Elemance

Examining the Relationship Between Quasi-Static Testing and Dynamic Crash Response of Heavy Truck Rear Impact Guards through Simulation

Alex J. Kalmar-Gonzalo, Berkan Guleyupoglu, Derek A. Jones

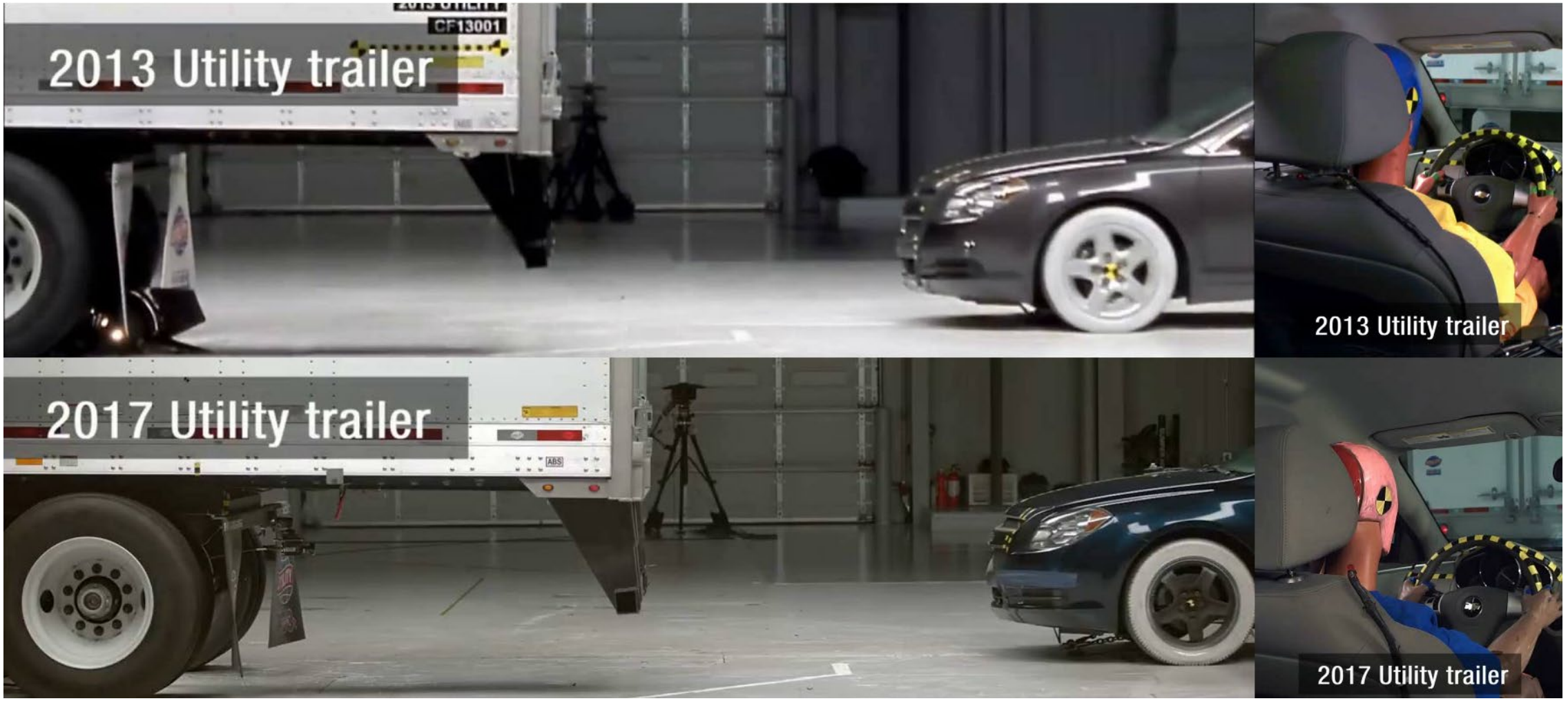
SAE Government-Industry Meeting, 2024

5,788 deaths in traffic crashes involving large trucks in USA 2021[1]

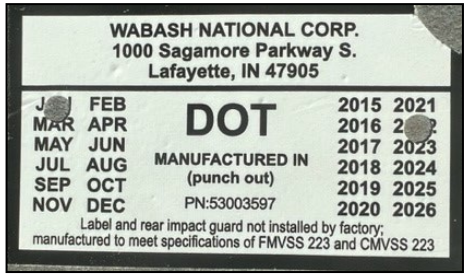
- Increased 17% compared to 2020
- Account for 13% of all motor vehicle traffic fatalities
- 72% of these traffic fatalities were occupants of vehicles other than the large truck

Between 2008-2009, 977 fatalities from rear-end strikes[2]

[1]FARS 2021 Annual Report
[2]DOT HS 811 725, March 2023


CF13001
2013 Utility trailer
2013 Utility trailer
2017 Utility trailer
ABS
2017 Utility trailer

Introduction: History of Testing



1996 – FMVSS 223 & 224 Established

2016 – IIHS Semitrailer Underride Testing Introduced

2021 – IIHS Semitrailer Underride Testing Updated

2022 FMVSS 223 & 224 Upgraded

IIHS TOUGHGUARD

DEPARTMENT OF TRANSPORTATION

National Highway Traffic Safety Administration

49 CFR Part 571

[Docket No. NHTSA–2022–0053]

RIN 2127–AL58

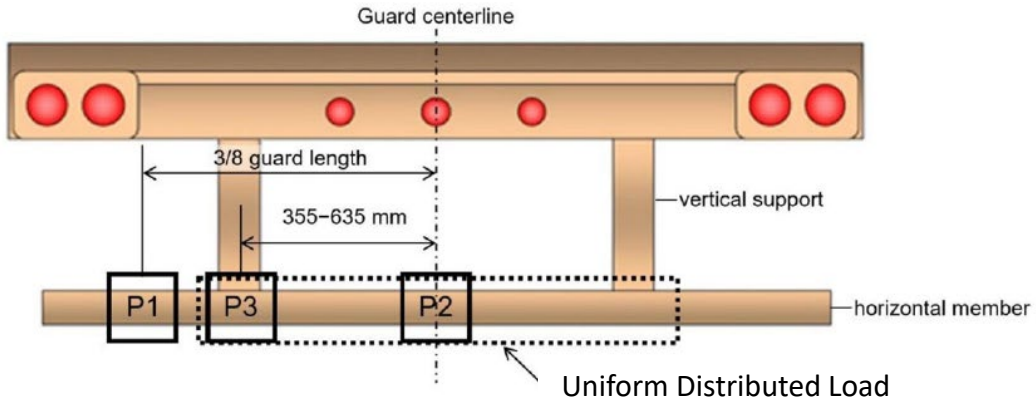
Federal Motor Vehicle Safety Standards; Rear Impact Guards, Rear Impact Protection

AGENCY: National Highway Traffic Safety Administration (NHTSA), Department of Transportation (DOT).

ACTION: Final rule.

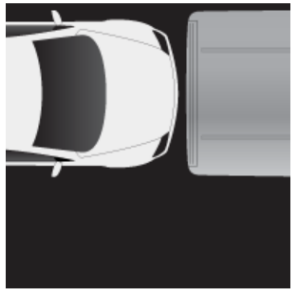
Elemance | Introduction: Testing Methodologies

Quasi-Static Loading per 2022 Final Rule:

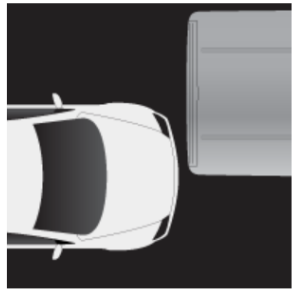


Regulation	Force within 125 mm			Energy Absorption
	P1	P2	UDL	
FMVSS No. 223 (2022)	50 kN	50 kN	350 kN	20 kJ in UDL

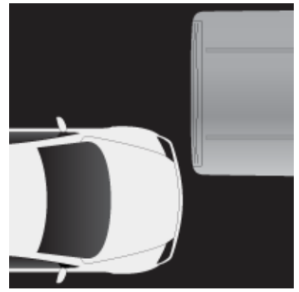
Dynamic Testing per IIHS Toughguard award:



FULL WIDTH
The car crashes into the center of the truck's rear.



50 PERCENT OVERLAP
Half of the car's width overlaps the rear of the truck.



30 PERCENT OVERLAP
Thirty percent of the car's width overlaps the rear of the truck.

Study Goal: Examine the relationship between quasi-static rear impact guard requirements and dynamic crash structural performance, including occupant response

- Aim 1: Develop Model of 3 Rear Impact Guards and Validate Against Quasi-Static Testing
- Aim 2: Modify guard models to minimally pass FMVSS regulations. Evaluate performance in simulated full crash tests. Strengthen guards to prevent PCI in 30% overlap and re-test in quasi-static conditions
- Aim 3: Investigate the effectiveness of guards at higher velocity crash modes

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Selection Criteria:

- Meets FMVSS 223 and report is available
- Has been tested in IIHS full vehicle crash tests
- Prevalent on US roadways
- Still available new from manufacturer

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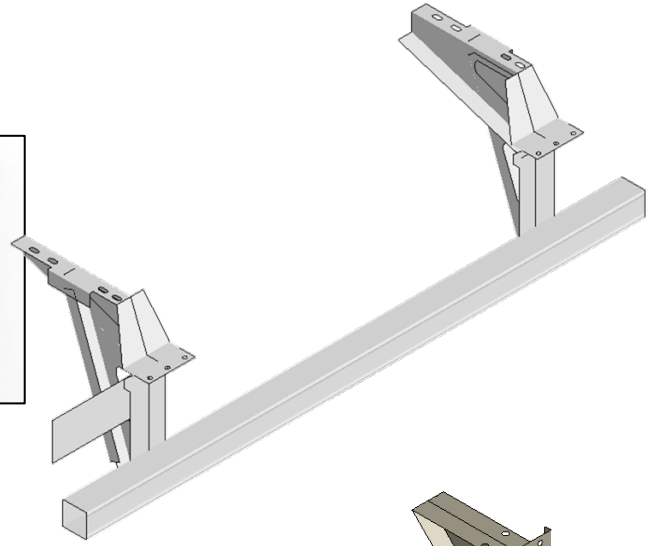

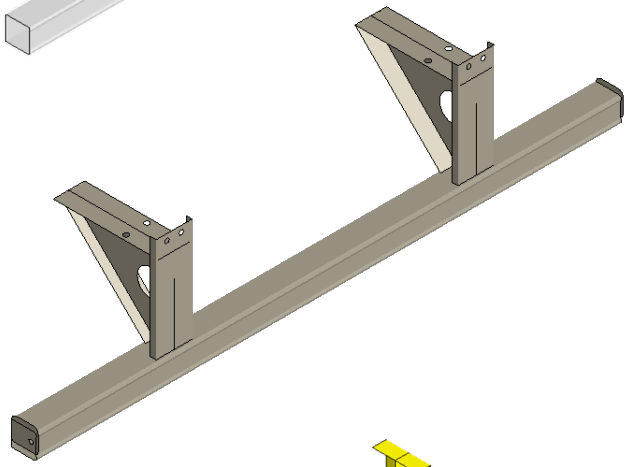

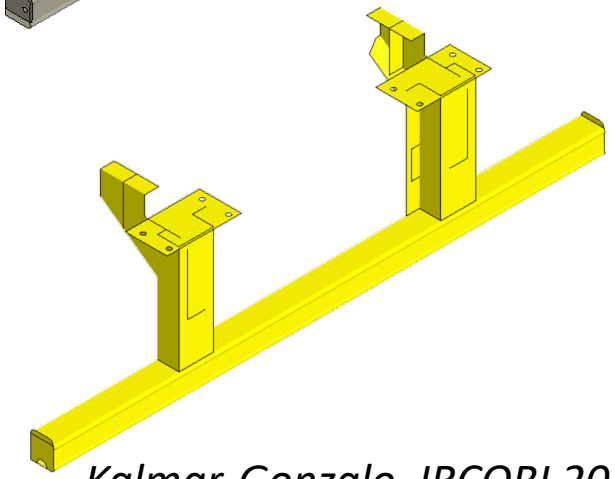

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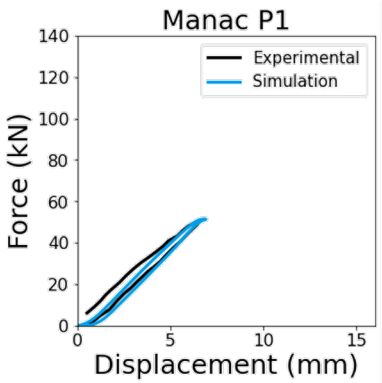
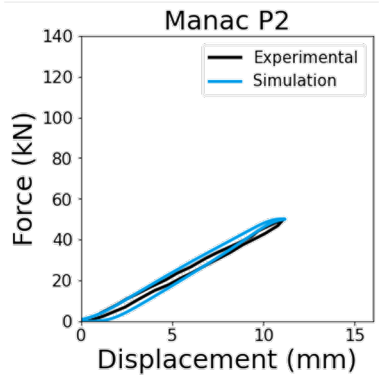
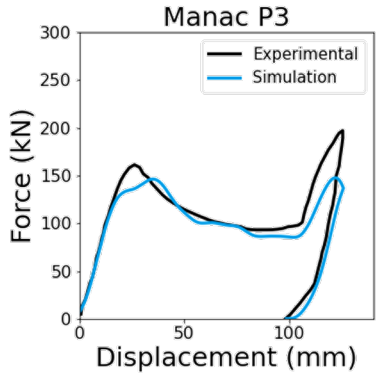
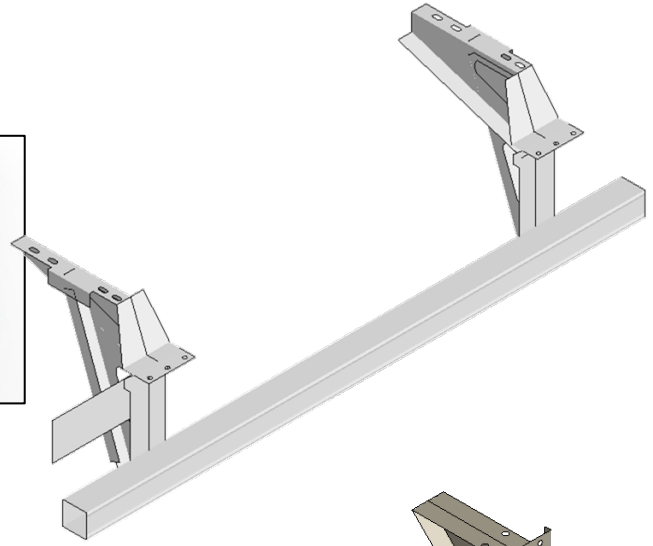
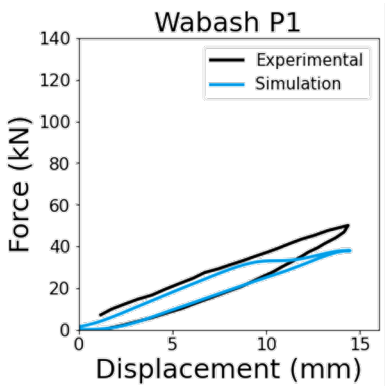
Elemance | Aim 1 Results

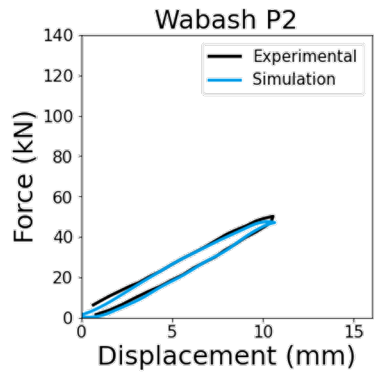


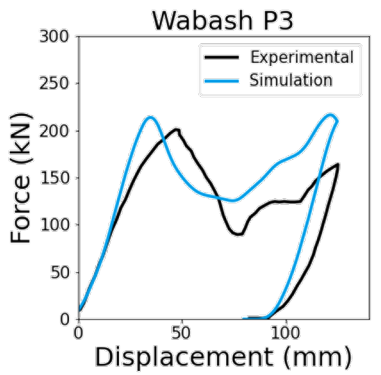


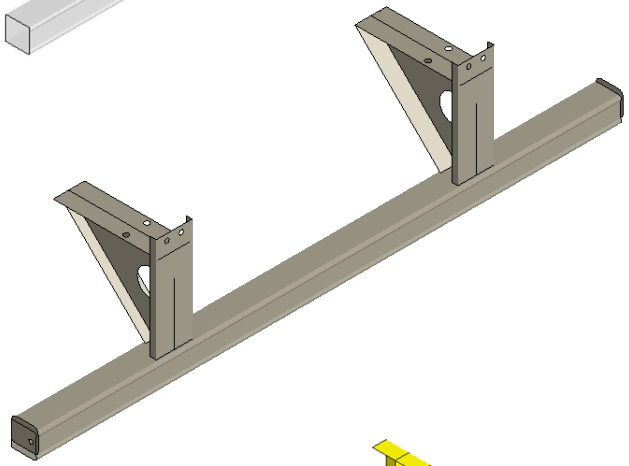


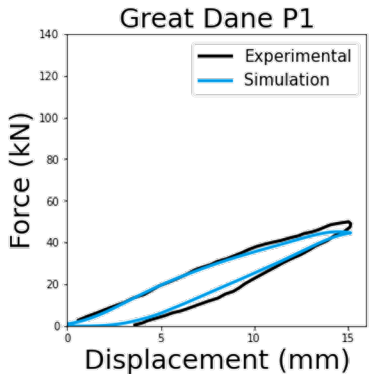


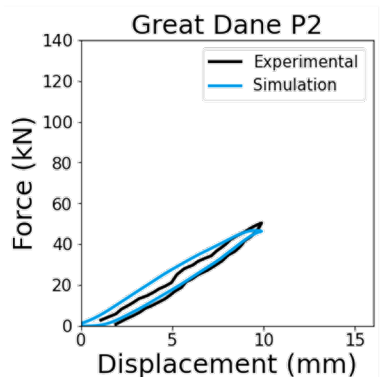


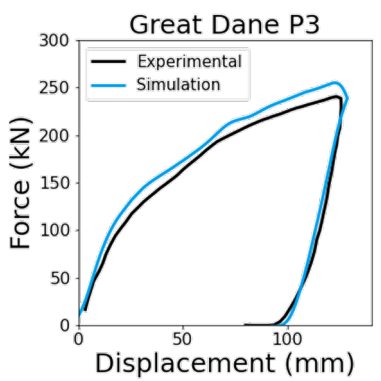


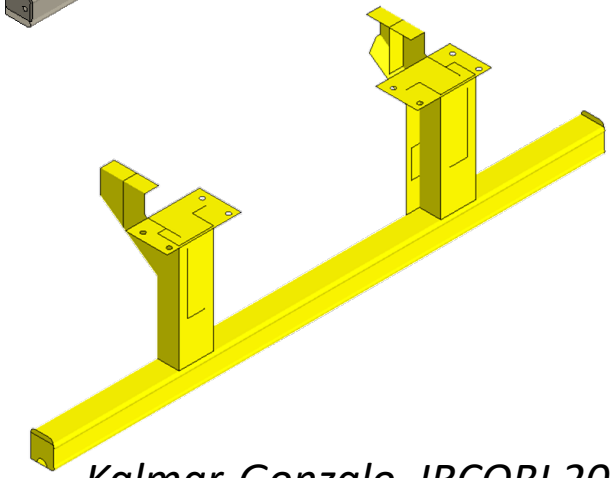












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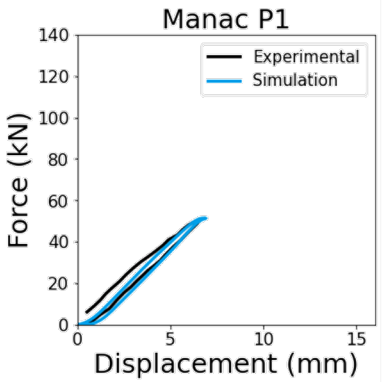
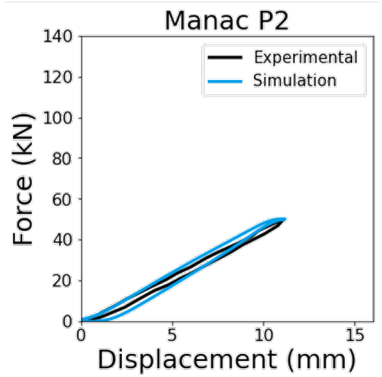
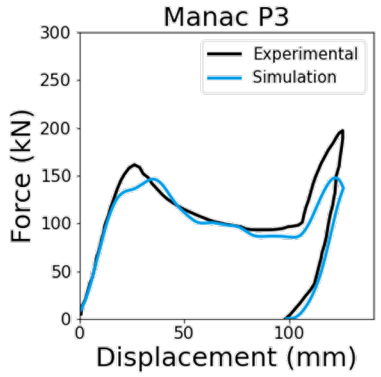
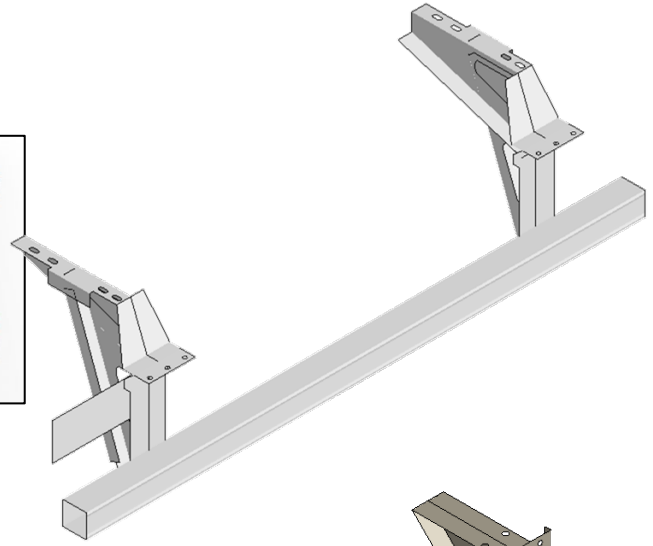
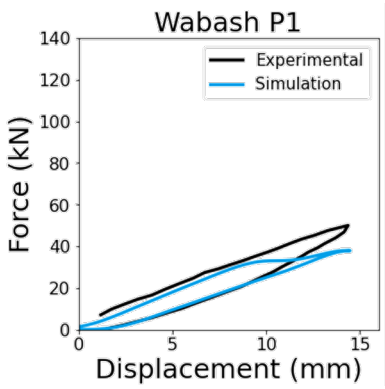
Elemance | Aim 1 Results

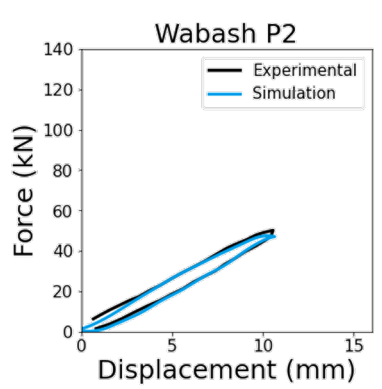


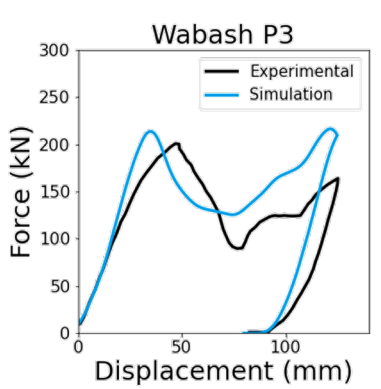


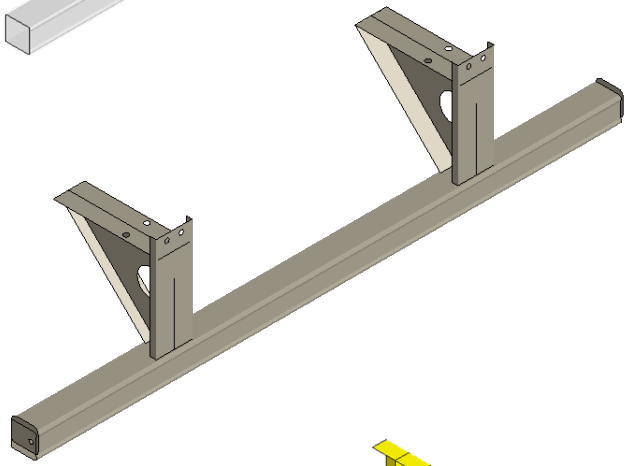


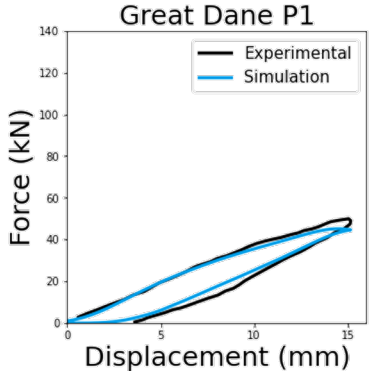


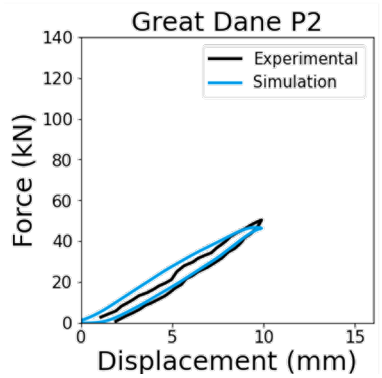


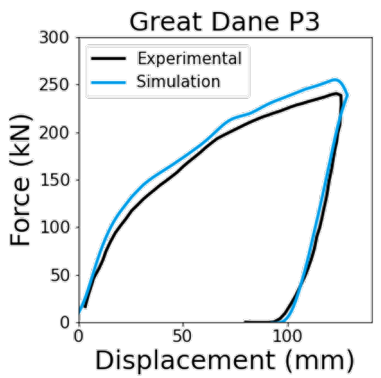


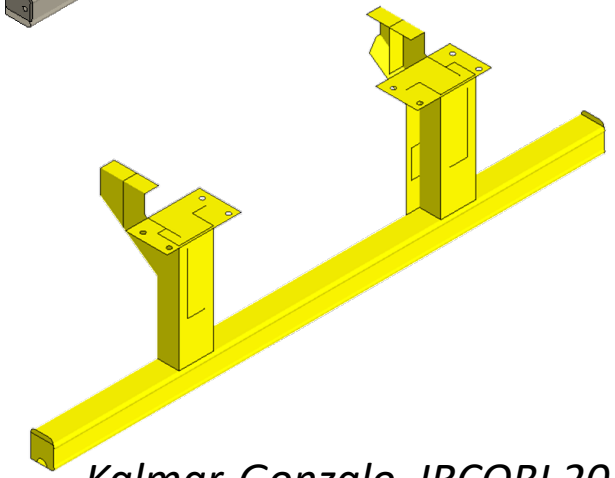












Average CORA Score = 0.942

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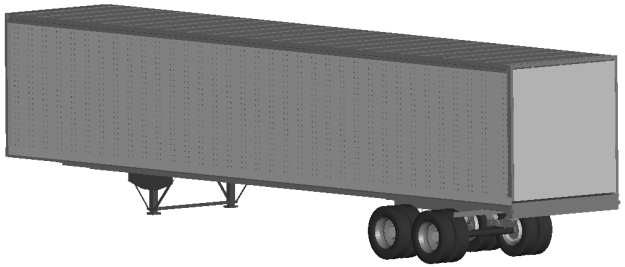
Elemance | Aim 2: Methods Overview

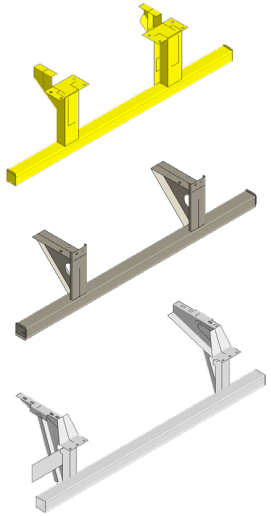
Attach Guards to FE Trailer & Validate Against IIHS Tests → Modify Guards to Minimally Comply with FMVSS 223 → Assess Dynamic Response → Strengthen Guards to Prevent PCI for Midsize Sedan at 30% Overlap → Re-Simulate Guards in FMVSS 223

