Appendix C: Finite Element Model Validations

For this effort, multiple validations were undertaken for each of the barriers selected for the analyses. These took advantage of the best available crash test data that exists. The cases used for the validations are noted below. Full verification and validations reports for the seven cases are included in this appendix.

Validation Summary for Vehicle Impacts with New Jersey Concrete Barrier

- Case-1: NJ Concrete Barrier Impact with 1100C Vehicle
- Case-2: NJ Concrete Barrier Impact with 2270P Vehicle

Validation Summary for Vehicle Impacts with G4(1S) W-Beam Guardrail

- Case-3: G4(1S) Barrier Impact with 2000P Vehicle
- Case-4: G4(1S) Barrier Impact with 2270P Vehicle

Validation Summary for Vehicle Impacts with Midwest Guardrail System Barrier

- Case-5: MGS Barrier Impact with 820C Vehicle
- Case-6: MGS Barrier Impact with 1100C Vehicle
- Case-7: MGS Barrier Impact with 2270P Vehicle

Each of the reports includes:

- Table 1A V&V Summary Table
- Table 1B V&V Analysis Solution Verification Summary Table & RSVVP Results
- Figure 1 Energy Balance Diagram
- Figure 2A RSVVP Multi-Channel Comparison
- Figure 2B RSVVP Longitudinal Acceleration Comparison
- Figure 2C RSVVP Lateral Acceleration Comparison
- Figure 2D RSVVP Vertical Acceleration Comparison
- Figure 2E RSVVP Roll Angle Comparison
- Figure 2F RSVVP Pitch Angle Comparison
- Figure 2G– RSVVP Yaw Angle Comparison
- Figure 3 Comparison of Changes in Vehicle Velocities
- Figure 4 Comparison of Changes in Vehicle Angles
- Table 1C V&V PIRTs Summary Table
- Figure 5 Full-Scale Test Summary
- Figure 6 Sequential Comparisons (Front, rear, and top views)
- Table 1D V&V Overall Summary Table



Case-1: New Jersey Concrete Barrier Impact with 1100C Vehicle

CCSA VALIDATION/VERIFICATION REPORT

Project:	CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections
Comparison Case:	1100C Vehicle with New Jersey Safety Shape Barrier
Impact Description:	25-deg impact into barrier at 100 km/h (62 mph)
Governing Criteria:	MASH TL-3
Report Date:	February 2013

Table A – Information Sources:

General Information	Known Solution	Analysis Solution			
Performing Organization	MwRSF	CCSA-GMU			
Test/Run Number	2214NJ-1	NA			
Vehicle	2002 Kia Rio	CCSA 2010 Yaris_C V1e Model			
Vehicle Mass (lb/kg)	2579 / 2290	2593 / 1176			
Impact Speed (mph/kph)	60.8 / 97.9	60.8 / 97.9			
Impact Angle (degrees)	26.1	26.1			

Table B - Evaluation Parameters Summary:

Category	Subset	Values
Evaluation Method	MASH (V1, 2009)	
Hardware Type	Longitudinal	
Test Number	3-10	
Test Vehicle	1100C	
	Structural	${f A}$ - Test article should contain and redirect the vehicle; the vehicle
Applied	Adequacy	should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.
	Occupant Risk	${f D}$ - Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone.
		${f F}$ - The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.
		H - The occupant impact velocity in the longitudinal direction should not exceed 40 ft/sec and the occupant ride-down acceleration in the longitudinal direction should not exceed 20 G ^{**} s.
		I - Longitudinal & lateral occupant ridedown accelerations (ORA) should fall below the preferred value of 15.0 g, or at least below the maximum allowed value of 20.49 g.
	Vehicle	For redirective devices the vehicle shall exit within the prescribed box.
	Trajectory	



Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 1100C Vehicle with New Jersey Safety Shape Barrier

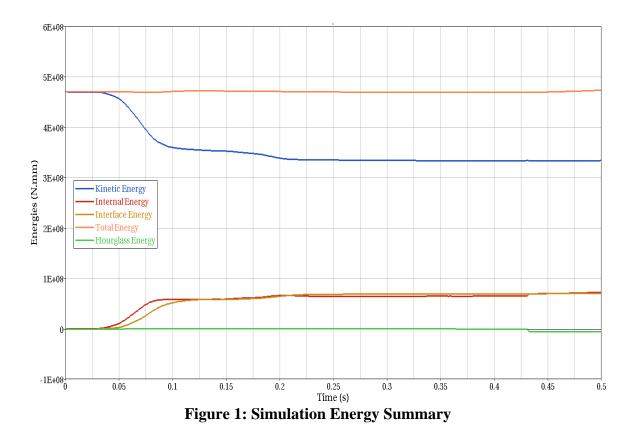
Verification Evaluation Criteria	Change (%)	Pass?
Total energy of the analysis solution (i.e., kinetic, potential, contact, etc.) must not vary more than 10 percent from the beginning of the run to the end of the run.	<1%	YES
Hourglass Energy of the analysis solution at the end of the run is less than 5 % of the total initial energy at the beginning of the run	<1%	YES
The part/material with the highest amount of hourglass energy at any time during the run is less than 5 % of the total initial energy at the beginning of the run.	<1%	YES
Mass added to the total model is less than 5 % the total model mass at the start of the run.	<1%	YES
The part/material with the most mass added had less than 10 % of its initial mass added.	<1%	YES
The moving parts/materials in the model have less than 5 % of mass added to the initial moving mass of the model.	<1%	YES
There are no shooting nodes in the solution?	NA	YES
There are no solid elements with negative volumes?	NA	YES

Table C – Analysis Solution Verification Summary

Table D - RSVVP Results

Single Channel Time History Comparis	on Results	Time interval [0 sec - 0.5 sec				
O Sprauge-Geer Metrics		Μ	Р	Pass?		
X acceleration		7	18.8	YES		
Y acceleration		11.6	18.1	YES		
Z acceleration						
Yaw rate		4.4	7.1	YES		
Roll rate		45.6	27.3	NO		
Pitch rate		65.7	31.6	NO		
P ANOVA Metrics		Mean	SD	Pass?		
X acceleration/Peak		-2.1	11.75	YES		
Y acceleration/Peak		0.91	12.32	YES		
Z acceleration/Peak		9.92	15.57	NO		
Yaw rate		1.77	8.13	YES		
Roll rate		3.12	17.5	YES		
Pitch rate		3.34	35.2	NO		
Multi-Channel Weighting Factors		Time inter	rval [0 see	sec; 0.5 sec]		
Multi-Channel Weighting Method	X Channel	0.068377				
Peaks Area I	Y Channel	0.2165				
Area II Inertial	Z Channel		0.215123			
	Yaw Channel		0.407422			
	Roll Channel	0.032735				
	Pitch Channel		0.059843			
Sprauge-Geer Metrics		Μ	Р	Pass?		
All Channels (weighted)		18.2	17.3	YES		
ANOVA Metrics		Mean	SD	Pass?		
All Channels (weighted)		3.2	12.8	YES		





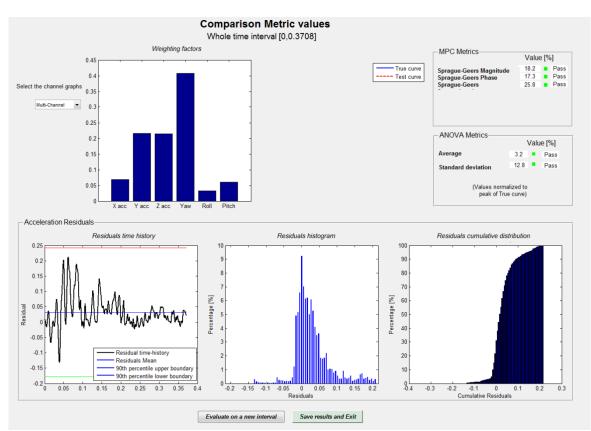


Figure 2a: RSVVP Results – All Channels



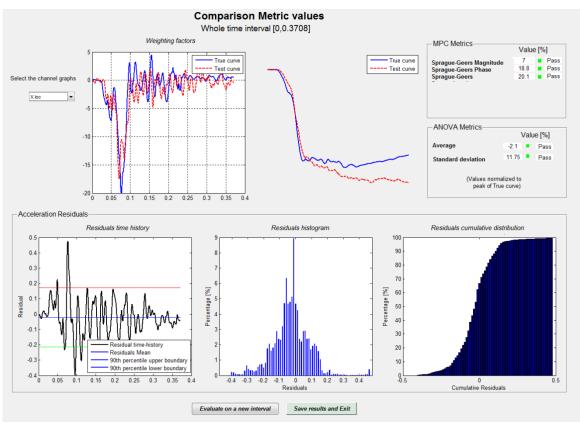


Figure 2b: RSVVP Results – Longitudinal Acceleration

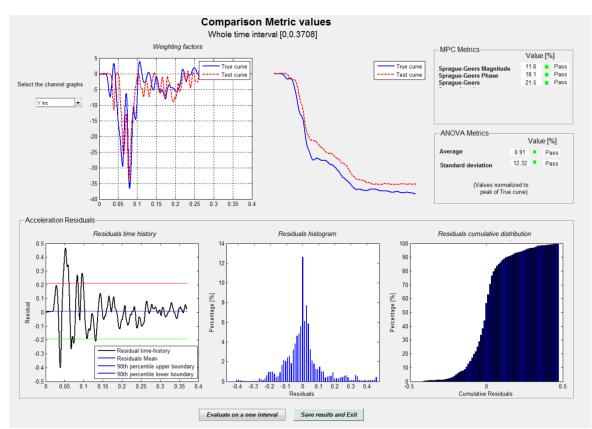
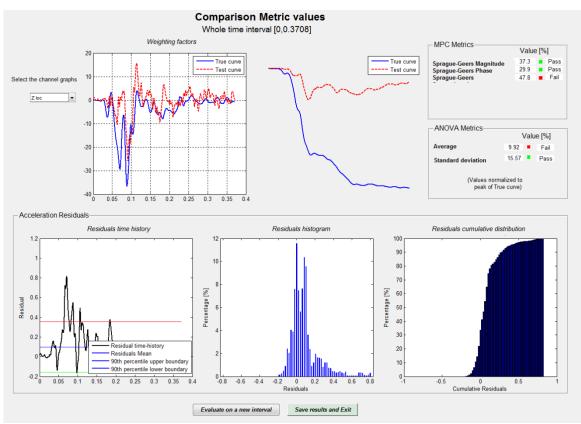


Figure 2c: RSVVP Results – Lateral Acceleration







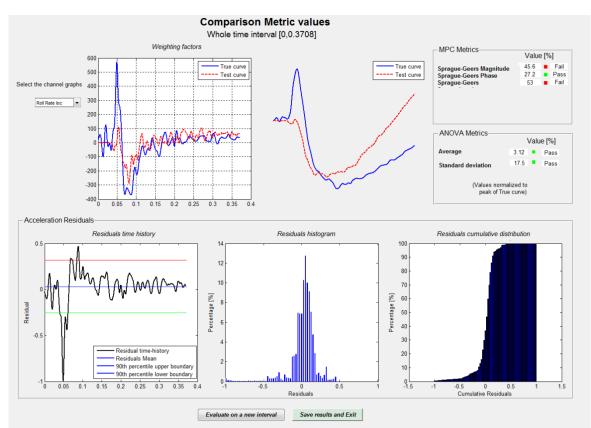
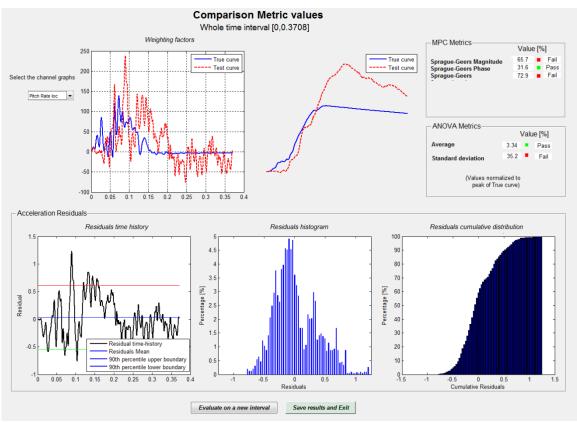


Figure 2e: RSVVP Results – Roll Angle







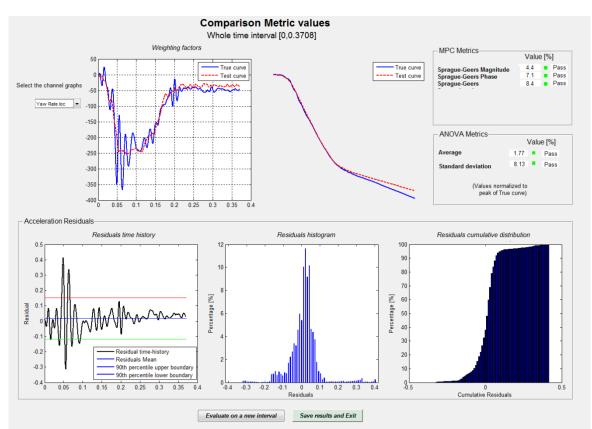
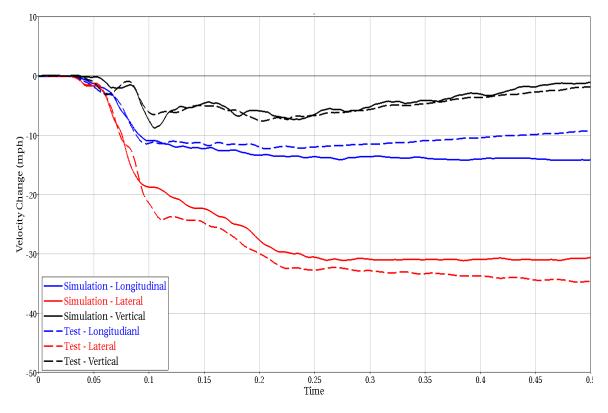
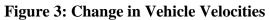


Figure 2g: RSVVP Results – Yaw Angle







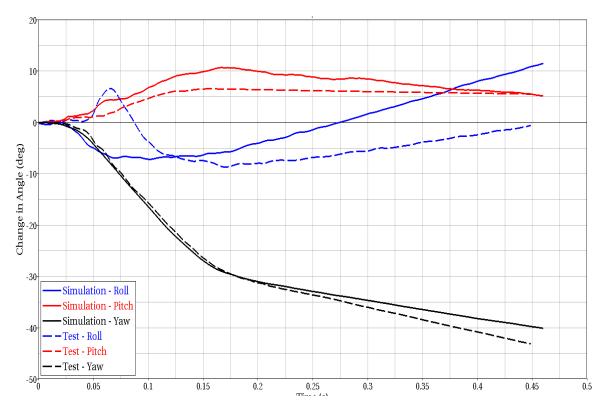


Figure 4: Change in Vehicle Angles



Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 1100C Vehicle with New Jersey Safety Shape Barrier

			Evaluation Criteria	Known Result	Analysis Result	Relative Diff. (%)	Agree?							
		A1	not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.	Yes	Yes		YES							
PerformanceResultResultResultResultResultDTotal article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.YesYesYesA 2The relative difference in the maximum dynamic deflection is less than 20 percent.0.0 m0.0 m0.0 mA 4The relative difference in the number of broken or significantly bent posts is less than 20 percent.YesYesA 4The relative difference in the number of broken or significantly bent posts is less than 20 percent.A 5Barrier did not fail (Answer Yes or No).YesYesA 6There was no significant snagging between the vehicle wheels and parrier elements (Answer Yes or No).YesYesA 7There was no significant snagging between vehicle body components and barrier elements (Answer Yes or No).YesYesPotached elements, fragments or other tarflic, pedestrians or personnel in a work zone (Answer Yes or No).YesYesYesYesF1The vehicle should remain upright during and after the collision. The maximum pitch grid methed eifference is less tha		0.0 m	0.0 m	0	YES									
	15	YES												
ral A		A4		Yes	Yes		YES							
ctu		A5	Barrier did not fail (Answer Yes or No).	Yes	Yes		YES							
ţŢ		A6	There were no failures of connector elements (Answer Yes or No).	Yes	Yes		YES							
S		A7	barrier elements (Answer Yes or No).	res	Yes		YES							
		A5Barrier did not fail (Answer Yes or No).YesYesYesA6There were no failures of connector elements (Answer Yes or No).YesYesYesA7There was no significant snagging between the vehicle wheels and barrier elements (Answer Yes or No).YesYesYesA8There was no significant snagging between vehicle body components and barrier elements (Answer Yes or No).YesYesYesDetached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone (Answer Yes or No).YesYesYesF1The vehicle should remain upright during and after the collision. The maximum pitch & roll angles are not to exceed 75 degrees.YesYesYesF2Maximum vehicle roll – relative difference is less than 20% or absolute difference is less than 5 degrees.7 (.5s)11 (.5s)57% 4 deg	YES											
		D	not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone (Answer Yes or No).	Yes	Yes		YES							
-	A7 A8 D F1 F2 F3 F4 H1 H2 H3 I1 I2	F1		Yes	Yes		YES							
		F2		7 (.5s)	11 (.5s)		YES							
		l						F3		10 (.5s)	7 (.5s)	30% 3 deg	YES	
Risk			43 (.5s)	40 (.5s)	7% 3 deg	YES								
cupant]		₿	H1	below the preferred value of 30 ft/s (9.1 m/s), or at least below the	Yes	Yes		YES						
Oc			₿	₿	₿ŧ	ł		I I	H2	Longitudinal OIV (m/s) - Relative difference is less than 20%t or absolute difference is less than 2 m/s	5.0	4.8	4% 0.2 m/s	YES
						H3		10.7	8.7	19% 2 m/s	YES			
		I1	fall below the preferred value of 15.0 g, or at least below the maximum	Yes	Yes		YES							
		I2	Longitudinal ORA (g) - Relative difference is less than 20% or	5.5	2.5	55% 3 g	YES							
		I3		8.1	8.2	1% 0.1 g	YES							
			The vehicle rebounded within the exit box. (Answer Yes or No)	Yes	Yes		YES							

Table E - Roadside Safety Phenomena Importance Ranking Table (MASH Evaluation)



	0.390 sec	1.70mm 1.	38ever-		⊥_ 383 eren Satisfactory	75.69 m downstream 0.64 m traffic-side face	5.02 m/s < 12 m/s	10.67 m/s < 12 m/s pdate) 5 49 Ge < 20 Ge	8.08 Gs < 20 Gs 12.38 m/s	8.10 Gs Minimal	V N	VN	46.5 mm Moderate	1-RFQ-4 1-RYEW5	57 mm at right-front floorpan
	0.196 sec	r ^{0.64} m			Post-Impact Trajectory Vehicle Stability	e	Occupant Impact Velocity (350 Update) Longitudinal	Lateral 10.67 Occupant Ridedown Deceleration (350 Update) Loneitudinal 5 49 (Lateral		Test Article Deflections Dominant Sat	Dynamic	Vehicle Damage	VDS ⁴	ation
	0.160 sec	75.69 m			Permanent New Jersey Safety Shape Barrier 24.38 m • Po	rsey Shape Barrier	•	•	•	• •	• Te		•		
	0.102 sec					Half-Section New Jersey Shape Barrier		I Grade 60 Rebar NA	1170C 2002 Kia Rio			97.9 km/h	5.63 m downstream from upstream end	79.4 km/h	
1	0.000 sec	Ser.	 Test Agency Test Number 	 Date NCHRP 350 Update Test Designation 	Appurtenance Total Length Kev Elements - Barrier	11.1	Height Concrete Material	Type of Soil Test Vehicle	Type/Designation Make and Model	Curb Test Inertial	Gross Static		ation	Exit Conditions Speed	Angle Exit Box Criterion

