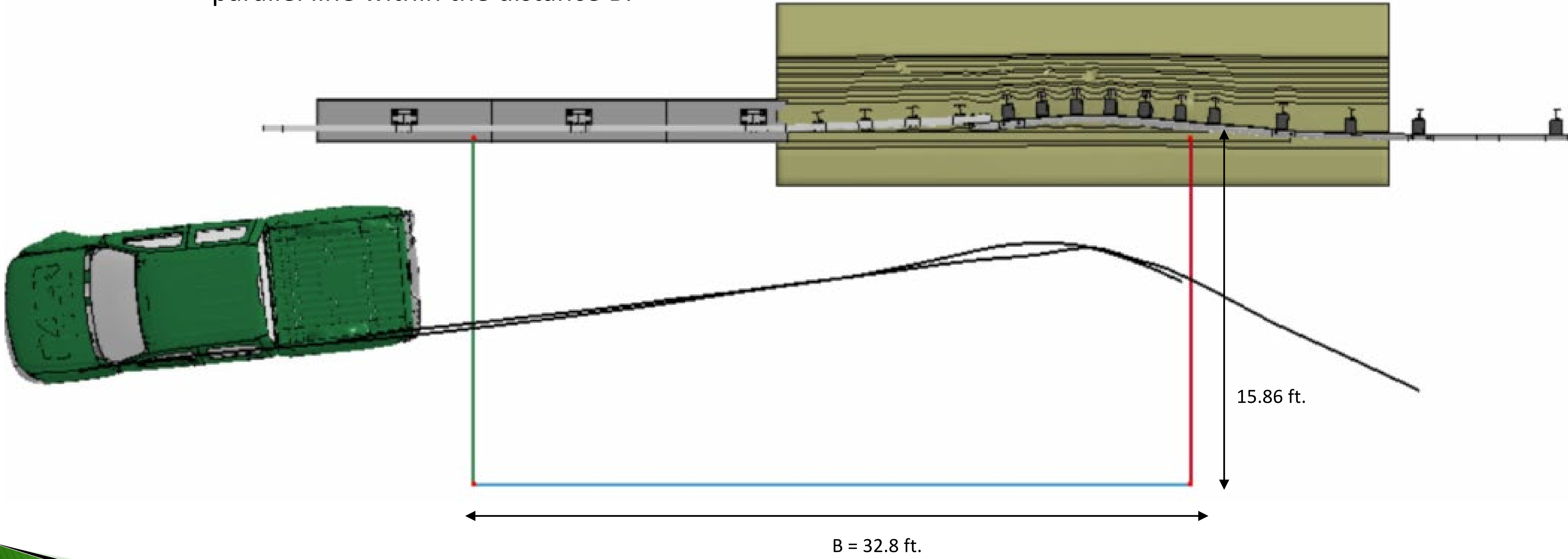
Occupant Compartment Intrusion (OCI)



OCI was negligible (≈ 1 inch)

Exit Box – 4-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."



Conclusions on Test 4-21 on the MEDOT 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 = **9.3 degrees** and Max Pitch = **5.5 degrees**.
- The OIV was within preferred limits and the maximum ORA was within critical limits specified in MASH.
  - OIV_x = **17.4 ft/s** and OIV_y = **23.3 ft/s**
  - ORA_x = **4.8 G** and ORA_y = **17.2 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 = **11.8 inches**; Max Permanent = **10.4 inches**

Conclusions on Test 4-21 on the MEDOT Transition

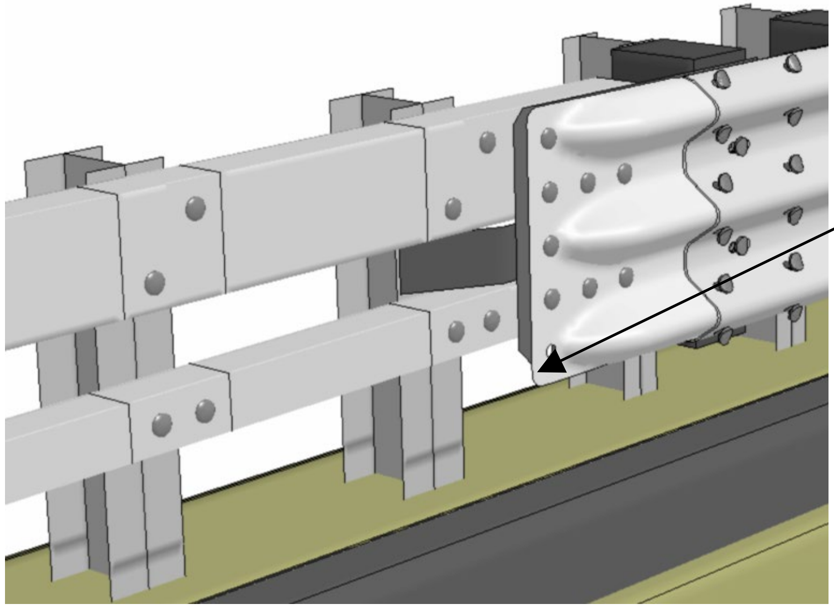
Evaluation Factors		Evaluation Criteria	Results
Structural Adequacy	A	Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is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

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.
  - 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
      - 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.

Reverse Impact Case

- There is one additional analysis case that we will run for the 2-Bar Transition, which involves impact from the opposing traffic direction and focuses on possible wheel snag against the lower edge of the thrie-beam terminal connector and the 3/8" thick connector plate.



Possible snag points in reverse direction impacts

Transportation Engineering and Research