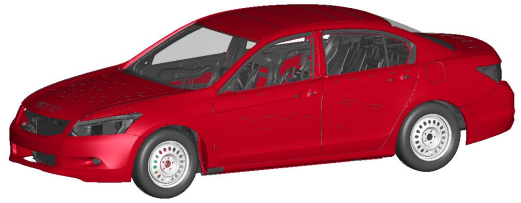
2.1 2.2 2.3 2.4 2.5

Dynamic Simulations



48’ Trailer, NTRCI

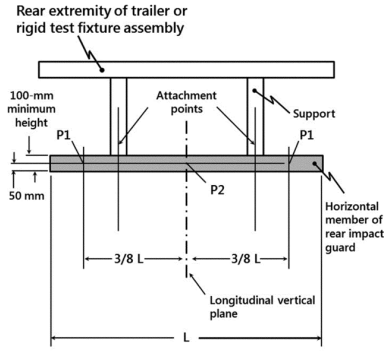




2014 Honda Accord, GMU

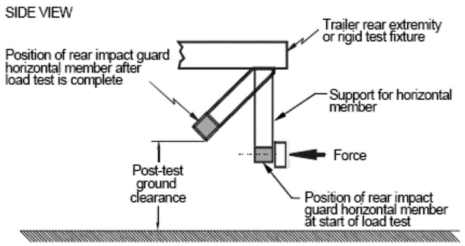
Quasi-Static Simulations

P1, P2



UDL

Notes:
1. L means width of the horizontal member.
2. Drawing not to scale



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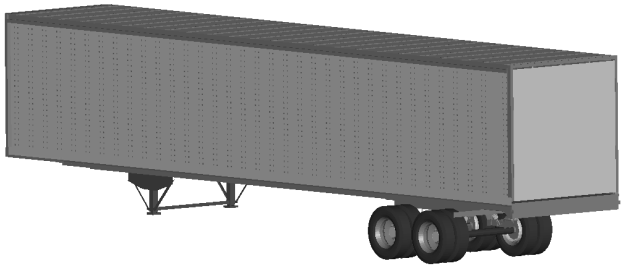

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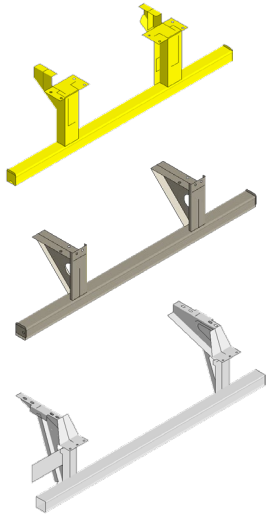

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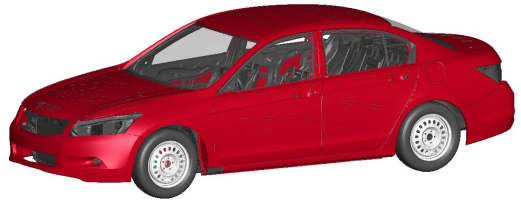

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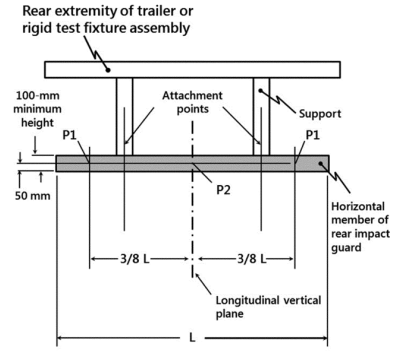

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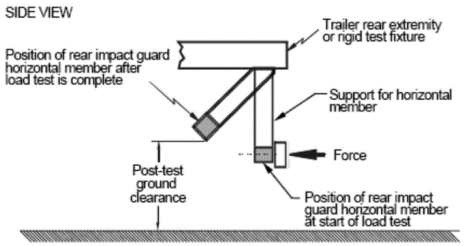
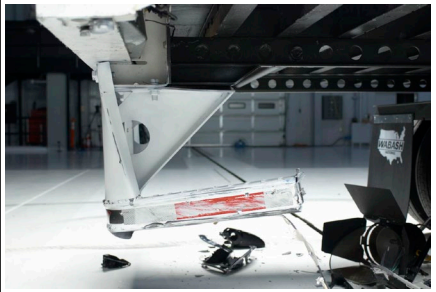
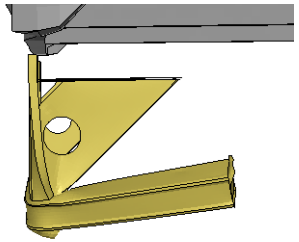
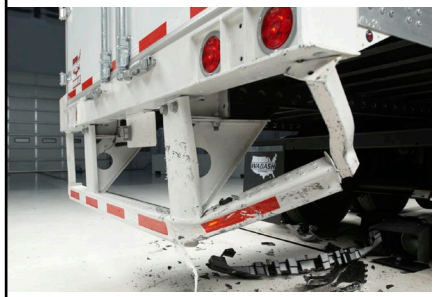


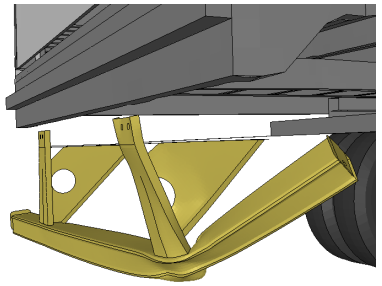
Elemance | Aim 2.1: Validation of Guards + Truck Models @ 35 mph; Wabash



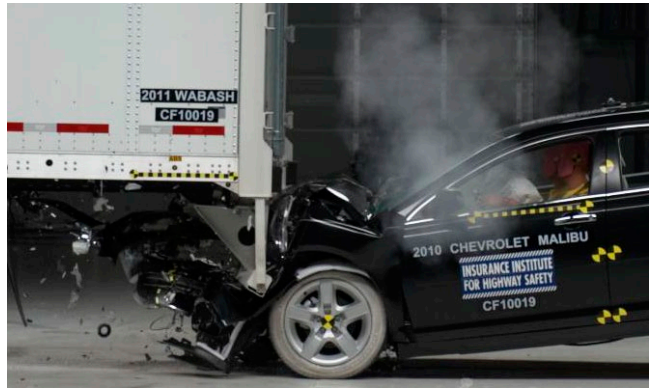


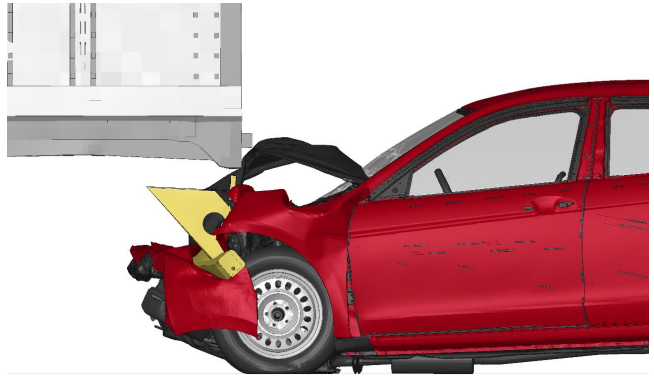
30% Overlap



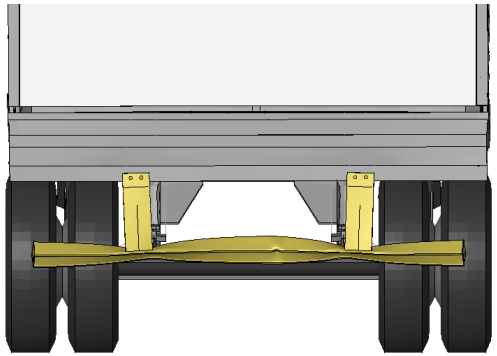


50% Overlap



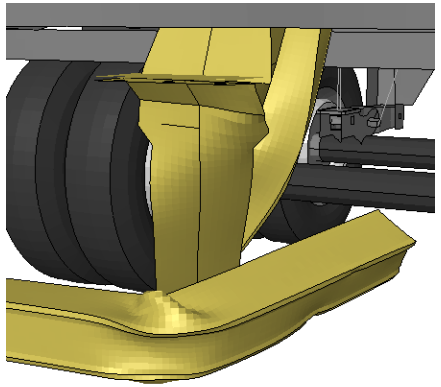


Full Overlap:
Physical vs Simulation



Full Overlap

Elemance | Aim 2.1: Validation of Guards + Truck Models @ 35 mph; Manac



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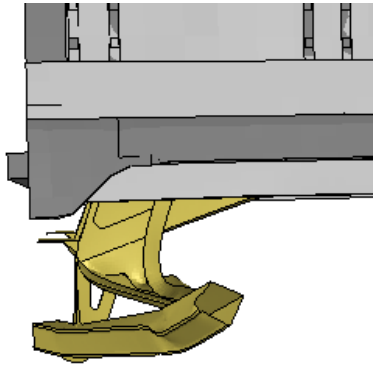
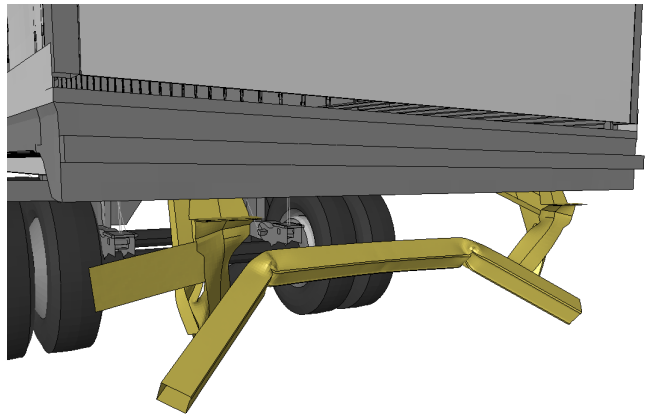
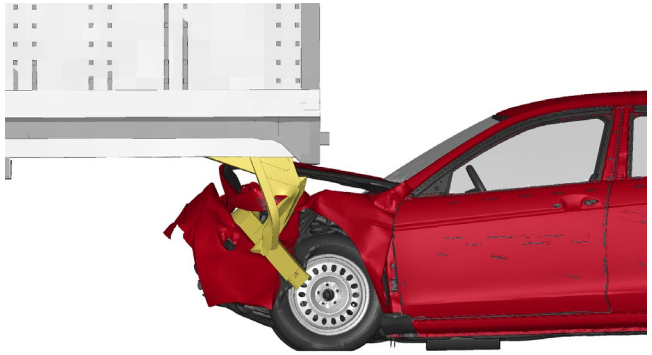


50% Overlap

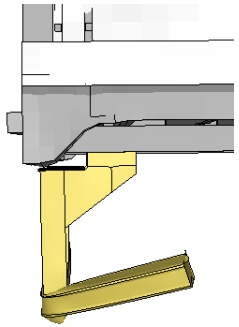


Full Overlap

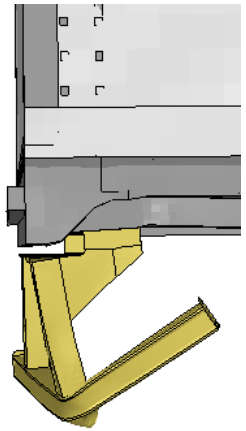


Full Overlap:
Physical vs Simulation

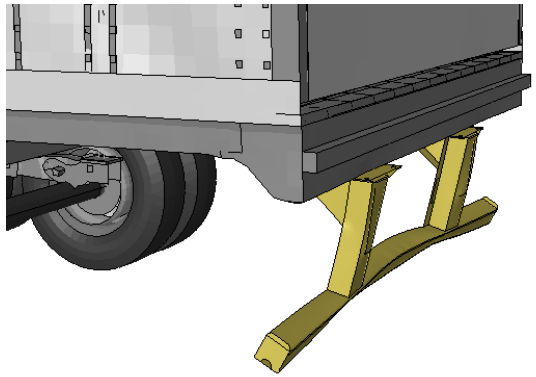
Elemance | Aim 2.1: Validation of Guards + Truck Models @ 35 mph; Great Dane



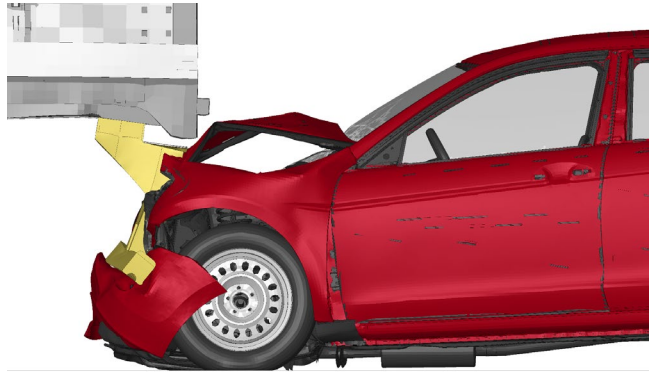
30% Overlap



50% Overlap



Full Overlap



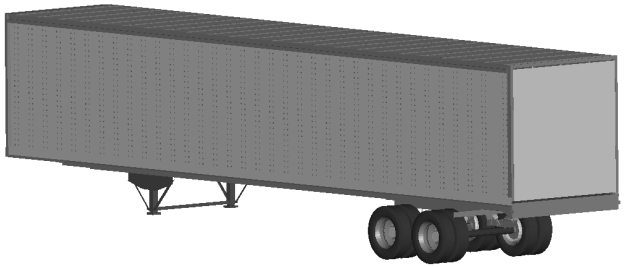
Full Overlap:
Physical vs Simulation

Elemance | Aim 2: Methods Overview

Attach Guards to FE Trailer & Validate Against IIHS Tests → Modify Guards to Minimally Comply with FMVSS 223 → Assess Dynamic Response → Strengthen Guards to Prevent PCI for Midsize Sedan at 30% Overlap → Re-Simulate Guards in FMVSS 223

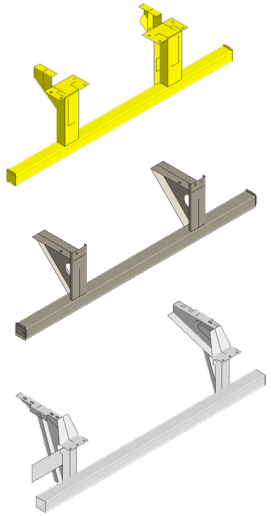
2.1 2.2 2.3 2.4 2.5

Dynamic Simulations



48’ Trailer, NTRCI

+



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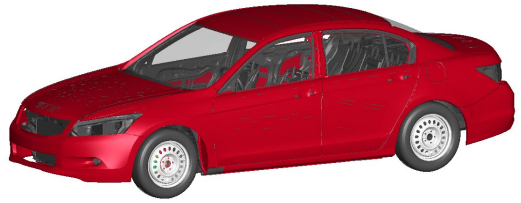
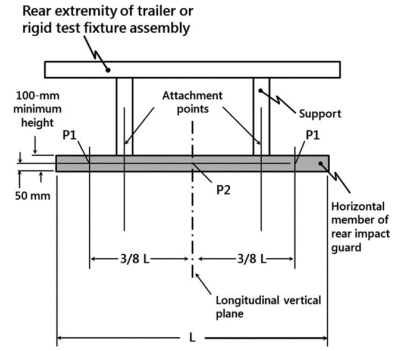


2014 Honda Accord, GMU

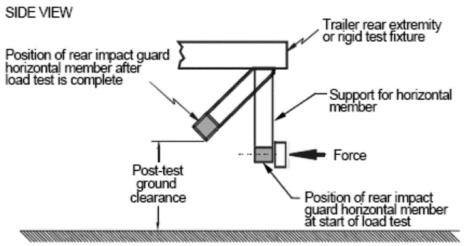
Quasi-Static Simulations

P1, P2

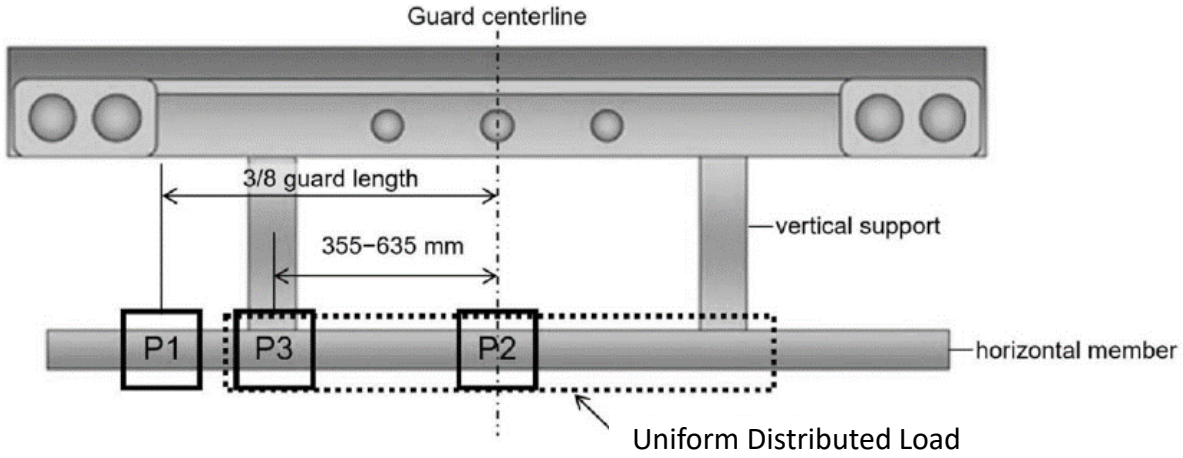


UDL

Notes:
1. L means width of the horizontal member.
2. Drawing not to scale

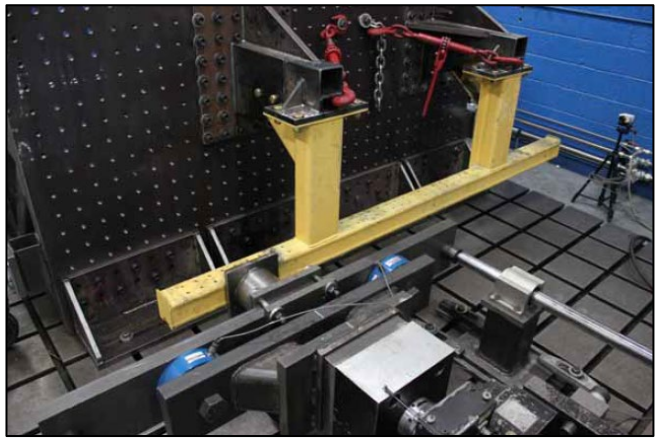


Aim 2.2: Modify Guards to minimally comply with FMVSS 223

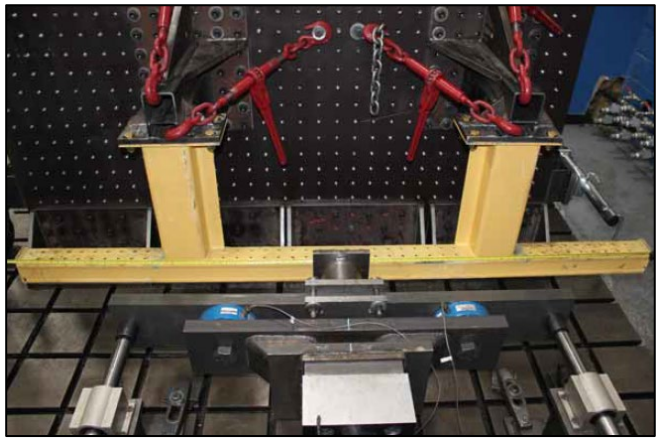


FMVSS No. 223 (2022):

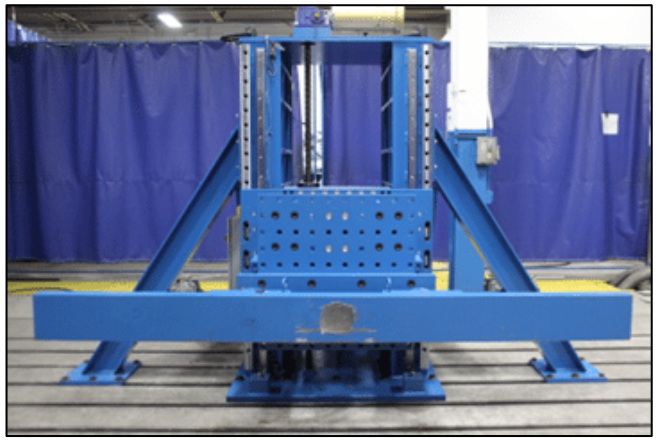
- P1, P2 must resist 50 kN before 125 mm
- UDL must resist 350 kN before 125mm & absorb 20 kJ of energy through plastic deformation
- Final Ground Clearance ≤ 22 in



P1

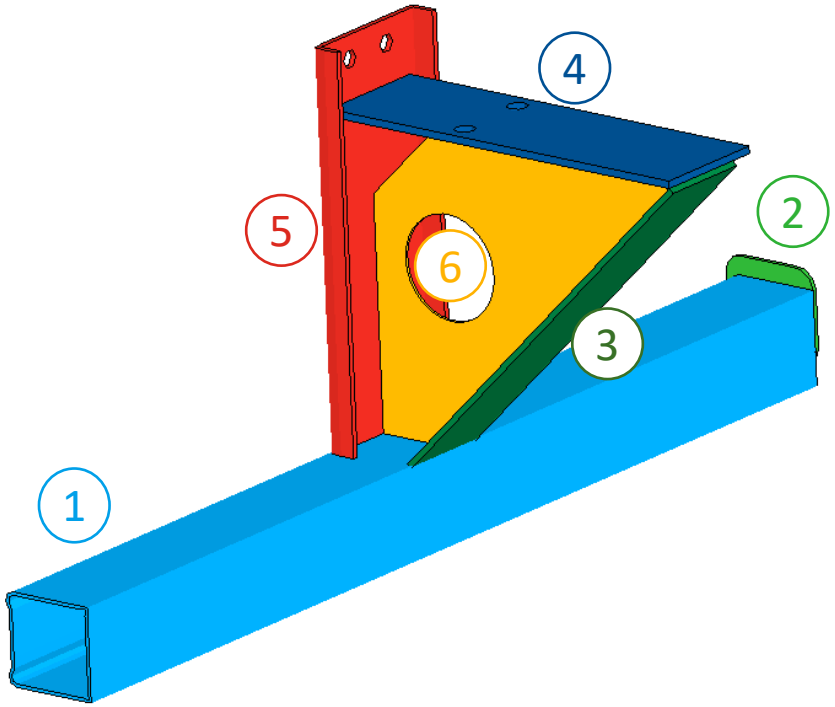


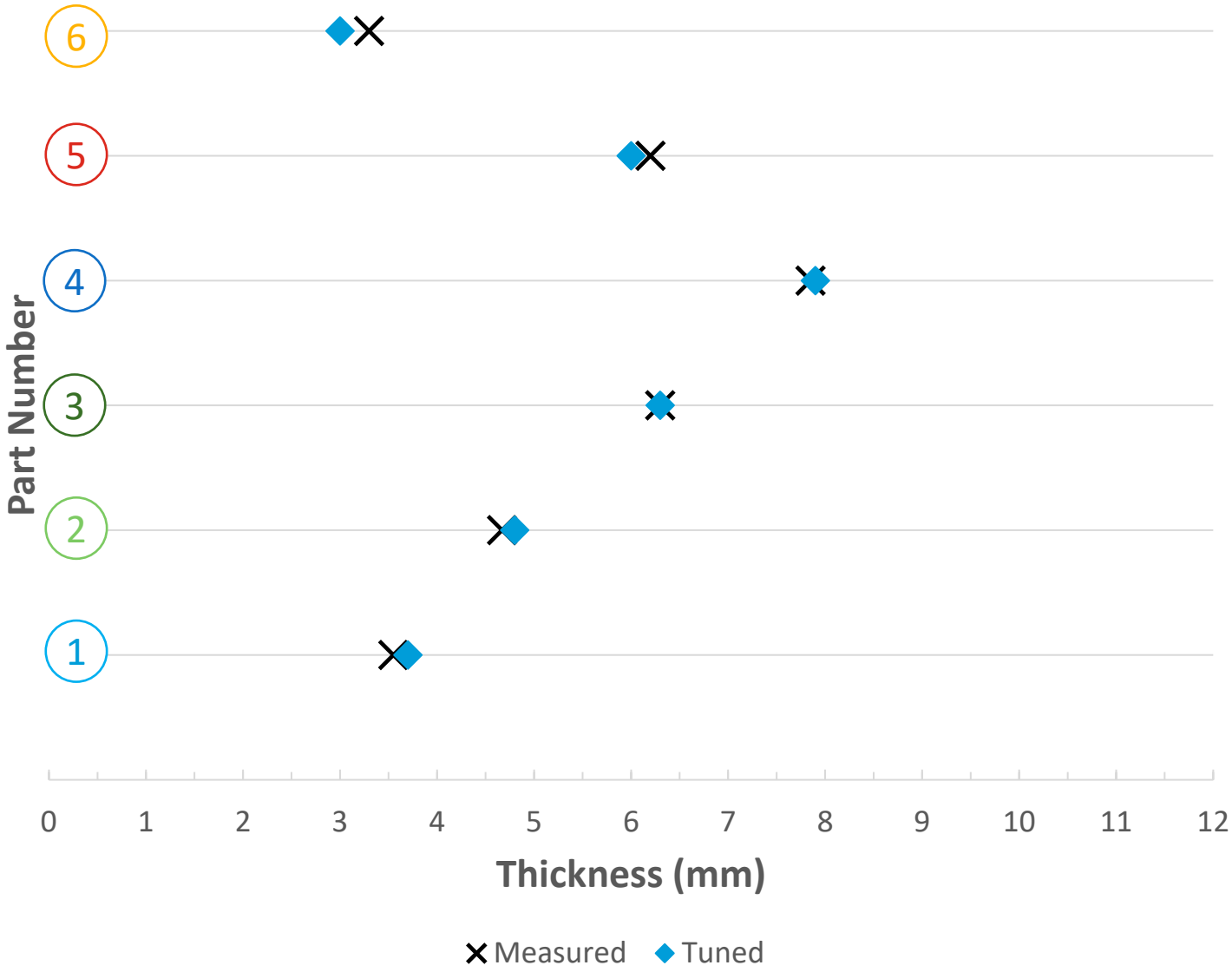
P2



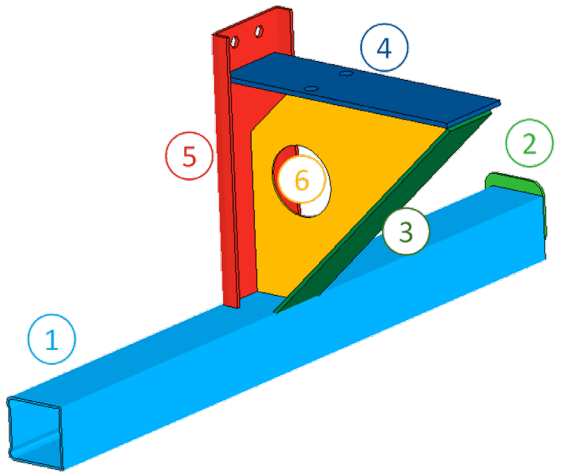
UDL

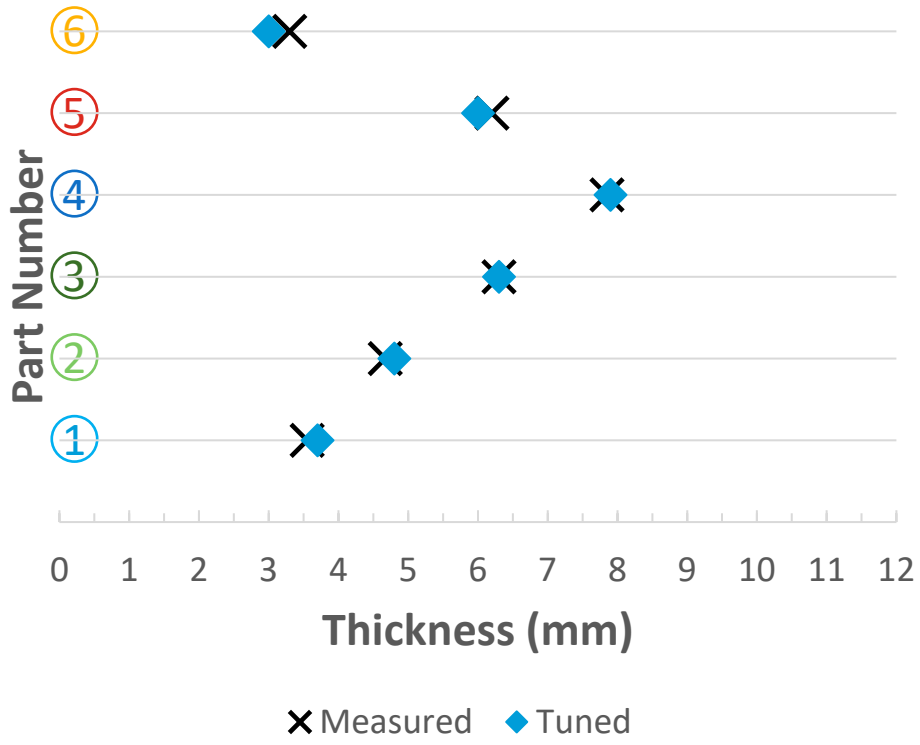
Aim 2.2: Modify Guards to minimally comply with FMVSS 223 : Wabash