Figure 5: Full-Scale Test Summary





Figure 6a: Sequential Comparisons – Front View





Figure 6b: Sequential Comparisons – Rear View



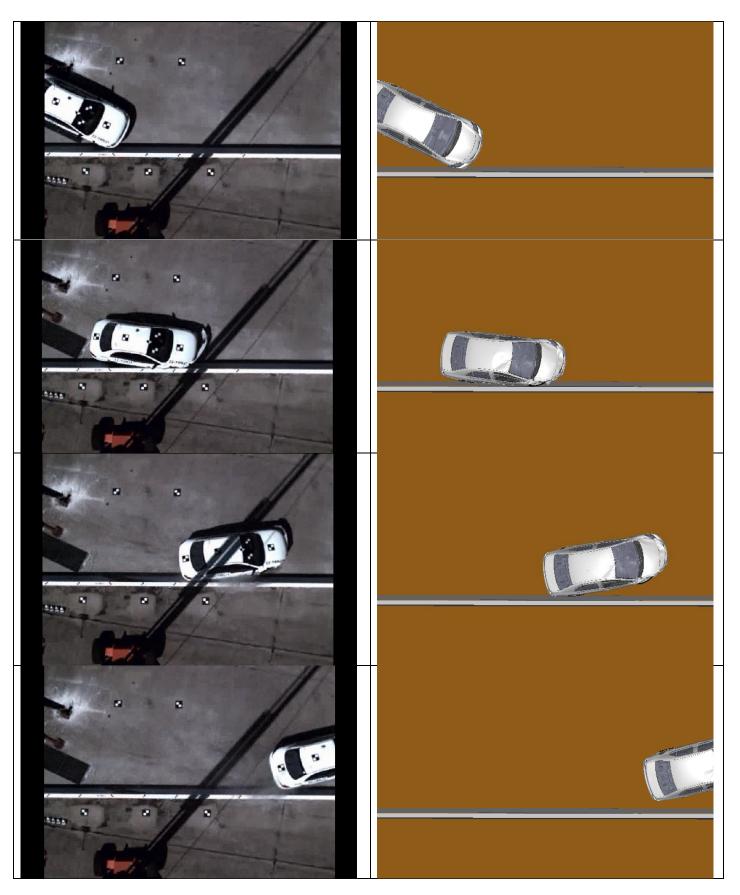


Figure 6c: Sequential Comparisons – Top View



Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 1100C Vehicle with New Jersey Safety Shape Barrier

	SH08 Test Number	
Table C – Analysis Solution Verification	Did all solution verification criteria in table pass?	YES
Table D - RSVVP Results	Do all the time history evaluation scores from the single channel factors result in a satisfactory comparison (i.e., the comparison passes the criterion)?	NO
	If all the values for Single Channel comparison did not pass, did the weighted procedure result in an acceptable comparison.	
Table E - Roadside Safety Phenomena Importance Ranking Table	Did all the critical criteria in the PIRT Table pass? Note: Tire deflation was observed in the test but not in the simulation. This due to the fact that tire deflation in not incorporated in the model. This is considered not to have a critical effect on the outcome of the test	YES
Overall	Are the results of Steps I through III all affirmative (i.e., YES)? If all three steps result in a "YES" answer, the comparison can be considered validated or verified. If one of the steps results in a negative response, the result cannot be considered validated or verified.	YES

Table F - Composite Verification and Validation Summary:

NOTES:

(none)



Case-2: New Jersey Concrete Barrier Impact with 2270P Vehicle

CCSA VALIDATION/VERIFICATION REPORT

Project:CCSA Longitudinal Barriers on Curved, Superelevated Roadway SectionsComparison Case:2270P Vehicle with New Jersey Safety Shape BarrierImpact Description:25-deg impact into barrier at 100 km/h (62 mph)Governing Criteria:MASH TL-3Report Date:February 2013

Table A – Information Sources:

General Information	Known Solution	Analysis Solution
Performing Organization	TTI	CCSA-GMU
Test/Run Number	RF476460-1-4	
Vehicle	2007 Chevrolet Silverado	CCSA - 2007 Silverado Model
Vehicle Mass (lb/kg)	5049 / 2290	5005 / 2270
Impact Speed (mph/kph)	62.6 / 100.75	62.6 / 100.75
Impact Angle (degrees)	25.2	25.2

Table B - Evaluation Parameters Summary:

Category	Subset	Values
Evaluation Method	MASH (V1, 2009)	
Hardware Type	Longitudinal	
Test Number	3-11	
Test Vehicle	2270P	
Criterion to be Applied	Structural Adequacy	${\bf A}$ - Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.
	Occupant Risk	${f D}$ - Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone.
		${f F}$ - The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.
		H - The occupant impact velocity in the longitudinal direction should not exceed 40 ft/sec and the occupant ride-down acceleration in the longitudinal direction should not exceed 20 G [°] s.
		I - Longitudinal & lateral occupant ridedown accelerations (ORA) should fall below the preferred value of 15.0 g, or at least below the maximum allowed value of 20.49 g.
	Vehicle	For redirective devices the vehicle shall exit within the prescribed box.
	Trajectory	



Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 2270P Vehicle with New Jersey Safety Shape Barrier

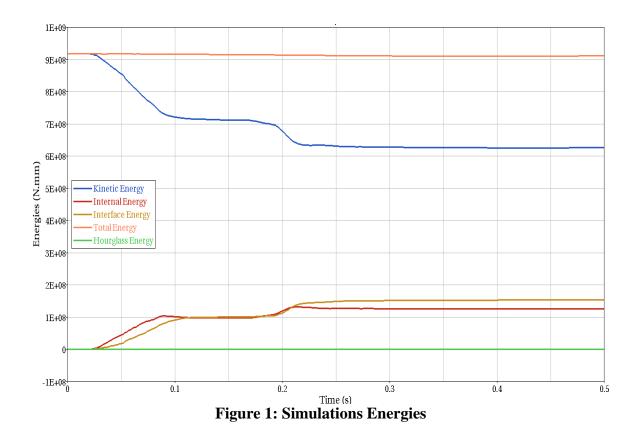
Table C – Analysis Solution Verification Summary

Verification Evaluation Criteria	Change (%)	Pass?
Total energy of the analysis solution (i.e., kinetic, potential, contact, etc.) must not vary more than 10 percent from the beginning of the run to the end of the run.	<1%	YES
Hourglass Energy of the analysis solution at the end of the run is less than 5 % of the total initial energy at the beginning of the run	<1%	YES
The part/material with the highest amount of hourglass energy at any time during the run is less than 5 % of the total initial energy at the beginning of the run.	<1%	YES
Mass added to the total model is less than 5 % the total model mass at the start of the run.	<1%	YES
The part/material with the most mass added had less than 10 % of its initial mass added.	<1%	YES
The moving parts/materials in the model have less than 5 % of mass added to the initial moving mass of the model.	<1%	YES
There are no shooting nodes in the solution?	NA	YES
There are no solid elements with negative volumes?	NA	YES

Table D - RSVVP Results

Si	ngle Channel Time History Comparison	Results	Time inter	Time interval [0 sec - 0.5 sec]			
0	Sprauge-Geer Metrics		М	Р	Pass?		
	X acceleration		52.9	35.6	NO		
	Y acceleration	3.2	16.2	YES			
	Z acceleration	71.7	45.3	NO			
	Yaw rate		13.4	9.5	YES		
	Roll rate		16.8	24.4	YES		
	Pitch rate	35.4	39.9	YES			
Р	ANOVA Metrics		Mean	SD	Pass?		
	X acceleration/Peak	1.32	29.37	YES			
	Y acceleration/Peak			12.15	YES		
	Z acceleration/Peak		0.66	44.94	NO		
	Yaw rate			14.87	YES		
	Roll rate		0.21	17.28	YES		
	Pitch rate		10.86	53.95	NO		
	ulti-Channel Weighting Factors		Time inter	rval [0 sec	; 0.5 sec]		
Μ	ulti-Channel Weighting Method	X Channel	0.142263141				
	Peaks Area I	Y Channel	0.312496147				
	Area II Inertial	Z Channel	0.	04524071	2		
		Yaw Channel	0	0.19476326			
		Roll Channel Pitch Channel	0.1	20082680	8		
			10440993				
Sp	rauge-Geer Metrics		Μ	Р	Pass?		
	All Channels (weighted)		21.4	23.1	YES		
A l	NOVA Metrics		Mean	SD	Pass?		
	All Channels (weighted)		1.5	22	YES		





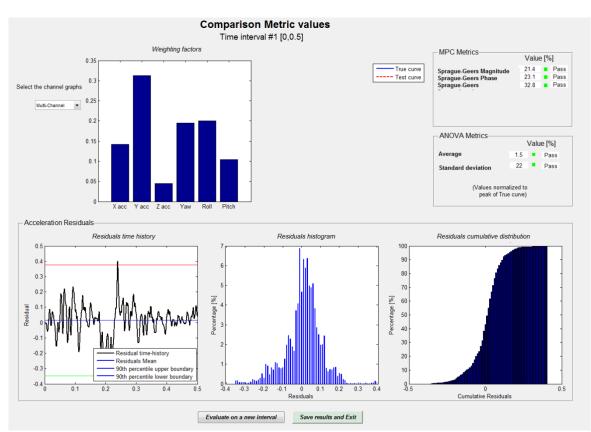
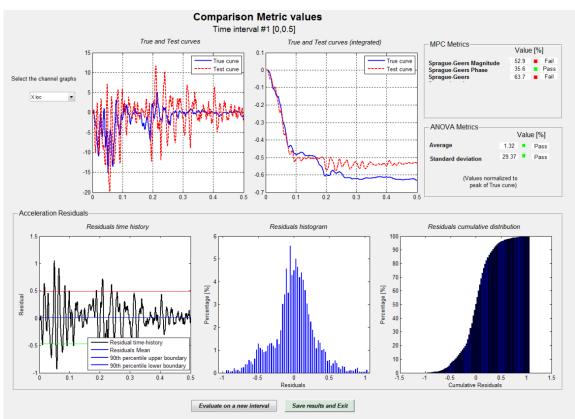
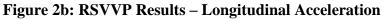


Figure 2a: RSVVP Results – All Channels







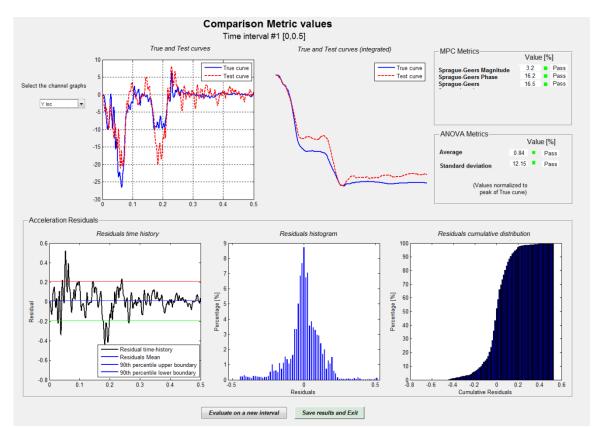
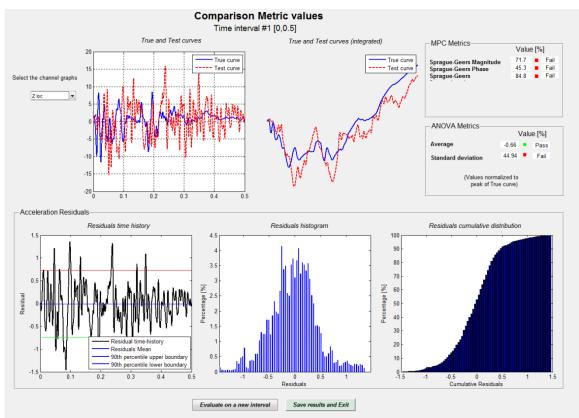
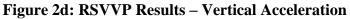


Figure 2c: RSVVP Results – Lateral Acceleration







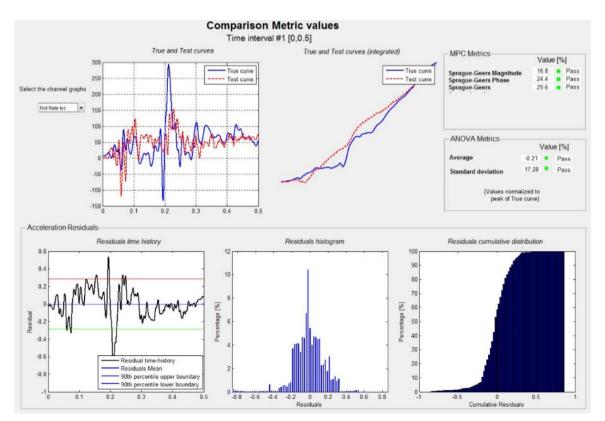
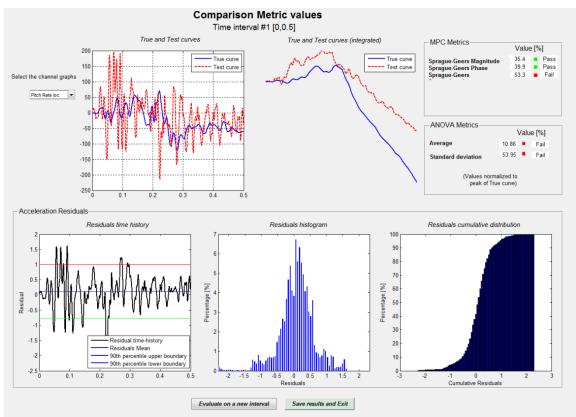


Figure 2e: RSVVP Results – Roll Angle







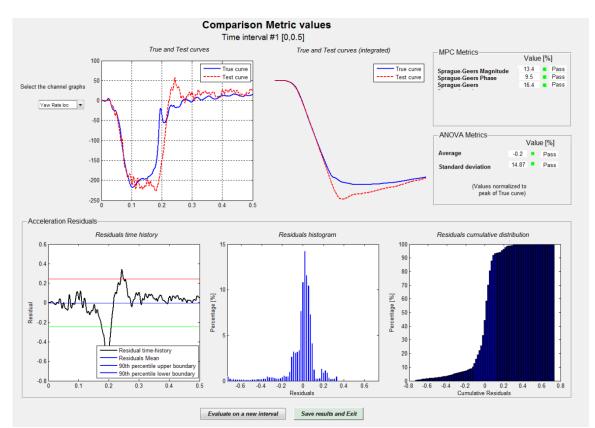
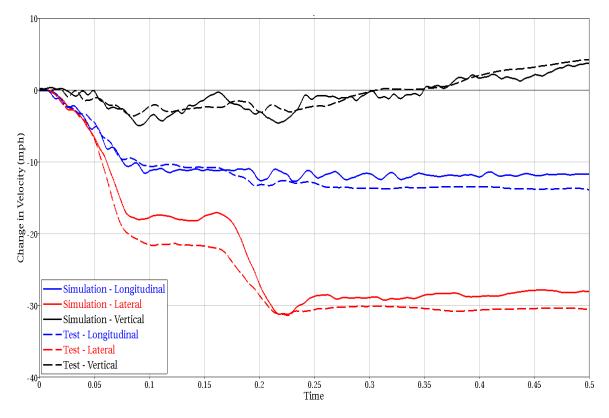
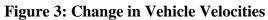


Figure 2g: RSVVP Results – Yaw Angle







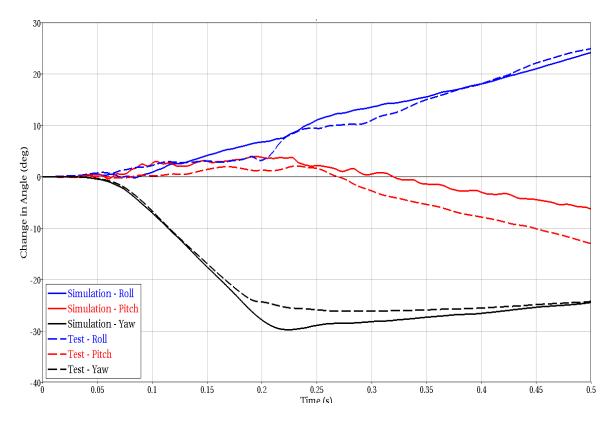


Figure 4: Change in Vehicle Angles



Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 2270P Vehicle with New Jersey Safety Shape Barrier

Table E - Roadside Safety Phenomena Importance Ranking Table (MASH Evaluation)

			Evaluation Criteria	Known Result	Analysis Result	Relative Diff. (%)	Agree?
Structural Adequacy		A1	Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.	Yes	Yes		YES
		A2	The relative difference in the maximum dynamic deflection is less than 20 percent.	0.0 m	0.0 m	0%	YES
		A3	The relative difference in the time of vehicle-barrier contact is less than 20 percent.	0.238 s	0.214 s	10%	YES
		A4	The relative difference in the number of broken or significantly bent posts is less than 20 percent.	Yes	Yes		YES
tu		A5	Barrier did not fail (Answer Yes or No).	Yes	Yes		YES
Ind		A6	There were no failures of connector elements (Answer Yes or No).	Yes	Yes		YES
\mathbf{S}		A7	There was no significant snagging between the vehicle wheels and barrier elements (Answer Yes or No).	Yes	Yes		YES
		A8	There was no significant snagging between vehicle body components and barrier elements (Answer Yes or No).	Yes	Yes		YES
		D	Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone (Answer Yes or No).		Yes		YES
		F1	The vehicle should remain upright during and after the collision. The maximum pitch & roll angles are not to exceed 75 degrees.	Yes	Yes		YES
		F2	Maximum vehicle roll – relative difference is less than 20% or absolute difference is less than 5 degrees.	25 (.5s)	24 (.5s)	4% 1 deg	YES
		F3	Maximum vehicle pitch – relative difference is less than 20% or absolute difference is less than 5 deg.	12 (.5s)	7 (.5s)	41% 5 deg	YES
Risk		F4	Maximum vehicle yaw – relative difference is less than 20% or absolute difference is less than 5 deg.	30 (.5s)	26 (.5s)	13% 4 deg	YES
Occupant Risk	₿	H1	Longitudinal & lateral occupant impact velocities (OIV) should fall below the preferred value of 30 ft/s (9.1 m/s), or at least below the maximum allowed value of 40 ft/s (12.2 m/s)	Yes	Yes		YES
õ		H2	Longitudinal OIV (m/s) - Relative difference is less than 20% t or absolute difference is less than 2 m/s	4.3	4.7	9% 0.4 m/s	YES
		H3	Lateral OIV (m/s - Relative difference is less than 20% or absolute difference is less than 2 m/s	9.2	7.9	14% 1.3 m/s	YES
		I1	Longitudinal & lateral occupant ridedown accelerations (ORA) should fall below the preferred value of 15.0 g, or at least below the maximum allowed value of 20.49 g.	Yes	Yes		YES
		I2	Longitudinal ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g's	5.6	7.6	35% 2 g	YES
		I3	Lateral ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g's	9.6	12.9	34% 3 g	YES
Vehicle Trajectory			The vehicle rebounded within the exit box. (Answer Yes or No)	Yes	Yes		YES



