

## **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
<b>Evaluation Method</b>	MASH (V1, 2009)	
<b>Hardware Type</b>	Longitudinal	
<b>Test Number</b>	3-10	
<b>Test Vehicle</b>	1100C	
<b>Criterion to be Applied</b>	<b>Structural Adequacy</b>	<b>A</b> - 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.
	<b>Occupant Risk</b>	<b>D</b> - 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.
		<b>F</b> - The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.
		<b>H</b> - 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.
		<b>I</b> - 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.
	<b>Vehicle Trajectory</b>	For redirective devices the vehicle shall exit within the prescribed box.

# CCSA VALIDATION/VERIFICATION REPORT

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

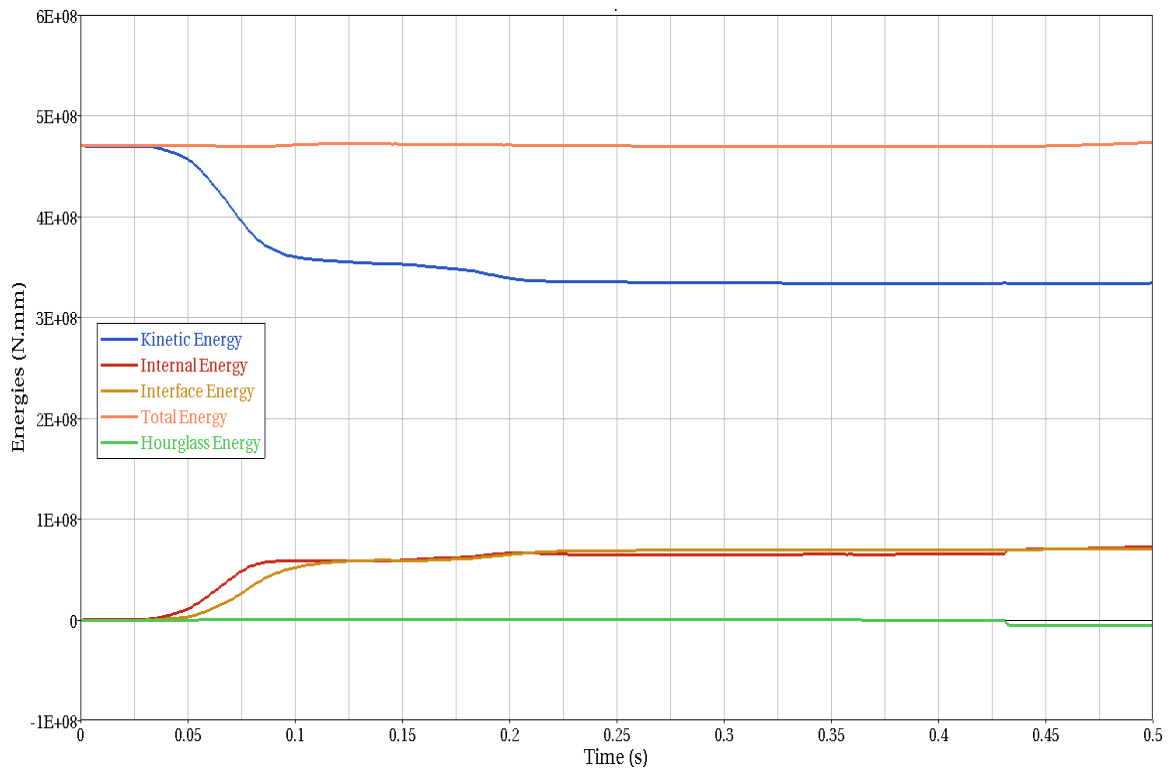
**Table C – Analysis Solution Verification Summary**