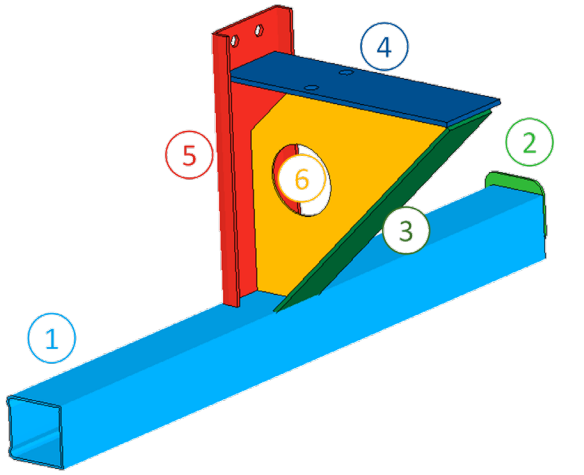
Elemance | Aim 2.2: Modify Guards to minimally comply with FMVSS 223 : Wabash



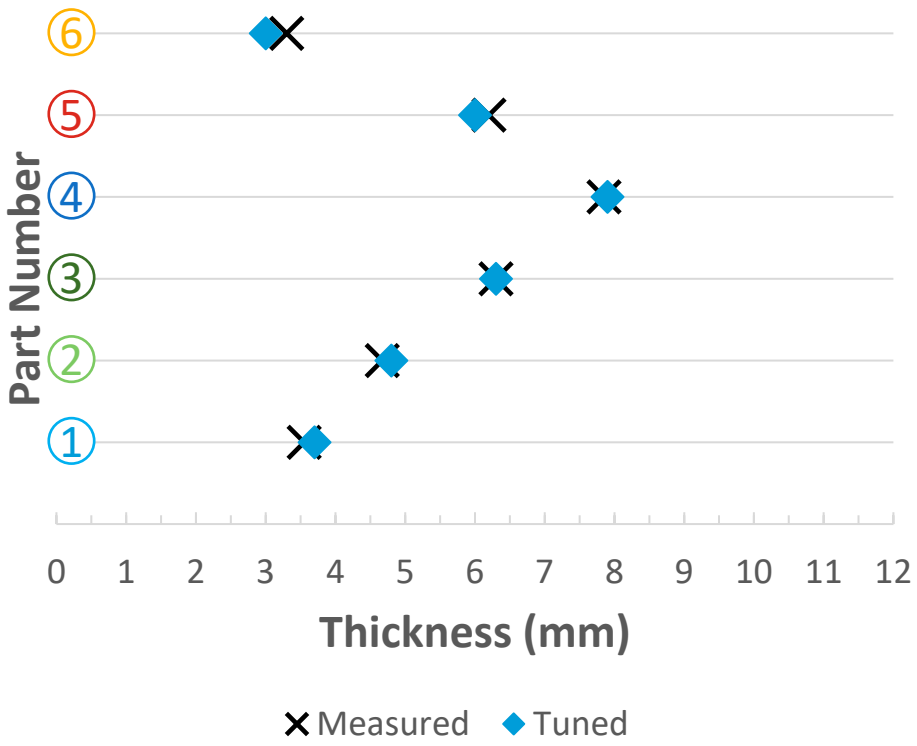


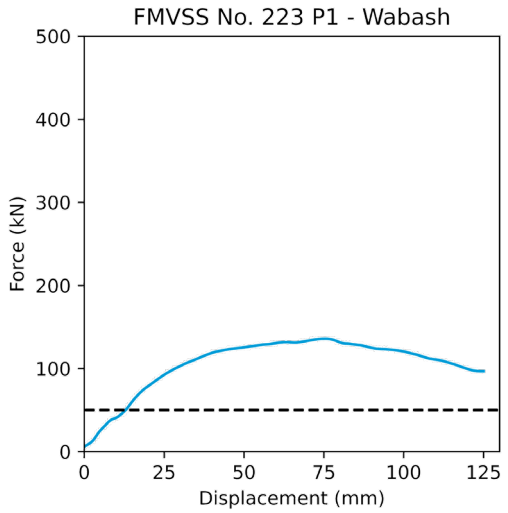
Wabash	Quasi-Static Response				Mass (kg)
	P1 Force (kN)	P2 Force (kN)	UDL Force (kN)	UDL Energy (kJ)	
Baseline					
Minimally Compliant					
FMVSS Req.	**≥50**	**≥50**	**≥350**	**≥20**	**N/A**

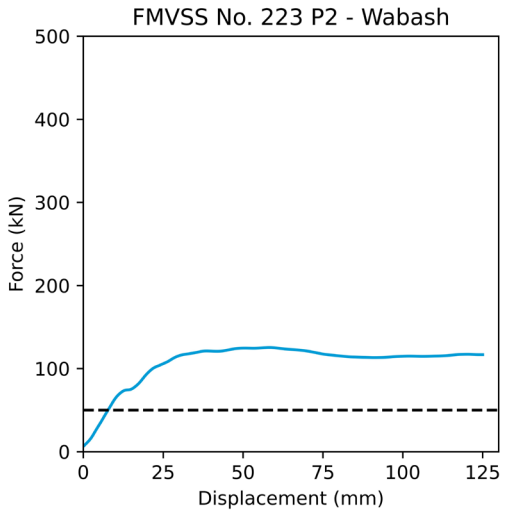
Aim 2.2: Modify Guards to minimally comply with FMVSS 223 : Wabash

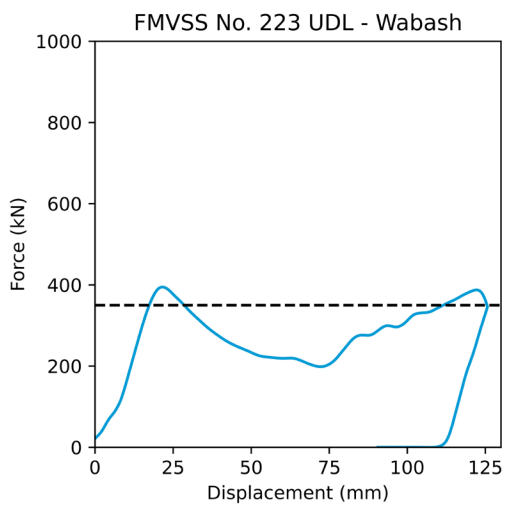


Wabash	Quasi-Static Response				Mass (kg)
	P1 Force (kN)	P2 Force (kN)	UDL Force (kN)	UDL Energy (kJ)	
Baseline					
Minimally Compliant					
FMVSS Req.	**≥50**	**≥50**	**≥350**	**≥20**	**N/A**

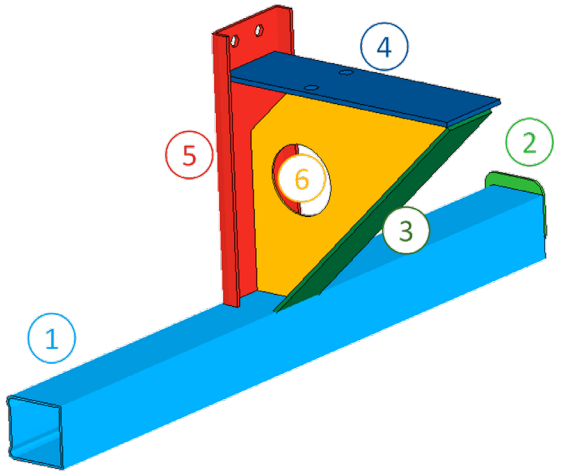




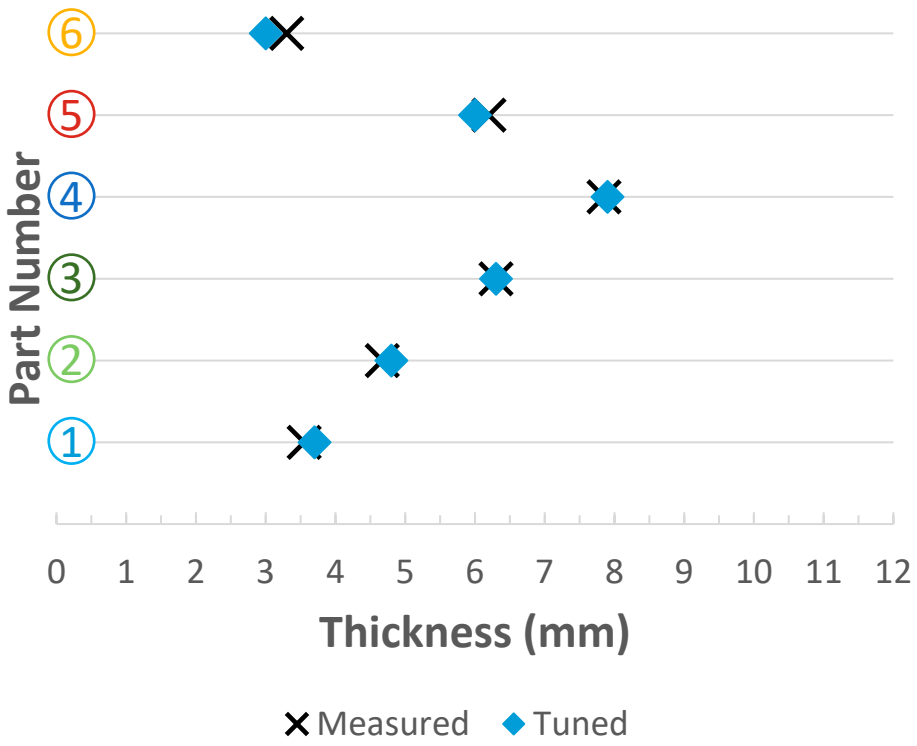


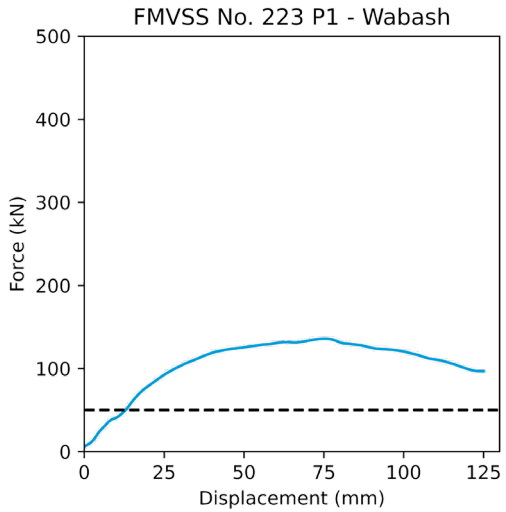


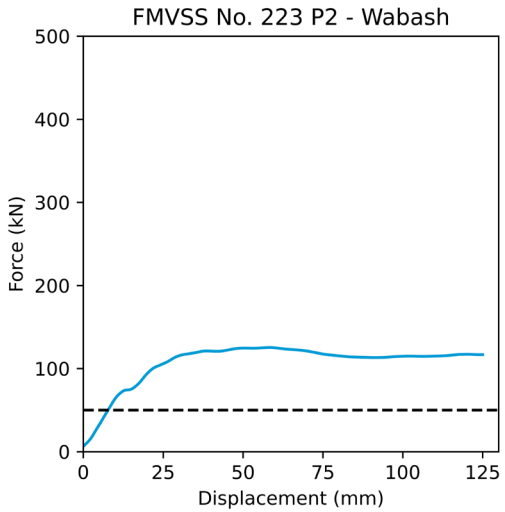
Aim 2.2: Modify Guards to minimally comply with FMVSS 223 : Wabash

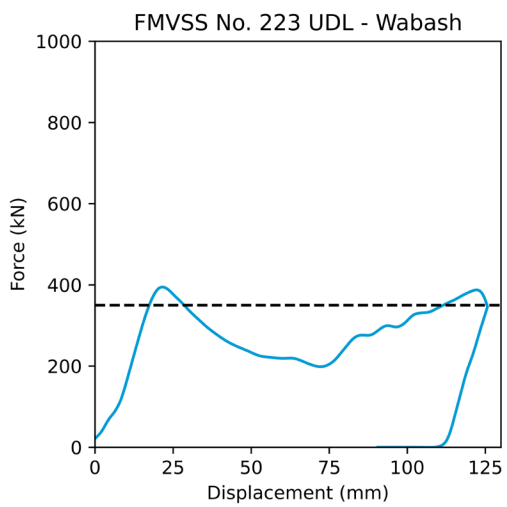


Wabash	Quasi-Static Response				Mass (kg)
	P1 Force (kN)	P2 Force (kN)	UDL Force (kN)	UDL Energy (kJ)	
Baseline	135.8	125.4	394.7	32.1	54.4
Minimally Compliant					
FMVSS Req.	≥50	≥50	≥350	≥20	N/A

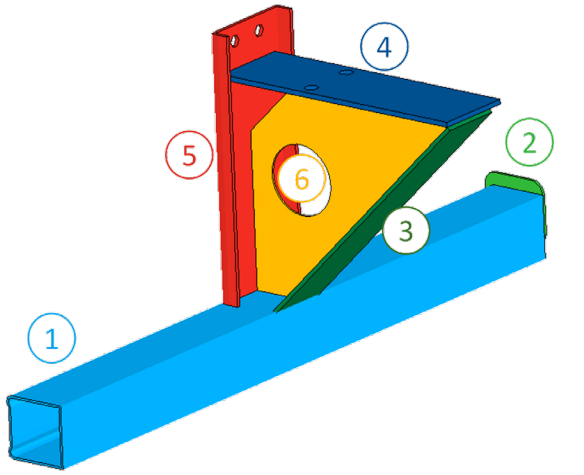




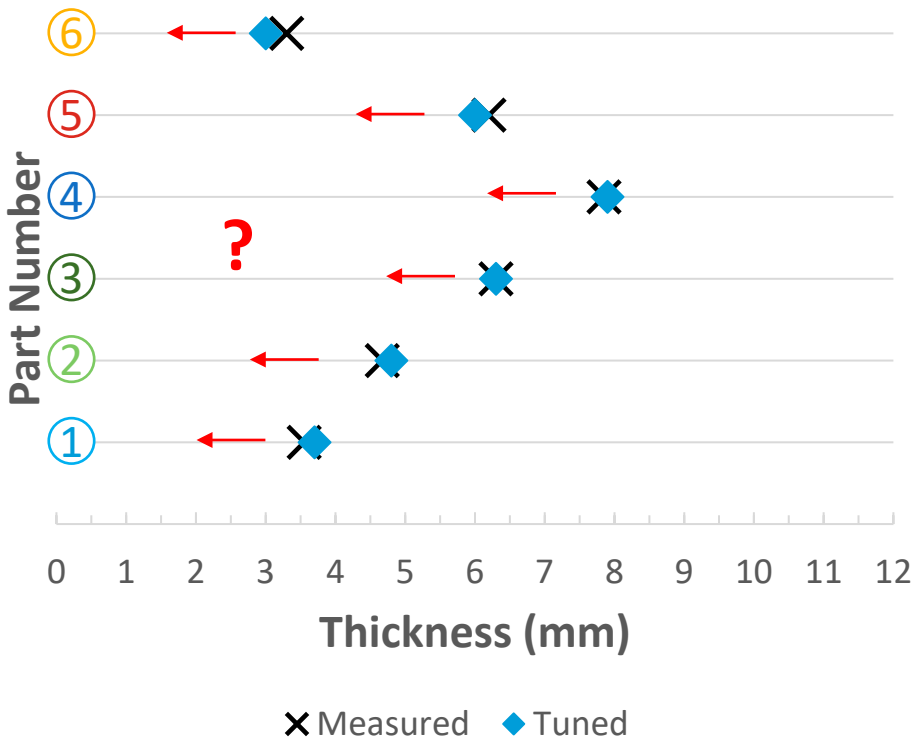


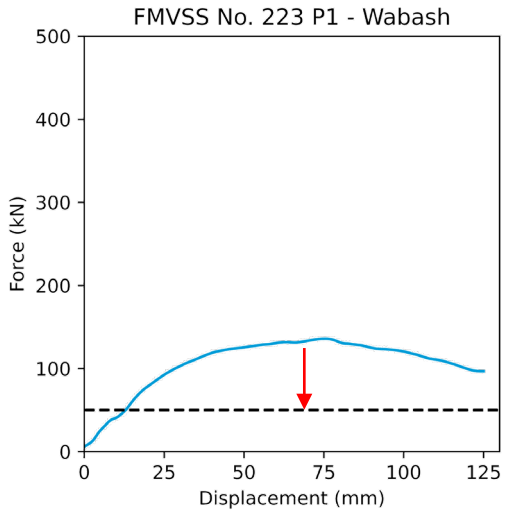


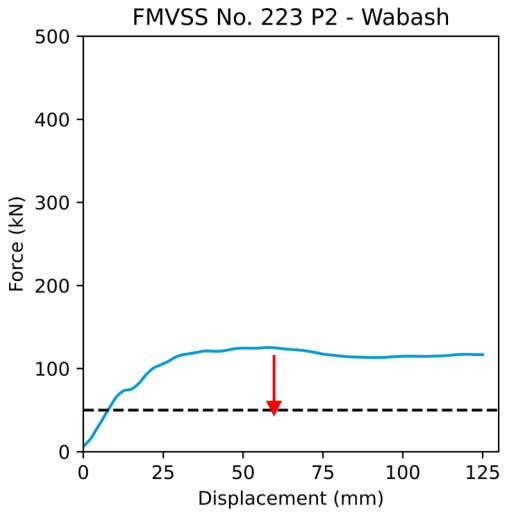
Elemance | Aim 2.2: Modify Guards to minimally comply with FMVSS 223 : Wabash

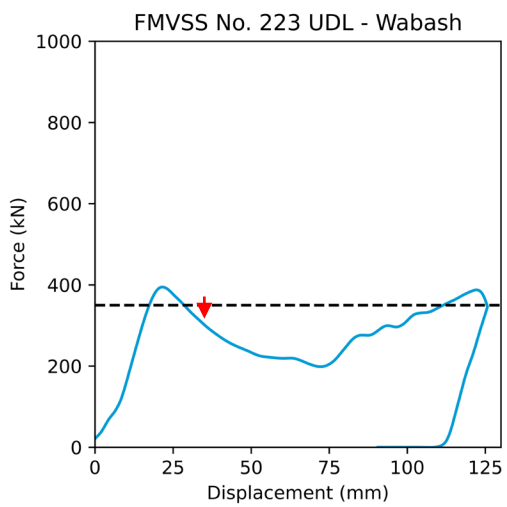


Wabash	Quasi-Static Response				Mass (kg)
	P1 Force (kN)	P2 Force (kN)	UDL Force (kN)	UDL Energy (kJ)	
Baseline	135.8	125.4	394.7	32.1	54.4
Minimally Compliant					
FMVSS Req.	≥50	≥50	≥350	≥20	N/A



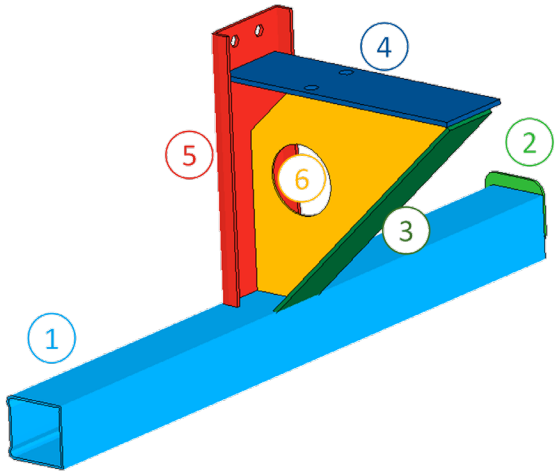


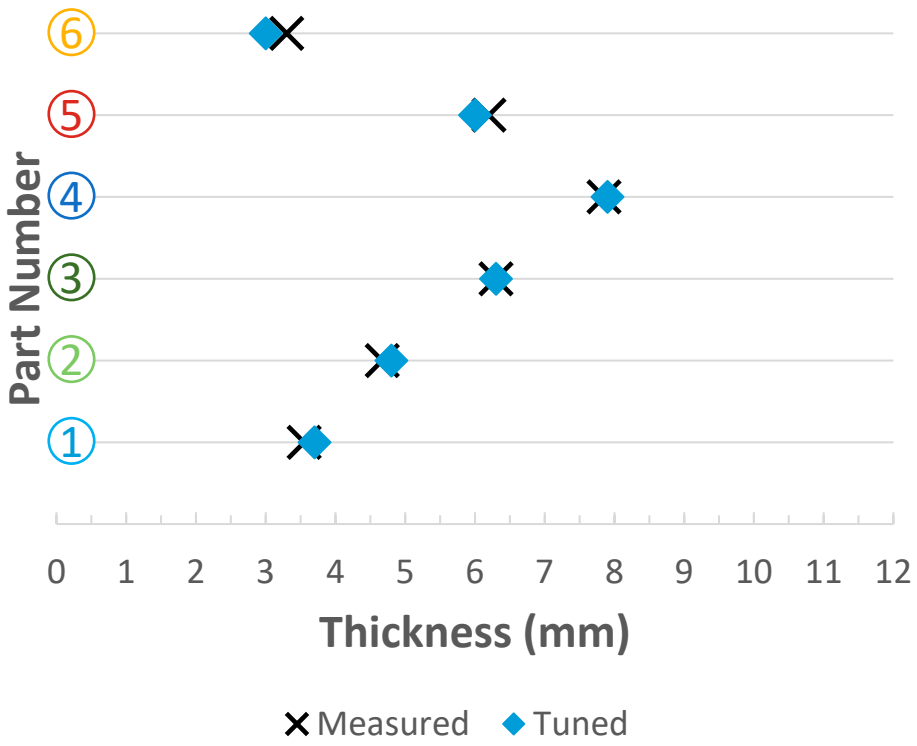




What is the minimum thickness that still passes FMVSS No. 223?

Aim 2.2: Modify Guards to minimally comply with FMVSS 223 : Wabash

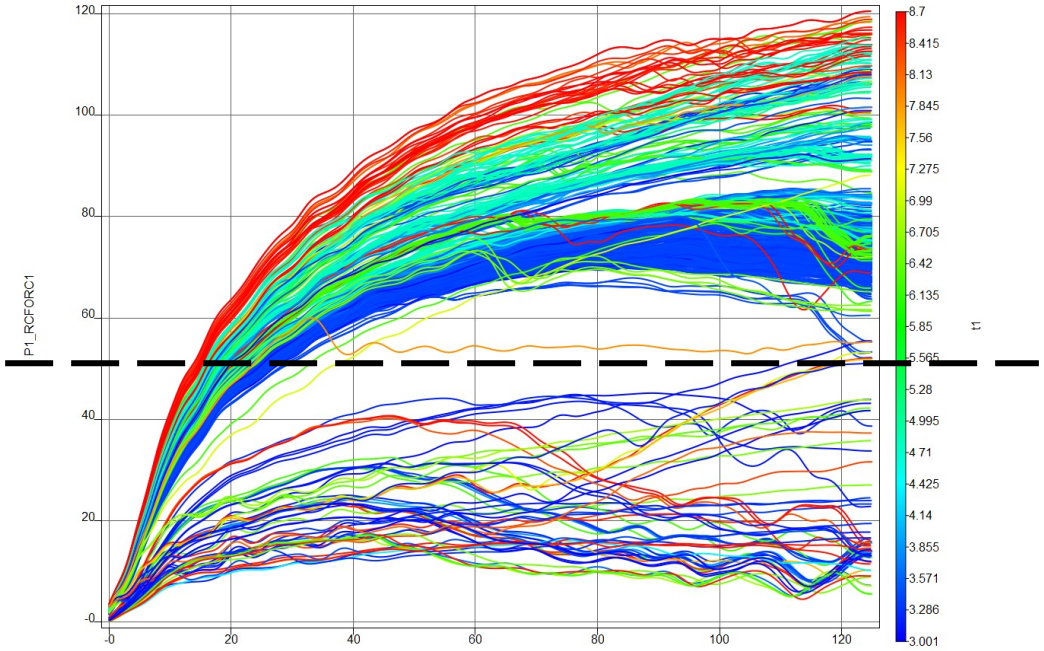




Modified guards using LS-OPT

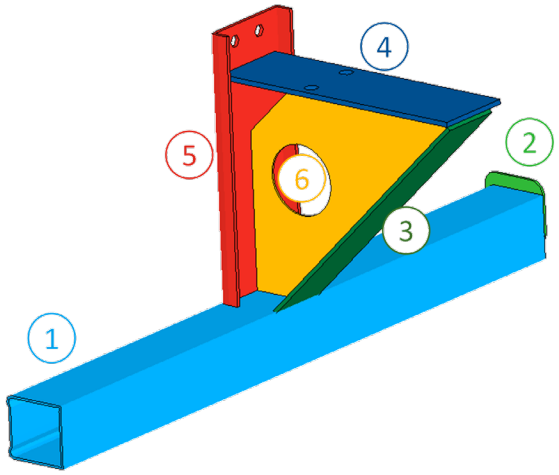
- Each part thickness independently modified
- Considered P1, P2, UDL
- Small weighting factor on mass of guard

FMVSS Req.

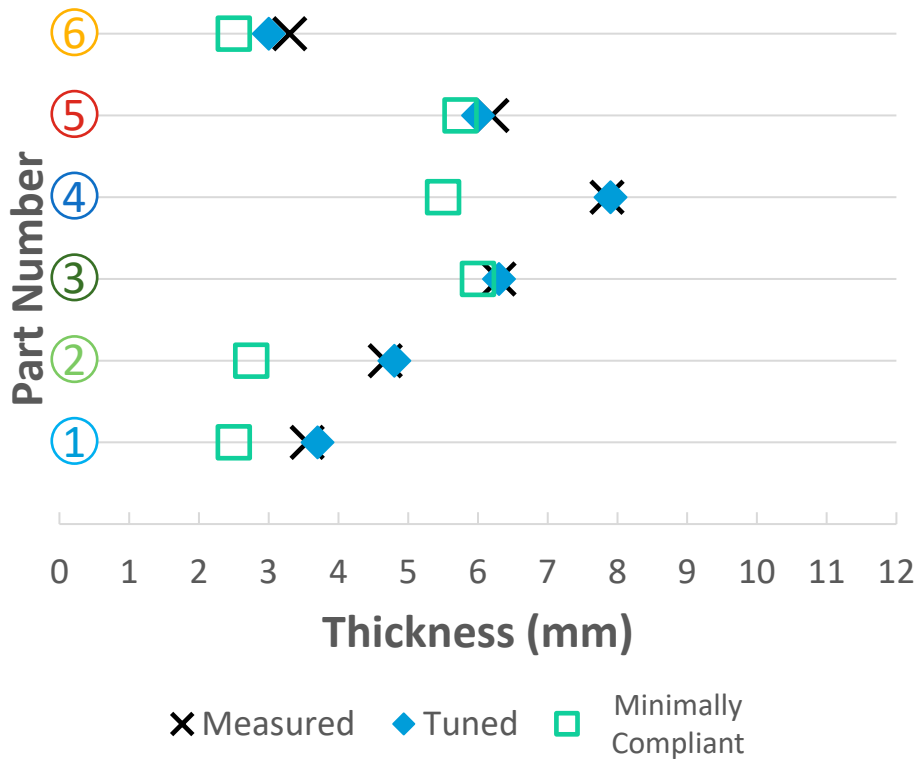


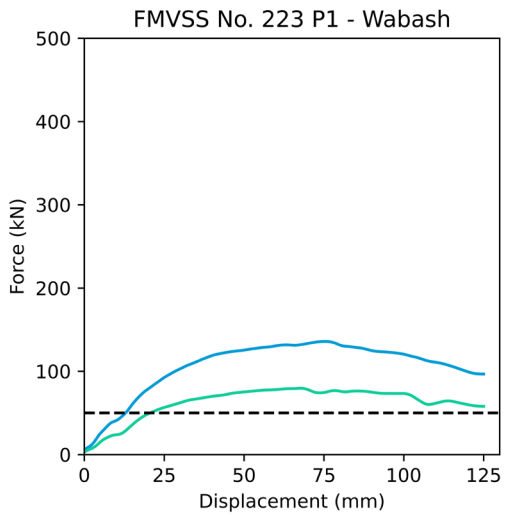
What is the minimum thickness that still passes FMVSS No. 223?