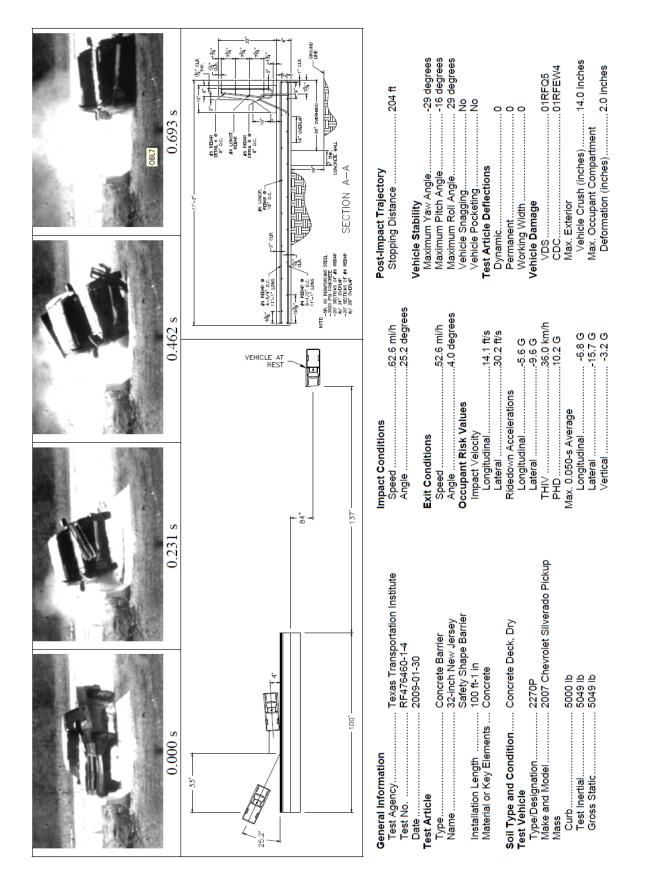


Figure 5: Full-Scale Test Summary



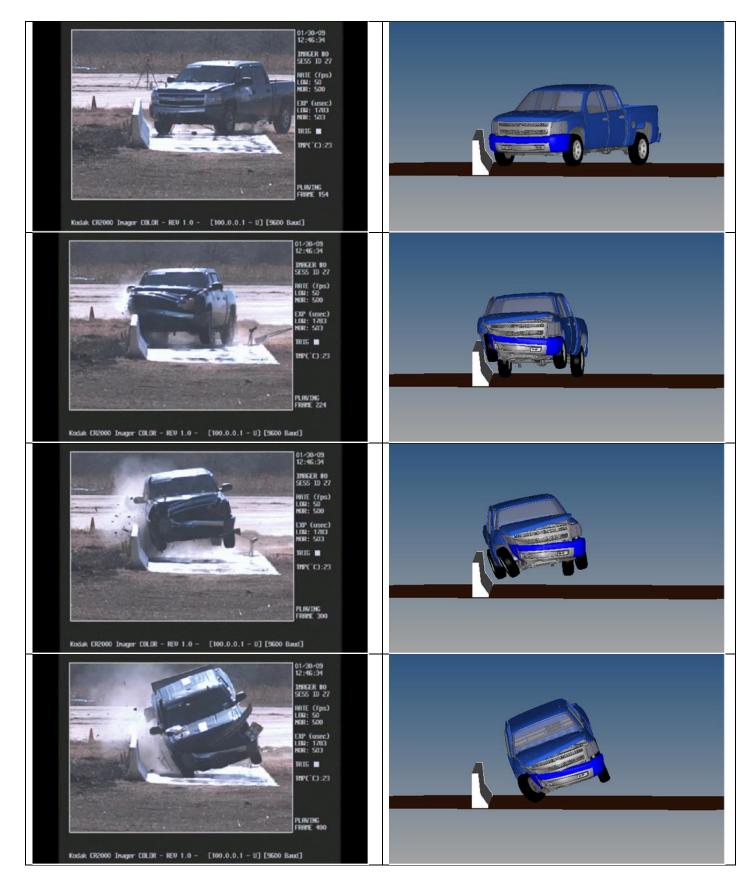


Figure 6a: Sequential Comparisons – Front View



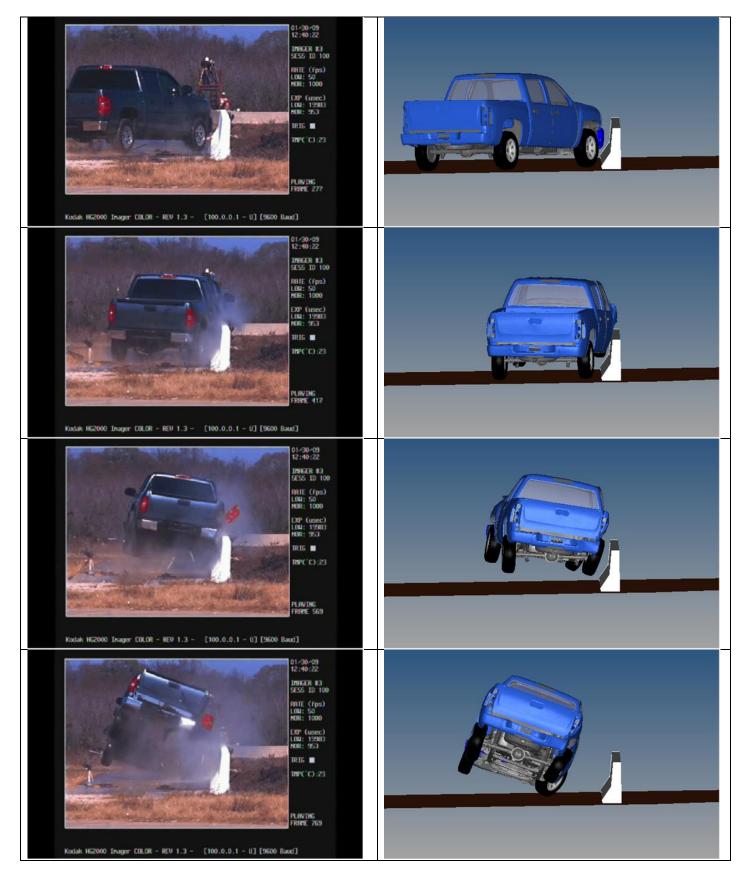


Figure 6b: Sequential Comparisons – Rear View



C-26

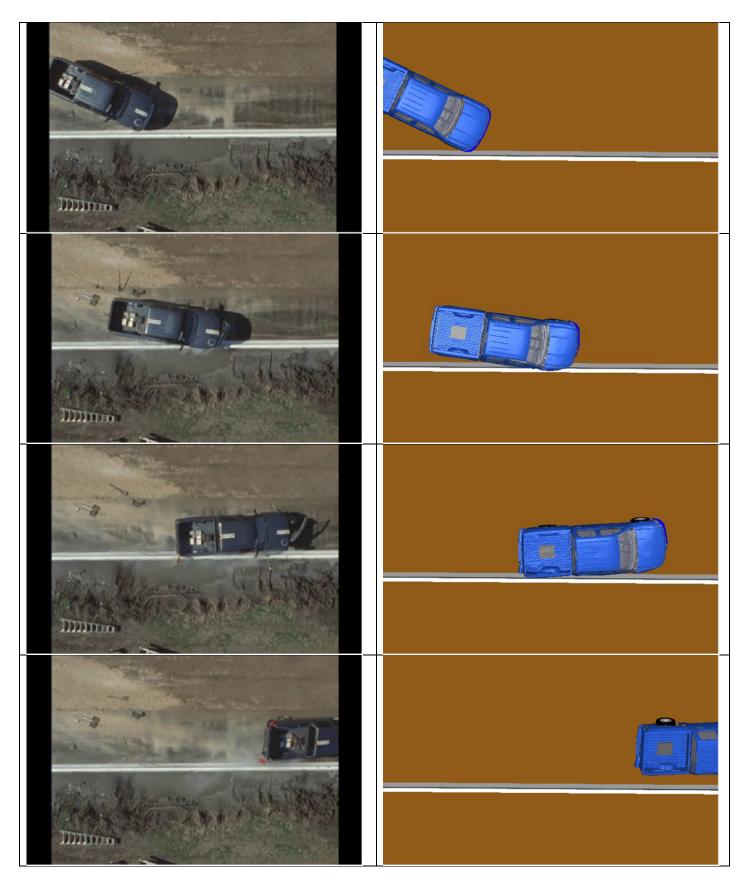


Figure 6c: Sequential Comparisons – Top View



Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 2270P Vehicle with New Jersey Safety Shape Barrier

List the Report MA			
Table C – Analysis Solution Verification	Did all solution verification criteria in	table pass?	YES
Table D - RSVVP Results	Do all the time history evaluation scores from the single channel factors result in a satisfactory comparison (i.e., the comparison passes the criterion)?		NO
	If all the values for Single Channel con did the weighted procedure result		YES
Table E - Roadside Safety Phenomena Importance Ranking Table	Did all the critical criteria in the PIRT Note: Tire deflation was observed in the simulation. This due to the fact th not incorporated in the model. This is have a critical effect on the outcome o	the test but not in at tire deflation in considered not to	YES
Overall	Are the results of Steps I through III YES)? If all three steps result in a comparison can be considered validate of the steps results in a negative response be considered validated or verified.	all affirmative (i.e., "YES" answer, the ed or verified. If one	YES

Table F - Composite Verification and Validation Summa	ry:
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NOTES:

(none)

Case-3: G4(1S) Barrier Impact with 2000P Vehicle

CCSA VALIDATION/VERIFICATION REPORT

Project:CCSA Longitudinal Barriers on Curved, Superelevated Roadway SectionsComparison Case:2000P (Pickup Truck) with G41S BarrierImpact Description:25.5-deg impact into barrier at 101.5 km/h (63.1 mph)Governing Criteria:NCHRP Report 350 TL-3Report Date:June 2013

Table A – Information Sources:

General Information	Known Solution	Analysis Solution
Performing Organization	TTI	CCSA-GMU
Test/Run Number	405421-1	C2500_G41S_18c
Vehicle	Chevrolet C2500	C2500 D
Vehicle Mass (lb/kg)	4409 / 2000	4409 / 2000
Impact Speed (mph/kph)	63.1 / 101.5	63.1 / 101.5
Impact Angle (degrees)	25.5	25.5

Table B - Evaluation Parameters Summary:

Category	Subset	Values
Evaluation Method	NCHRP Report	
Hardware Type	Longitudinal	
Test Number	3-11	
Test Vehicle	2000P	
Criterion to be Applied	Structural Adequacy	A - Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.
	Occupant Risk	${f D}$ - Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone.
		${f F}$ - The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.
		L - The occupant impact velocity in the longitudinal direction should not exceed 40 ft/sec and the occupant ride-down acceleration in the longitudinal direction should not exceed 20 G's.
	Vehicle Trajectory	${\bf M}$ - The exit angle from the test article preferable should be less than 60 percent of test impact angle, measured at the time of vehicle loss of contact with test device

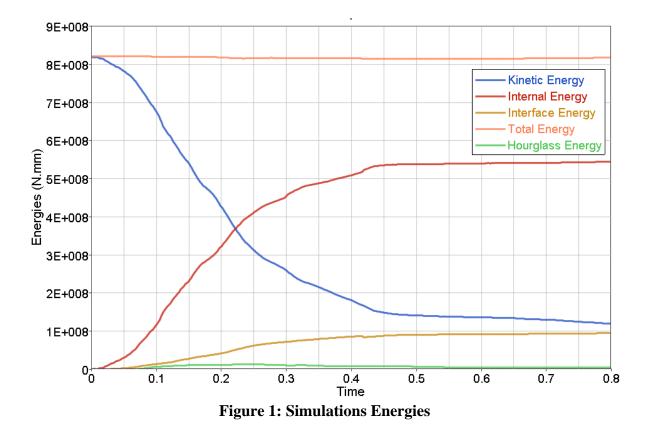
Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 2000P (Pickup Truck) with G41S Barrier

Verification Evaluation Criteria	Change (%)	Pass?
Total energy of the analysis solution (i.e., kinetic, potential, contact, etc.) must not vary more than 10 percent from the beginning of the run to the end of the run.	< 1%	YES
Hourglass Energy of the analysis solution at the end of the run is less than 5 % of the total initial energy at the beginning of the run	< 1%	YES
The part/material with the highest amount of hourglass energy at any time during the run is less than 5 % of the total initial energy at the beginning of the run.	< 1%	YES
Mass added to the total model is less than 5 % the total model mass at the start of the run.	< 1%	YES
The part/material with the most mass added had less than 10 % of its initial mass added.	< 1%	YES
The moving parts/materials in the model have less than 5 % of mass added to the initial moving mass of the model.	< 1%	YES
There are no shooting nodes in the solution?	NA	YES
There are no solid elements with negative volumes?	NA	YES

Table C – Analysis Solution Verification Summary

Table D - RSVVP Results

Single Char	nel Time History Comparison R	esults	Time inter	val [0 sec	- 0.89 sec]		
O Sprauge	-Geer Metrics		М	P	Pass?		
X ac	celeration		22.2	33.6	YES		
Y ac	celeration		42.9	33.2	NO		
Z ac	celeration		120.2	43.1	NO		
Yaw	Yaw rate Roll rate		0	12.2	YES		
Roll	rate		235.5	46	NO		
	n rate		145.4	61.2	NO		
P ANOVA	Metrics		Mean	SD	Pass?		
X ac	celeration/Peak		-2.22	33.38	YES		
Y ac	celeration/Peak		0.41	24.44	YES		
Z ac	celeration/Peak		-1.36	59.37	NO		
Yaw	rate		-1.85	15.78	YES		
Roll	rate		7.17	107.68	NO		
Pitch	n rate		63.57	62.77	NO		
Multi-Chan	nel Weighting Factors		Time inter	val [0 sec	; 0.89 sec]		
Multi-Chan	nel Weighting Method	X Channel	0.261526				
P	eaks Area I	Y Channel	().220749			
Α	rea II Inertial	Z Channel	0.017725				
		Yaw Channel	0.397255				
		Roll Channel	0.060756				
	Pitch Channel			0.04199			
Sprauge-Ge			Μ	Р	Pass?		
	nannels (weighted)		37.8 27.1 YE				
ANOVA Me	trics		Mean	SD	Pass?		
All Cl	nannels (weighted)		1.9	30.6	YES		



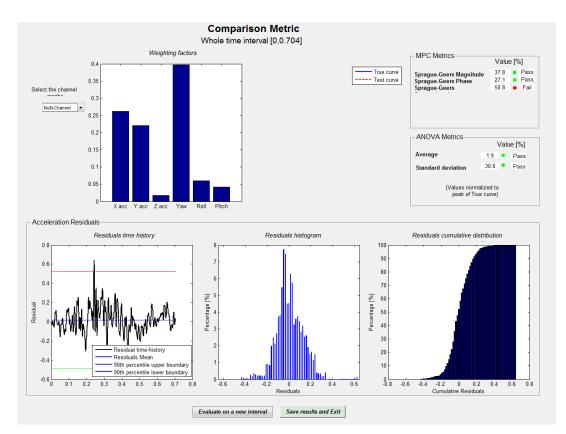


Figure 2a: RSVVP Results – All Channels

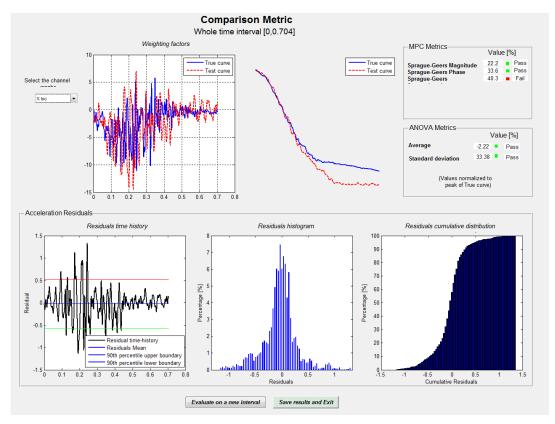


Figure 2b: RSVVP Results – Longitudinal Acceleration

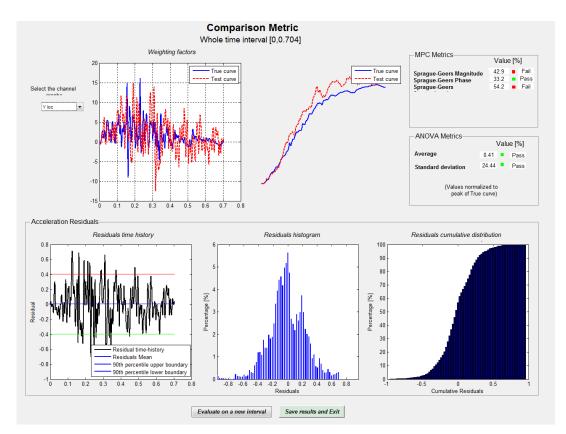


Figure 2c: RSVVP Results – Lateral Acceleration

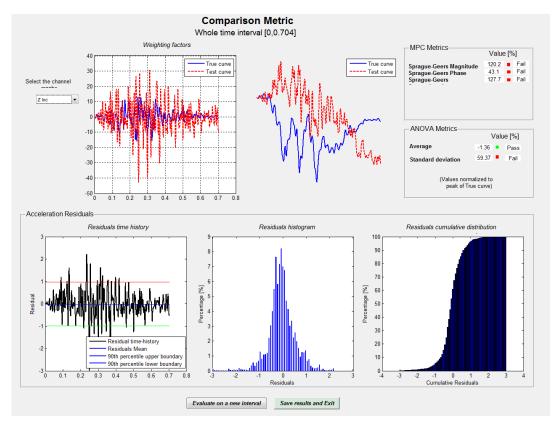


Figure 2d: RSVVP Results – Vertical Acceleration

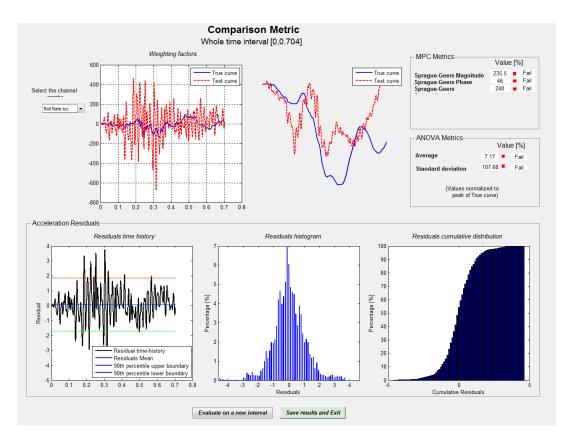


Figure 2e: RSVVP Results – Roll Angle Rate

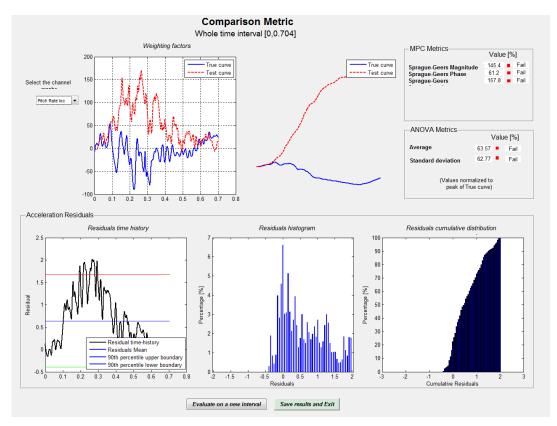


Figure 2f: RSVVP Results – Pitch Angle Rate

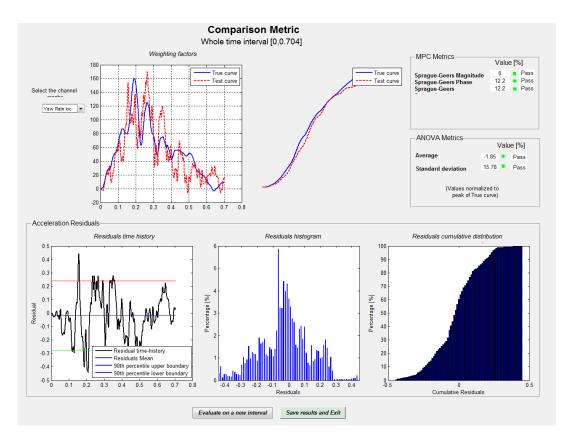
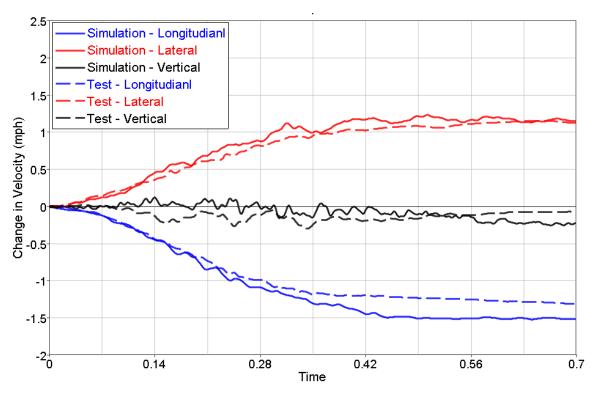
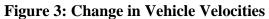
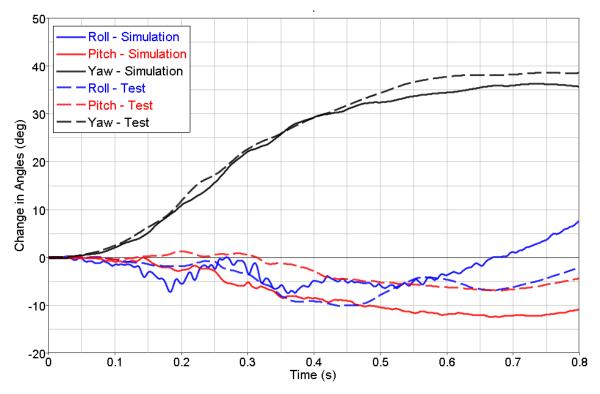
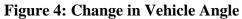


Figure 2g: RSVVP Results – Yaw Angle Rate









Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 2000P (Pickup Truck) with G41S Barrier

Table E - Roadside Safety Phenomena Importance Ranking Table (MASH Evaluation)