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

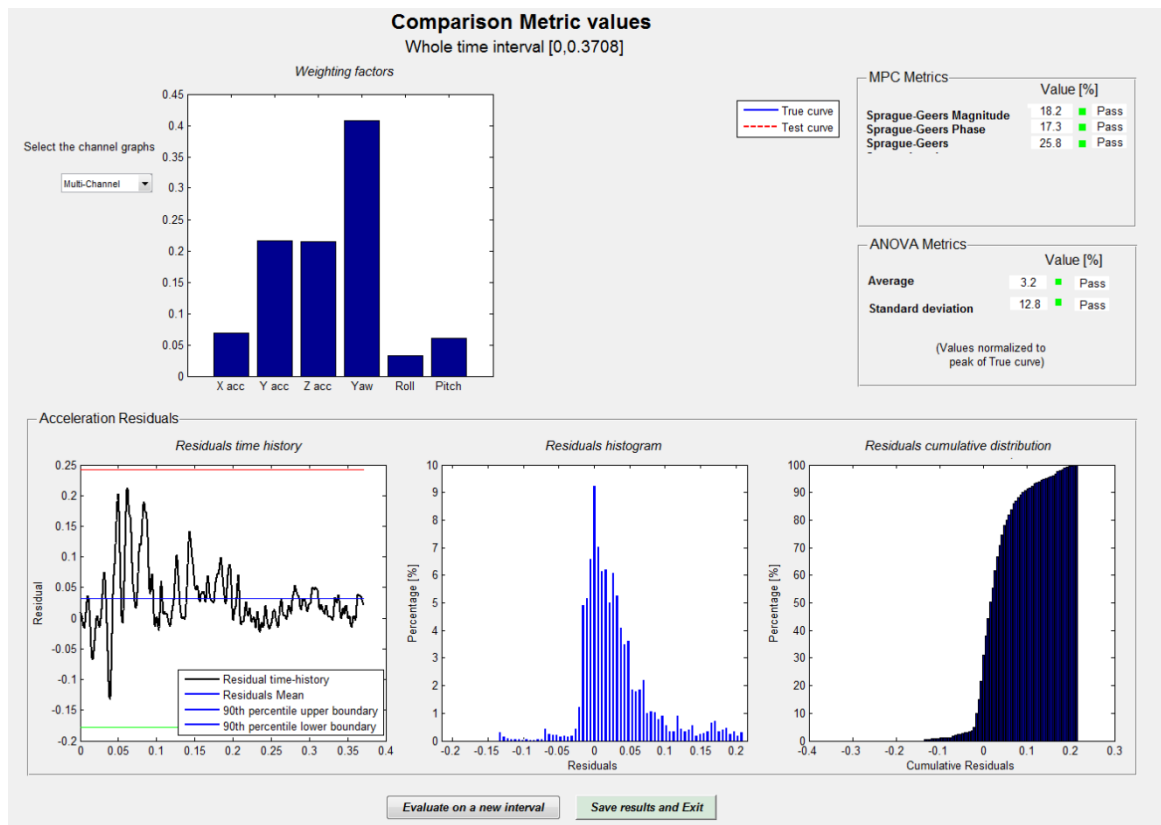
**Table D - RSVVP Results**

Single Channel Time History Comparison Results		Time interval [0 sec - 0.5 sec]		
O	<i>Sprague-Geer Metrics</i>	M	P	Pass?
	X acceleration	7	18.8	YES
	Y acceleration	11.6	18.1	YES
	Z acceleration	37.3	29.9	YES
	Yaw rate	4.4	7.1	YES
	Roll rate	45.6	27.3	NO
	Pitch rate	65.7	31.6	NO
P	<i>ANOVA Metrics</i>	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 interval [0 sec; 0.5 sec]		
Multi-Channel Weighting Method Peaks Area I Area II Inertial	X Channel	0.068377		
	Y Channel	0.2165		
	Z Channel	0.215123		
	Yaw Channel	0.407422		
	Roll Channel	0.032735		
	Pitch Channel	0.059843		
<i>Sprague-Geer Metrics</i>		M	P	Pass?
	All Channels (weighted)	18.2	17.3	YES
<i>ANOVA Metrics</i>		Mean	SD	Pass?
	All Channels (weighted)	3.2	12.8	YES