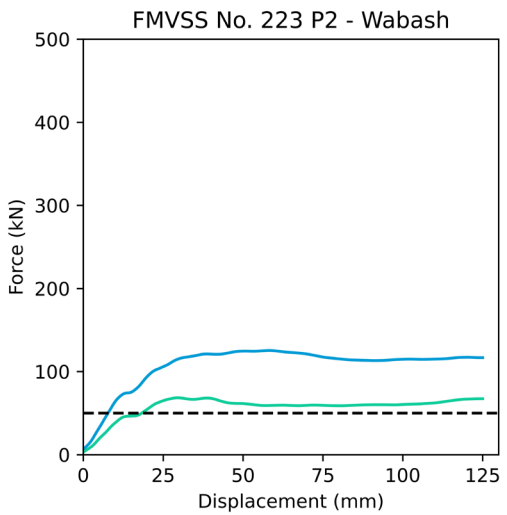
Elemance | Aim 2.2: Modify Guards to minimally comply with FMVSS 223 : Wabash

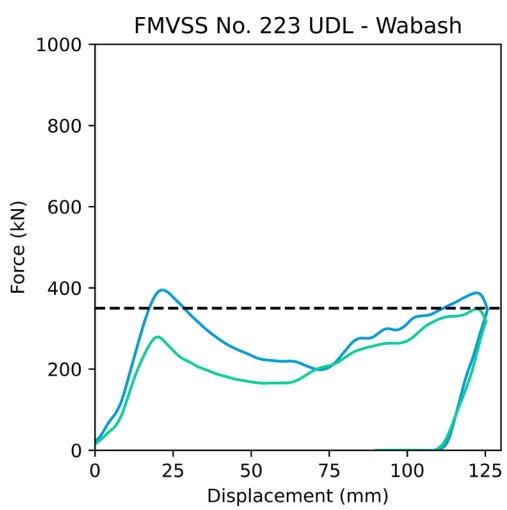


Wabash	Quasi-Static Response				Mass (kg)
	P1 Force (kN)	P2 Force (kN)	UDL Force (kN)	UDL Energy (kJ)	
Baseline	135.8	125.4	394.7	32.1	54.4
Minimally Compliant	79.6	68.5	350.4	25.6	38.9
FMVSS Req.	≥50	≥50	≥350	≥20	N/A

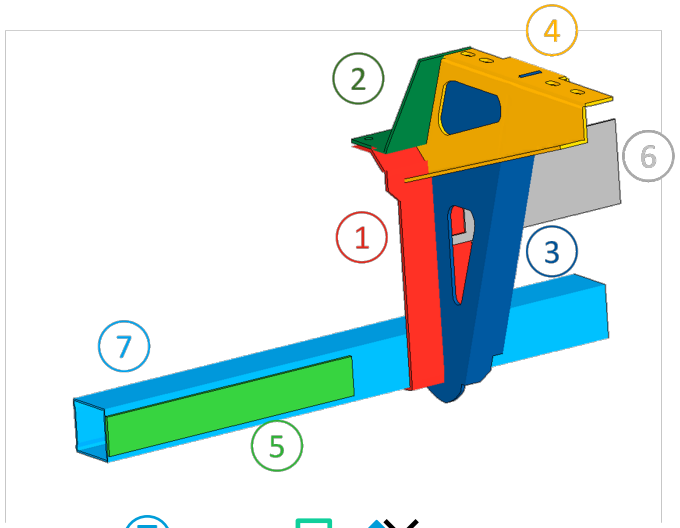




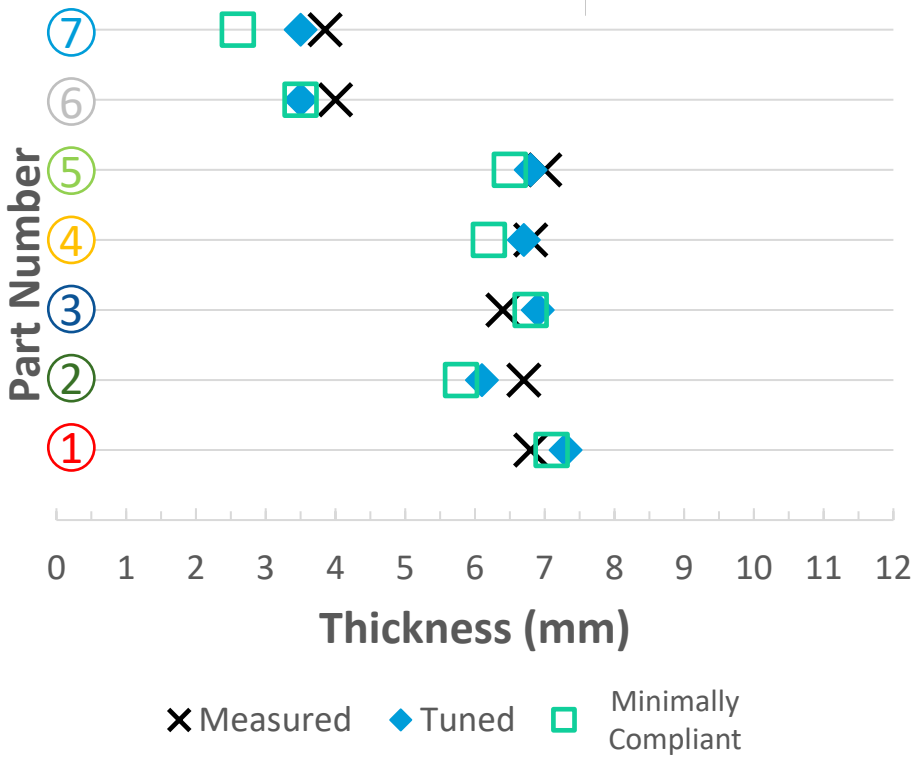


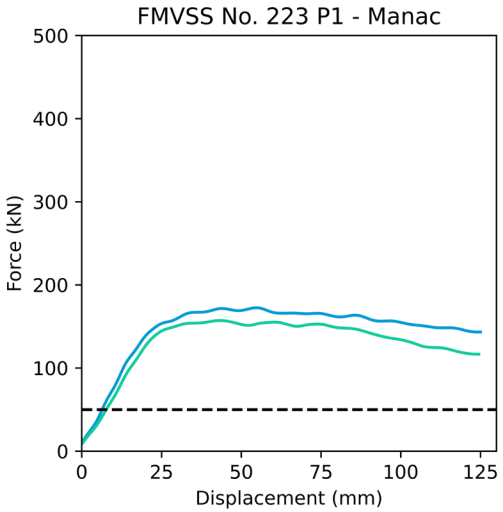


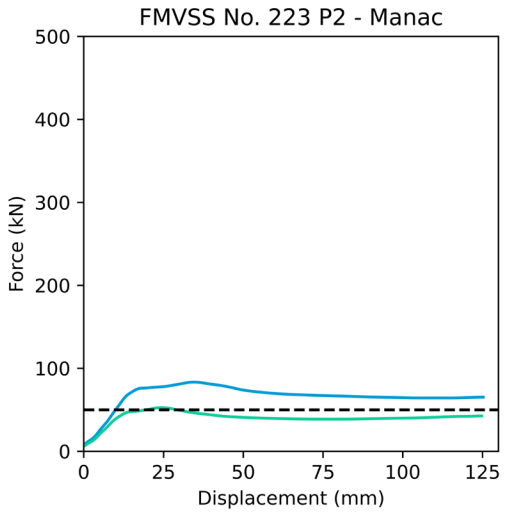
Aim 2.2: Modify Guards to minimally comply with FMVSS 223 : Manac

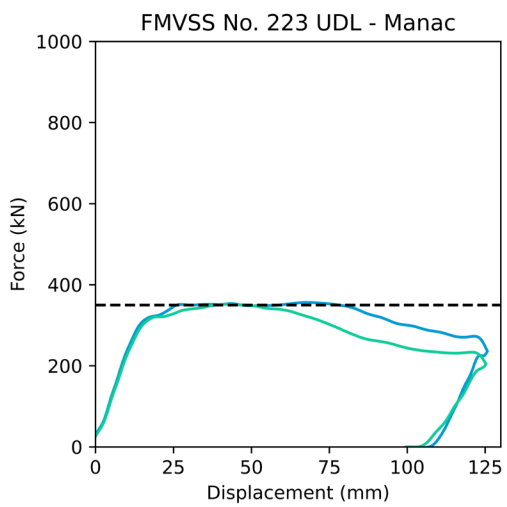


Wabash	Quasi-Static Response				Mass (kg)
	P1 Force (kN)	P2 Force (kN)	UDL Force (kN)	UDL Energy (kJ)	
Baseline	172.5	83.3	356.2	36.8	84.8
Minimally Compliant	157.1	52.5	351.9	33.3	75.7
FMVSS Req.	≥50	≥50	≥350	≥20	N/A

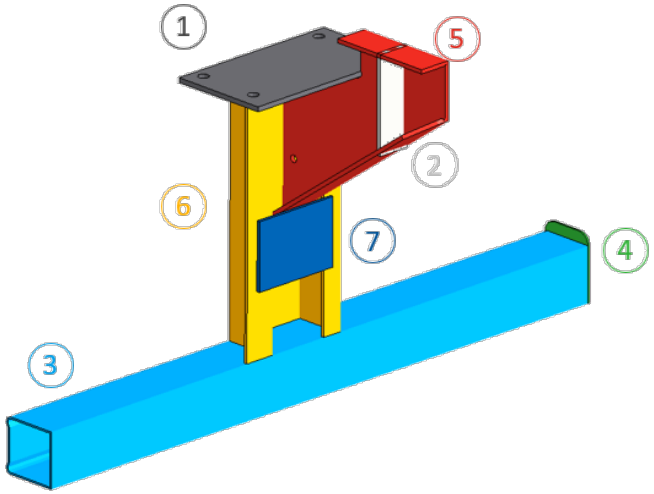




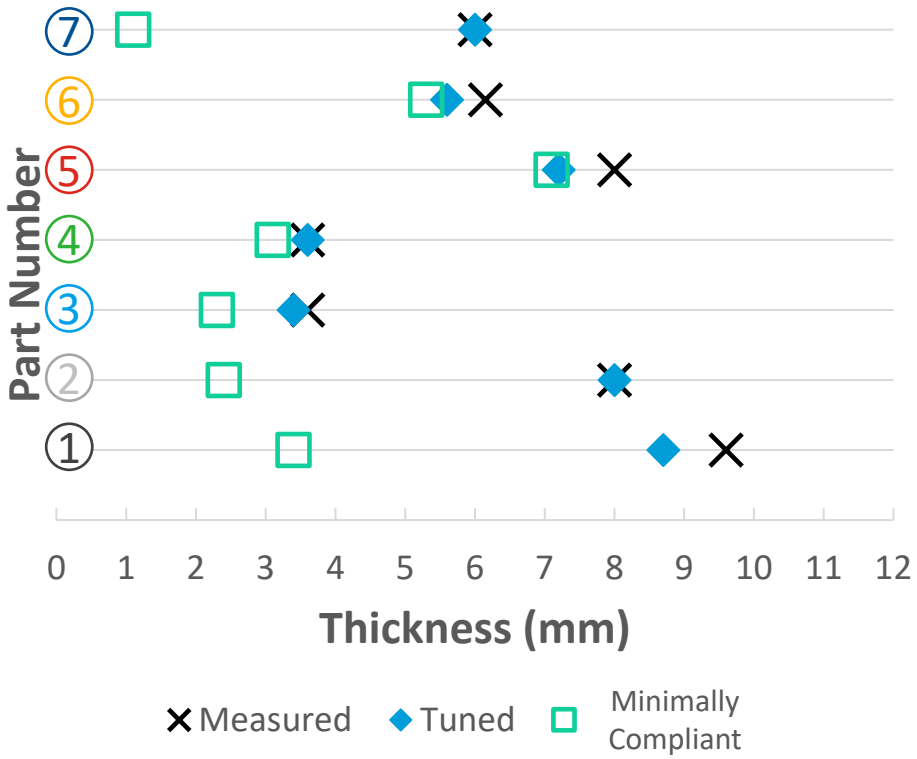


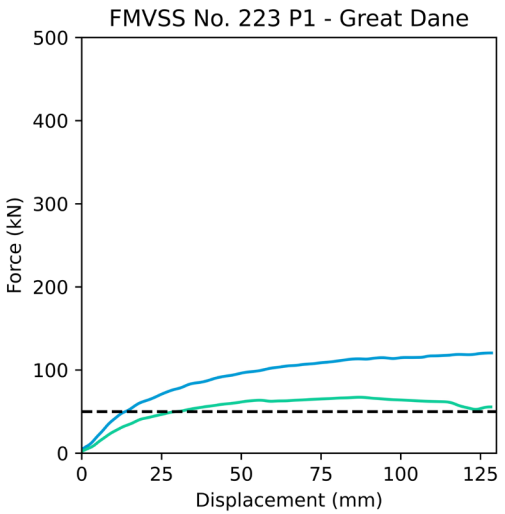


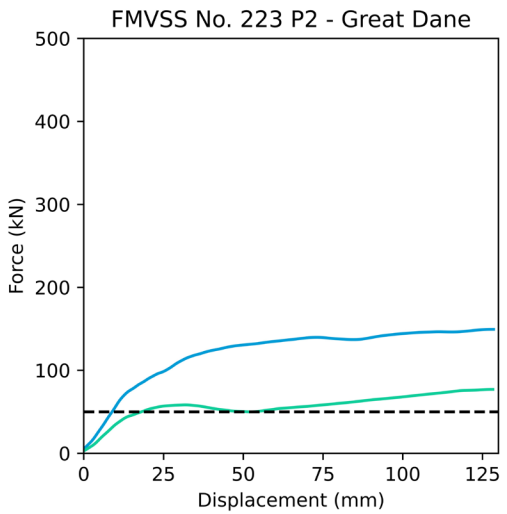
Elemance | Aim 2.2: Modify Guards to minimally comply with FMVSS 223 : Great Dane

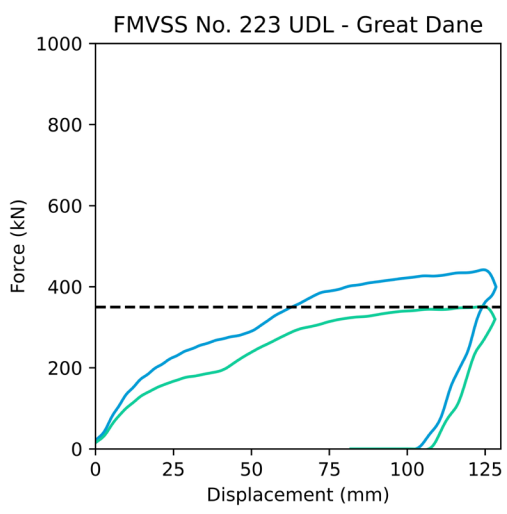


Wabash	Quasi-Static Response				Mass (kg)
	P1 Force (kN)	P2 Force (kN)	UDL Force (kN)	UDL Energy (kJ)	
Baseline	120.5	149.4	441.7	36.6	69.4
Minimally Compliant	67.2	77.0	350.4	29.4	52.5
FMVSS Req.	≥50	≥50	≥350	≥20	N/A







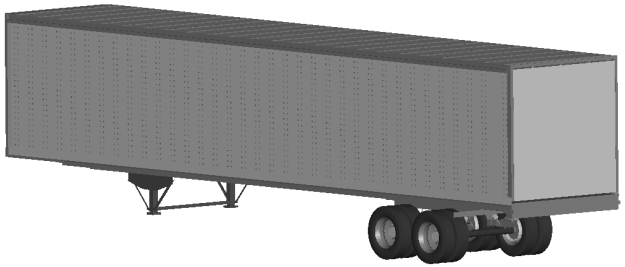


Elemance | Aim 2: Methods Overview

Attach Guards to FE Trailer & Validate Against IIHS Tests → Modify Guards to Minimally Comply with FMVSS 223 → Assess Dynamic Response → Strengthen Guards to Prevent PCI for Midsize Sedan at 30% Overlap → Re-Simulate Guards in FMVSS 223

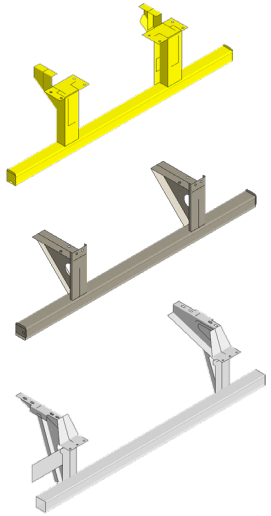
2.1 2.2 2.3 2.4 2.5

Dynamic Simulations



48’ Trailer, NTRCI

+



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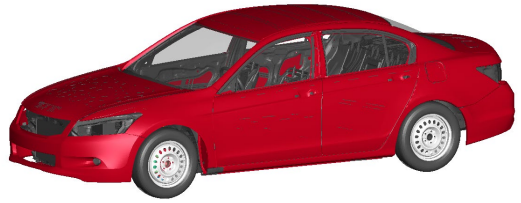
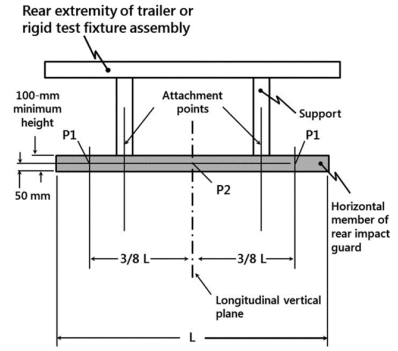


2014 Honda Accord, GMU

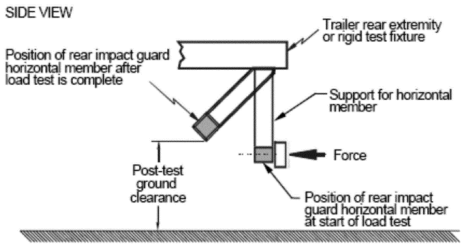
Quasi-Static Simulations

P1, P2

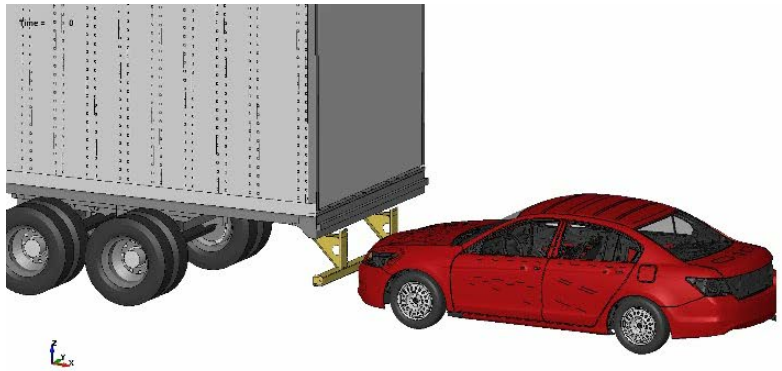
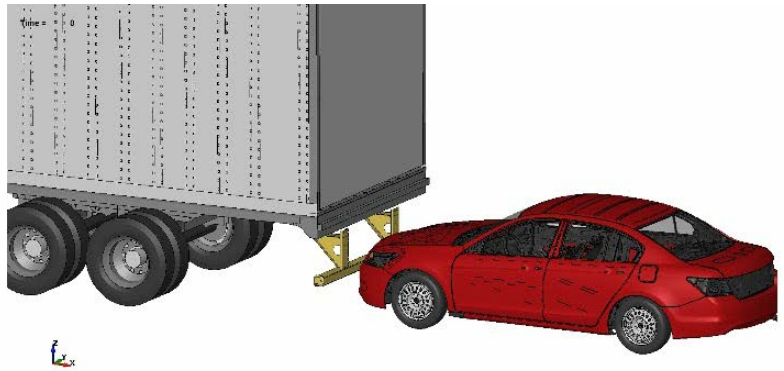
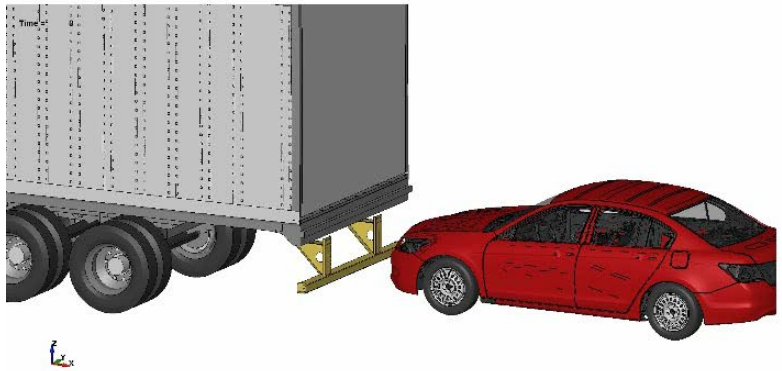
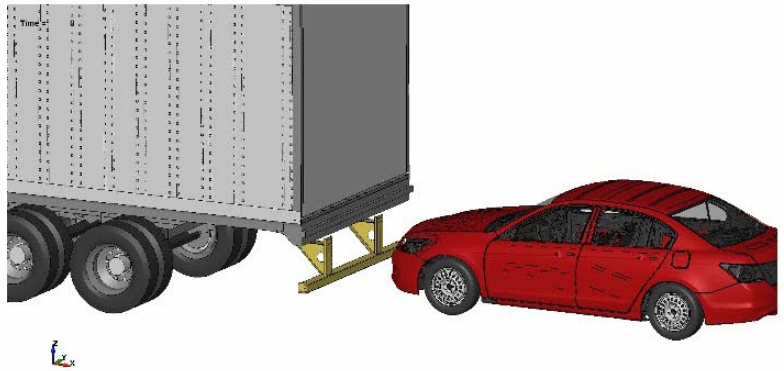
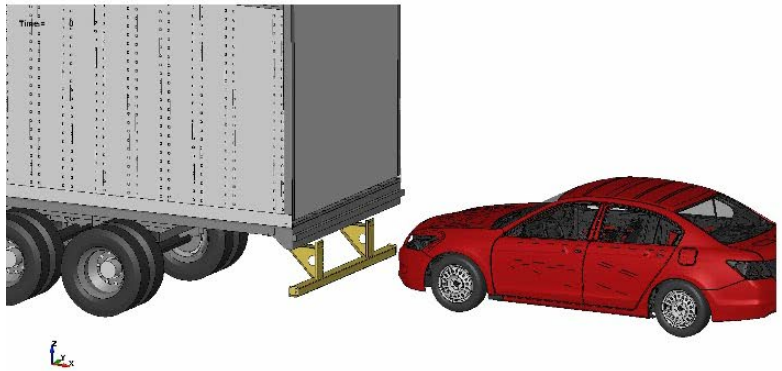
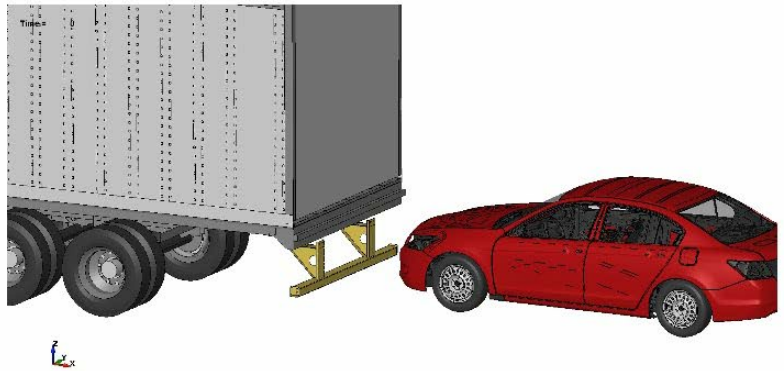


UDL

Notes:
1. L means width of the horizontal member.
2. Drawing not to scale



Aim 2.3: Assess Dynamic Response with Minimally Compliant Guards - Wabash

	Baseline	Minimally Compliant
FW		
50%		
30%		

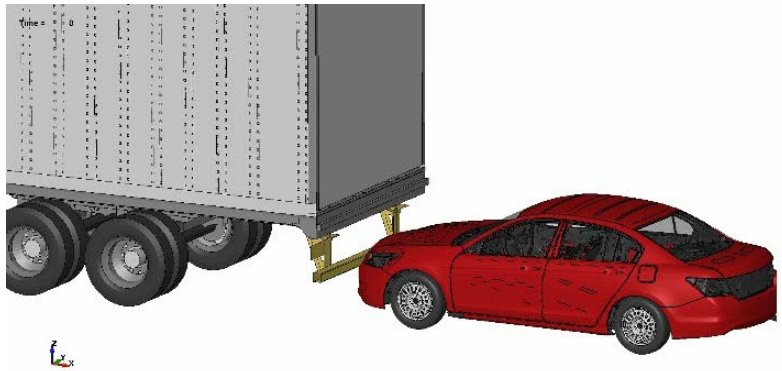
Wabash	Dynamic Response PCI Prevented?		
	FW	50%	30%
Baseline	Yes	Yes	No
Minimally Compliant	Yes	Yes	No

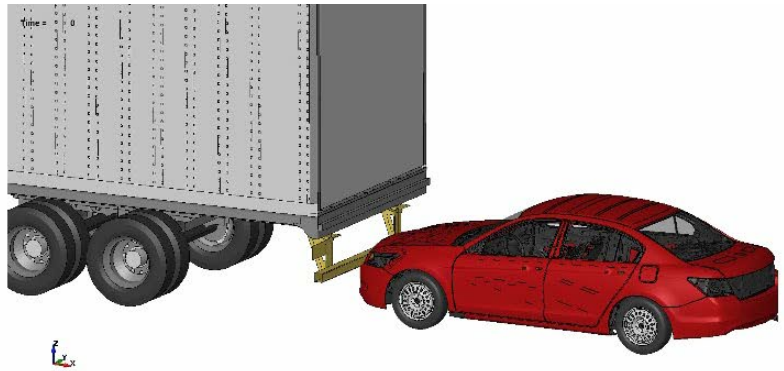
Aim 2.3: Assess Dynamic Response with Minimally Compliant Guards - Manac