			Evaluation Criteria	Known Result	Analysis Result	Relative Diff. (%)	Agree?			
		A1	Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.	Yes	Yes		YES			
ICY		A2	The relative difference in the maximum dynamic deflection is less than 20 percent.	1. m	0.960 m	4.0 %	YES			
Structural Adequacy		A3	The relative difference in the time of vehicle-barrier contact is less than 20 percent.	0.7 s	0.65 s	7.1 %	YES			
ıral A	4	A4	The relative difference in the number of broken or significantly bent posts is less than 20 percent.	4	4		YES			
ictu		A5	Barrier did not fail (Answer Yes or No).	Yes	Yes		YES			
itru		A6	There were no failures of connector elements (Answer Yes or No).	Yes	Yes		YES			
		A7	There was no significant snagging between the vehicle wheels and barrier elements (Answer Yes or No).	No	No		YES			
		A8	There was no significant snagging between vehicle body components and barrier elements (Answer Yes or No).	Yes	Yes		YES			
	D		Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone (Answer Yes or No).	Yes	Yes		YES			
		F1	The vehicle should remain upright during and after the collision. The maximum pitch & roll angles are not to exceed 75 degrees.	Yes	Yes		YES			
	•	F2	Maximum vehicle roll – relative difference is less than 20% or absolute difference is less than 5 degrees.	10 (0.45s)	9 (0.35s)	10% 1 deg	YES			
sk		F3	Maximum vehicle pitch – relative difference is less than 20% or absolute difference is less than 5 deg.	7 (0.67s)	12 (0.67s)	71% 5 deg	YES			
Occupant Risk		F4	Maximum vehicle yaw – relative difference is less than 20% or absolute difference is less than 5 deg.	38 (0.8s)	36 (0.72s)	5.2% 2 deg	YES			
Occup		L1	The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's.	Yes	Yes		YES			
		L2	Longitudinal OIV (m/s) - Relative difference is less than 20% or absolute difference is less than 2 m/s	7.1	6.4	9.8% 0.7 m/s	YES			
	1	L3	Lateral OIV (m/s) - Relative difference is less than 20% or absolute difference is less than 2 m/s	4.4	5.4	22.7% 1.0 m/s	YES			
					L4	Longitudinal ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g's	7.9	11.5	45.6% 3.6 g	YES
		L5	Lateral ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g's	8.4	10.1	20.2% 1.7 g	YES			
Vehicle Trajectory	Ø	M1	The exit angle from the test article preferable should be less than 60 percent of test impact angle, measured at the time of vehicle loss of contact with test device.	No	No		YES			
Vehicle T.		M2	Exit angle at loss of contact: relative difference is less than 20% or absolute difference is less than 5 deg.	16	18	11% 2 deg	YES			

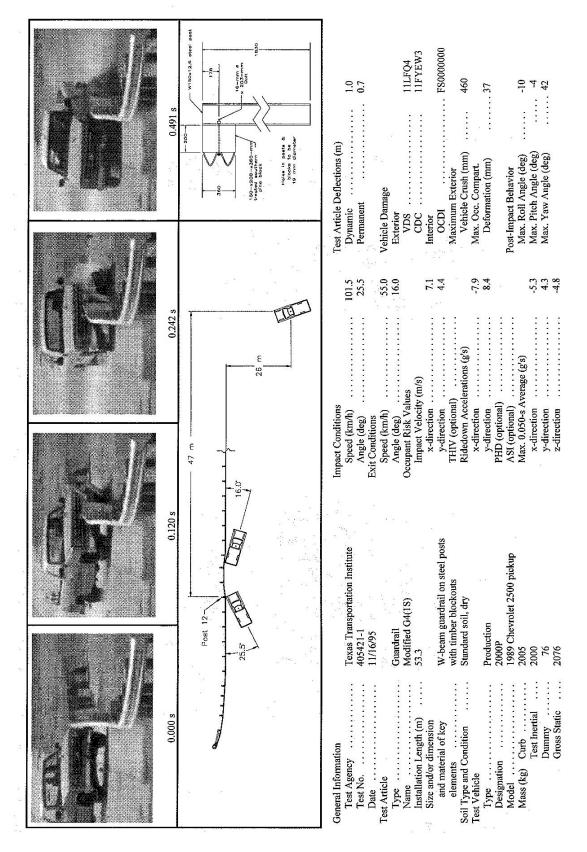


Figure 5: Full-Scale Test Summary

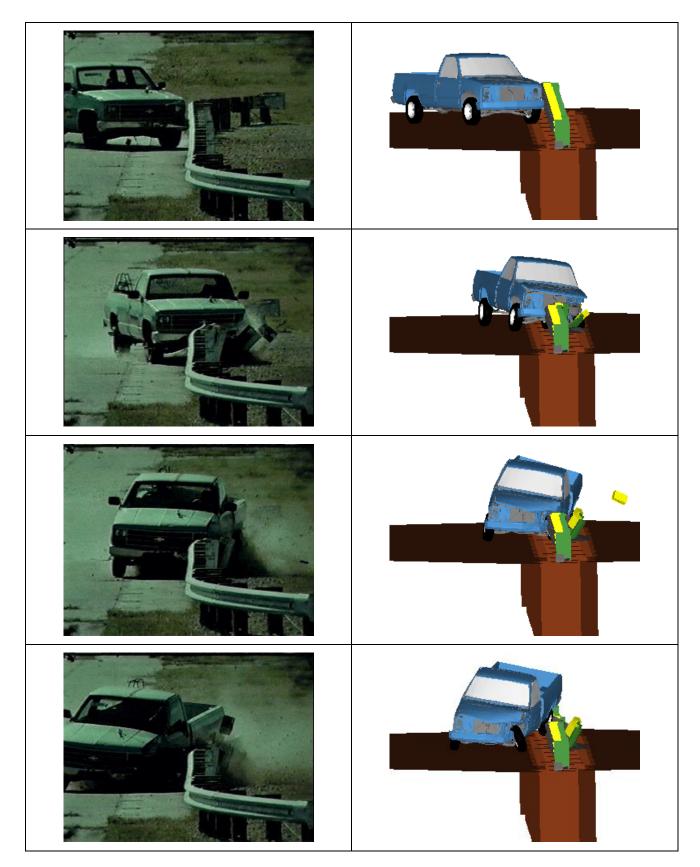


Figure 6a: Sequential Comparisons – Front View

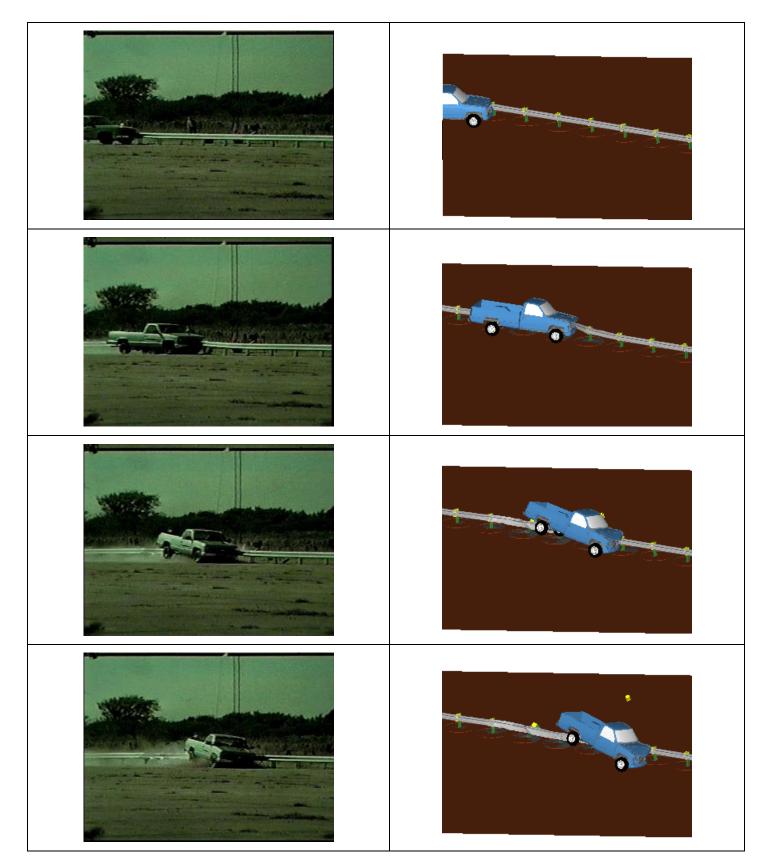


Figure 6b: Sequential Comparisons – Iso View

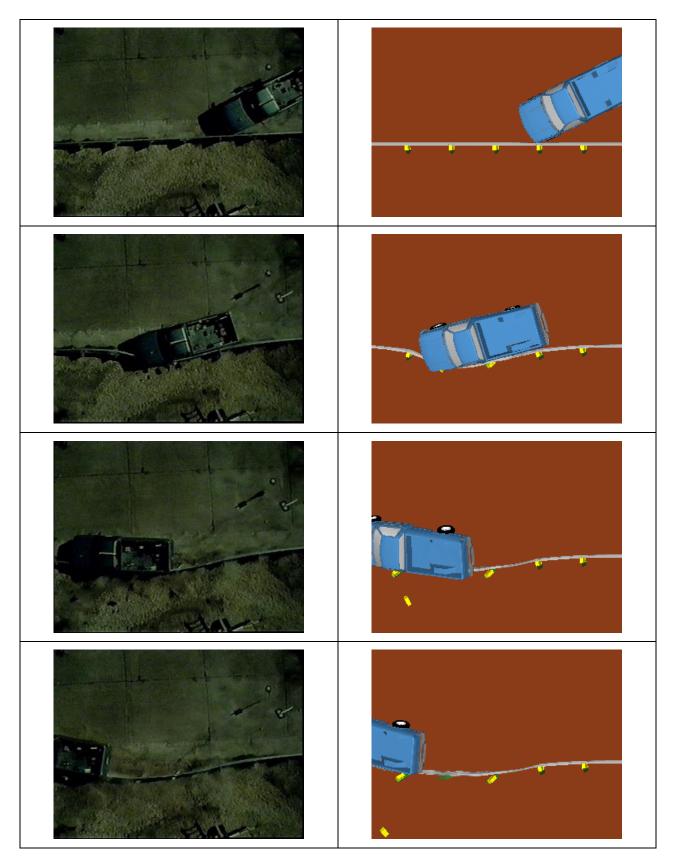


Figure 6c: Sequential Comparisons – Top View

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 2000P (Pickup Truck) with G41S Barrier

1	List the Report MASH08 Test Number				
Table C – AnalysisSolutionVerification	Did all solution verification criteria in table pass?	YES			
Table D - RSVVP Results	Do all the time history evaluation scores from the single channel factors result in a satisfactory comparison (i.e., the comparison passes the criterion)?	NO			
	If all the values for Single Channel comparison did not pass, did the weighted procedure result in an acceptable comparison.	YES			
Table E - Roadside Safety Phenomena Importance Ranking Table	Did all the critical criteria in the PIRT Table pass? Note: Tire deflation was observed in the test but not in the simulation. This due to the fact that tire deflation in not incorporated in the model. This is considered not to have a critical effect on the outcome of the test	YES			
Overall	Are the results of Steps I through III all affirmative (i.e., YES)? If all three steps result in a "YES" answer, the comparison can be considered validated or verified. If one of the steps results in a negative response, the result cannot be considered validated or verified.	YES			

Table F - Composite Verification and Validation Summary	/:
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NOTES:

(none)

Case-4: G4(1S) Barrier Impact with 2270P Vehicle

CCSA VALIDATION/VERIFICATION REPORT

Project:CCSA Longitudinal Barriers on Curved, Superelevated Roadway SectionsComparison Case:2270P (Pickup Truck) with G41S BarrierImpact Description:25.8-deg impact into barrier at 100.4 km/h (62.4 mph)Governing Criteria:MASH TL-3Report Date:March 2013

Table A – Information Sources:

General Information	Known Solution	Analysis Solution	
Performing Organization	MwRSF	CCSA-GMU	
Test/Run Number	2214WB-2	RR130422b	
Vehicle	Dodge Ram 1500 Quad Cab	Silverado C	
Vehicle Mass (lb/kg)	5000 / 2268	4918 / 2231	
Impact Speed (mph/kph)	62.4 / 100.4	62.4 / 100.4	
Impact Angle (degrees)	25.8	25.8	

Table B - Evaluation Parameters Summary:

Category	Subset	Values
Evaluation Method	MASH (V1, 2009)	
Hardware Type	Longitudinal	
Test Number	3-11	
Test Vehicle	2270C	
Criterion to be Applied	Structural Adequacy	${\bf A}$ - Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.
	Occupant Risk	${f D}$ - Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone.
		${f F}$ - The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.
		H - The occupant impact velocity in the longitudinal direction should not exceed 40 ft/sec and the occupant ride-down acceleration in the longitudinal direction should not exceed 20 G [°] s.
		I - Longitudinal & lateral occupant ridedown accelerations (ORA) should fall below the preferred value of 15.0 g, or at least below the maximum allowed value of 20.49 g.
	Vehicle Trajectory	For redirective devices the vehicle shall exit within the prescribed box.

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 2270P (Pickup Truck) with G41S Barrier

Table C – Analysis Solution Verification Summary

Verification Evaluation Criteria	Change (%)	Pass?
Total energy of the analysis solution (i.e., kinetic, potential, contact, etc.) must not vary more than 10 percent from the beginning of the run to the end of the run.	< 1%	YES
Hourglass Energy of the analysis solution at the end of the run is less than 5 % of the total initial energy at the beginning of the run	< 1%	YES
The part/material with the highest amount of hourglass energy at any time during the run is less than 5 % of the total initial energy at the beginning of the run.	< 1%	YES
Mass added to the total model is less than 5 % the total model mass at the start of the run.	< 1%	YES
The part/material with the most mass added had less than 10 % of its initial mass added.	< 1%	YES
The moving parts/materials in the model have less than 5 % of mass added to the initial moving mass of the model.	< 1%	YES
There are no shooting nodes in the solution?	NA	YES
There are no solid elements with negative volumes?	NA	YES

Table D - RSVVP Results

-	<u>D - KSVVP Results</u> ngle Channel Time History Comparison R	Time interval [0 sec - 0.89 sec]				
	Sprauge-Geer Metrics		M	P	Pass?	
	X acceleration	75	38.3	NO		
	Y acceleration	29.9	32.6	YES		
	Z acceleration		168.7	45.3	NO	
	Yaw rate		14.1	12.7	YES	
	Roll rate (test data not available)					
	Pitch rate (test data not available)					
Р	ANOVA Metrics		Mean	SD	Pass?	
	X acceleration/Peak		-1.79	41.87	NO	
	Y acceleration/Peak		1.54	31.86	YES	
	Z acceleration/Peak		0.16	73.73	NO	
	Yaw rate		32	18.97	YES	
	Roll rate (test data not available)					
	Pitch rate (test data not available)					
Mu	ulti-Channel Weighting Factors		Time interval [0 sec; 0.89 sec			
Mı	ulti-Channel Weighting Method	X Channel	0.22878683			
	Peaks Area I	Y Channel	0.225135792			
	Area II Inertial	Z Channel	0.046077378			
		Yaw Channel		0.5		
		Roll Channel Pitch Channel	(test data not available)			
		(test data not available) M P Pass?				
Spi	Sprauge-Geer Metrics			Р	Pass?	
	All Channels (weighted)	36.7 Mean	24.6	YES		
$A\Lambda$	ANOVA Metrics			SD	Pass?	
	All Channels (weighted)		02	29.6	YES	

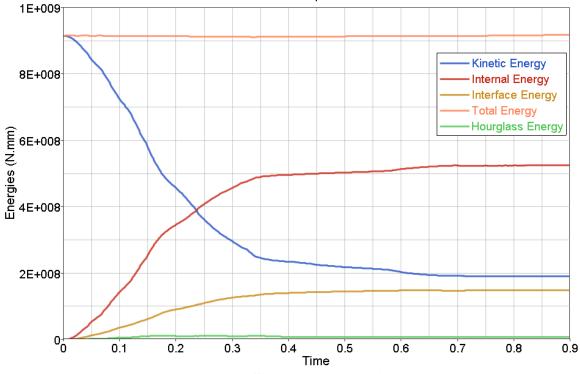


Figure 1: Simulations Energies

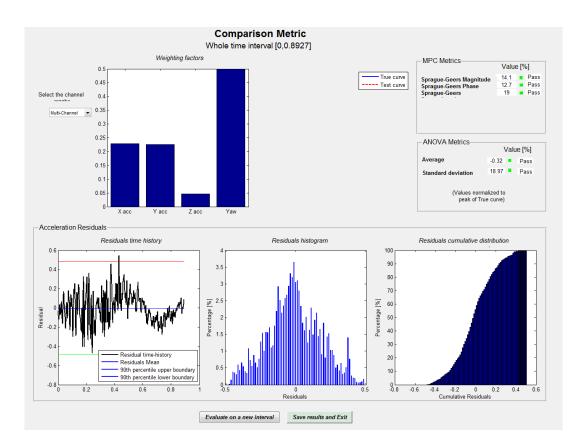


Figure 2a: RSVVP Results – All Channels

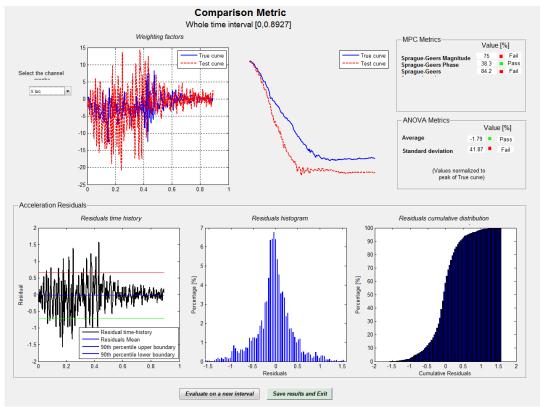


Figure 2b: RSVVP Results – Longitudinal Acceleration

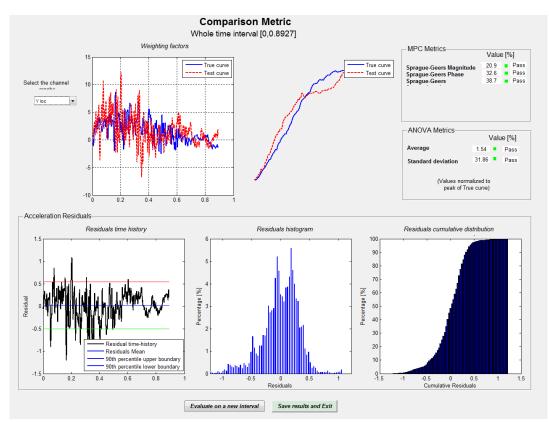
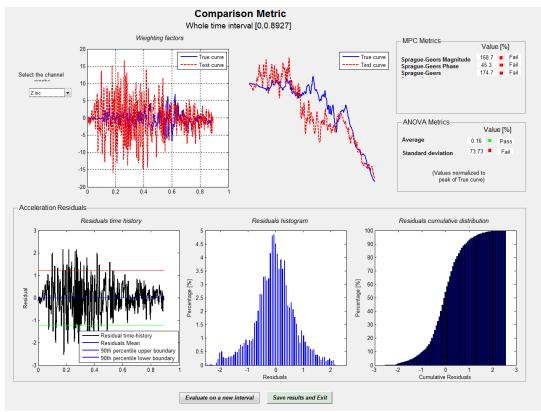
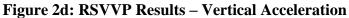


Figure 2c: RSVVP Results – Lateral Acceleration





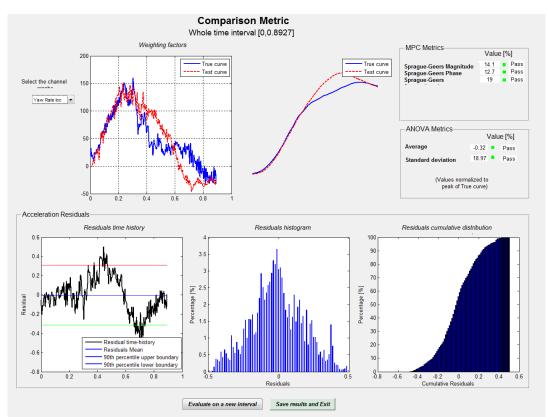


Figure 2e: RSVVP Results – Yaw Angle

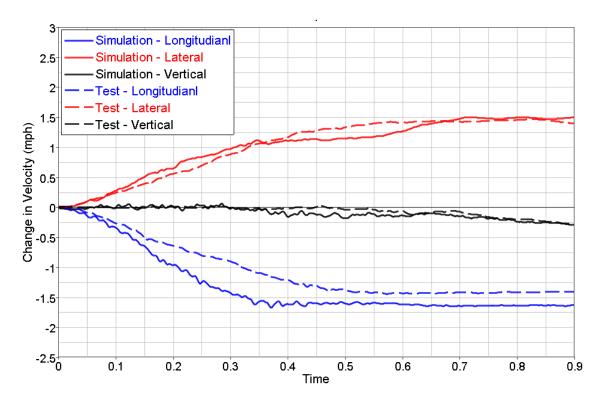


Figure 3: Change in Vehicle Velocities

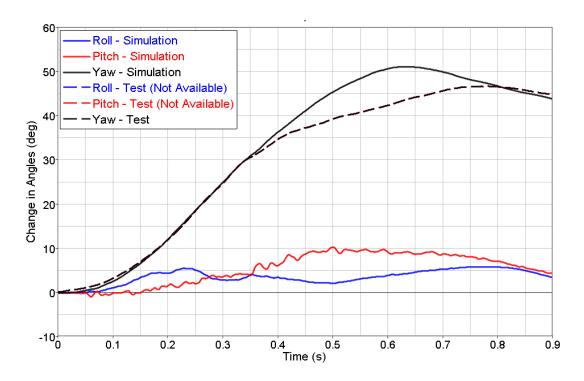


Figure 4: Change in Vehicle Angle

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 2270P (Pickup Truck) with G41S Barrier

Table E - Roadside Safety Phenomena Importance Ranking Table (MASH Evaluation)

			Evaluation Criteria	Known Result	Analysis Result	Relative Diff. (%)	Agree?		
		A1	Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.	Yes	Yes		YES		
acy		A2	The relative difference in the maximum dynamic deflection is less than 20 percent.	1.196 m	0.980 m	18.0 %	YES		
Structural Adequacy		A3	The relative difference in the time of vehicle-barrier contact is less than 20 percent.	0.84 s	0.72 s	7.1 %	YES		
ıral A		A4	The relative difference in the number of broken or significantly bent posts is less than 20 percent.	3	3		YES		
ctu		A5	Barrier did not fail (Answer Yes or No).	Yes	Yes		YES		
tru		A6	There were no failures of connector elements (Answer Yes or No).	Yes	Yes		YES		
S		A7	There was no significant snagging between the vehicle wheels and barrier elements (Answer Yes or No).	Yes	Yes		YES		
		A8	There was no significant snagging between vehicle body components and barrier elements (Answer Yes or No).	Yes	Yes		YES		
	D		Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone (Answer Yes or No).	Yes	Yes		YES		
		F1	The vehicle should remain upright during and after the collision. The maximum pitch & roll angles are not to exceed 75 degrees.	Yes	Yes		YES		
		F2	Maximum vehicle roll – relative difference is less than 20% or absolute difference is less than 5 degrees.	NA	NA	NA			
		F3	Maximum vehicle pitch – relative difference is less than 20% or absolute difference is less than 5 deg.	NA	NA	NA			
Risk		F4	Maximum vehicle yaw – relative difference is less than 20% or absolute difference is less than 5 deg.	51 (.62s)	47 (.78s)	7.8% 4 deg	YES		
Occupant Risk				H1	Longitudinal & lateral occupant impact velocities (OIV) should fall below the preferred value of 30 ft/s (9.1 m/s), or at least below the maximum allowed value of 40 ft/s (12.2 m/s)	Yes	Yes		YES
Occ		H2	Longitudinal OIV (m/s) - Relative difference is less than 20%t or absolute difference is less than 2 m/s	5.38	6.1	13.4% 0.72 m/s	YES		
		H3	Lateral OIV (m/s) - Relative difference is less than 20% or absolute difference is less than 2 m/s	3.99	5.0	25.3% 1.01 m/s	YES		
		I1	Longitudinal & lateral occupant ridedown accelerations (ORA) should fall below the preferred value of 15.0 g, or at least below the maximum allowed value of 20.49 g.	Yes	Yes		YES		
		I2	Longitudinal ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g's	6.92	10.72	54.9% 3.8 g	YES		
		I3	Lateral ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g's	6.61	9.86	49.2% 3.25 g	YES		
	Vehicle Trajectory		The vehicle rebounded within the exit box. (Answer Yes or No)	Yes	Yes		YES		

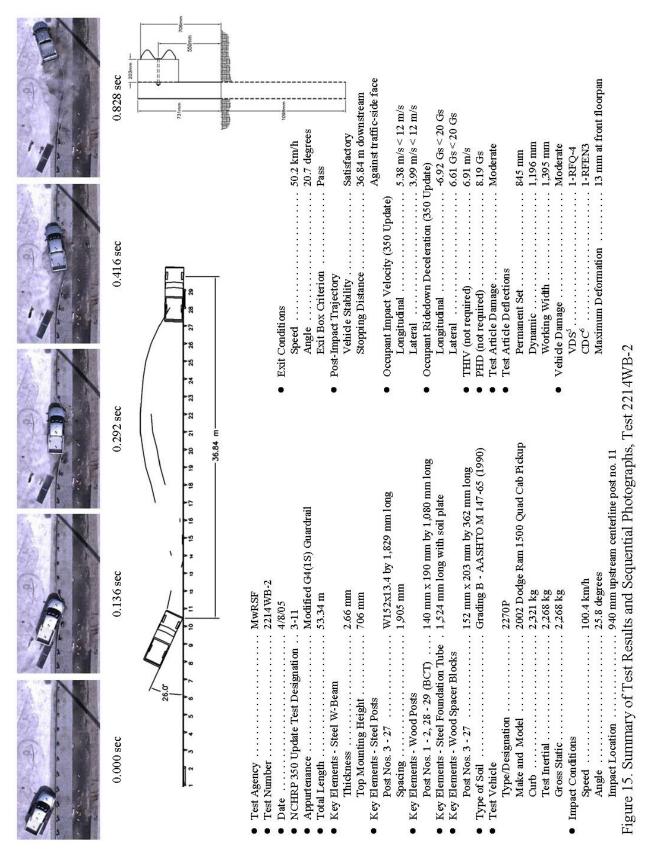


Figure 5: Full-Scale Test Summary

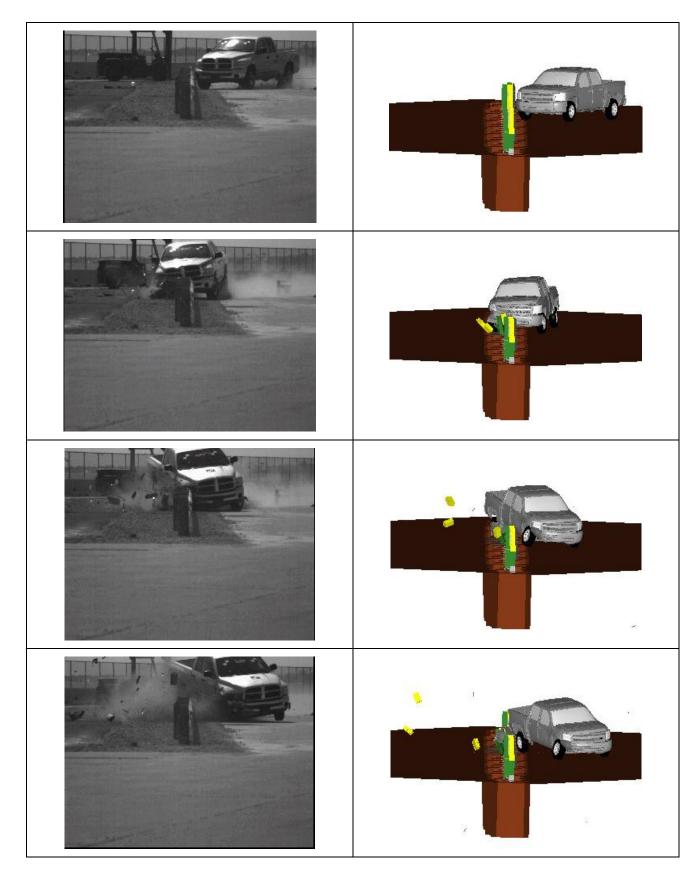


Figure 6a: Sequential Comparisons – Front View

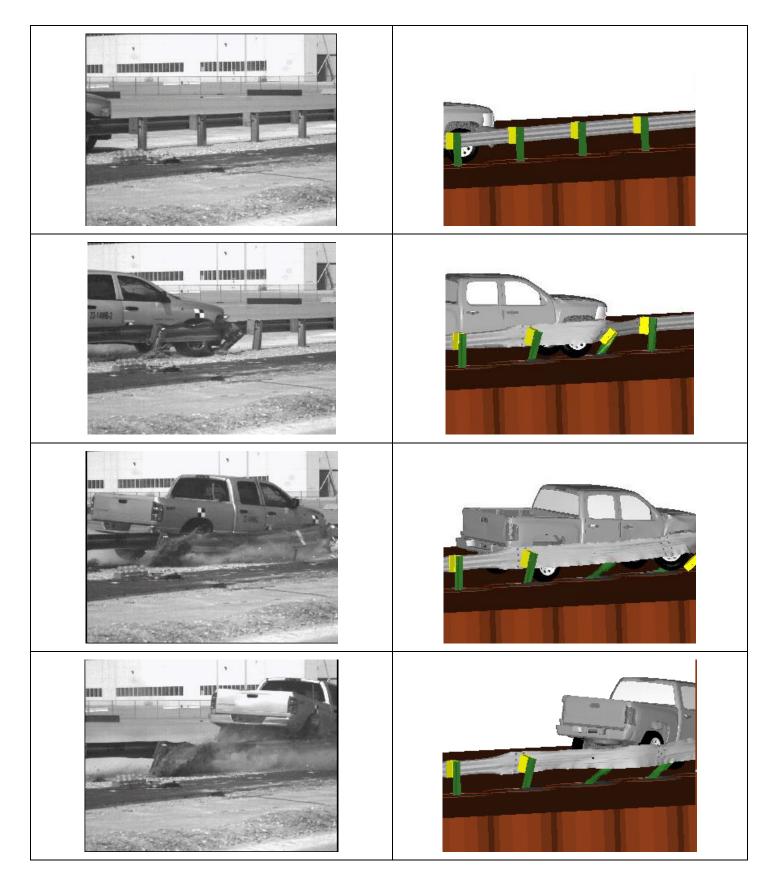


Figure 6b: Sequential Comparisons – Rear View

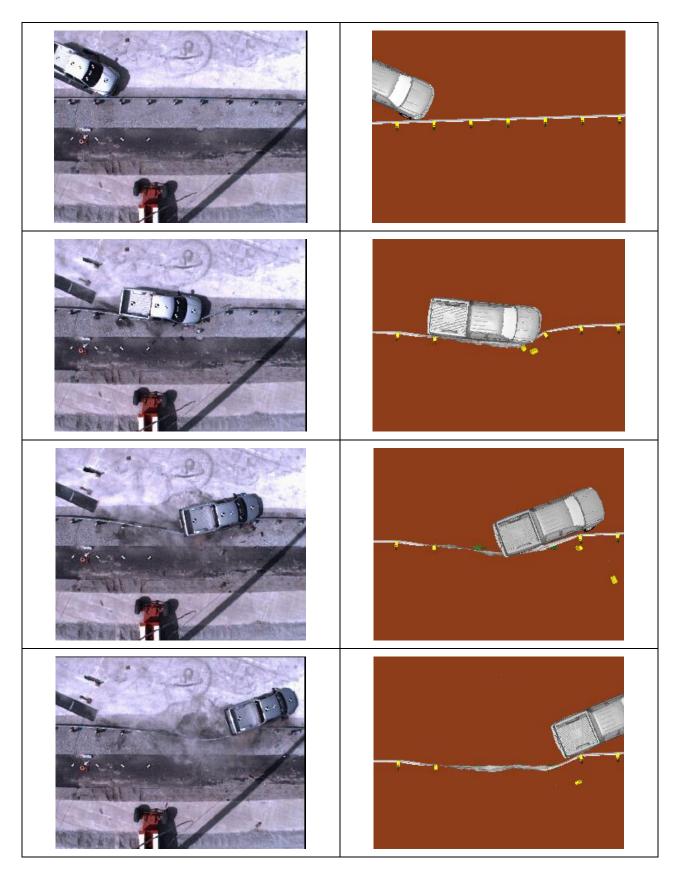


Figure 6c: Sequential Comparisons – Top View

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 2270P (Pickup Truck) with G41S Barrier

-	SH08 Test Number		
Table C – Analysis Solution Verification	Did all solution verification criteria in	table pass?	YES
Table D - RSVVP Results	Do all the time history evaluation score channel factors result in a satisfactory the comparison passes the criterion)?	0	NO
	If all the values for Single Channel condid the weighted procedure result comparison.		YES
Table E - Roadside Safety Phenomena Importance Ranking Table	Did all the critical criteria in the PIRT Note: Tire deflation was observed in the the simulation. This due to the fact that not incorporated in the model. This is have a critical effect on the outcome of	the test but not in at tire deflation in considered not to	YES
Overall	Are the results of Steps I through III YES)? If all three steps result in a comparison can be considered validated or verified. If one in a negative response, the result ca validated or verified.	"YES" answer, the e of the steps results	YES

NOTES:

(none)

Case-5: MGS Barrier Impact with 820C Vehicle

CCSA VALIDATION/VERIFICATION REPORT

Project:CCSA Longitudinal Barriers on Curved, Superelevated Roadway SectionsComparison Case:820C Vehicle with Midwest Guardrail Security BarrierImpact Description:20-deg impact into barrier at 100 km/h (62 mph)Governing Criteria:Report 350 TL-3Report Date:June 2013

Table A – Information Sources:

General Information	Known Solution	Analysis Solution
Performing Organization	MwRSF	CCSA-GMU
Test/Run Number	NPG-1	NA
Vehicle	1994 Goe Metro	CCSA Geo Metro Model
Vehicle Mass (lb/kg)	887 / 1956	895 / 1973
Impact Speed (mph/kph)	63.9 / 102.9	63.9 / 102.9
Impact Angle (degrees)	20	20

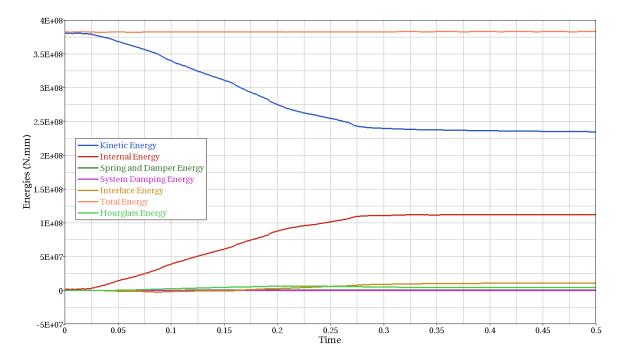
Table B - Evaluation Parameters Summary:

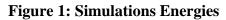
Category	Subset	Values
Evaluation Method	MASH (V1, 2009)	
Hardware Type	Longitudinal	
Test Number	3-10	
Test Vehicle	820C	
Criterion to be Applied	Structural Adequacy	A - Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.
	Occupant Risk	${f D}$ - Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone.
		\mathbf{F} - The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.
		H - The occupant impact velocity in the longitudinal direction should not exceed 40 ft/sec and the occupant ride-down acceleration in the longitudinal direction should not exceed 20 G [°] s.
		I - Longitudinal & lateral occupant ridedown accelerations (ORA) should fall below the preferred value of 15.0 g, or at least below the maximum allowed value of 20.49 g.
	Vehicle Trajectory	For redirective devices the vehicle shall exit within the prescribed box.

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 820C Vehicle with Midwest Guardrail System Barrier

Verification Evaluation Criteria				Pass?
Total energy of the analysis solution (i.e., kinetic, potential, contact, etc.) must not vary more than 10 percent from the beginning of the run to the end of the run.			<1%	YES
Hourglass Energy of the analysis solution at the end of the run is less than 5 % of the total initial energy at the beginning of the run			l <1%	YES
The part/material with the highest amount of hour less than 5 % of the total initial energy at the begin		luring the run is	<1%	YES
Mass added to the total model is less than 5 % the t	total model mass at the star	t of the run.	<1%	YES
The part/material with the most mass added had less	ss than 10 % of its initial m	ass added.	<1%	YES
The moving parts/materials in the model have less the mass of the model.	han 5 % of mass added to th	ie initial moving	g <1%	YES
There are no shooting nodes in the solution?			NA	YES
There are no solid elements with negative volumes	?		NA	YES
le D - RSVVP Results				
Single Channel Time History Compariso	n Results	Time inter	val [0 sec	- 0.5 sec
O Sprauge-Geer Metrics		Μ	Р	Pass?
X acceleration		14.8	34.7	YES
Y acceleration		15.8	22.1	YES
Z acceleration		50.4	40	NO
Yaw rate		10.4	7.5	YES
Roll rate		40.2	47	NO
Pitch rate		120	51.5	NO
P ANOVA Metrics		Mean	SD	Pass?
X acceleration/Peak		0.0	0.27	YES
Y acceleration/Peak		-0.02	0.21	YES
Z acceleration/Peak		0.01	0.36	NO
Yaw rate		-0.04	0.11	NO
Roll rate		0.1	0.59	NO
Pitch rate		-0.12	0.85	NO
Multi-Channel Weighting Factors		Time inter	val [0 sec	; 0.5 sec]
Multi-Channel Weighting Method	X Channel	(0.190111	
Peaks Area I	Y Channel	0.362535		
Area II Inertial Z Channel			0.002645	
		0.362535		
Pitch Channel (0.072564	
			0.009609	
Sprauge-Geer Metrics		Μ	Р	Pass?
All Channels (weighted)		16.5	21.4	YES
ANOVA Metrics		Mean	SD	Pass?
All Channels (weighted)		-0.02	0.22	YES

Table C – Analysis Solution Verification Summary





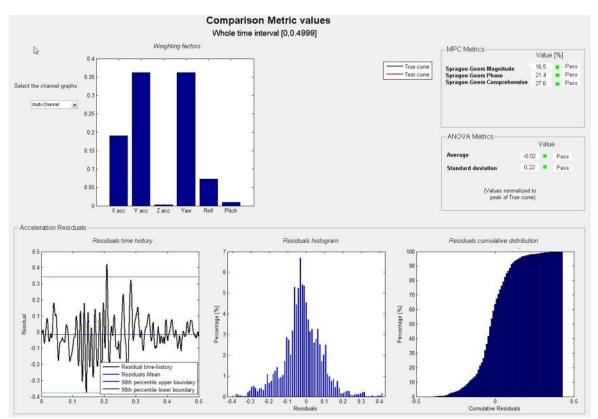
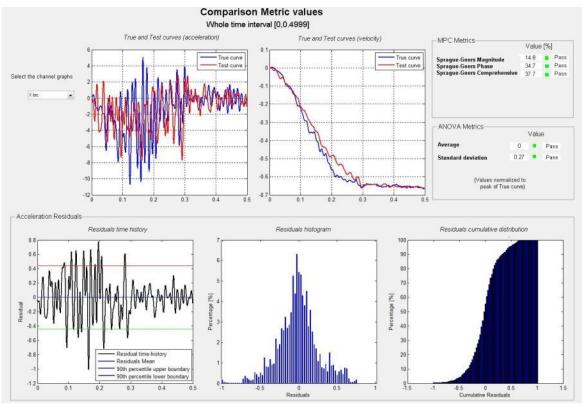
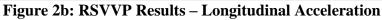


Figure 2a: RSVVP Results – All Channels





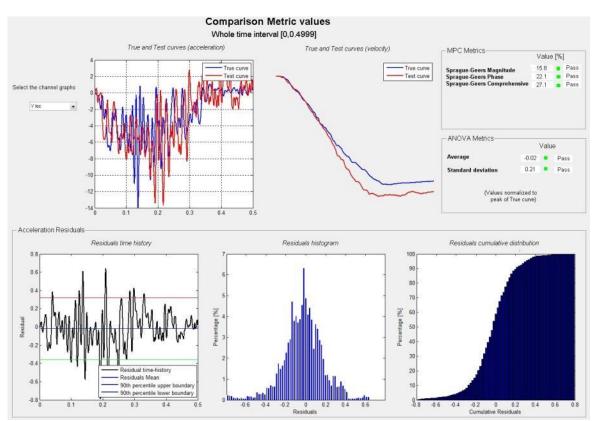
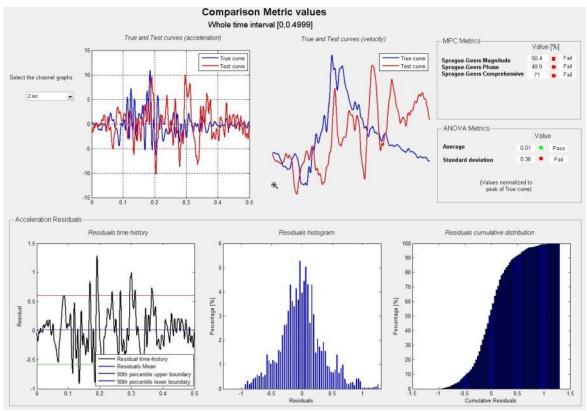
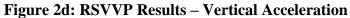