Baseline

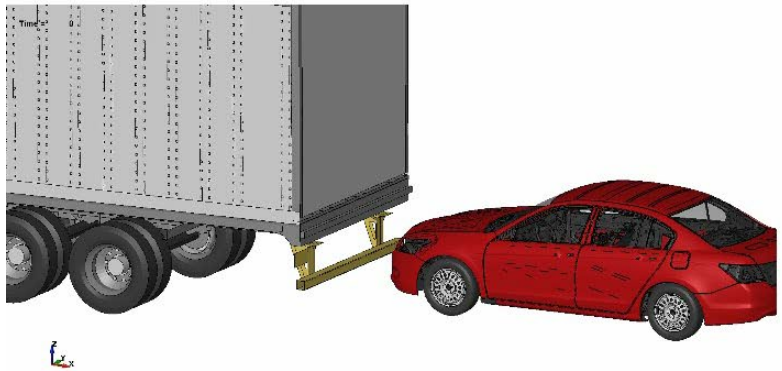
Minimally Compliant

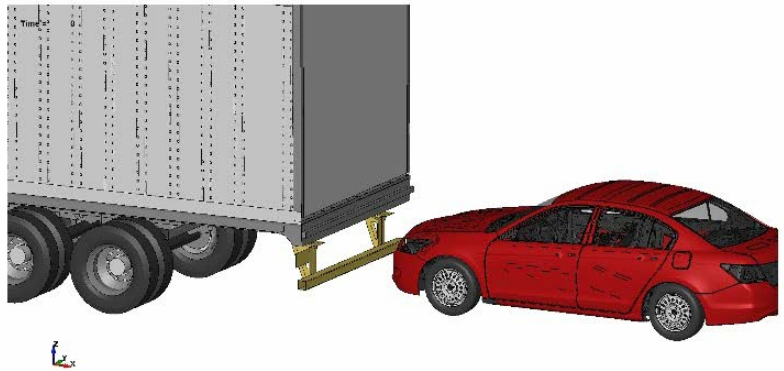
FW



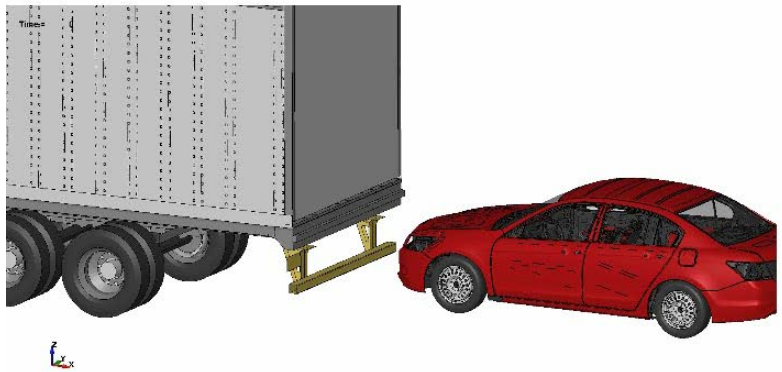


50%



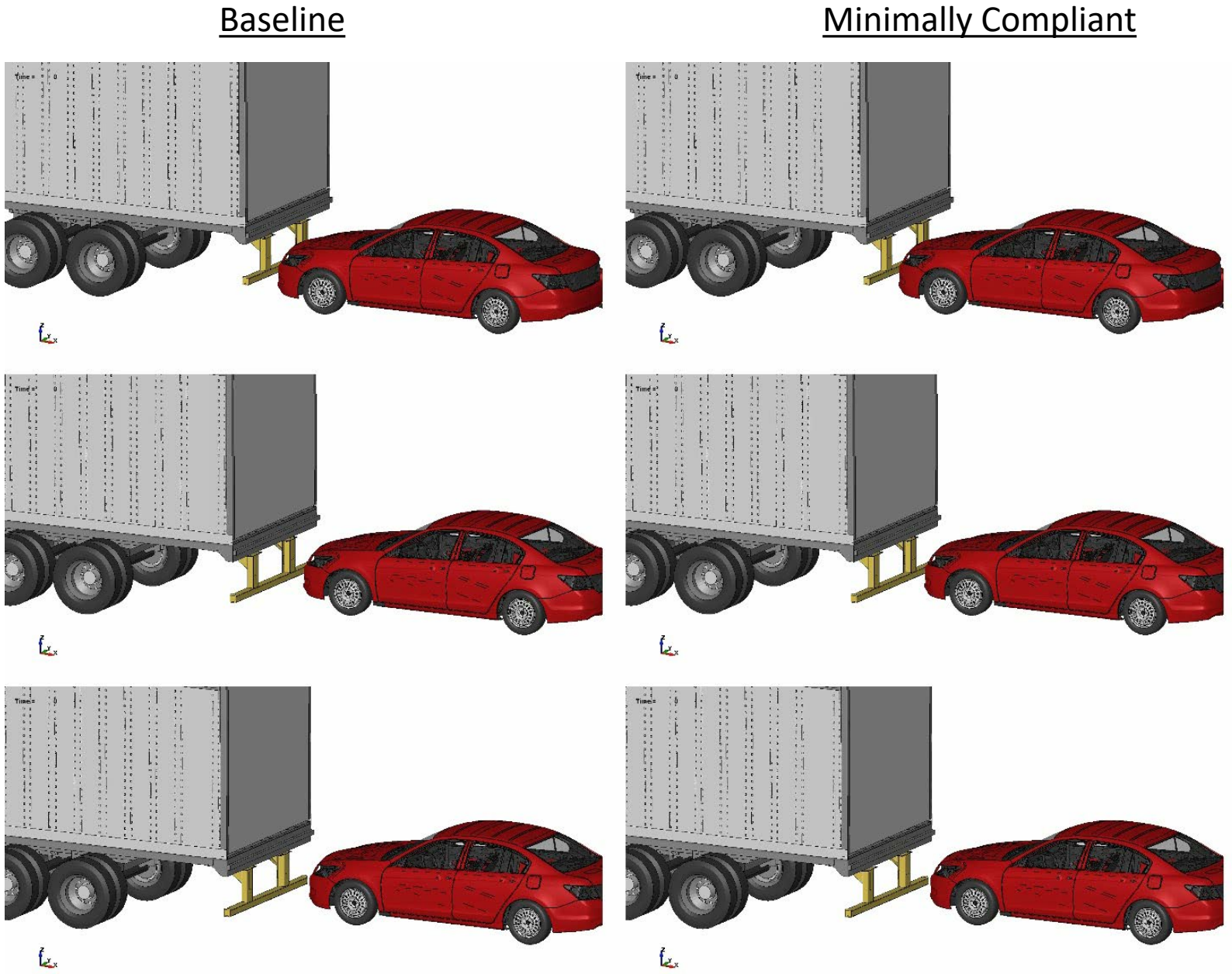


30%



Manac	Dynamic Response PCI Prevented?		
	FW	50%	30%
Baseline	Yes	Yes	Yes
Minimally Compliant	Yes	Yes	Yes

Aim 2.3: Assess Dynamic Response with Minimally Compliant Guards – Great Dane



Great Dane	Dynamic Response PCI Prevented?		
	FW	50%	30%
Baseline	Yes	Yes	No
Minimally Compliant	Yes	Yes	No

Elemance | Aim 2: Results Table

✓ PCI Prevented

✖ PCI Not Prevented

Guard Model		PCI Dynamic Response			Quasi-Static Response				Mass (kg)
		FW	50%	30%	P1 Force (kN)	P2 Force (kN)	UDL Force (kN)	UDL Energy (kJ)	
Manac	Baseline	✓	✓	✓	**172.5**	**83.3**	**356.2**	**36.8**	**84.8**
	Minimally Compliant	✓	✓	✓	**157.1**	**52.5**	**351.9**	**33.3**	**75.7**
	~~Strengthened– Midsize~~								
Wabash	Baseline	✓	✓	✖	**135.8**	**125.4**	**394.7**	**32.1**	**54.4**
	Minimally Compliant	✓	✓	✖	**79.6**	**68.5**	**350.4**	**25.6**	**38.9**
	Strengthened– Midsize	✓	✓	✓	→	→	→	→	?
Great Dane	Baseline	✓	✓	✖	**120.5**	**149.4**	**441.7**	**36.6**	**69.4**
	Minimally Compliant	✓	✓	✖	**67.2**	**77.0**	**350.4**	**29.4**	**52.5**
	Strengthened– Midsize	✓	✓	✓	→	→	→	→	?
FMVSS No. 223 Requirement					**≥50**	**≥50**	**≥350**	**≥20**	**N/A**

Aim 2: Results Table

✓ PCI Prevented

✖ PCI Not Prevented

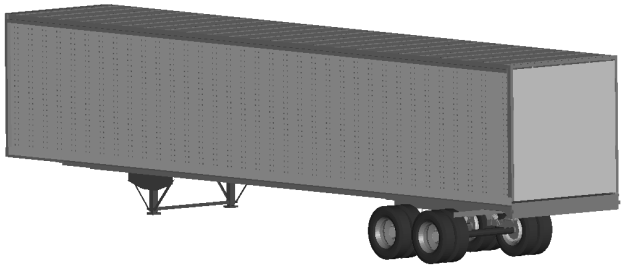
Guard Model		PCI Dynamic Response			Quasi-Static Response				Mass (kg)
		FW	50%	30%	P1 Force (kN)	P2 Force (kN)	UDL Force (kN)	UDL Energy (kJ)	
Manac	Baseline	✓	✓	✓	172.5	83.3	356.2	36.8	84.8
	Minimally Compliant	✓	✓	✓	157.1	52.5	351.9	33.3	75.7
	~~Strengthened– Midsize~~								
Wabash	Baseline	✓	✓	✖	135.8	125.4	394.7	32.1	54.4
	Minimally Compliant	✓	✓	✖	79.6	68.5	350.4	25.6	38.9
	Strengthened– Midsize								
Great Dane	Baseline	✓	✓	✖	120.5	149.4	441.7	36.6	69.4
	Minimally Compliant	✓	✓	✖	67.2	77.0	350.4	29.4	52.5
	Strengthened– Midsize								
FMVSS No. 223 Requirement					≥50	≥50	≥350	≥20	N/A

Elemance | Aim 2: Methods Overview

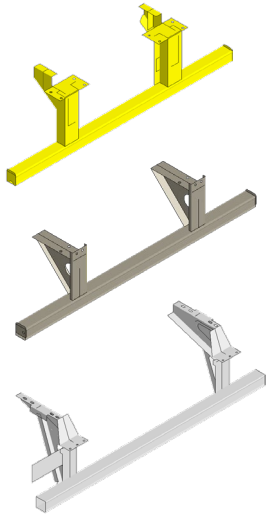
Attach Guards to FE Trailer & Validate Against IIHS Tests → Modify Guards to Minimally Comply with FMVSS 223 → Assess Dynamic Response → Strengthen Guards to Prevent PCI for Midsize Sedan at 30% Overlap → Re-Simulate Guards in FMVSS 223

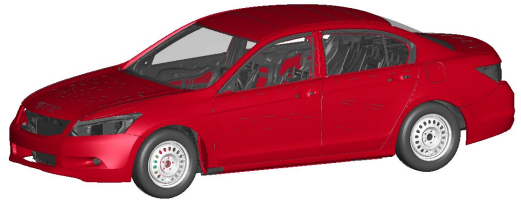
2.1 2.2 2.3 2.4 2.5

Dynamic Simulations



48’ Trailer, NTRCI

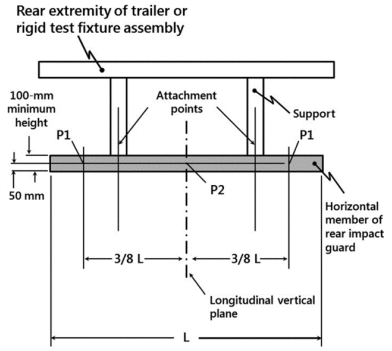




2014 Honda Accord, GMU

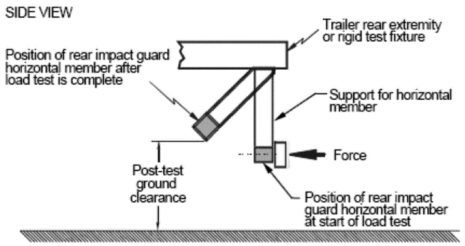
Quasi-Static Simulations

P1, P2



UDL

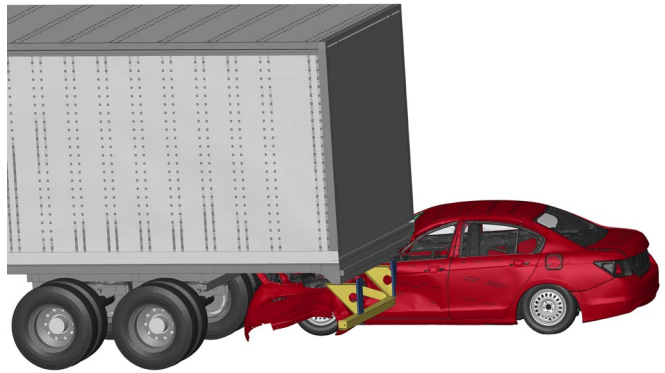
Notes:
1. L means width of the horizontal member.
2. Drawing not to scale

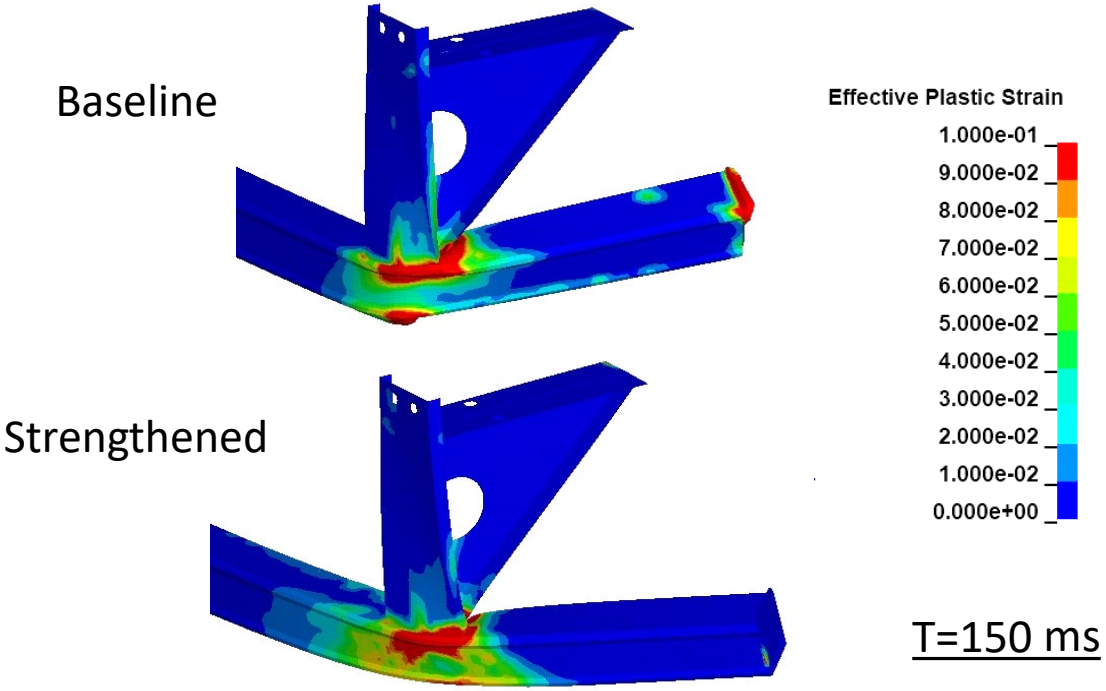


Aim 2.4: Strengthen Guards to prevent PCI in 30% Overlap @ 35 mph

Strengthening Guards:

- Identified parts that were carrying majority of load
- Increase thicknesses of parts in build-simulate-build iterative manner
- <u>Goal:</u> Find minimum thicknesses that still prevent PCI



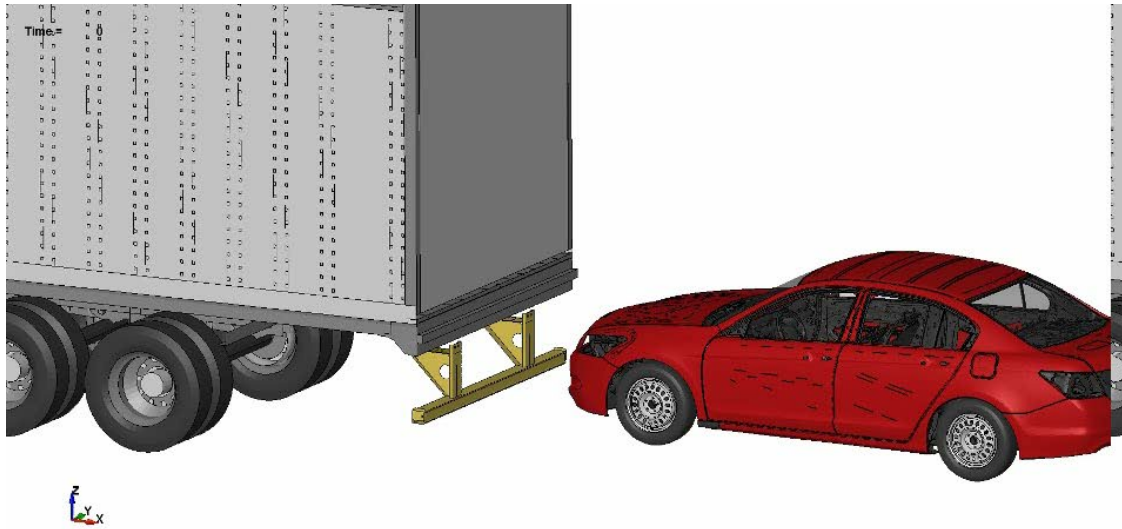


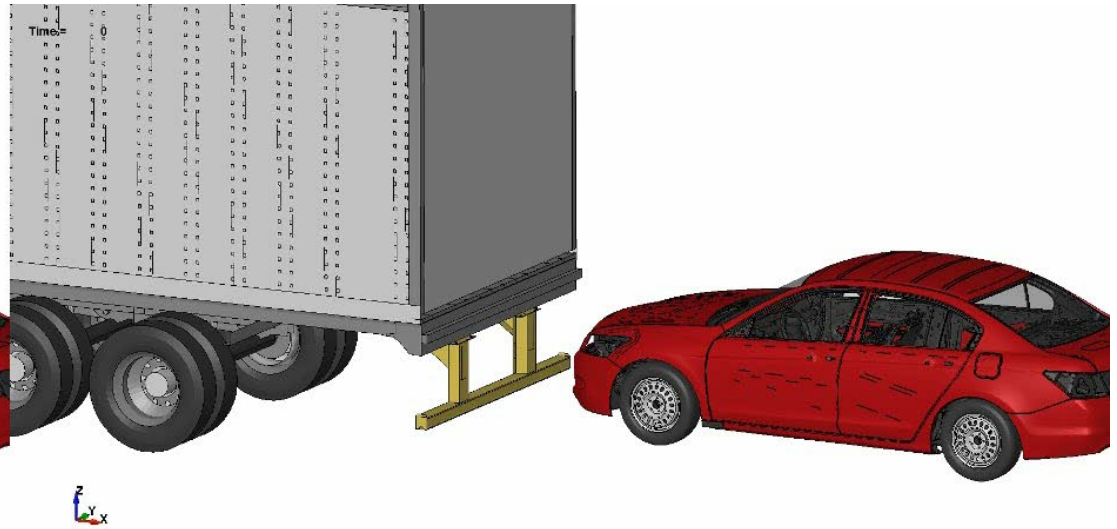
Aim 2.4: Strengthen Guards to prevent PCI in 30% Overlap @ 35 mph – Wabash/Great Dane

Wabash

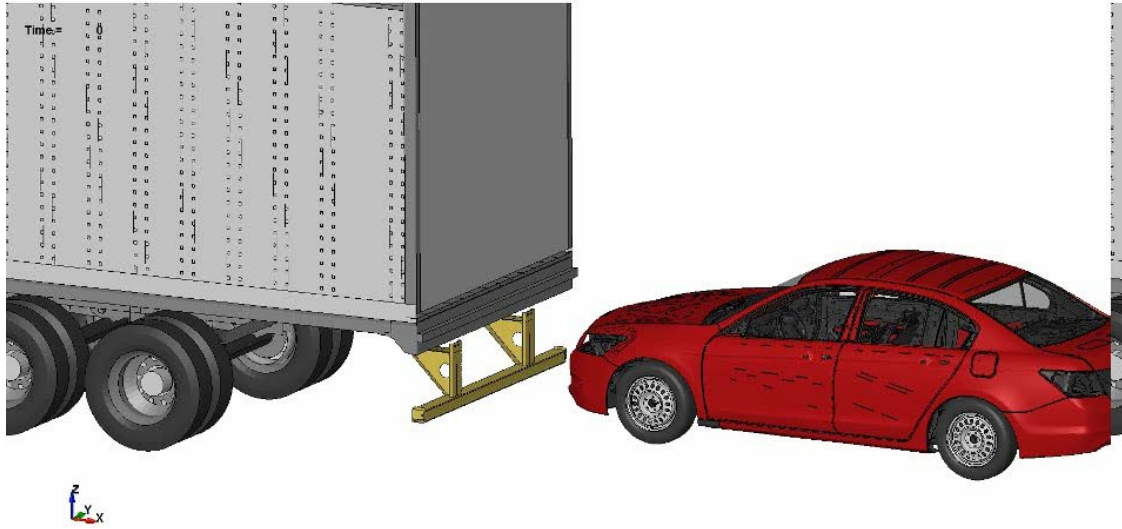
Great Dane

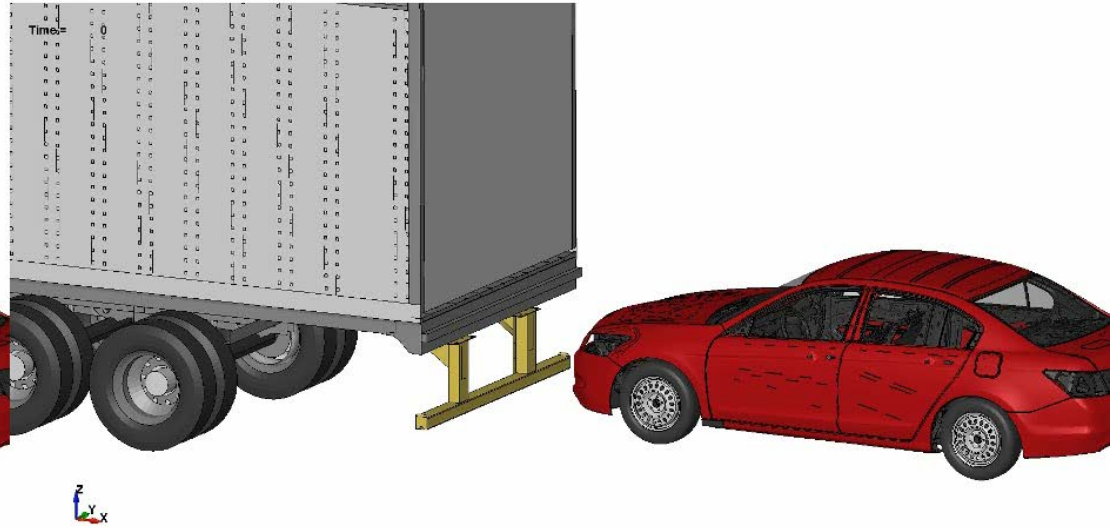
Baseline





Strengthened



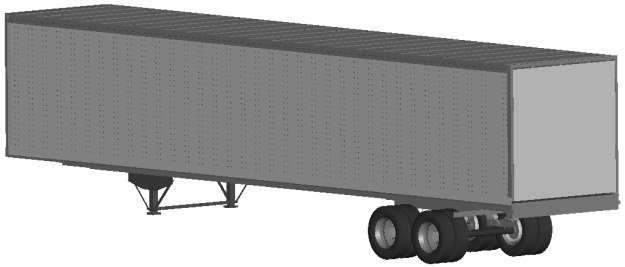


Elemance | Aim 2: Methods Overview

Attach Guards to FE Trailer & Validate Against IIHS Tests → Modify Guards to Minimally Comply with FMVSS 223 → Assess Dynamic Response → Strengthen Guards to Prevent PCI for Midsize Sedan at 30% Overlap → Re-Simulate Guards in FMVSS 223

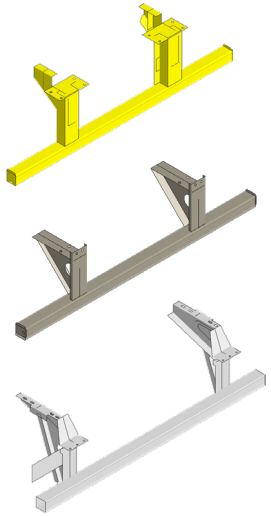
2.1 2.2 2.3 2.4 2.5

Dynamic Simulations



48’ Trailer, NTRCI

+



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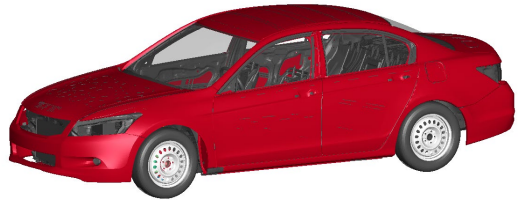
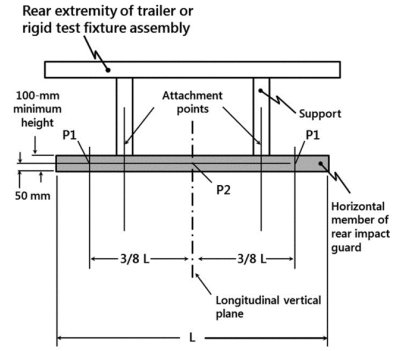


2014 Honda Accord, GMU

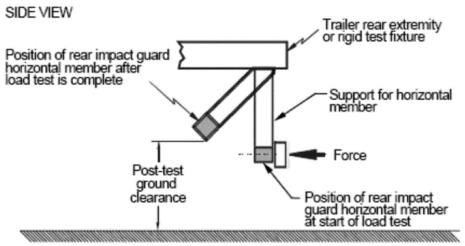
Quasi-Static Simulations

P1, P2

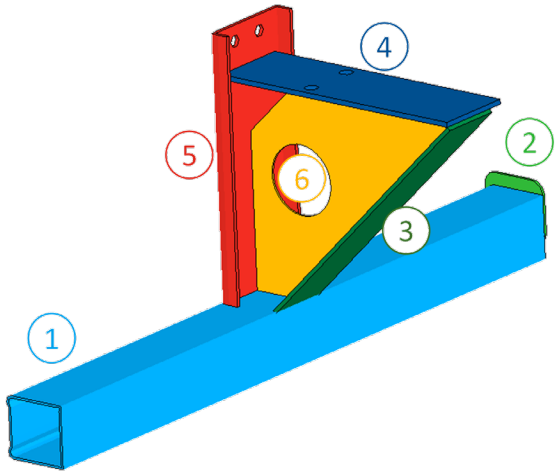


UDL

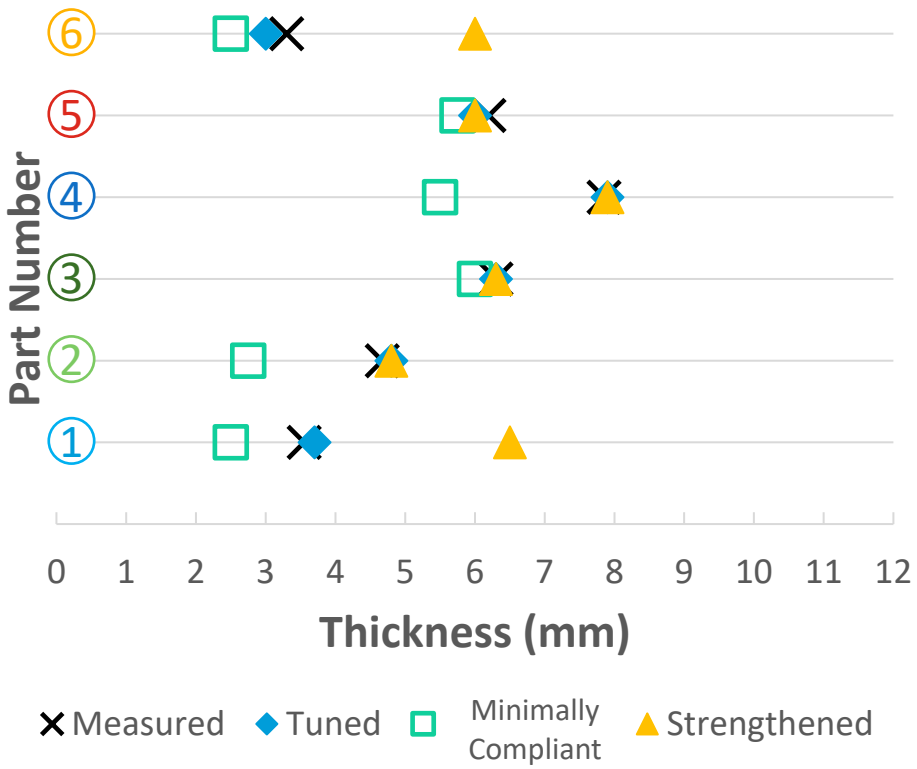
Notes:
1. L means width of the horizontal member.
2. Drawing not to scale

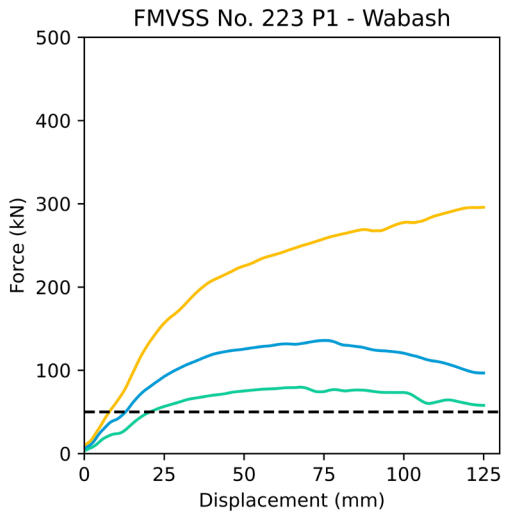


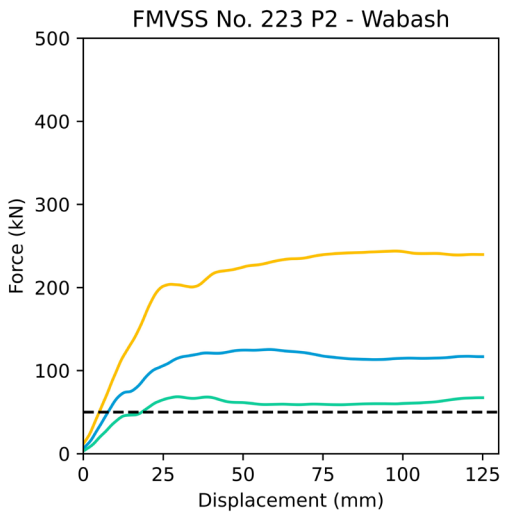
Elemance | Aim 2.5: Re-Test Strengthened Guards in FMVSS 223: Wabash