Figure 2c: RSVVP Results – Lateral Acceleration





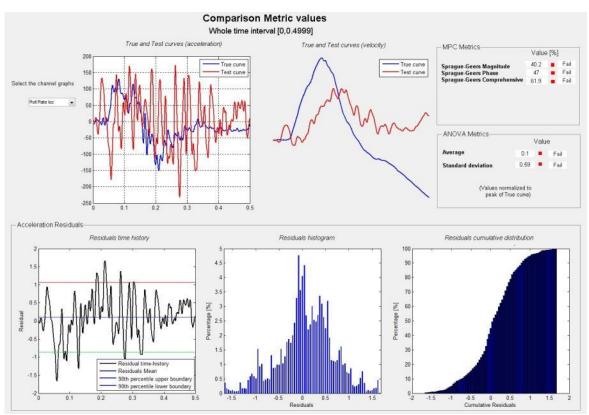
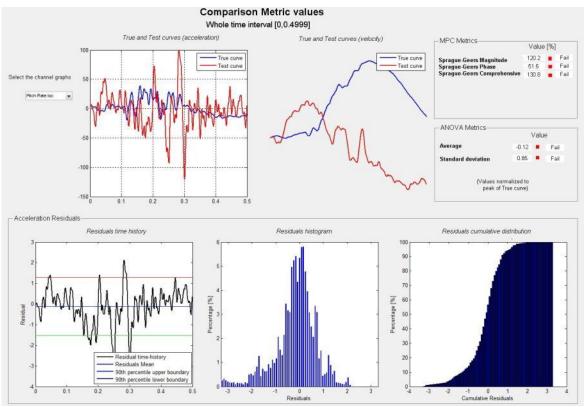


Figure 2e: RSVVP Results – Roll Angle





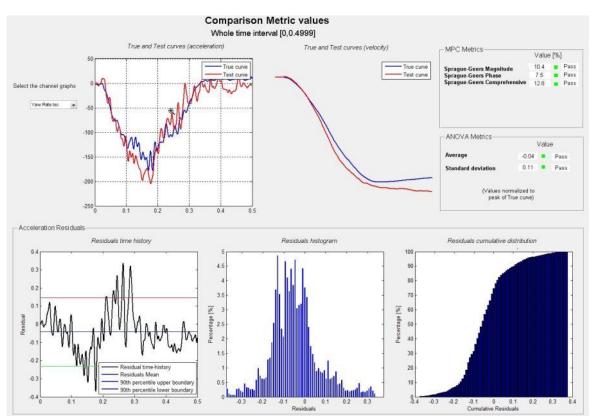


Figure 2g: RSVVP Results – Yaw Angle

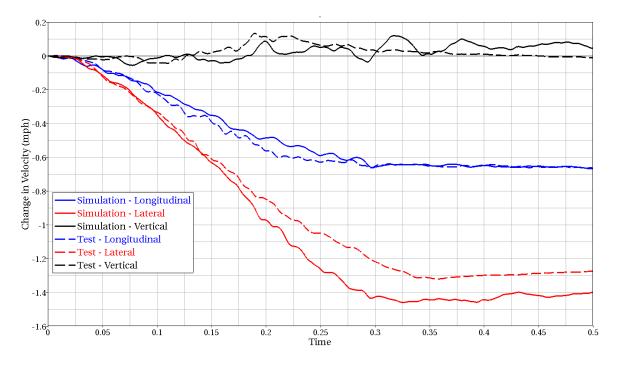


Figure 3: Change in Vehicle Velocities

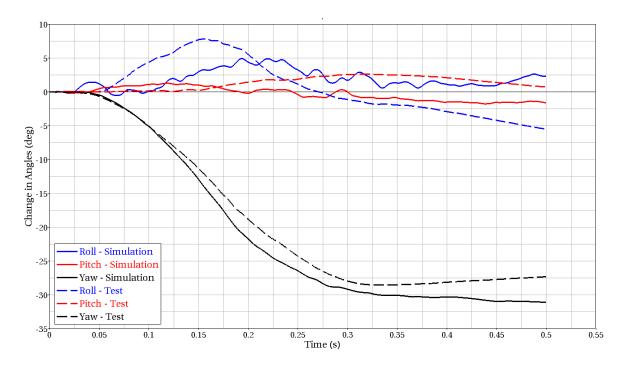


Figure 4: Change in Vehicle Angles

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 820C Vehicle with Midwest Guardrail System Barrier

Table E - Roadside Safety Phenomena Importance Ranking Table (MASH Evaluation)

			Evaluation Criteria	Known Result	Analysis Result	Relative Diff. (%)	Agree?		
Structural Adequacy		A1	Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.	Yes	Yes		YES		
		A2	The relative difference in the maximum dynamic deflection is less than 20 percent.	0.44 m	0.58 m	31	NO		
	8	A3	The relative difference in the time of vehicle-barrier contact is less than 20 percent.	S	0.36 s	15	YES		
A la			A4	The relative difference in the number of broken or significantly bent posts is less than 20 percent.	Yes	Yes		YES	
ctun		A5	Barrier did not fail (Answer Yes or No).	Yes	Yes		YES		
JUL		A6	There were no failures of connector elements (Answer Yes or No).	No	Yes		NO		
\mathbf{S}		A7	There was no significant snagging between the vehicle wheels and barrier elements (Answer Yes or No).		Yes		YES		
		A8	There was no significant snagging between vehicle body components and barrier elements (Answer Yes or No).	Yes	Yes		YES		
		D	Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone (Answer Yes or No).		Yes		YES		
		F1	The vehicle should remain upright during and after the collision. The maximum pitch & roll angles are not to exceed 75 degrees.	Yes	Yes		YES		
		F2	Maximum vehicle roll – relative difference is less than 20% or absolute difference is less than 5 degrees.	7.8 (0.16s)	4.9 (0.19s)	37% 2.9 deg	YES		
Risk		F3	Maximum vehicle pitch – relative difference is less than 20% or absolute difference is less than 5 deg.		1.25 (0.12s)	51% 1.35 deg	YES		
		F4	Maximum vehicle yaw – relative difference is less than 20% or absolute difference is less than 5 deg.		31.0 (0.5s)	8% 2.5 deg	YES		
Occupant Risk	8		H1	Longitudinal & lateral occupant impact velocities (OIV) should fall below the preferred value of 30 ft/s (9.1 m/s), or at least below the maximum allowed value of 40 ft/s (12.2 m/s)	Yes	Yes		YES	
ŏ		H2	Longitudinal OIV (m/s) - Relative difference is less than 20%t or absolute difference is less than 2 m/s	3.5	3.1	11% 0.4 m/s	YES		
			H3	Lateral OIV (m/s - Relative difference is less than 20% or absolute difference is less than 2 m/s	5.6	5.4	3% 0.2 m/s	YES	
				I1	Longitudinal & lateral occupant ridedown accelerations (ORA) should fall below the preferred value of 15.0 g, or at least below the maximum allowed value of 20.49 g.	Yes	Yes		YES
			I2	Longitudinal ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g's	6.1	6.2	2% 0.1 g	YES	
		I3	Lateral ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g's	7.9	10.5	33% 2.6 g	YES		
	/ehio ajec	cle tory:	The vehicle rebounded within the exit box. (Answer Yes or No)	Yes	Yes		YES		

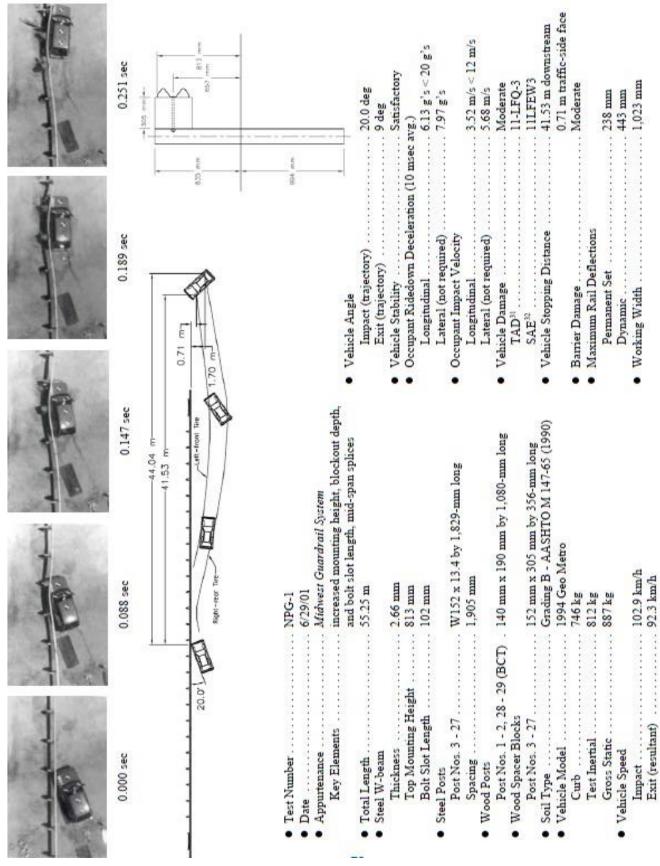


Figure 5 – Full Scale Test Summary

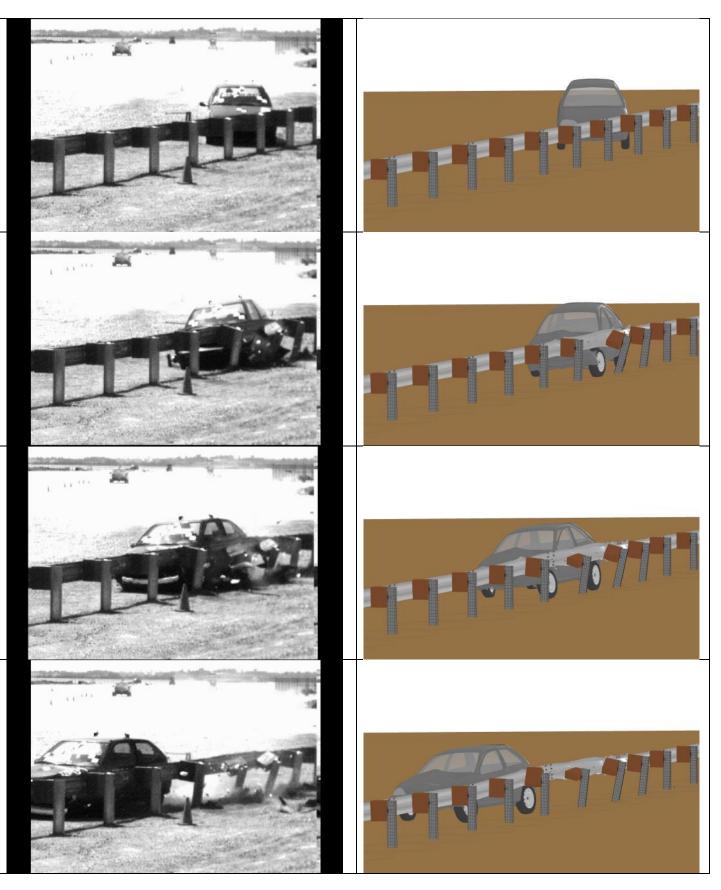


Figure 6a: Sequential Comparisons – Front View

C-64

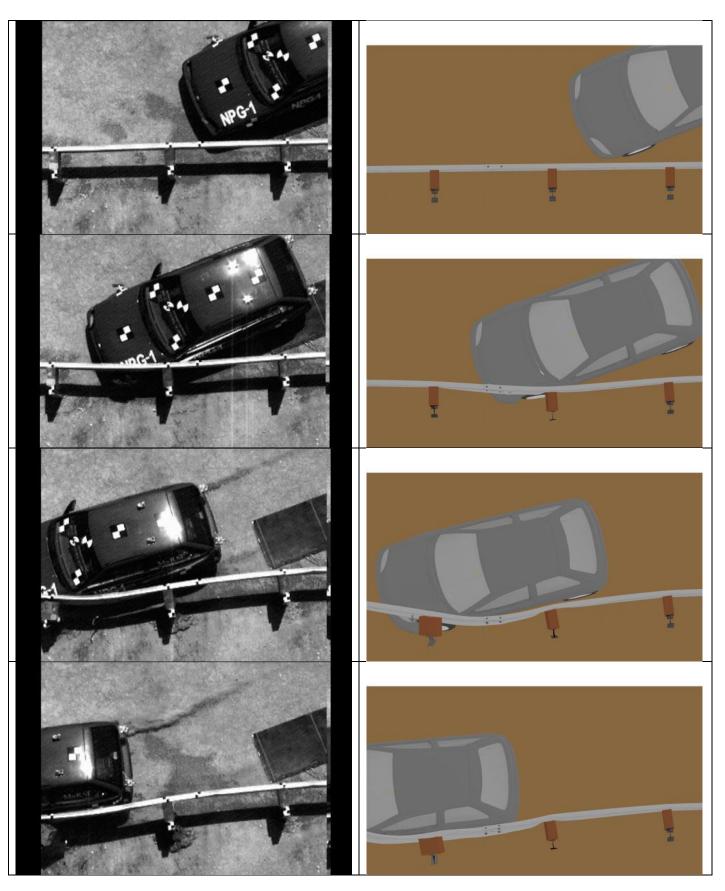


Figure 6b: Sequential Comparisons – Top View

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 820C Vehicle with Midwest Guardrail System Barrier

1	lication and vanuation Summary:		
-	SH08 Test Number		
Table C – AnalysisSolutionVerification			
Table D - RSVVP Results	Do all the time history evaluation scores from the single channel factors result in a satisfactory comparison (i.e., the comparison passes the criterion)?		
	If all the values for Single Channel co did the weighted procedure result in an comparison.		YES
Table E - Roadside Safety Phenomena Importance Ranking Table	Did all the critical criteria in the PIRT Note: Tire deflation was observed in the simulation. This due to the fact that incorporated in the model. This is cor a critical effect on the outcome of the t	he test but not in the tire deflation in not nsidered not to have	YES
Overall	Are the results of Steps I through II YES)? If all three steps result in a comparison can be considered validate the steps results in a negative response considered validated or verified.	a "YES" answer, the ed or verified. If one of	YES

Table F - Composite Verification and Validation Summary:

NOTES:

(none)

Case-6: MGS Barrier Impact with 1100C Vehicle

CCSA VALIDATION/VERIFICATION REPORT

Project:CCSA Longitudinal Barriers on Curved, Superelevated Roadway SectionsComparison Case:1100C Vehicle with MGS BarrierImpact Description:25.4-deg impact into barrier at 97.8 km/h (60.8mph) Governing Criteria:MASH TL-3Report Date:July 2013

Table A – Information Sources:

General Information	Known Solution	Analysis Solution	
Performing Organization	MwRSF	CCSA-GMU	
Test/Run Number	2214NJ-1	130306b	
Vehicle	2002 Kia Rio	CCSA 2010 Yaris_C V1h Model	
Vehicle Mass (lb/kg)	2588 / 1174	2593 / 1176	
Impact Speed (mph/kph)	60.8 / 97.8	62.1 / 100	
Impact Angle (degrees)	25.4	25	

Table B - Evaluation Parameters Summary:

De D - Evaluation I al a	v	¥7 1
Category	Subset	Values
Evaluation Method	MASH (V1, 2009)	
Hardware Type	Longitudinal	
Test Number	3-10	
Test Vehicle	1100C	
Criterion to be	Structural	A - Test article should contain and redirect the vehicle; the vehicle
Applied	Adequacy	should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.
	Occupant Risk	${f D}$ - Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone.
		${f F}$ - The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.
		\mathbf{H} - The occupant impact velocity in the longitudinal direction should not exceed 40 ft/sec and the occupant ride-down acceleration in the longitudinal direction should not exceed 20 G [°] s.
		I - Longitudinal & lateral occupant ridedown accelerations (ORA) should fall below the preferred value of 15.0 g, or at least below the maximum allowed value of 20.49 g.
	Vehicle	For redirective devices the vehicle shall exit within the prescribed box.
	Trajectory	

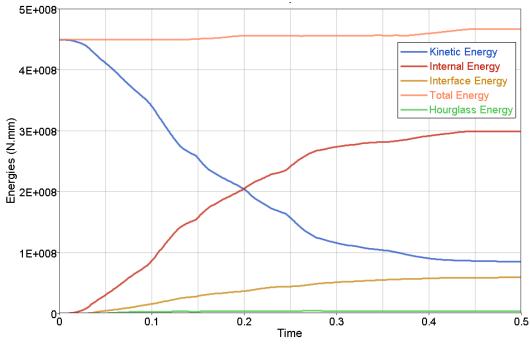
Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 1100C Vehicle with MGS Barrier

Table C – Analysis Solution Verification Summary

Verification Evaluation Criteria	Change (%)	Pass?
Total energy of the analysis solution (i.e., kinetic, potential, contact, etc.) must not vary more than 10 percent from the beginning of the run to the end of the run.	2.64	YES
Hourglass Energy of the analysis solution at the end of the run is less than 5 % of the total initial energy at the beginning of the run	1.70	YES
The part/material with the highest amount of hourglass energy at any time during the run is less than 5 % of the total initial energy at the beginning of the run.	2.05	YES
Mass added to the total model is less than 5 % the total model mass at the start of the run.	< 1%	YES
The part/material with the most mass added had less than 10 % of its initial mass added.	< 1%	YES
The moving parts/materials in the model have less than 5 % of mass added to the initial moving mass of the model.	< 1%	YES
There are no shooting nodes in the solution?	NA	YES
There are no solid elements with negative volumes?	NA	YES

Table D - RSVVP Results

Singl	le Channel Time History Comparison R	esults	Time inter	val [0 sec	e - 0.5 sec]
0 <i>S</i>	O Sprauge-Geer Metrics			P	Pass?
	X acceleration		21	29.6	YES
	Y acceleration		42.6	30.4	NO
	Z acceleration		110.2	43.5	NO
	Yaw rate		1.8	16.6	YES
	Roll rate		1.5	29.9	YES
	Pitch rate		85.7	43.6	NO
P A	NOVA Metrics		Mean	SD	Pass?
	X acceleration/Peak		2.74	20.94	YES
	Y acceleration/Peak		-1.88	44.09	NO
	Z acceleration/Peak		-3.3	71.18	NO
	Yaw rate		-10.25	20.02	NO
	Roll rate		-1.97	36.54	NO
	Pitch rate		6.35	53.36	NO
Mult	i-Channel Weighting Factors		Time inter	val [0 sec	; 0.5 sec]
Mult	i-Channel Weighting Method	X Channel		0.222365	
	Peaks Area I	Y Channel	0.236344		
	Area II Inertial	Z Channel	0.041289		
		Yaw Channel	0.412014		
	Roll Channel		0.052883		
		Pitch Channel		0.035101	
Spra	uge-Geer Metrics		Μ	Р	Pass?
	All Channels (weighted)		23.1	25.5	YES
ANO	VA Metrics		Mean	SD	Pass?
	All Channels (weighted)		-4.1	30.1	YES





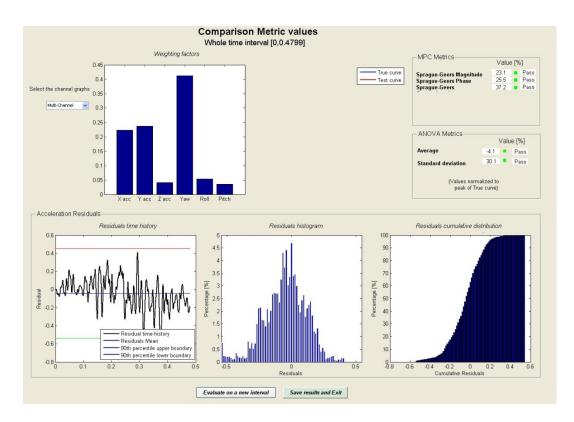


Figure 2a: RSVVP Results – All Channels

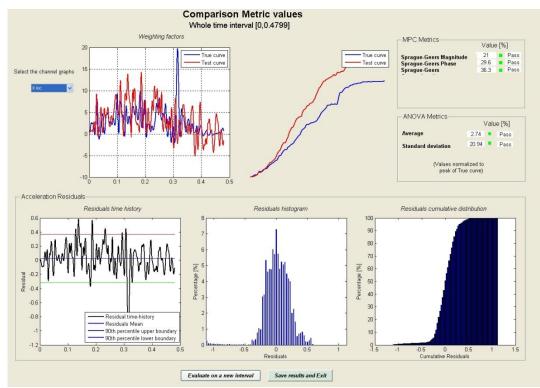


Figure 2b: RSVVP Results – Longitudinal Acceleration

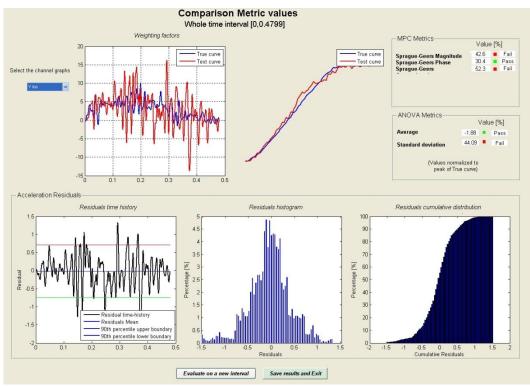
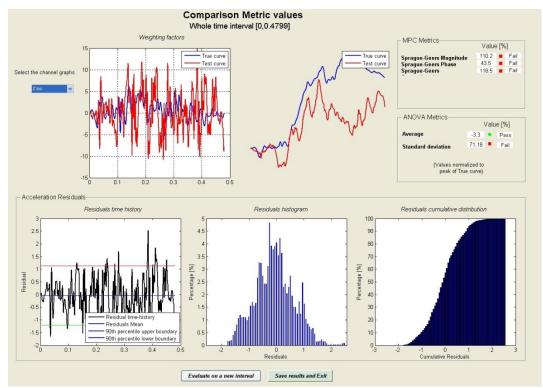


Figure 2c: RSVVP Results – Lateral Acceleration





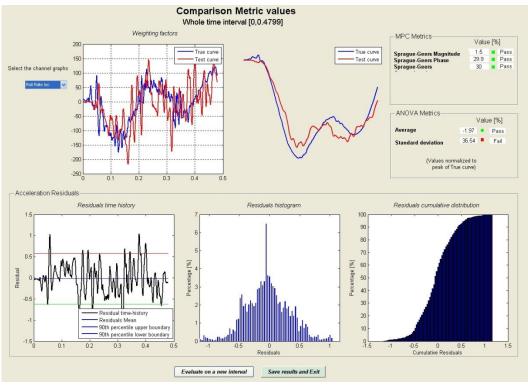
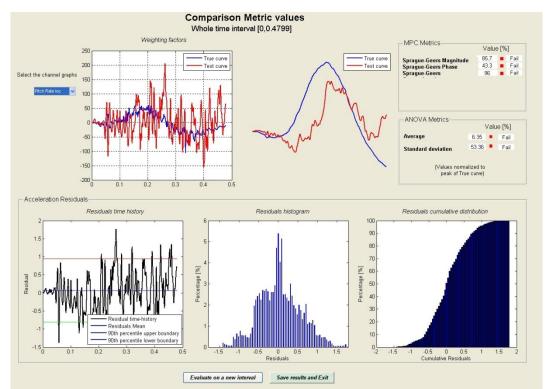


Figure 2e: RSVVP Results – Roll Angle





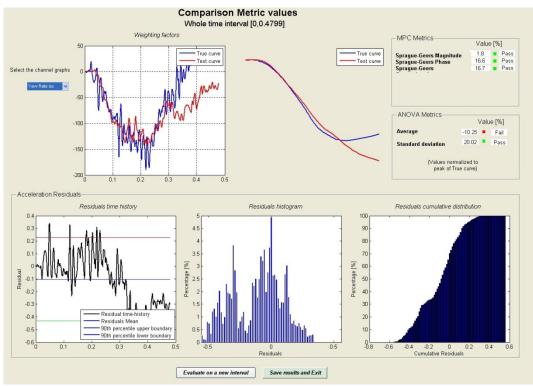
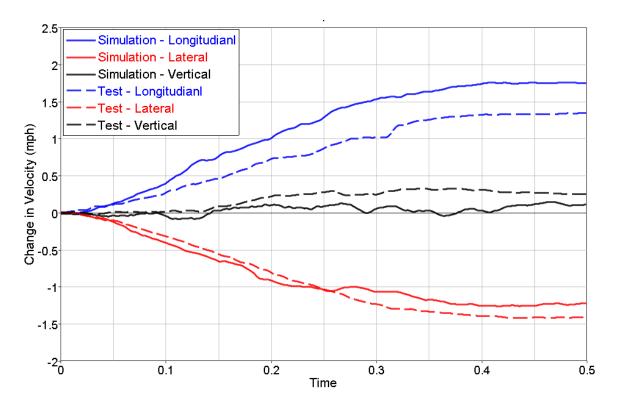
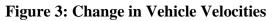


Figure 2g: RSVVP Results – Yaw Angle





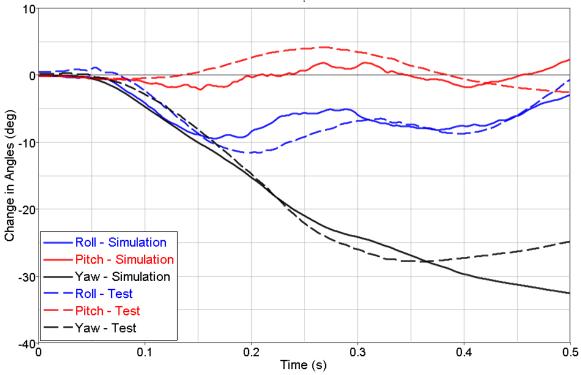


Figure 4: Change in Vehicle Angle

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 1100C Vehicle with MGS Barrier

Table E - Roadside Safety Phenomena Importance Ranking Table (MASH Evaluation)

	Evaluation Criteria			Known Result	Analysis Result	Relative Diff. (%)	Agree?
Structural Adequacy		A1	Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.	Yes	Yes		YES
		A2	The relative difference in the maximum dynamic deflection is less than 20 percent.	0.91m	0.82mm	9.9%	YES
		A3	The relative difference in the time of vehicle-barrier contact is less than 20 percent.	0.56s	0.50s	10.7%	YES
		A4	The relative difference in the number of broken or significantly bent posts is less than 20 percent.	3	2		NO
		A5	Barrier did not fail (Answer Yes or No).	Yes	Yes		YES
		A6	There were no failures of connector elements (Answer Yes or No).	No	No		YES
S		A7	There was no significant snagging between the vehicle wheels and barrier elements (Answer Yes or No).	No	No		YES
		A8	There was no significant snagging between vehicle body components and barrier elements (Answer Yes or No).	No	No		YES
	D		Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone (Answer Yes or No).	NO	No		YES
		F1	The vehicle should remain upright during and after the collision. The maximum pitch & roll angles are not to exceed 75 degrees.	Yes	Yes		YES
		F2	Maximum vehicle roll – relative difference is less than 20% or absolute difference is less than 5 degrees.	11.70 (0.5s)	10.74 (0.5s)	8.20% 0.96	YES
		F3	Maximum vehicle pitch – relative difference is less than 20% or absolute difference is less than 5 deg.	5.33 (0.5s)	2.66 (0.5s)	50.09% 2.67	YES
Risk		F4	Maximum vehicle yaw – relative difference is less than 20% or absolute difference is less than 5 deg.	27.94 (0.5s)	35.58 (0.5s)	21.47% 7.64	No
Occupant Risk	•	H1	Longitudinal & lateral occupant impact velocities (OIV) should fall below the preferred value of 30 ft/s (9.1 m/s), or at least below the maximum allowed value of 40 ft/s (12.2 m/s)	Yes	Yes		YES
Ос		H2	Longitudinal OIV (m/s) - Relative difference is less than 20%t or absolute difference is less than 2 m/s	4.52	5.59	19.12% 1.07	YES
		H3	Lateral OIV (m/s - Relative difference is less than 20% or absolute difference is less than 2 m/s	5.22	5.27	0.95% 0.05	YES
		I1	Longitudinal & lateral occupant ridedown accelerations (ORA) should fall below the preferred value of 15.0 g, or at least below the maximum allowed value of 20.49 g.	Yes	Yes		YES
		I2	Longitudinal ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g's	16.14	11.43	29.1% 4.71	NO
		I3	Lateral ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g's	8.37	12.72	34.19% 4.35	NO
	Vehicle Trajectory		The vehicle rebounded within the exit box. (Answer Yes or No)	Yes	Yes	YES	Yes

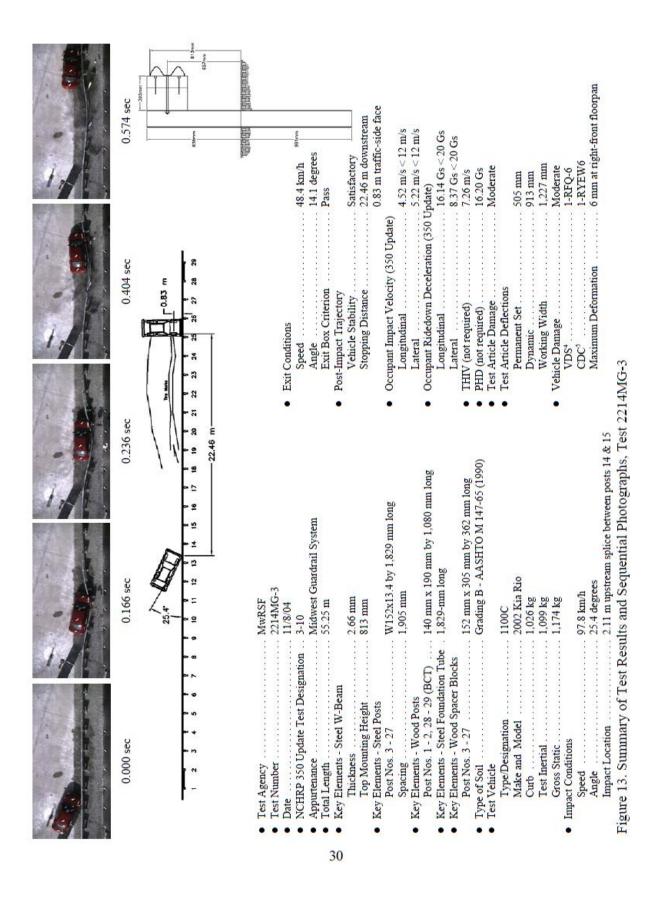


Figure 5: Full-Scale Test Summary

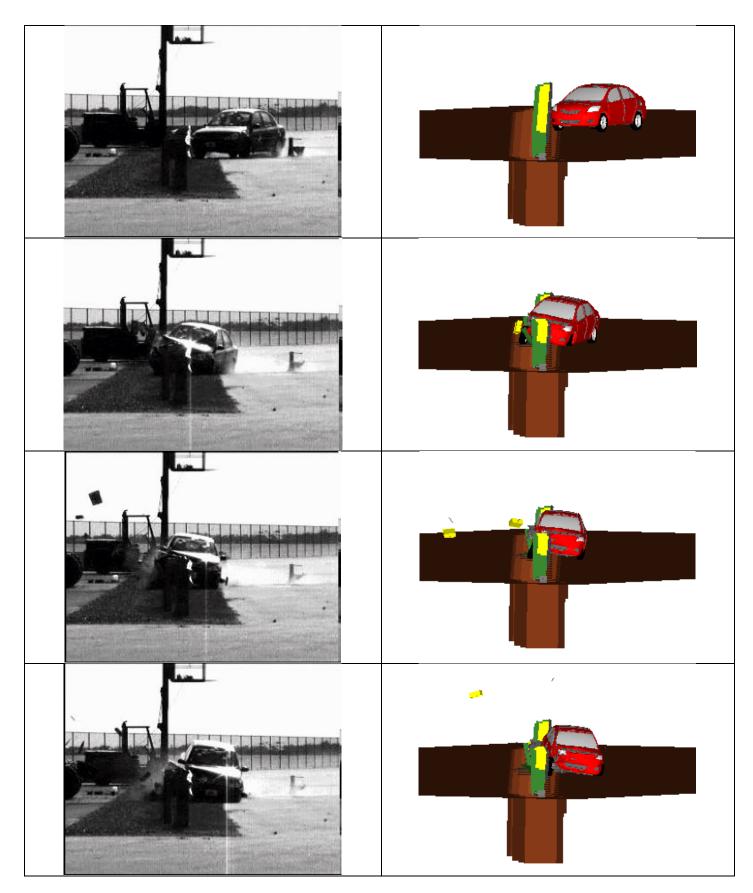


Figure 6a: Sequential Comparisons – Front View

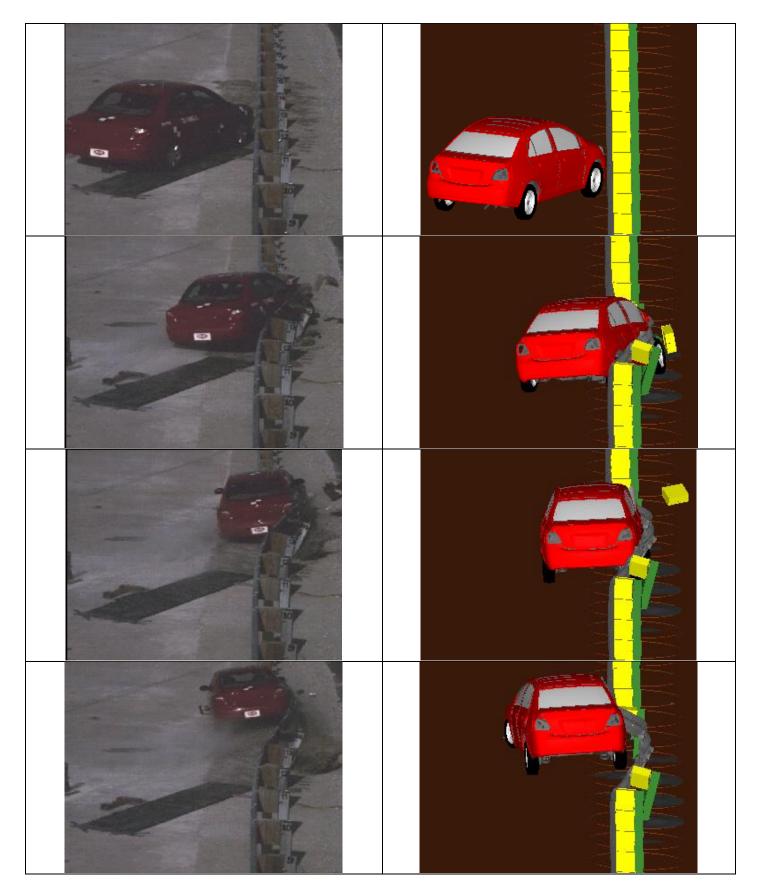


Figure 6b: Sequential Comparisons – Rear View

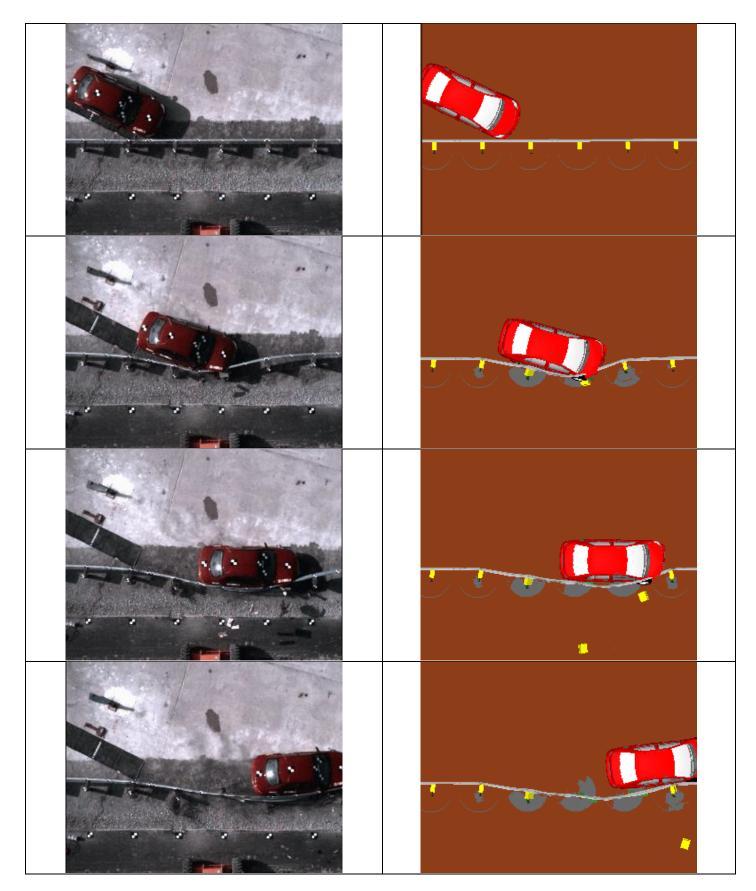


Figure 6c: Sequential Comparisons – Top View

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 1100C Vehicle with New Jersey Safety Shape Barrier

-	SH08 Test Number		
Table C – Analysis Solution Verification	Did all solution verification criteria in table pass?	YES	
Table D - RSVVP Results	P Do all the time history evaluation scores from the single channel factors result in a satisfactory comparison (i.e., the comparison passes the criterion)?		
	If all the values for Single Channel comparison did not pass, did the weighted procedure result in an acceptable. comparison.	YES	
Table E - Roadside Safety Phenomena Importance Ranking Table	Did all the critical criteria in the PIRT Table pass? Note: Tire deflation was observed in the test but not in the simulation. This due to the fact that tire deflation in not incorporated in the model. This is considered not to have a critical effect on the outcome of the test	NO	
Overall	Are the results of Steps I through III all affirmative (i.e., YES)? If all three steps result in a "YES" answer, the comparison can be considered validated or verified. If one of the steps results in a negative response, the result cannot be considered validated or verified.	NO	

Table F - Composite Verification and Validation Summary:

NOTES:

The vehicle used in the test was a Kia Rio while the one used in the simulation was a Toyota Yaris. These two vehicles meet the MASH requirements and are similar in mass and overall geometry. The Yaris bumper however is higher which let some differences in the results between the test and simulation.

Case-7: MGS Barrier Impact with 2270P Vehicle

CCSA VALIDATION/VERIFICATION REPORT

Project:CCSA Longitudinal Barriers on Curved, Superelevated Roadway SectionsComparison Case:2270P (Pickup Truck) with MGS BarrierImpact Description:25.5-deg impact into barrier at 101.1 km/h (62.82 mph)Governing Criteria:MASH TL-3Report Date:March 2013

Table A – Information Sources:

General Information	Known Solution	Analysis Solution
Performing Organization	MwRSF	CCSA-GMU
Test/Run Number	TRP-03-171-06	s130411a
Vehicle	Dodge Ram 1500 Quad Cab	Silverado C
Vehicle Mass (lb/kg)	5000 / 2268	4918 / 2231
Impact Speed (mph/kph)	62.82 / 101.1	62.82 / 101.1
Impact Angle (degrees)	25.5	25.5

Table B - Evaluation Parameters Summary:

Category	Subset	Values
Evaluation Method	MASH (V1, 2009)	
Hardware Type	Longitudinal	
Test Number	3-11	
Test Vehicle	2270C	
Criterion to be Applied	Structural Adequacy	${\bf A}$ - Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.
	Occupant Risk	${f D}$ - Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone.
		\mathbf{F} - The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.
		H - The occupant impact velocity in the longitudinal direction should not exceed 40 ft/sec and the occupant ride-down acceleration in the longitudinal direction should not exceed 20 G [°] s.
		I - Longitudinal & lateral occupant ridedown accelerations (ORA) should fall below the preferred value of 15.0 g, or at least below the maximum allowed value of 20.49 g.
	Vehicle Trajectory	For redirective devices the vehicle shall exit within the prescribed box.