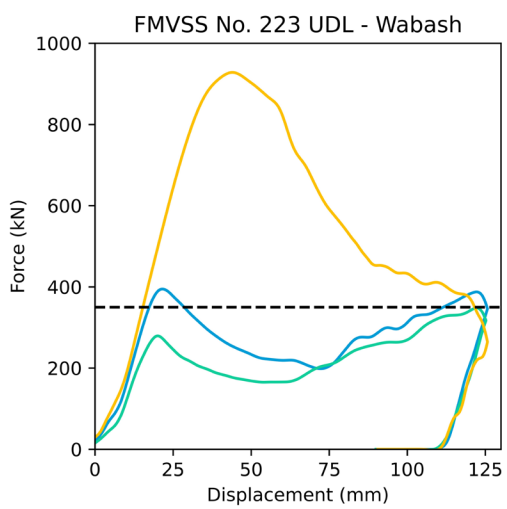


Wabash	Quasi-Static Response				Mass (kg)
	P1 Force (kN)	P2 Force (kN)	UDL Force (kN)	UDL Energy (kJ)	
Baseline	135.8	125.4	394.7	32.1	54.4
Minimally Compliant	79.6	68.5	350.4	25.6	38.9
Strengthened	295.7	243.8	928.1	68.0	75.8
FMVSS Req.	≥50	≥50	≥350	≥20	N/A

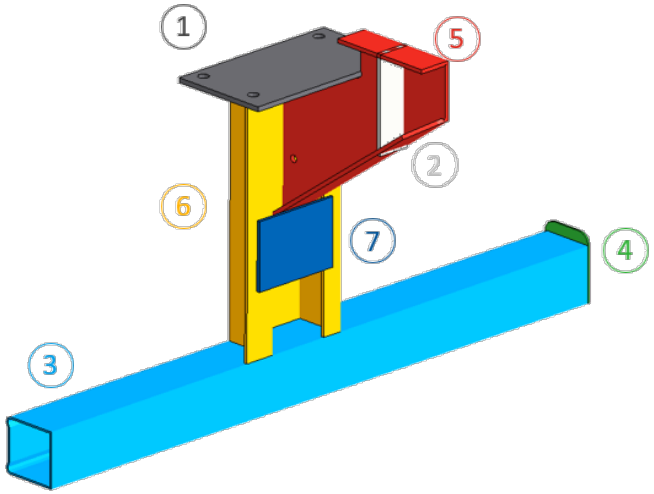




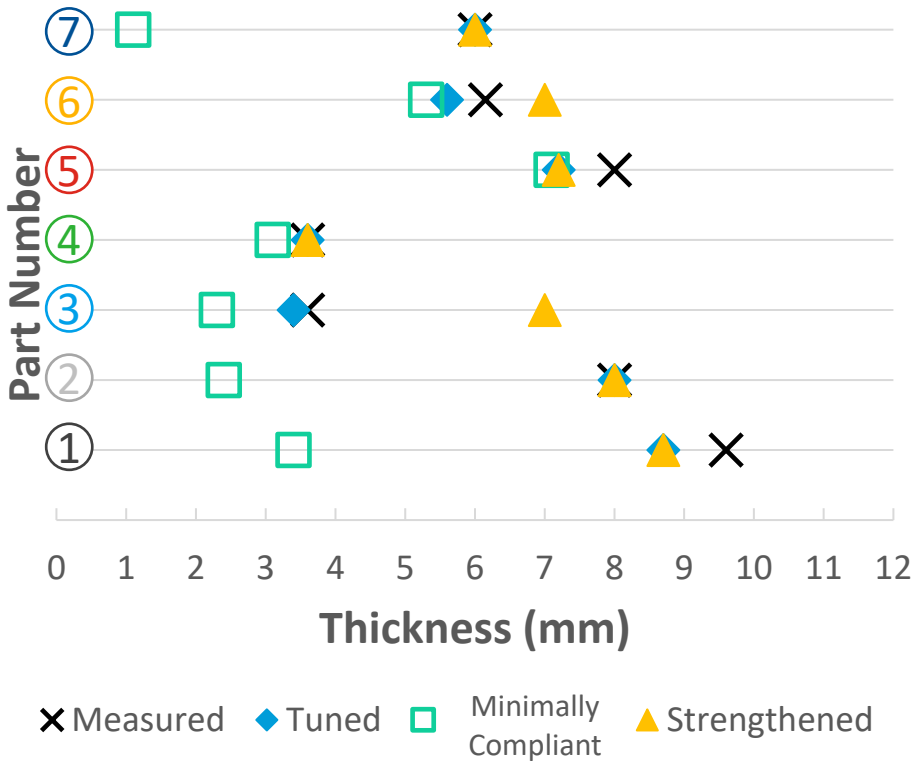


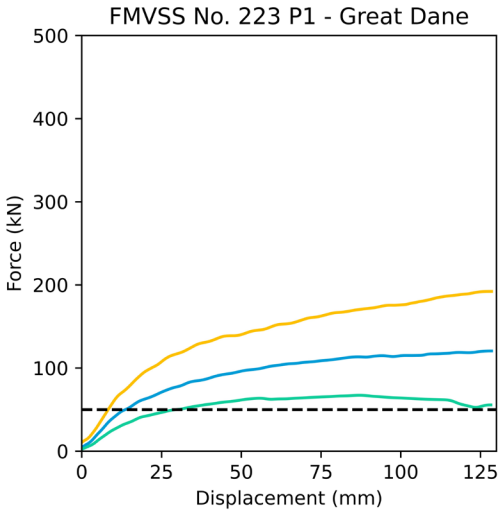


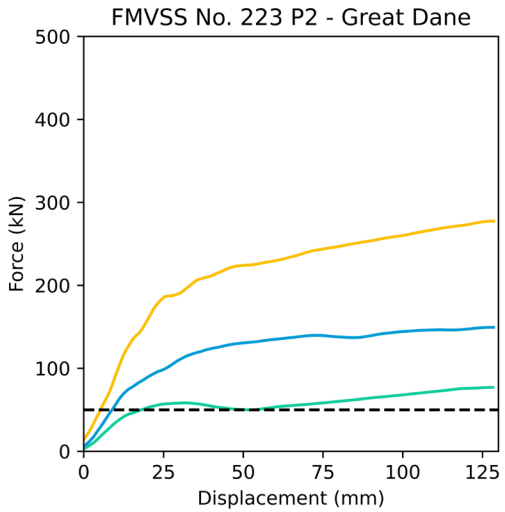
Elemance | Aim 2.5: Re-Test Strengthened Guards in FMVSS 223: Great Dane

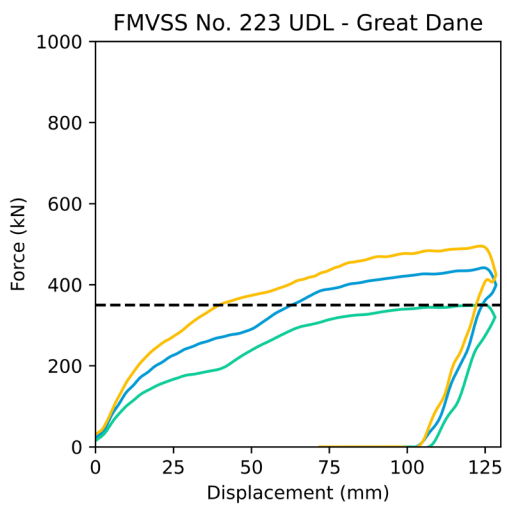


Wabash	Quasi-Static Response				Mass (kg)
	P1 Force (kN)	P2 Force (kN)	UDL Force (kN)	UDL Energy (kJ)	
Baseline	120.5	149.4	441.7	36.6	69.4
Minimally Compliant	67.2	77.0	350.4	29.4	52.5
Strengthened	192.1	277.3	495.4	42.8	101.1
FMVSS Req.	≥50	≥50	≥350	≥20	N/A

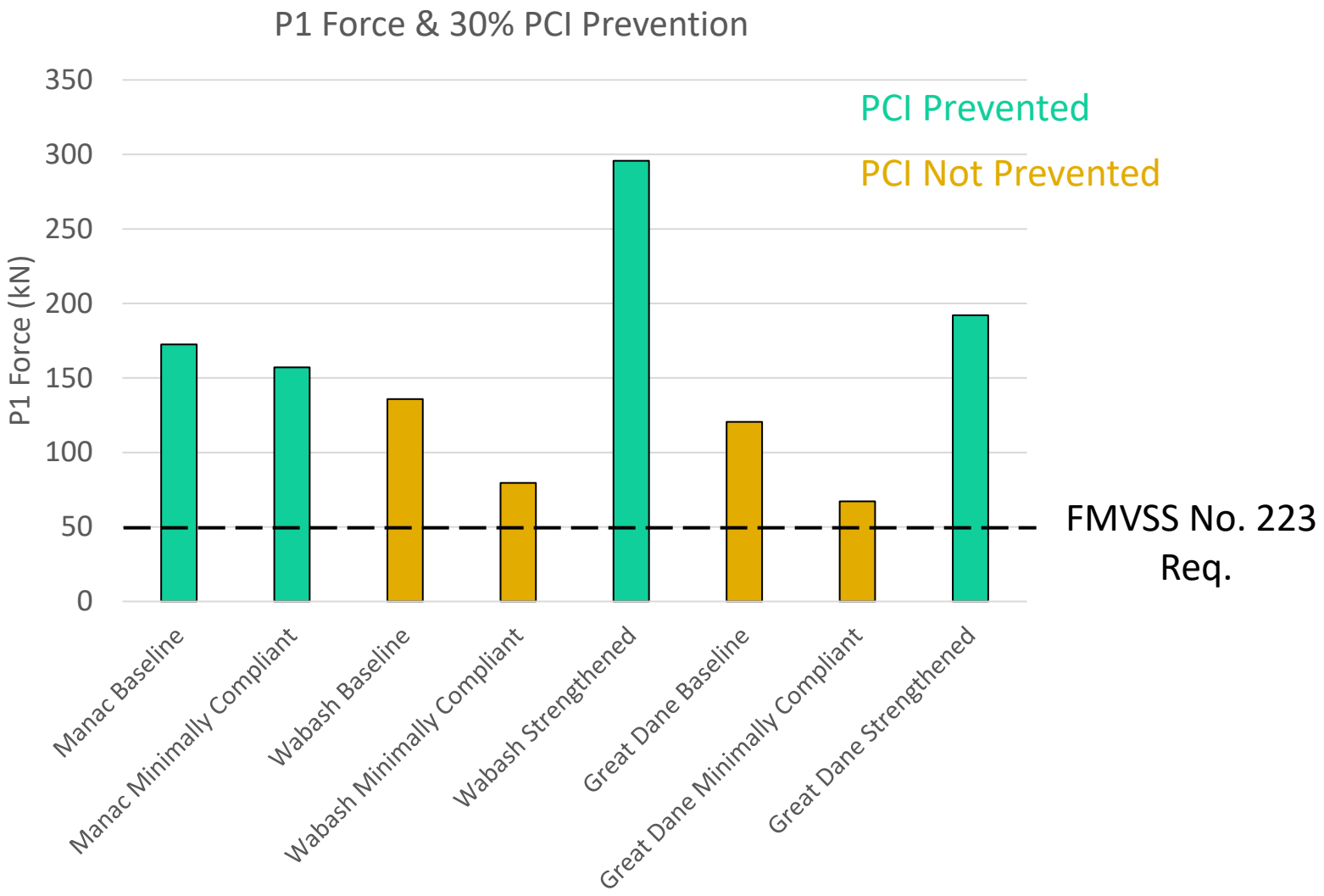


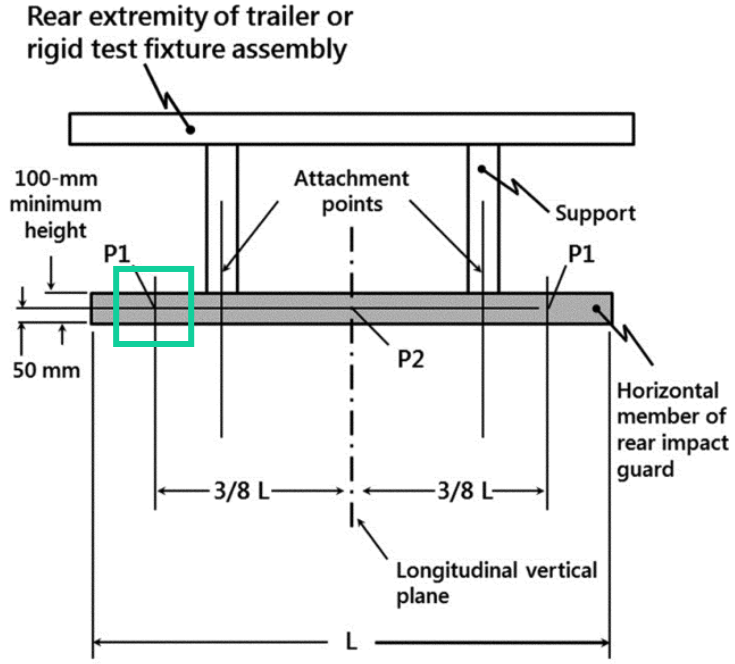






Elemance | Aim 2: Discussion





Notes:
1. L means width of the horizontal member.
2. Drawing not to scale

Elemance | Aim 2: Results Table

✓ PCI Prevented

✖ PCI Not Prevented

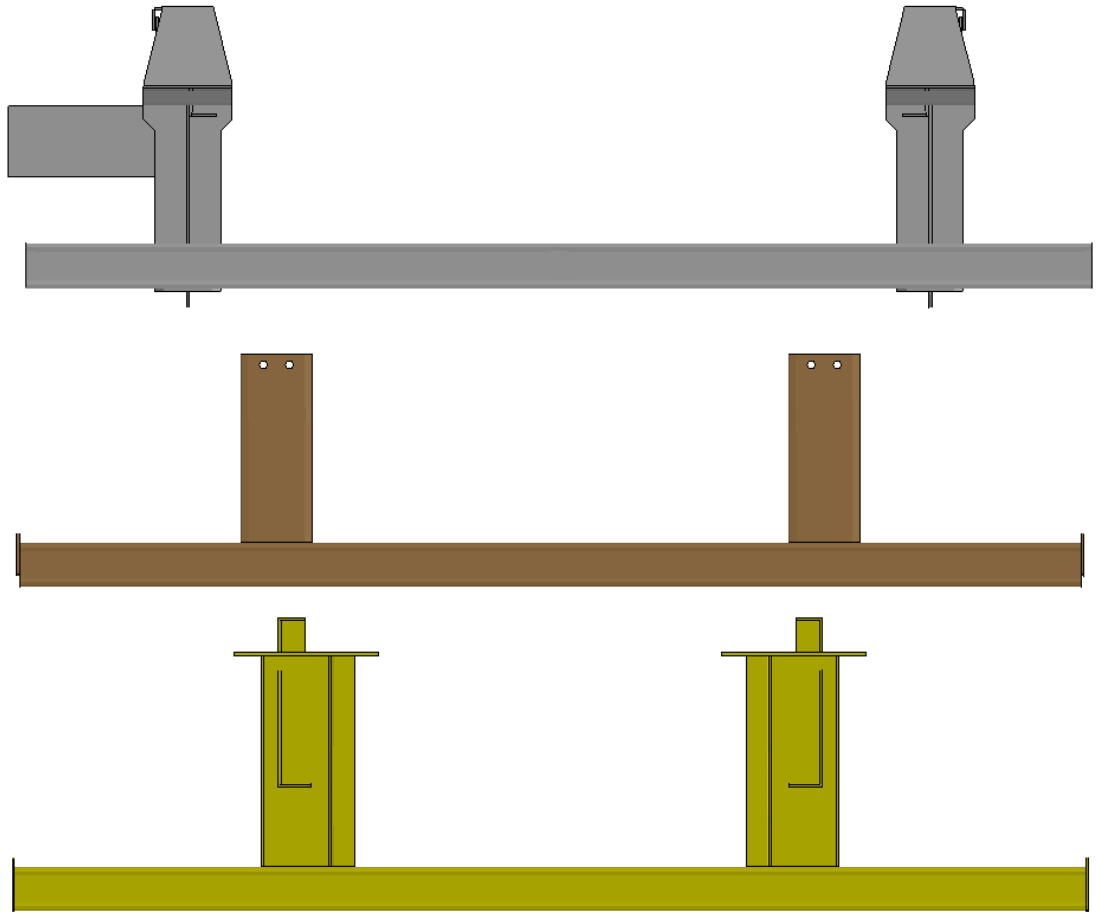
Guard Model		PCI Dynamic Response			Quasi-Static Response				Mass (kg)
		FW	50%	30%	P1 Force (kN)	P2 Force (kN)	UDL Force (kN)	UDL Energy (kJ)	
Manac	Baseline	✓	✓	✓	172.5	83.3	356.2	36.8	84.8
	Minimally Compliant	✓	✓	✓	157.1	52.5	351.9	33.3	75.7
	~~Strengthened– Midsize~~								
Wabash	Baseline	✓	✓	✖	135.8	125.4	394.7	32.1	54.4
	Minimally Compliant	✓	✓	✖	79.6	68.5	350.4	25.6	38.9
	Strengthened– Midsize	✓	✓	✓	295.7	243.8	928.1	68.0	75.8
Great Dane	Baseline	✓	✓	✖	120.5	149.4	441.7	36.6	69.4
	Minimally Compliant	✓	✓	✖	67.2	77.0	350.4	29.4	52.5
	Strengthened– Midsize	✓	✓	✓	192.1	277.3	495.4	42.8	101.1
FMVSS No. 223 Requirement					≥50	≥50	≥350	≥20	N/A

Elemance | Aim 2: Discussion

Manac

Wabash

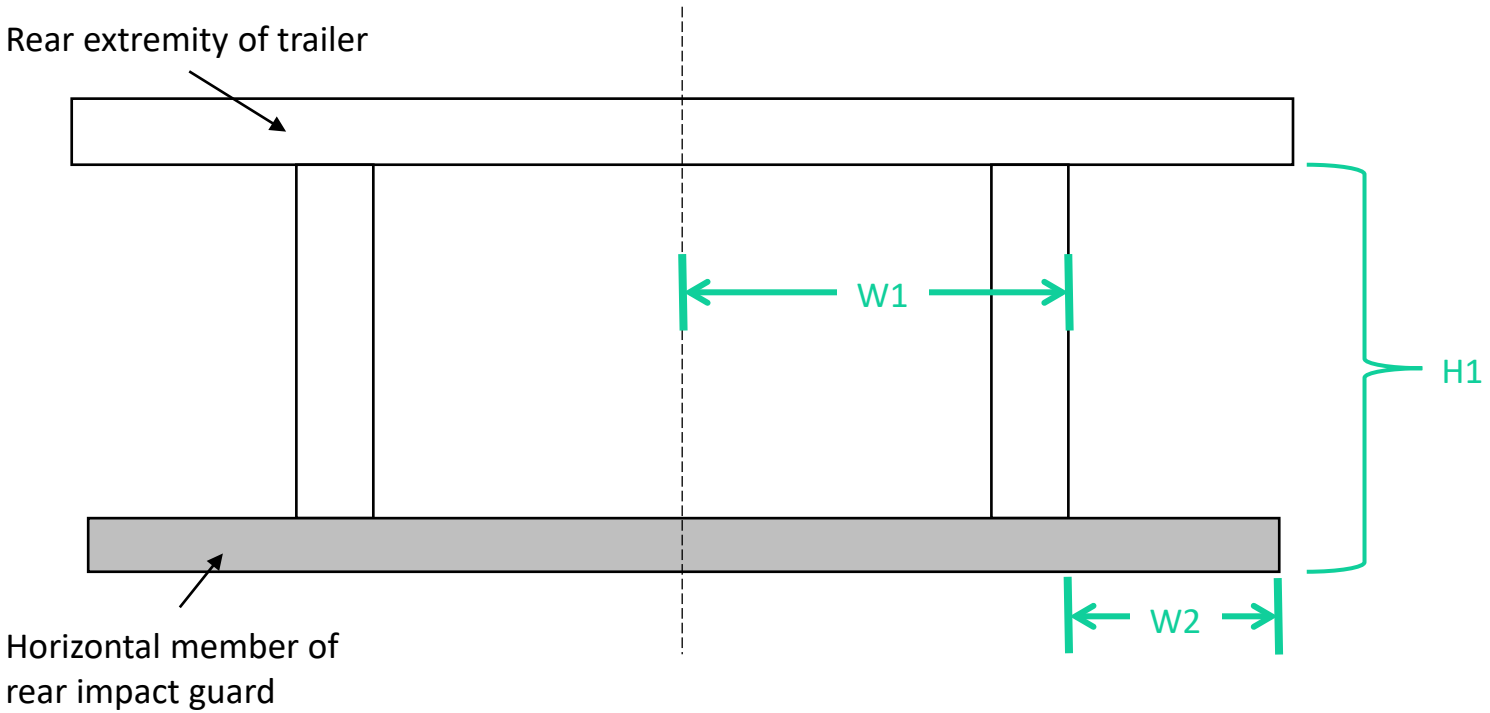
Great Dane



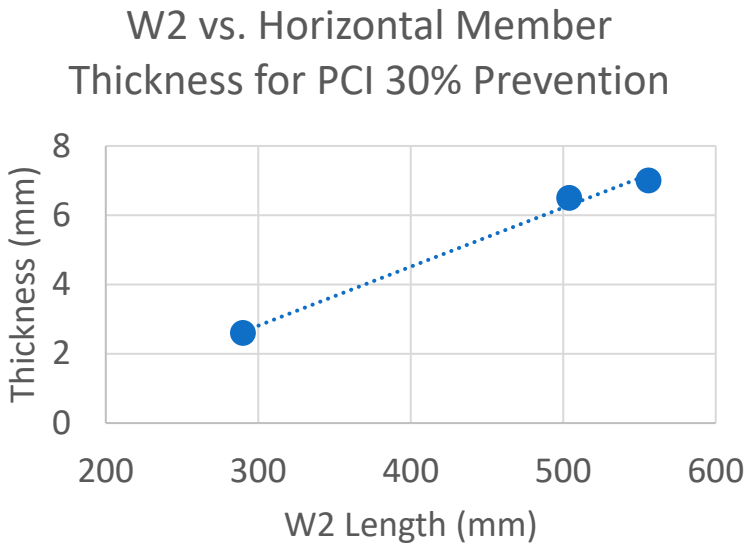
Decreasing Upright Width

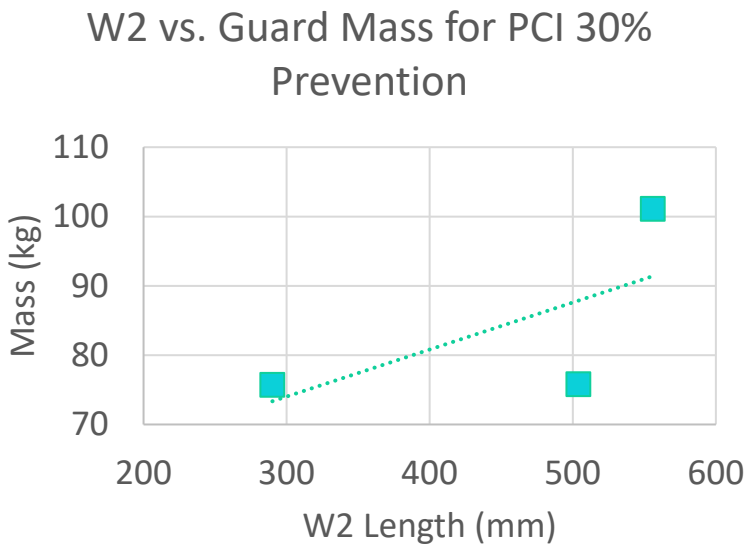
Model Version Preventing PCI @ 30% Overlap	
Horizontal Member Thickness (mm)	Guard Mass (kg)
2.6	75.7
6.5	75.8
7.0	101.1

Elemance | Aim 2: Discussion



Guard	H1	W1	W2
Manac	450	910	290
Wabash	525	690	504
Great Dane	575	650	556





- Bolt connections not explicitly modeled. Instead, rigid constraints at bolt holes
- Trailer model generic, not modified to replicate each manufacturer’s trailer
- Trailer ride height not adjusted between guards
- Preliminary validation only possible between physical Chevrolet Malibu and simulation Honda Accord

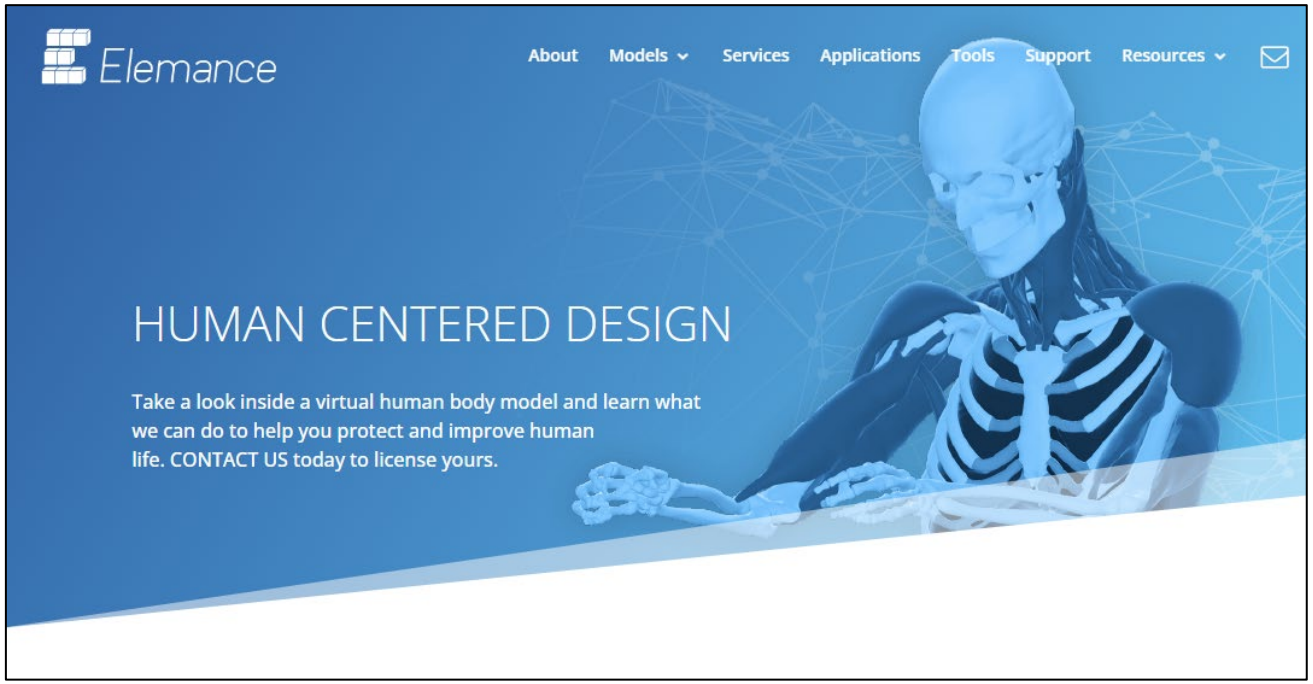
- PCI prevented in both baseline and minimally compliant conditions, 50% and Full Width 35 mph cases across all models
- 30% Overlap PCI prevention is particularly challenging; selectively increasing guard metal thicknesses can prevent PCI, but comes with large mass increases
- As width between the uprights decreases, required horizontal member strength increases

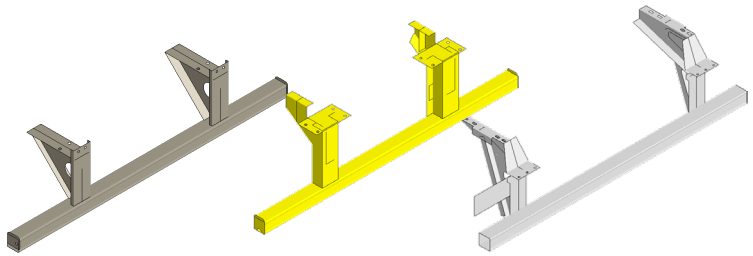
Elemance

Thank you!