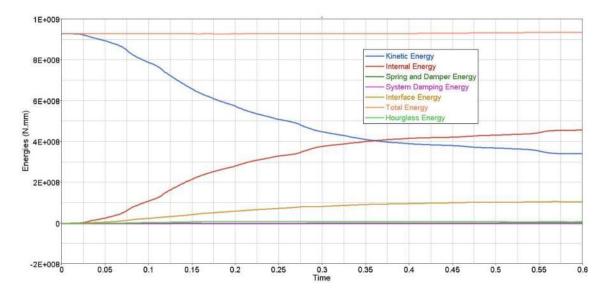
Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 2270P (Pickup Truck) with MGS Barr

Table C – Analysis Solution Verification Summary

Verification Evaluation Criteria	Change (%)	Pass?
Total energy of the analysis solution (i.e., kinetic, potential, contact, etc.) must not vary more than 10 percent from the beginning of the run to the end of the run.	1.07%	YES
Hourglass Energy of the analysis solution at the end of the run is less than 5 % of the total initial energy at the beginning of the run	< 1%	YES
The part/material with the highest amount of hourglass energy at any time during the run is less than 5 % of the total initial energy at the beginning of the run.	< 1%	YES
Mass added to the total model is less than 5 % the total model mass at the start of the run.	< 1%	YES
The part/material with the most mass added had less than 10 % of its initial mass added.	< 1%	YES
The moving parts/materials in the model have less than 5 % of mass added to the initial moving mass of the model.	< 1%	YES
There are no shooting nodes in the solution?	NA	YES
There are no solid elements with negative volumes?	NA	YES

Table D - RSVVP Results

-	<u>gle Channel Time History Comparison R</u>	esults	Time interval [0 sec - 0.67 s			
	Sprauge-Geer Metrics		М	P	Pass?	
	X acceleration		45	40	NO	
	Y acceleration		13.2	27.6	YES	
	Z acceleration		146.8	45.4	NO	
	Yaw rate		13.4	11.7	NO	
	Roll rate		9.6	52.7	NO	
	Pitch rate		251.3	48	YES	
Р	ANOVA Metrics		Mean	SD	Pass?	
	X acceleration/Peak		-1.92	39.08	NO	
	Y acceleration/Peak		5.81	35.92	NO	
	Z acceleration/Peak		1.09	65.76	NO	
	Yaw rate		0.79	20.97	NO	
	Roll rate		10.04	51.73	NO	
	Pitch rate		1.45	119.09	YES	
Mı	ilti-Channel Weighting Factors		Time inter	val [0 sec	; 0.67 sec]	
Mı	ilti-Channel Weighting Method	X Channel	0.206777873			
	Peaks Area I	Y Channel	annel 0.275396472		2	
	Area II Inertial	Z Channel	0.017825655			
		Yaw Channel	0.441018937			
	Roll Channel			0.032383125		
	Pitch Channel			0.026597937		
Spi	Sprauge-Geer Metrics		M 28.5	P	Pass?	
	All Channels (weighted)			24.8	YES	
AN	ANOVA Metrics		Mean	SD	Pass?	
	All Channels (weighted)		1.9	33.2	YES	





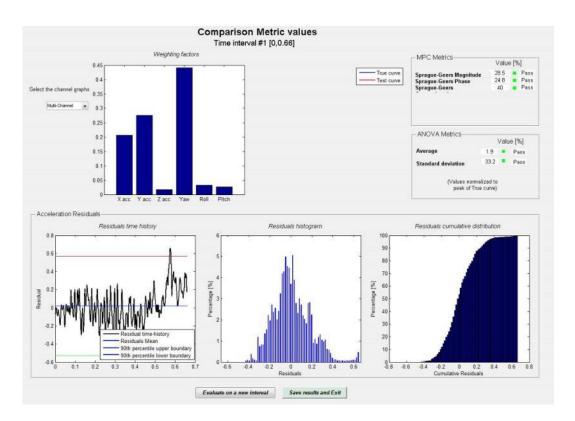


Figure 2a: RSVVP Results – All Channels

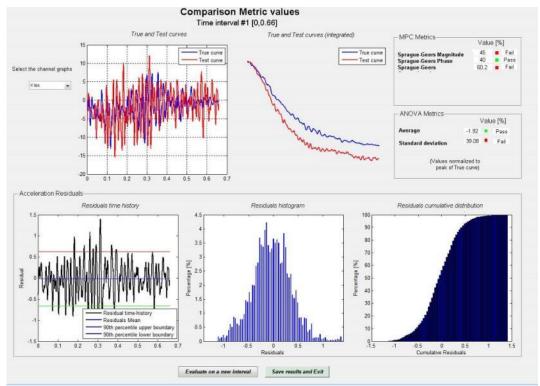


Figure 2b: RSVVP Results – Longitudinal Acceleration

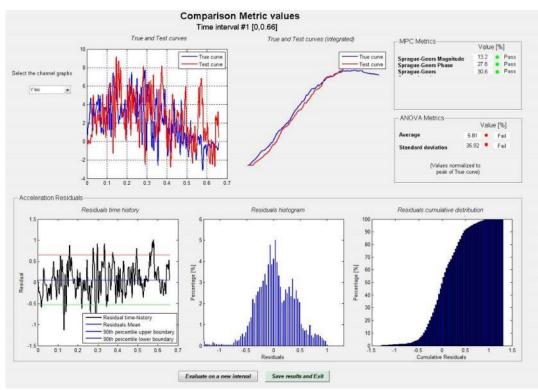
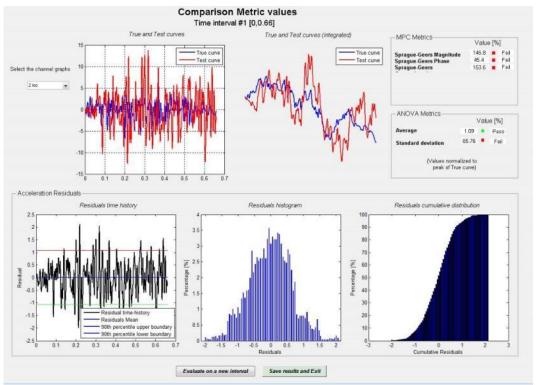
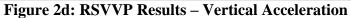


Figure 2c: RSVVP Results – Lateral Acceleration





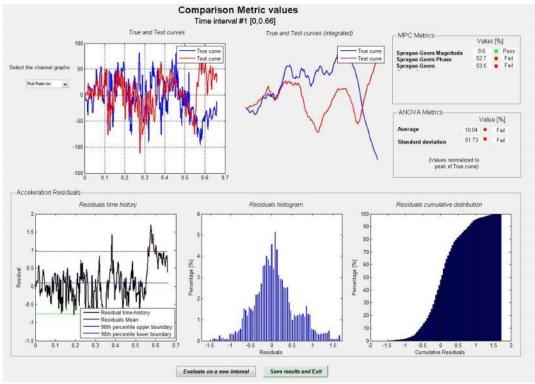
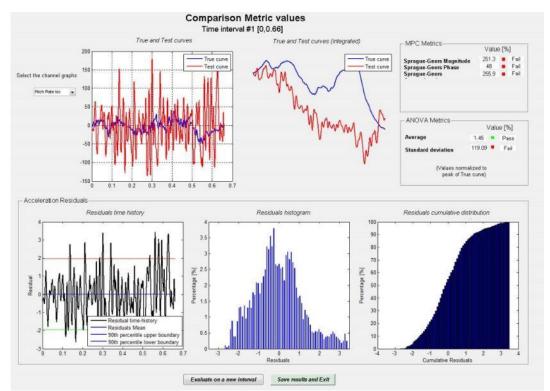


Figure 2e: RSVVP Results – Roll Angle





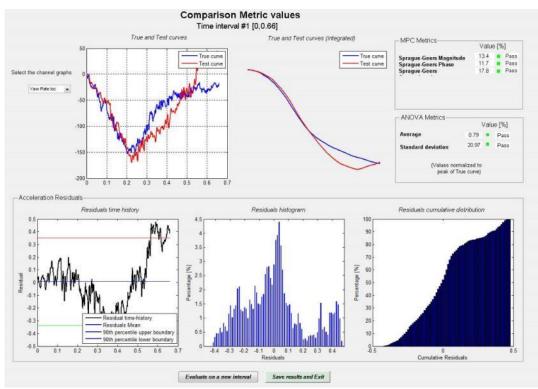


Figure 2g: RSVVP Results – Yaw Angle

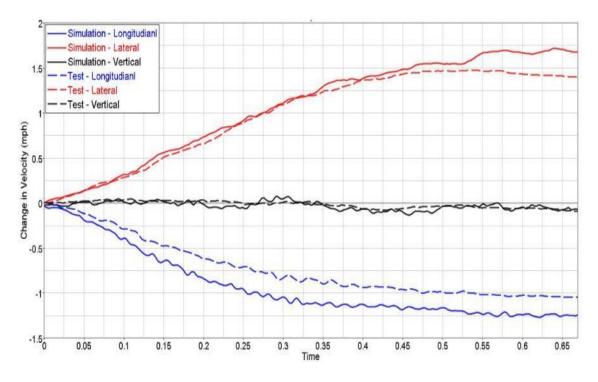


Figure 3: Change in Vehicle Velocities

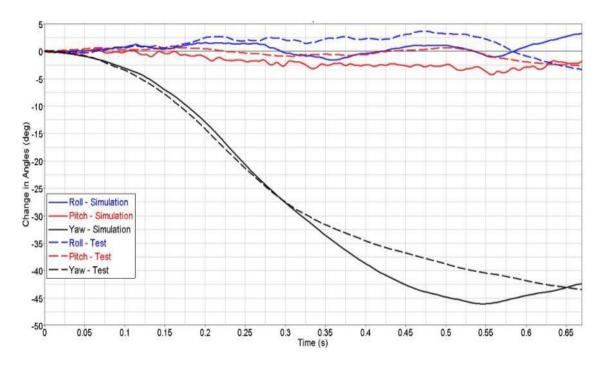


Figure 4: Change in Vehicle Angle

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 2270P (Pickup Truck) with MGS Barrier

Known Analysis Relative **Evaluation Criteria** Agree? Result Result **Diff.** (%) Test article should contain and redirect the vehicle; the vehicle should A1 not penetrate, under-ride, or override the installation although controlled Yes Yes YES lateral deflection of the test article is acceptable. The relative difference in the maximum dynamic deflection is less than Structural Adequacy A2 1.11 m 1.03 m 7% YES 20 percent. The relative difference in the time of vehicle-barrier contact is less than A3 0.72 s 0.63 s 12% 20 percent. The relative difference in the number of broken or significantly bent 3 3 YES A4 posts is less than 20 percent. Barrier did not fail (Answer Yes or No). Yes Yes YES A5 There were no failures of connector elements (Answer Yes or No). A6 Yes Yes YES There was no significant snagging between the vehicle wheels and Yes Yes YES A7 barrier elements (Answer Yes or No). There was no significant snagging between vehicle body components A8 Yes Yes YES and barrier elements (Answer Yes or No). Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant D YES Yes Yes compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone (Answer Yes or No). The vehicle should remain upright during and after the collision. The YES F1 Yes Yes maximum pitch & roll angles are not to exceed 75 degrees. Maximum vehicle roll – relative difference is less than 20% or absolute 3.58 3.49 3% YES F2 difference is less than 5 degrees. 0.09 deg (.68s)(.68s)Maximum vehicle pitch – relative difference is less than 20% or absolute 2.86 4.17 31.4% F3 YES difference is less than 5 deg. 1.31 deg (.68s)(.68s)Maximum vehicle yaw - relative difference is less than 20% or absolute 43.74 46.01 **Occupant Risk** 4.9% F4 YES difference is less than 5 deg. 2.27 deg (.68s)(.68s)Longitudinal & lateral occupant impact velocities (OIV) should fall H1 below the preferred value of 30 ft/s (9.1 m/s), or at least below the Yes Yes YES maximum allowed value of 40 ft/s (12.2 m/s) Longitudinal OIV (m/s) - Relative difference is less than 20%t or 16.4% I H2 4.67 5.59 YES absolute difference is less than 2 m/s 0.92 m/s Lateral OIV (m/s) - Relative difference is less than 20% or absolute 6.5% 5.09 4.76 YES H3 difference is less than 2 m/s 0.33 m/s Longitudinal & lateral occupant ridedown accelerations (ORA) should I1 fall below the preferred value of 15.0 g, or at least below the maximum Yes Yes YES allowed value of 20.49 g. Longitudinal ORA (g) - Relative difference is less than 20% or 31.9% 8.23 12.10 YES I2 absolute difference is less than 4 g's 3.87 g Lateral ORA (g) - Relative difference is less than 20% or absolute 28.4% 6.93 9.68 YES I3 difference is less than 4 g's 2.75 g The vehicle rebounded within the exit box. (Answer Yes or No) Vehicle Yes Yes YES Trajectory

Table E - Roadside Safety Phenomena Importance Ranking Table (MASH Evaluation)

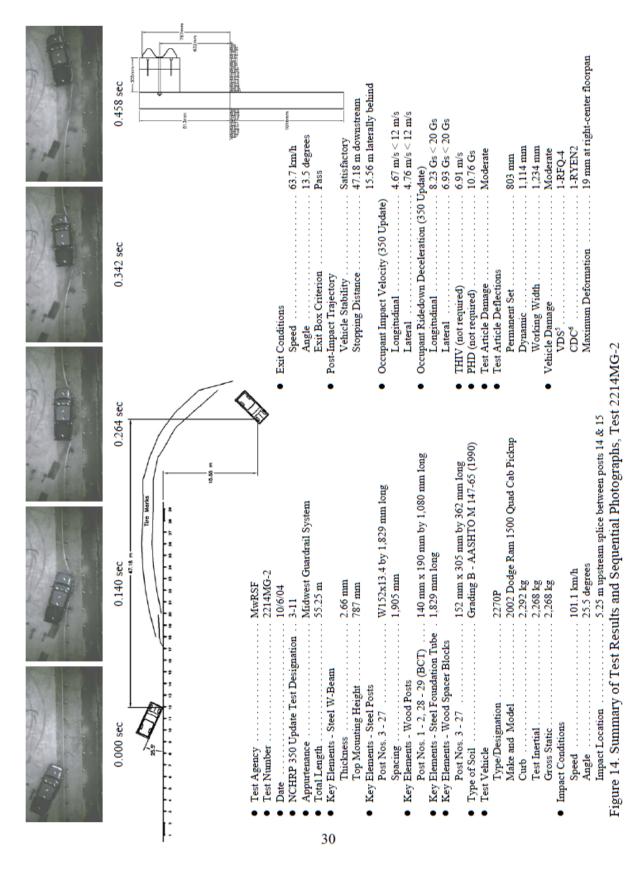


Figure 5: Full-Scale Test Summary

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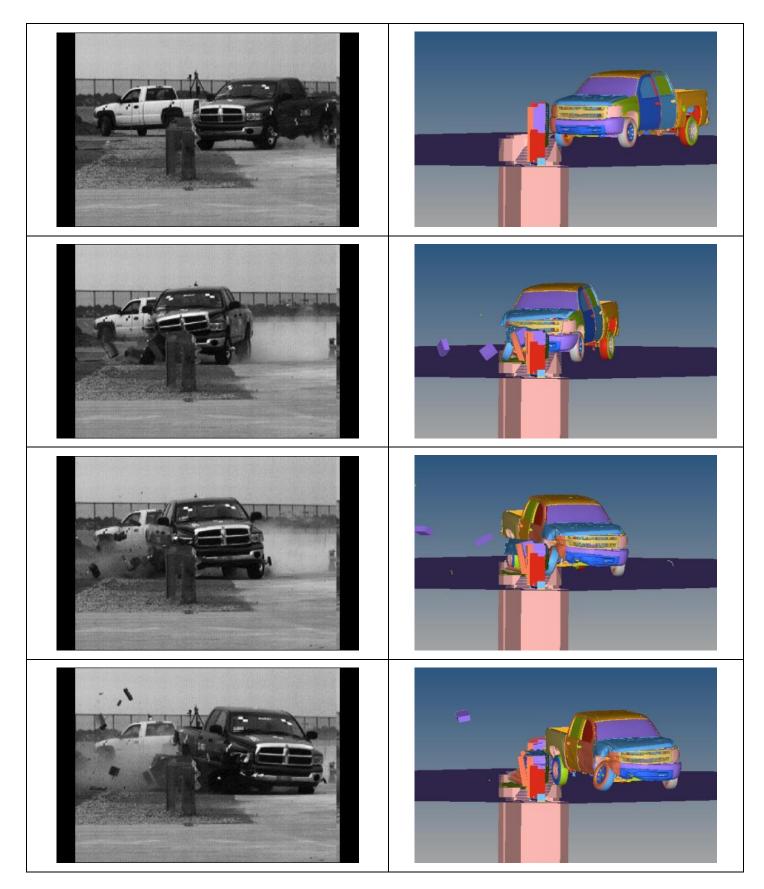


Figure 6a: Sequential Comparisons – Front View

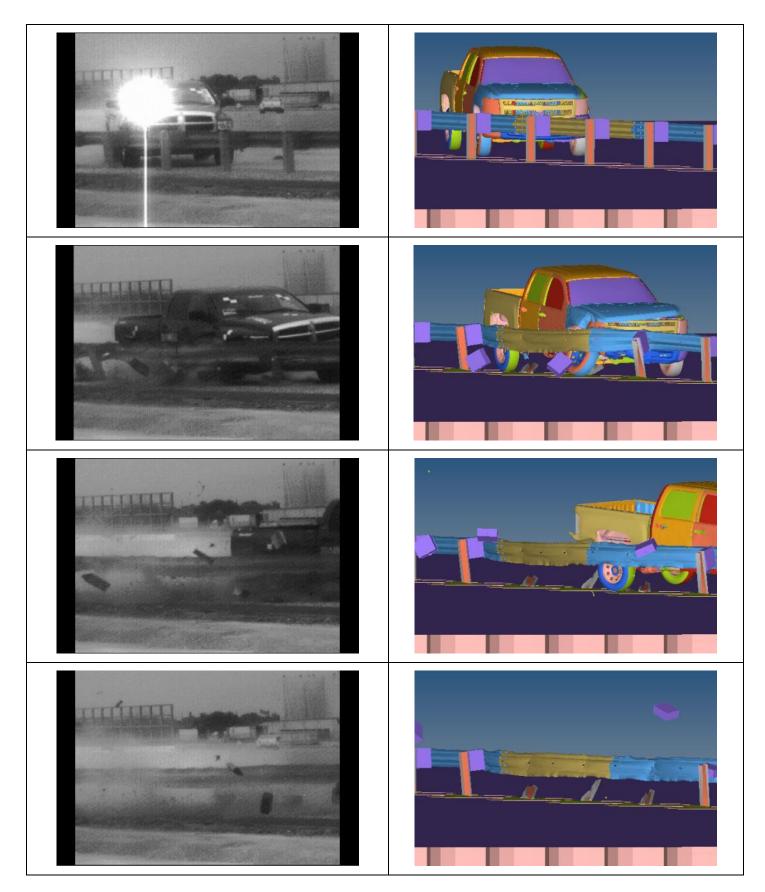


Figure 6b: Sequential Comparisons – Rear View

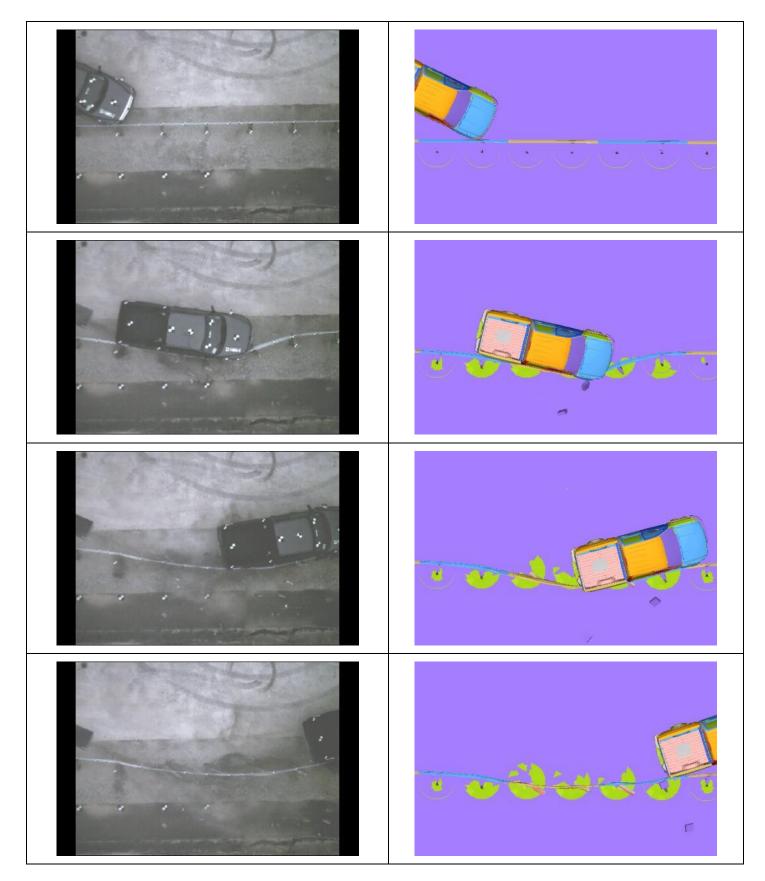


Figure 6c: Sequential Comparisons – Top View

Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections Comparison Case: 2270P (Pickup Truck) with MGS Barrier

List the Report MAS	H08 Test Number	
Table C – AnalysisSolution VerificationSummary	Did all solution verification criteria in table pass?	YES
Table D - RSVVP Results	Do all the time history evaluation scores from the single channel factors result in a satisfactory comparison (i.e., the comparison passes the criterion)?	NO
	If all the values for Single Channel comparison did not pass, did the weighted procedure result in an acceptable comparison.	YES
Table E - RoadsideSafetyPhenomenaImportanceRanking Table	Did all the critical criteria in the PIRT Table pass? Note: Tire deflation was observed in the test but not in the simulation. This due to the fact that tire deflation in not incorporated in the model. This is considered not to have a critical effect on the outcome of the test	YES
Overall	Are the results of Steps I through III all affirmative (i.e., YES)? If all three steps result in a "YES" answer, the comparison can be considered validated or verified. If one of the steps results in a negative response, the result cannot be considered validated or verified.	YES

Table F - Composite Verification and Validation Summary:

NOTES:

(none)