NHTSA Contract Number: 693JJ921D000042

NHTSA



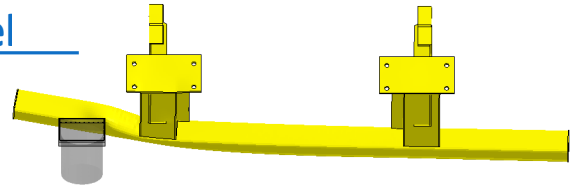


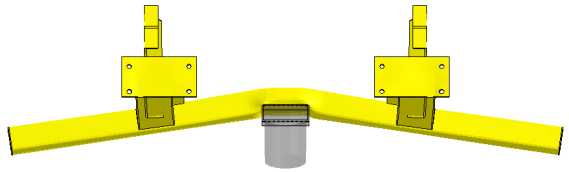
Models freely available at Elemance.com

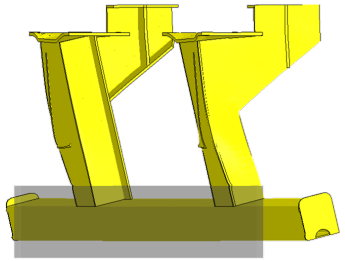

Elemance

Aim 2: Modify Guards to just pass FMVSS 223 – Great Dane

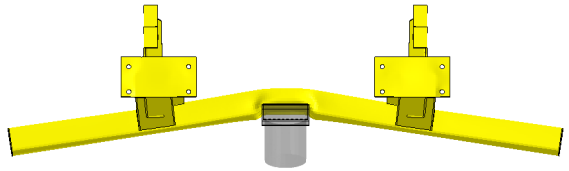
Basel

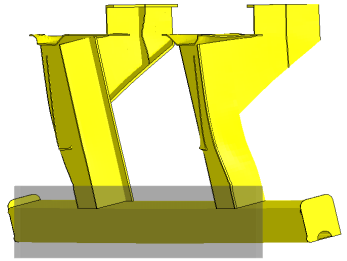


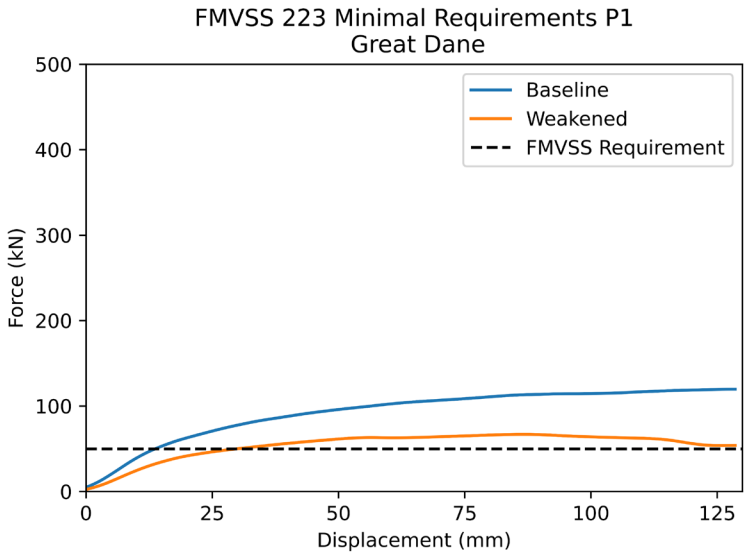


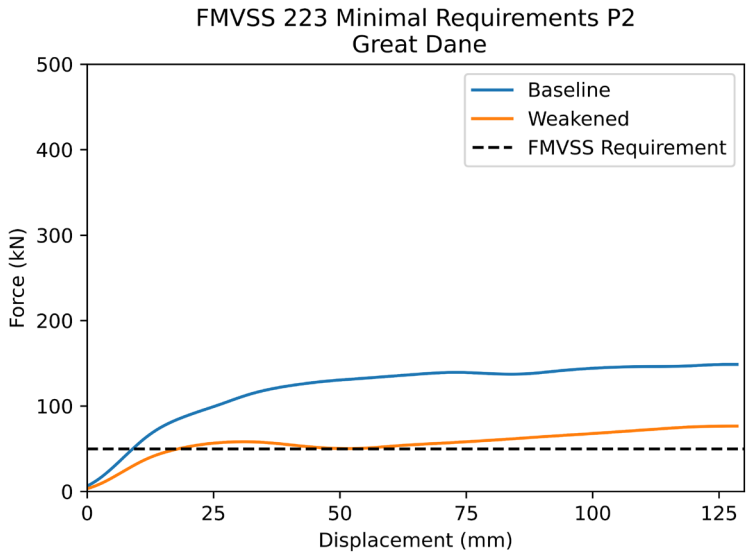


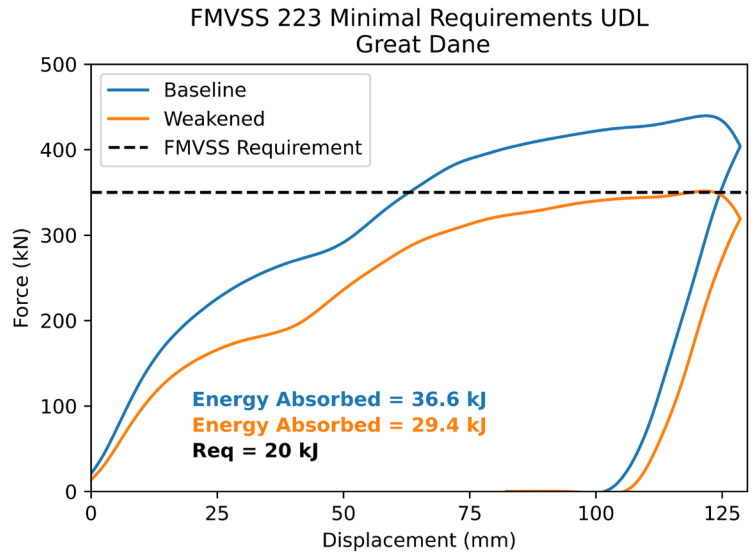
Minimally Compliant





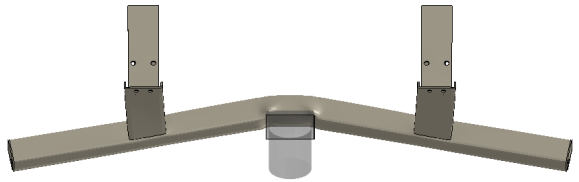


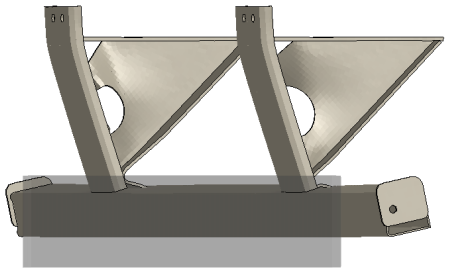




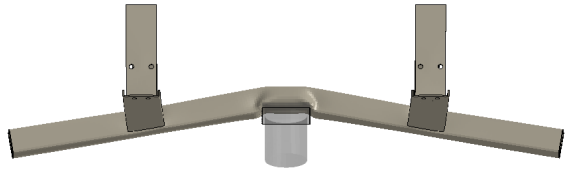
Aim 2: Modify Guards to just pass FMVSS 223 – Wabash

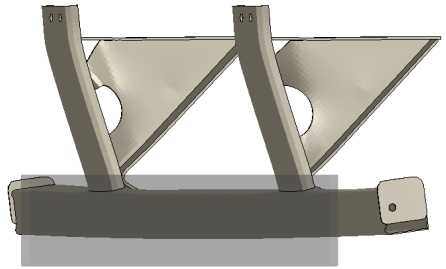
Baseline

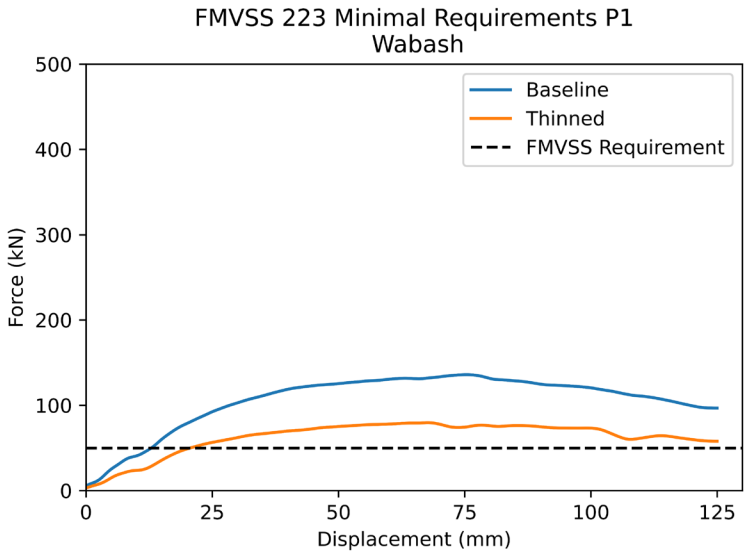


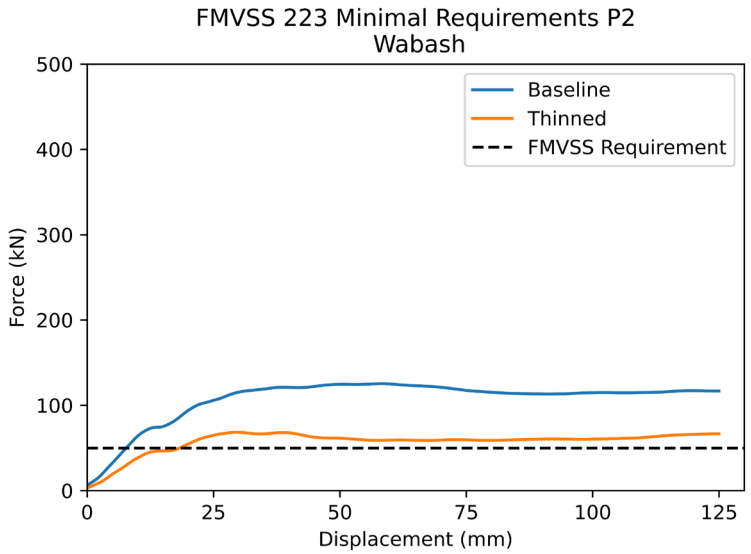


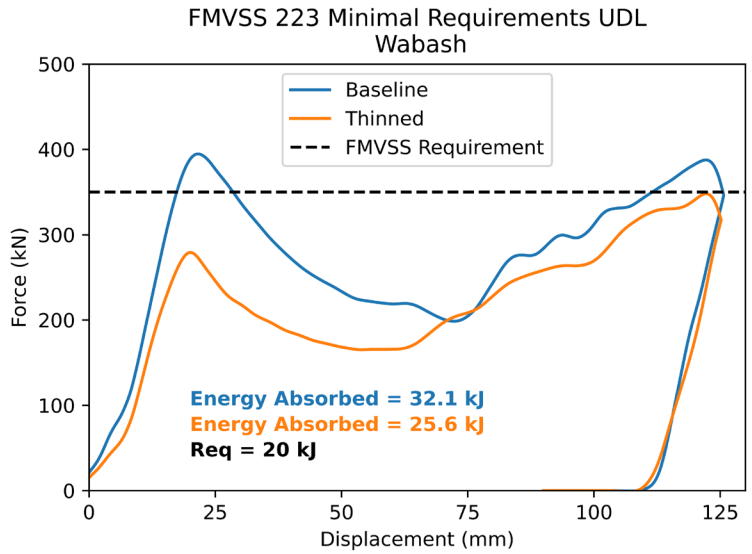
Minimally Compliant





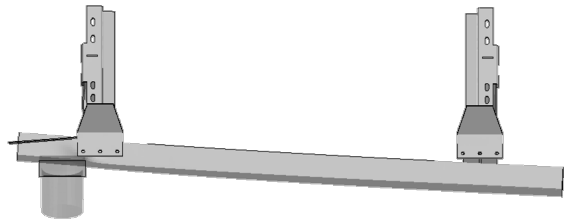


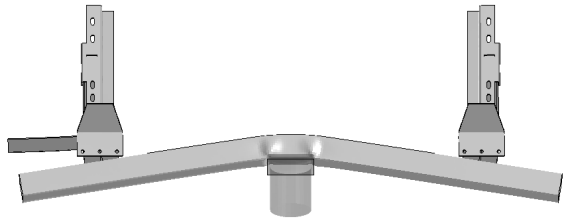


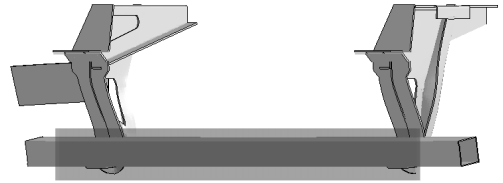


Aim 2: Modify Guards to just pass FMVSS 223 – Manac

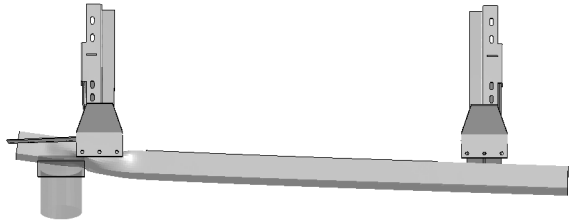
Baseline

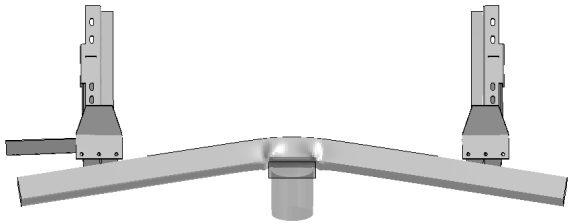


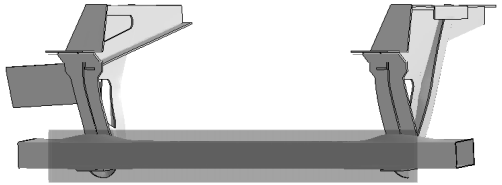


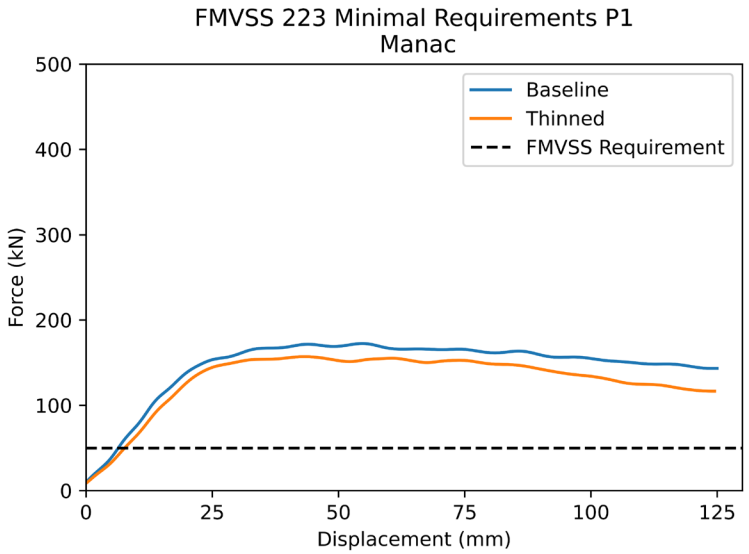


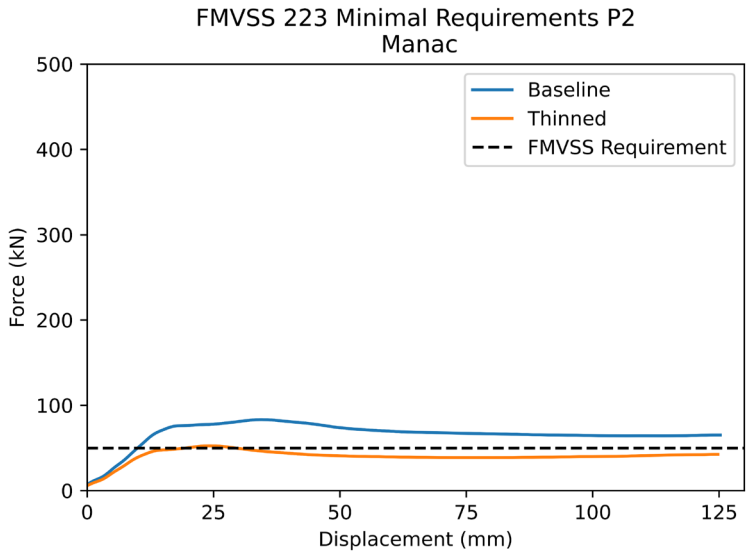
Minimally Compliant

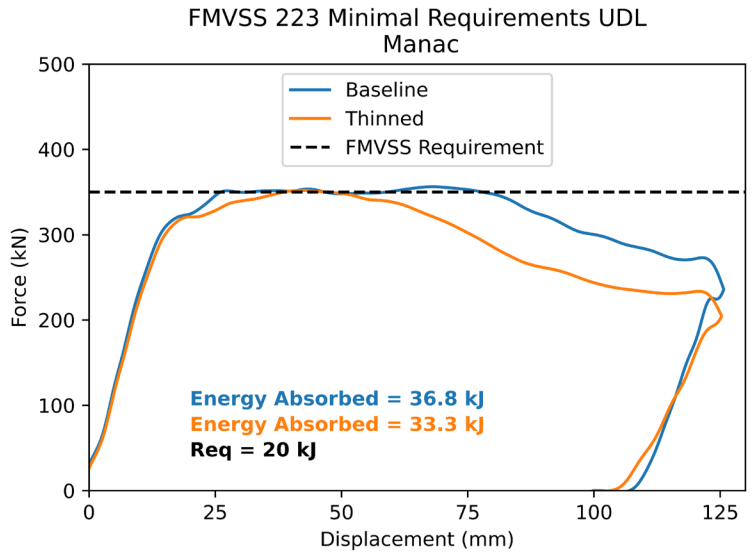




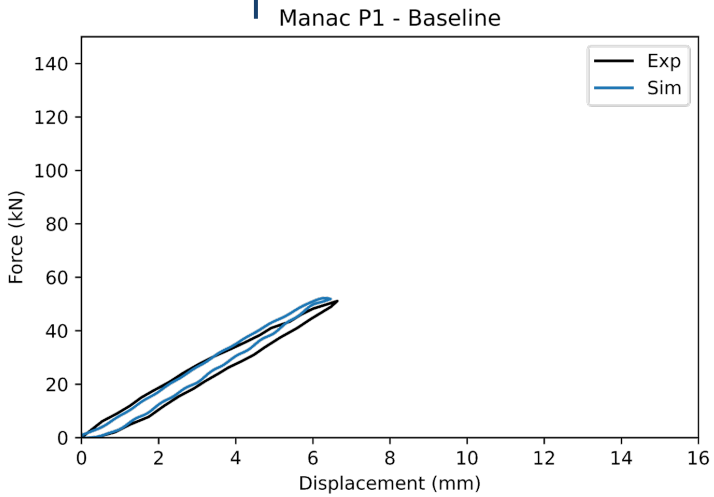


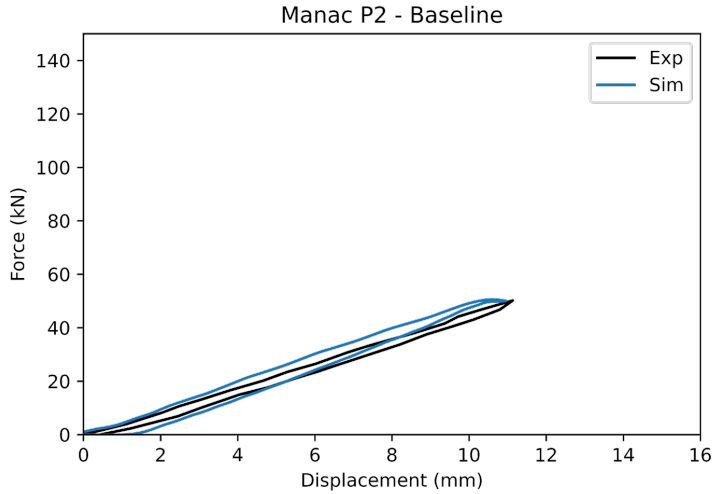


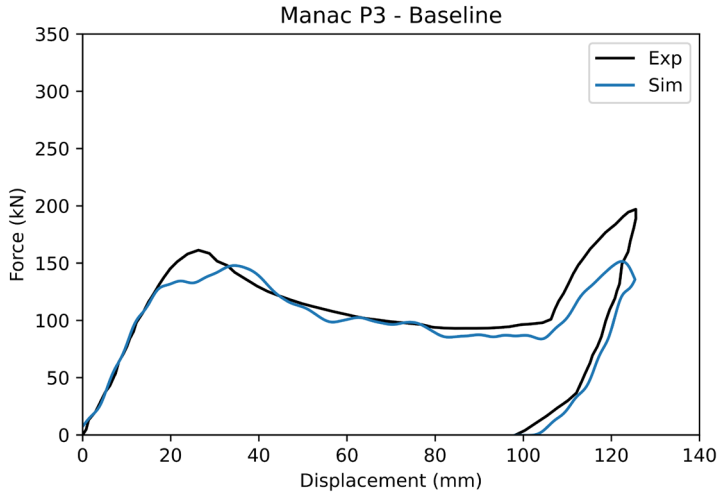




Elemance | Manac Model Summary Slide

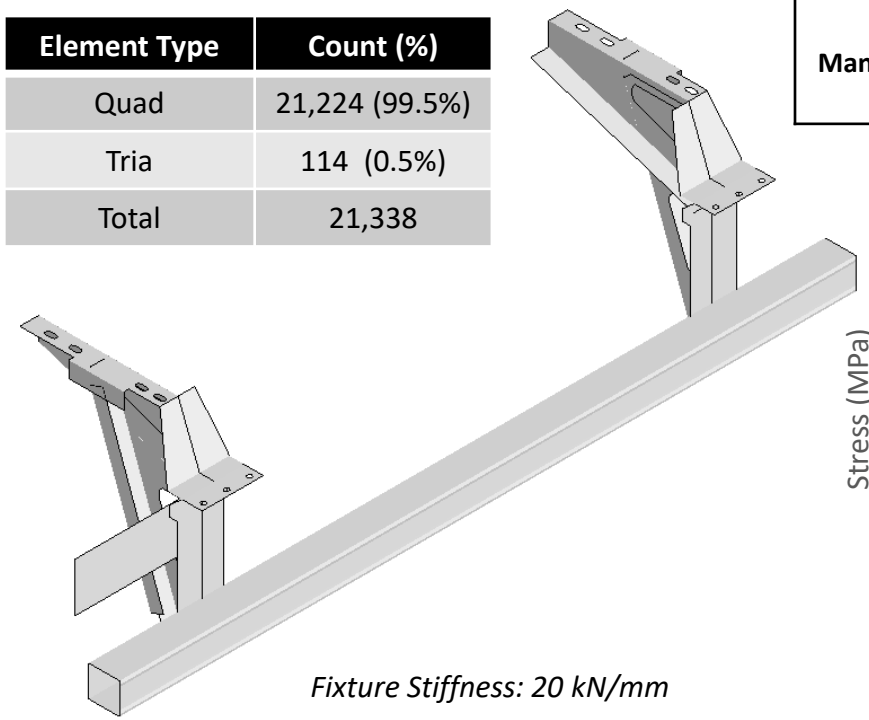




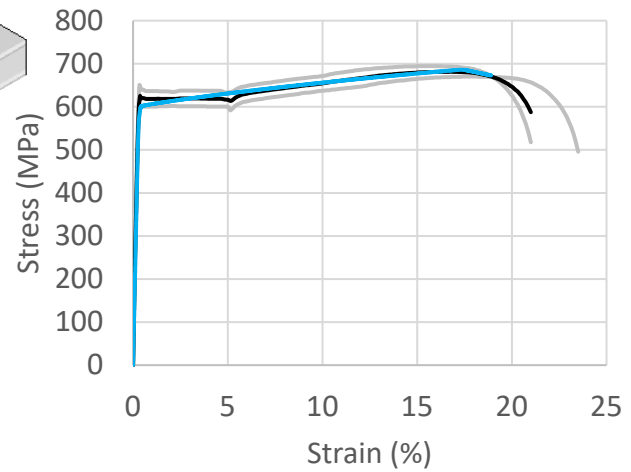


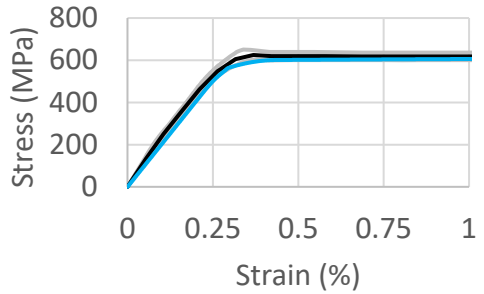
CORA Scores						
		Phase	Size	Shape	Total	Avg
Manac	P1	1.000	1.000	0.981	0.994	0.954
	P2	1.000	0.889	0.994	0.961	
	P3	1.000	0.780	0.943	0.908	

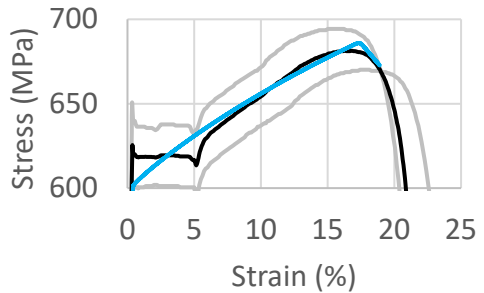
Element Type	Count (%)
Quad	21,224 (99.5%)
Tria	114 (0.5%)
Total	21,338



Fixture Stiffness: 20 kN/mm

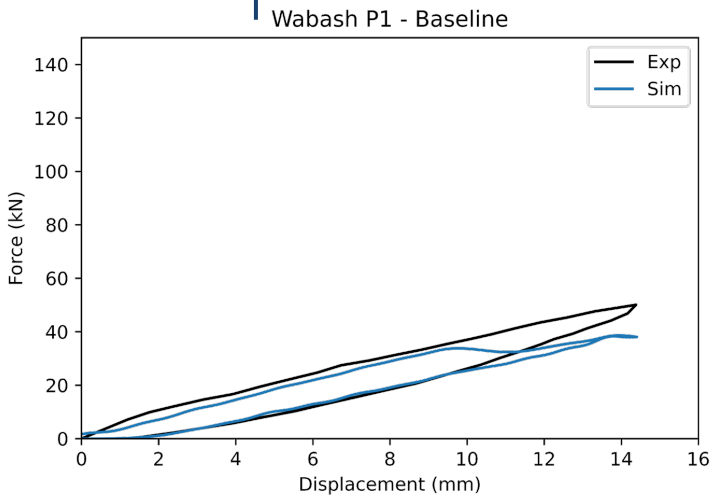


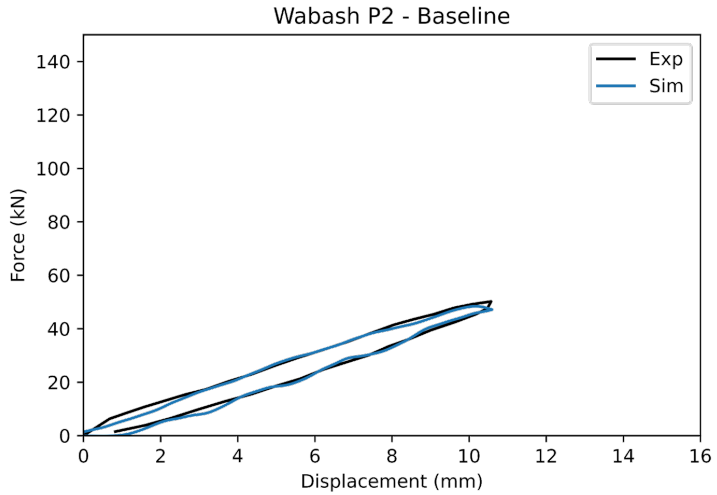


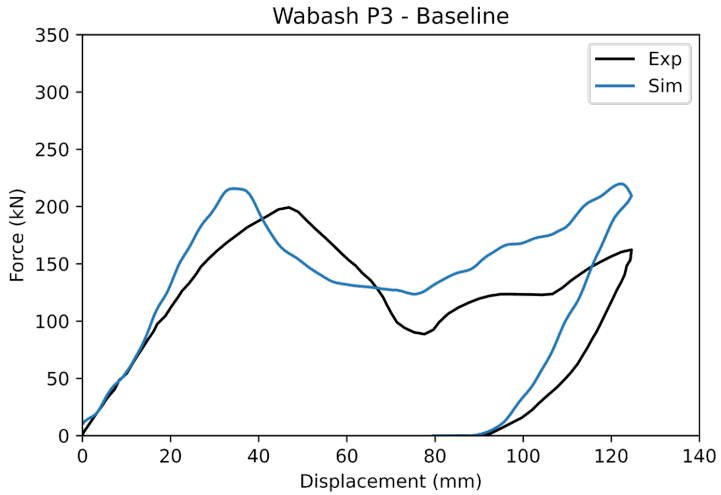


*MAT_098 (GPa) Manac	
E	209.91
A	0.6007
B	0.7271
N	0.8944
SIGMAX	0.7402

Elemance | Wabash Model Summary Slide

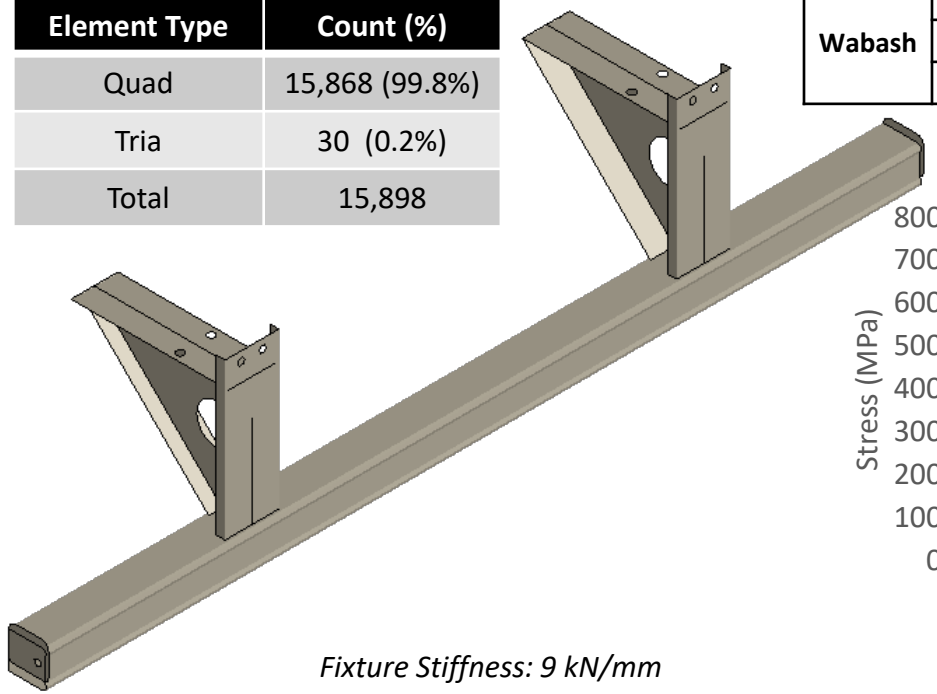




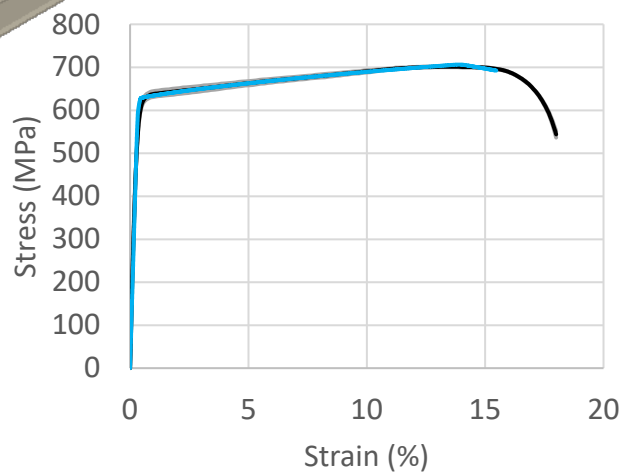


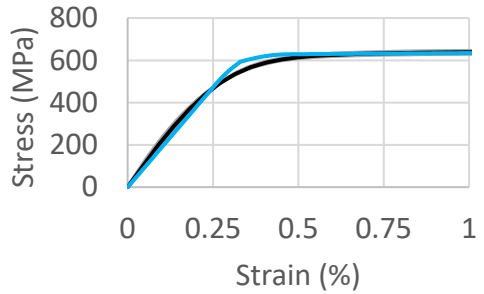
CORA Scores						
		Phase	Size	Shape	Total	Avg
Wabash	P1	1.000	0.734	0.976	0.903	0.921
	P2	1.000	0.985	0.995	0.993	
	P3	1.000	0.712	0.89	0.867	

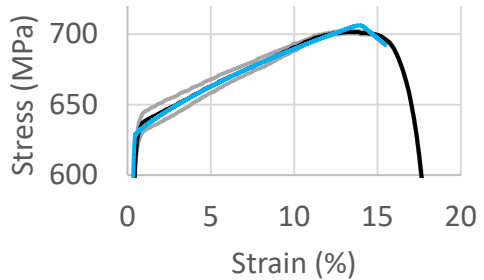
Element Type	Count (%)
Quad	15,868 (99.8%)
Tria	30 (0.2%)
Total	15,898



Fixture Stiffness: 9 kN/mm

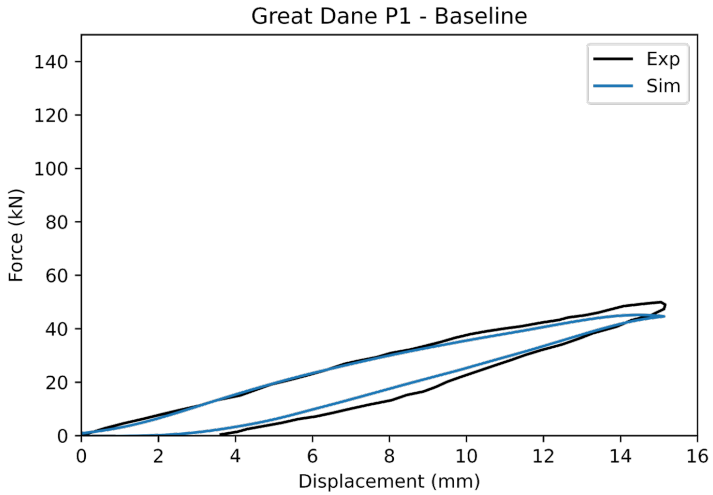


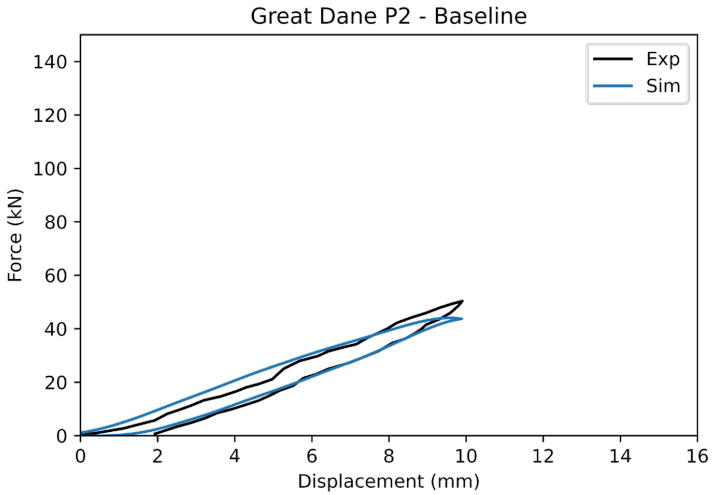


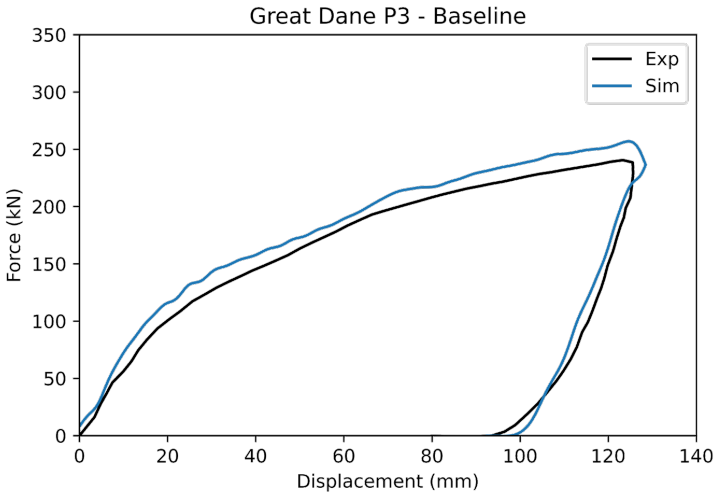


*MAT_098 (GPa) Wabash	
E	189.93
A	0.6274
B	0.7788
N	0.8780
SIGMAX	0.7057

Elemance | Great Dane Model Summary Slide

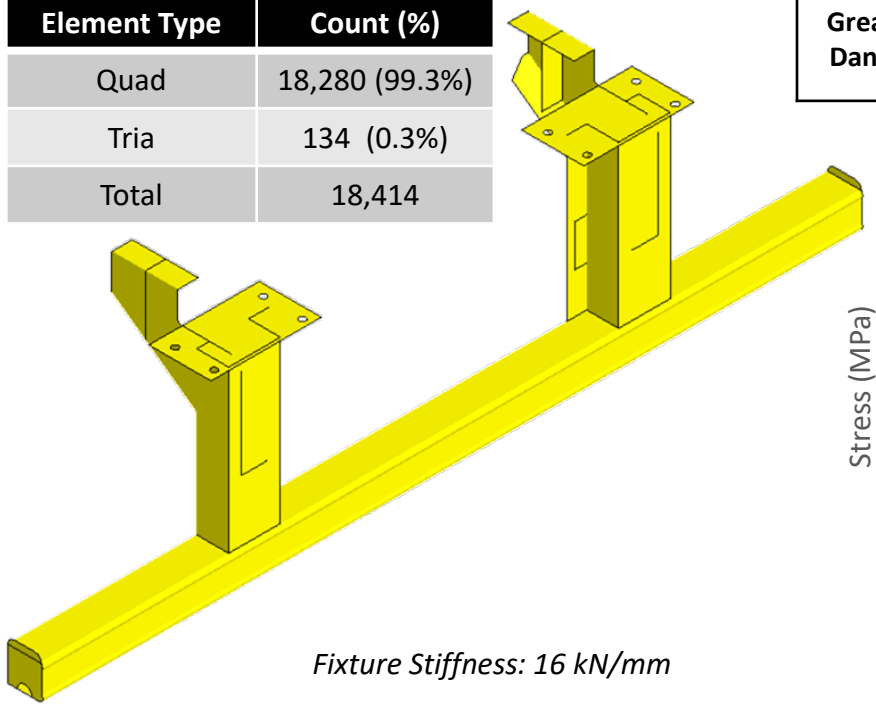




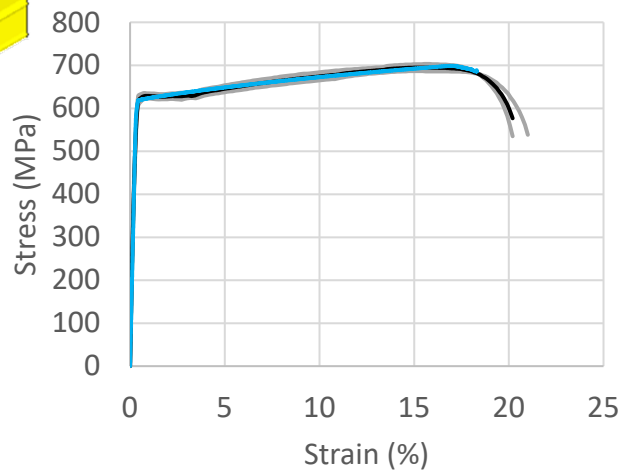


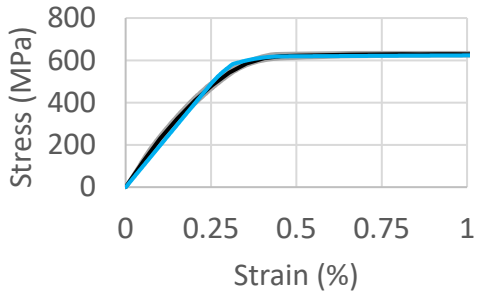
CORA Scores						
		Phase	Size	Shape	Total	Avg
Great Dane	P1	1.000	0.946	0.989	0.978	0.951
	P2	1.000	0.810	0.989	0.933	
	P3	1.000	0.836	0.989	0.942	

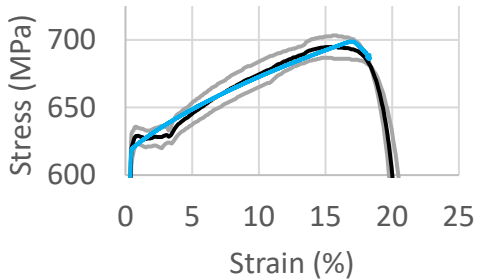
Element Type	Count (%)
Quad	18,280 (99.3%)
Tria	134 (0.3%)
Total	18,414



Fixture Stiffness: 16 kN/mm

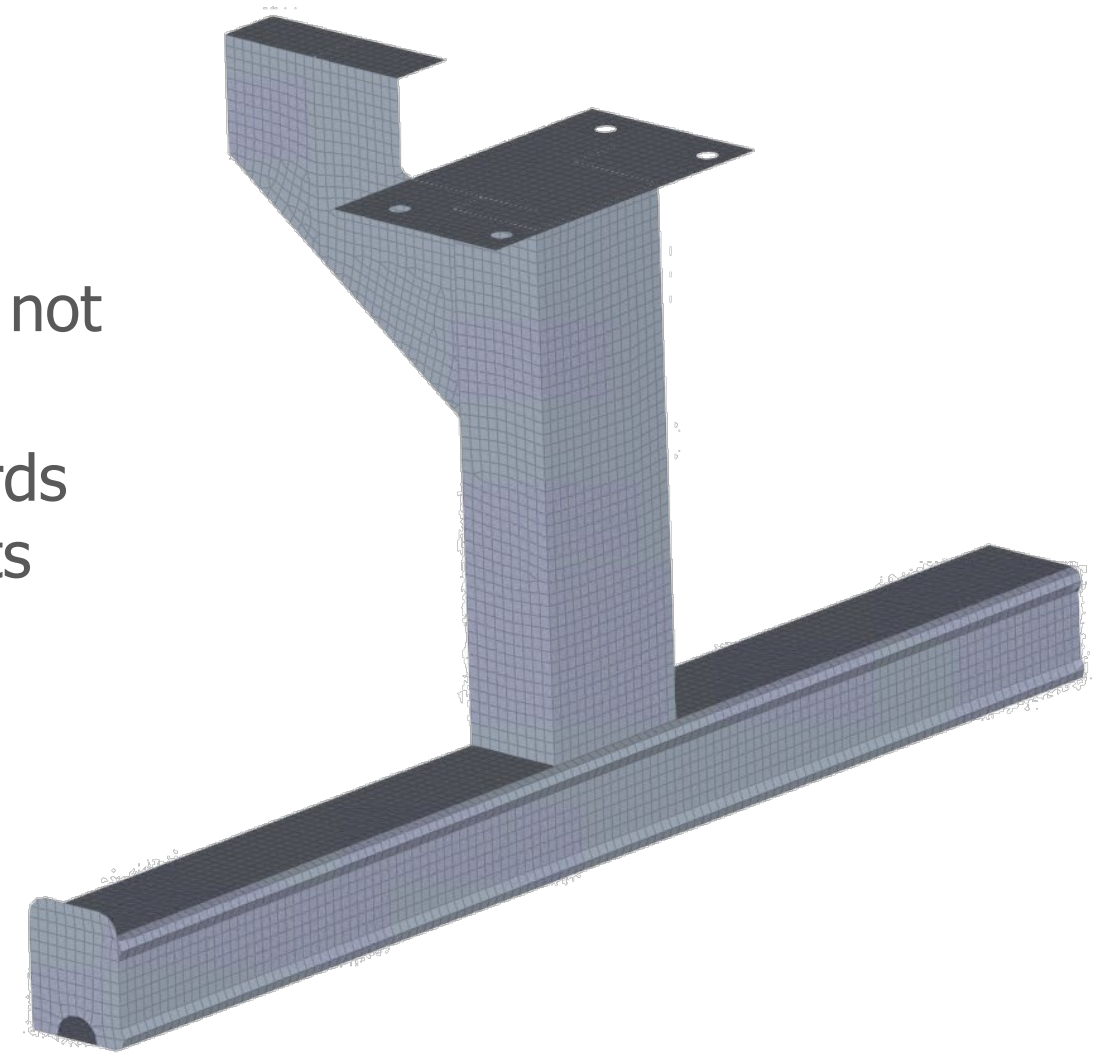




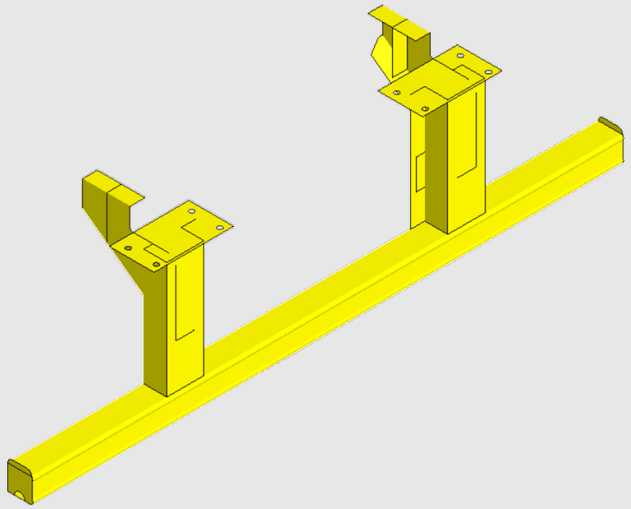
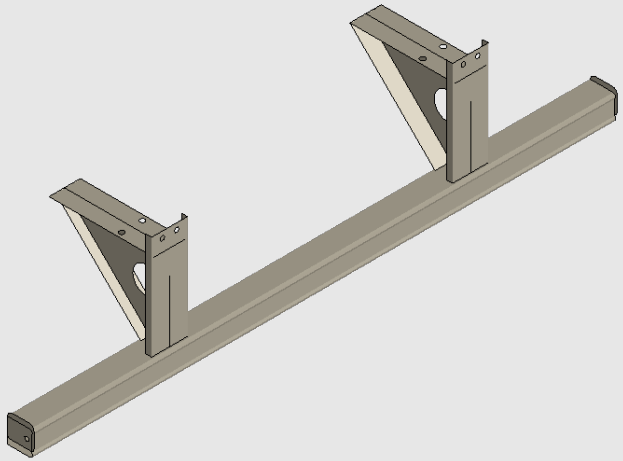
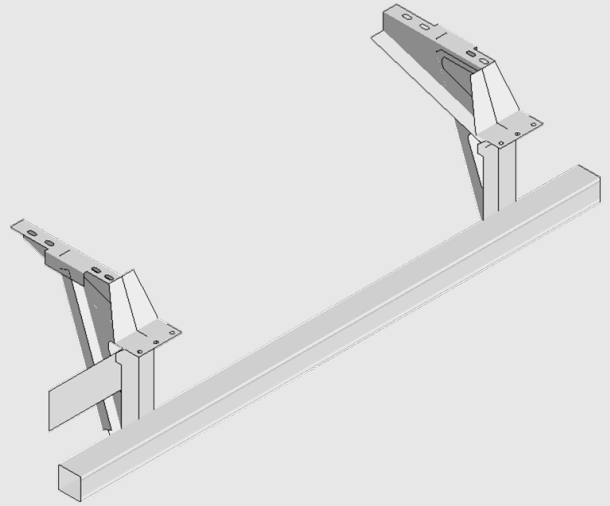


*MAT_098 (GPa) Great Dane	
E	196.84
A	0.6177
B	0.7432
N	0.8963
SIGMAX	0.7565

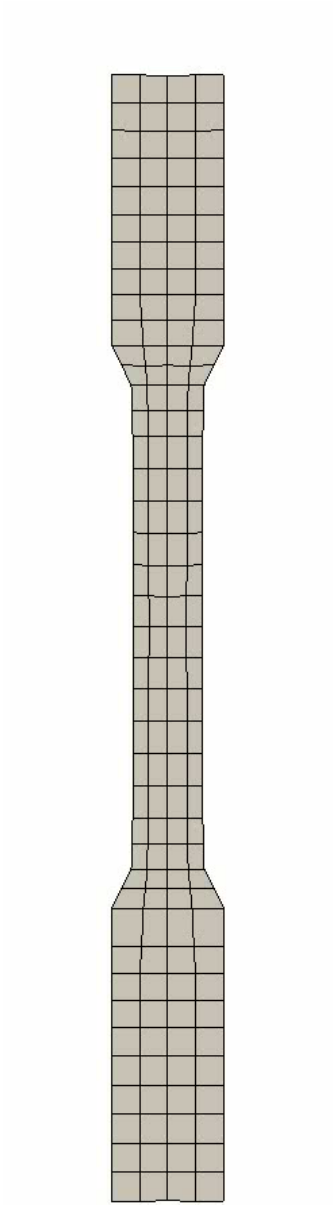
- Meshed in Beta ANSA:
  - Primarily quad shell elements
  - Target element length 10mm
  - Welds modeled as node-to-node connections or tied contacts where not possible
  - Thicknesses assigned in section cards according to physical measurements

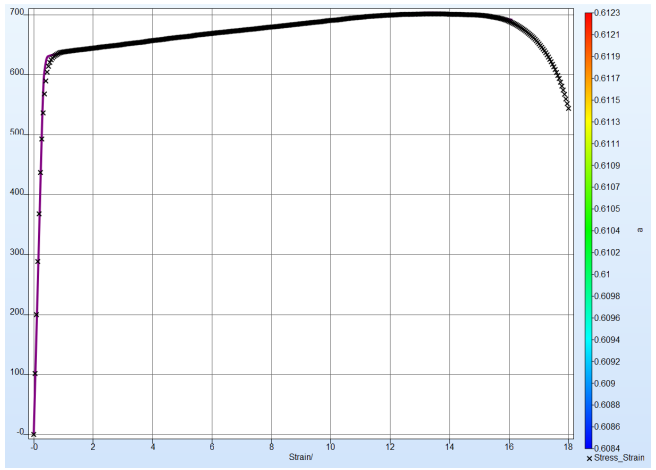


Elemance | Aim 1 Methods: Mesh CAD

Element Type	Great Dane	Wabash	Manac
Quad	18,280 (99.3%)	15,868 (99.8%)	21,224 (99.5%)
Tria	134 (0.3%)	30 (0.2%)	114 (0.5%)
Total	18,414	15,898	21,338
			

Aim 1 Methods: Material Model Development

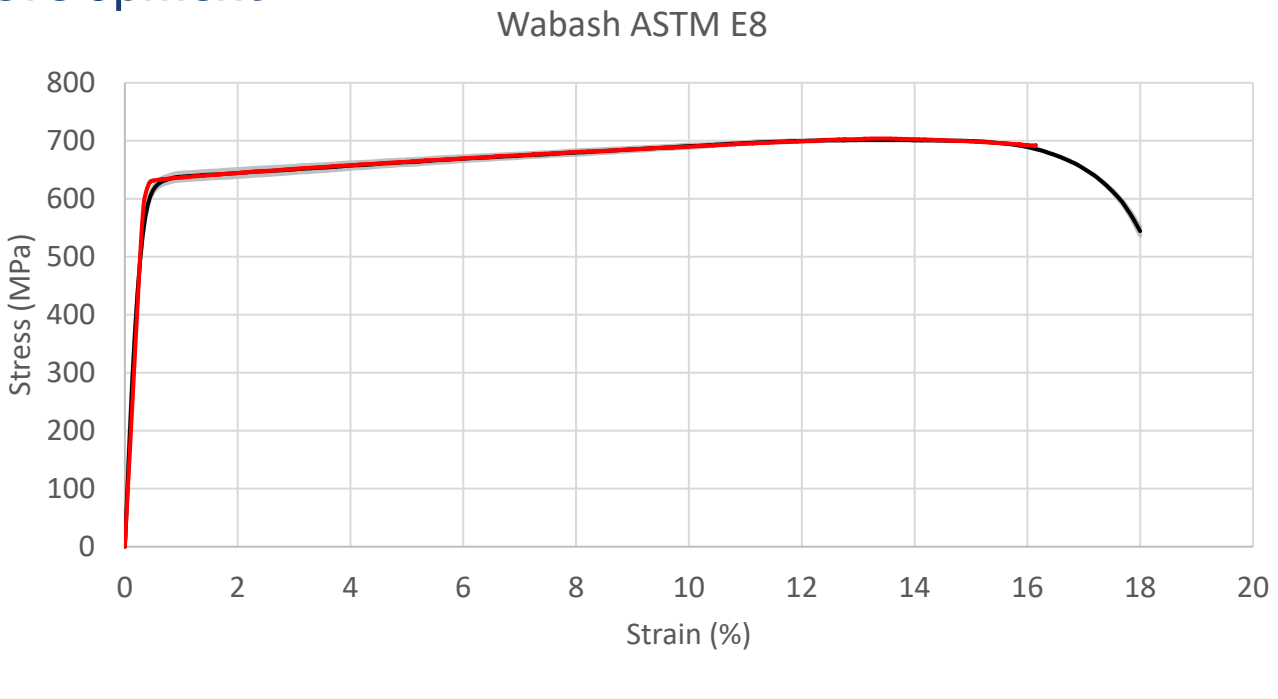


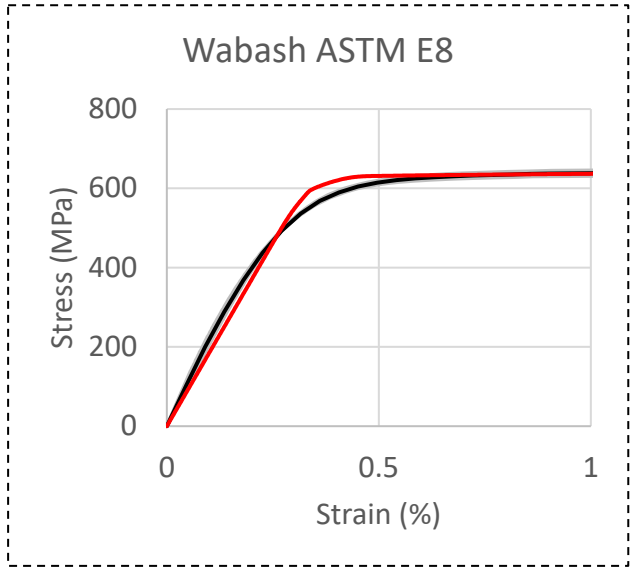


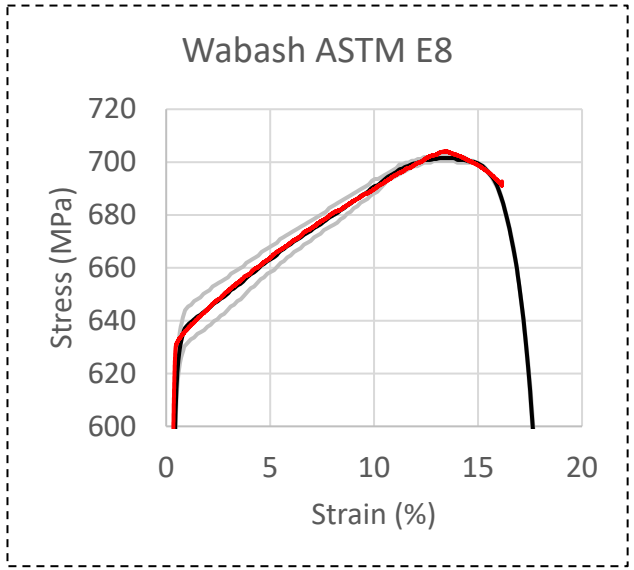
*MAT_98 Simplified Johnson Cook

$$\sigma_y = \left(A + B\bar{\varepsilon}^{p^n}\right)$$

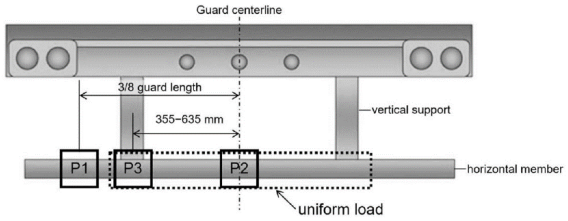
*MAT_098 (GPa) Wabash	
E	189.93
A	0.6274
B	0.7788
N	0.8780
SIGMAX	0.7057







Aim 2.2: Modify Guards to minimally comply with FMVSS 223



Minimize y:

$$y = \frac{P_{UDL} - 350\ kN}{350\ kN} + \frac{P_{P2} - 50\ kN}{50\ kN} + \frac{P_{P1} - 50\ kN}{50\ kN} + \frac{U_{UDL} - 20\ kJ}{20\ kJ} + 0.25\frac{M_{Sim}}{M_0}$$

Where:

- P_{UDL}, P_{P2}, and P_{P1} are the peak force from the UDL, P2, and P1 test locations
- U_{UDL} is the plastic energy absorbed during the UDL test
- M_{Sim} and M_0 are the current bumper mass and the baseline bumper mass, respectively

Constraints:

- P_{UDL} ≥ 350 kN
- U_{UDL} ≥ 20 kJ
- P_{P2} , P_{P1}≥ 50 kN
- Ground Clearance ≤ 22 in