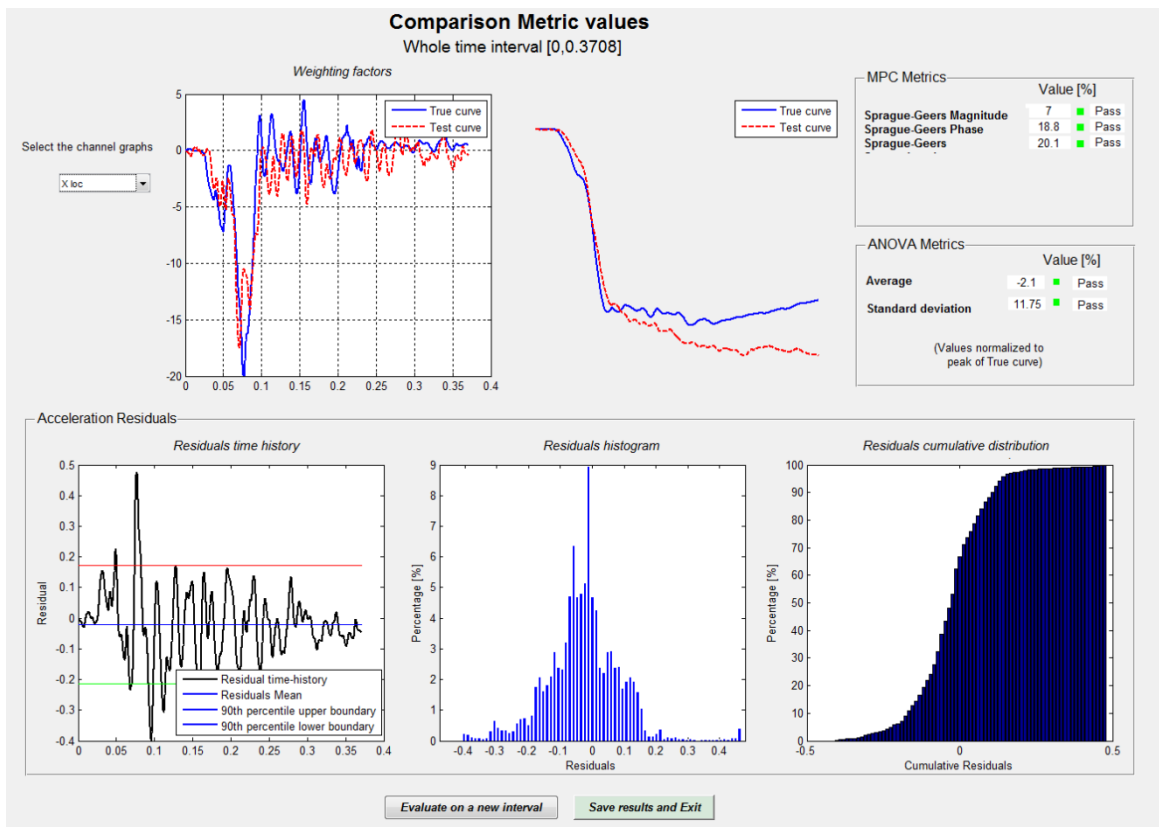




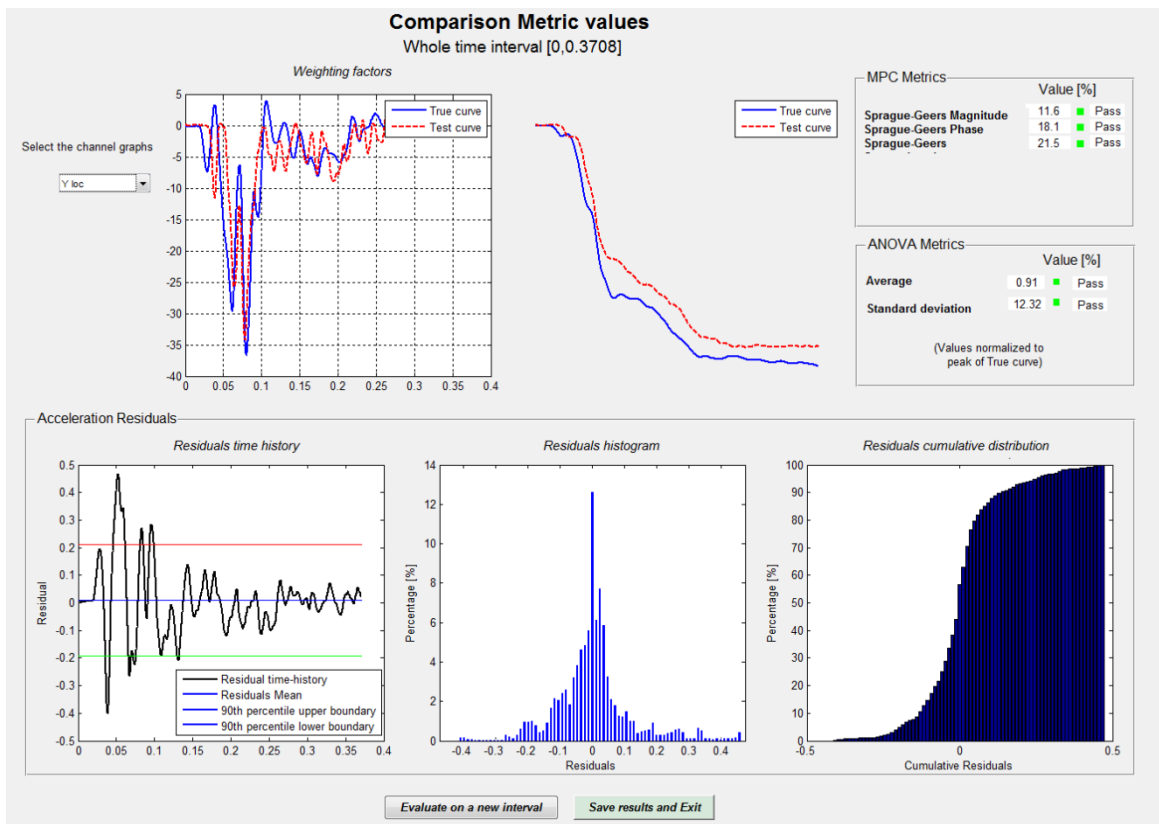
**Figure 1: Simulation Energy Summary**



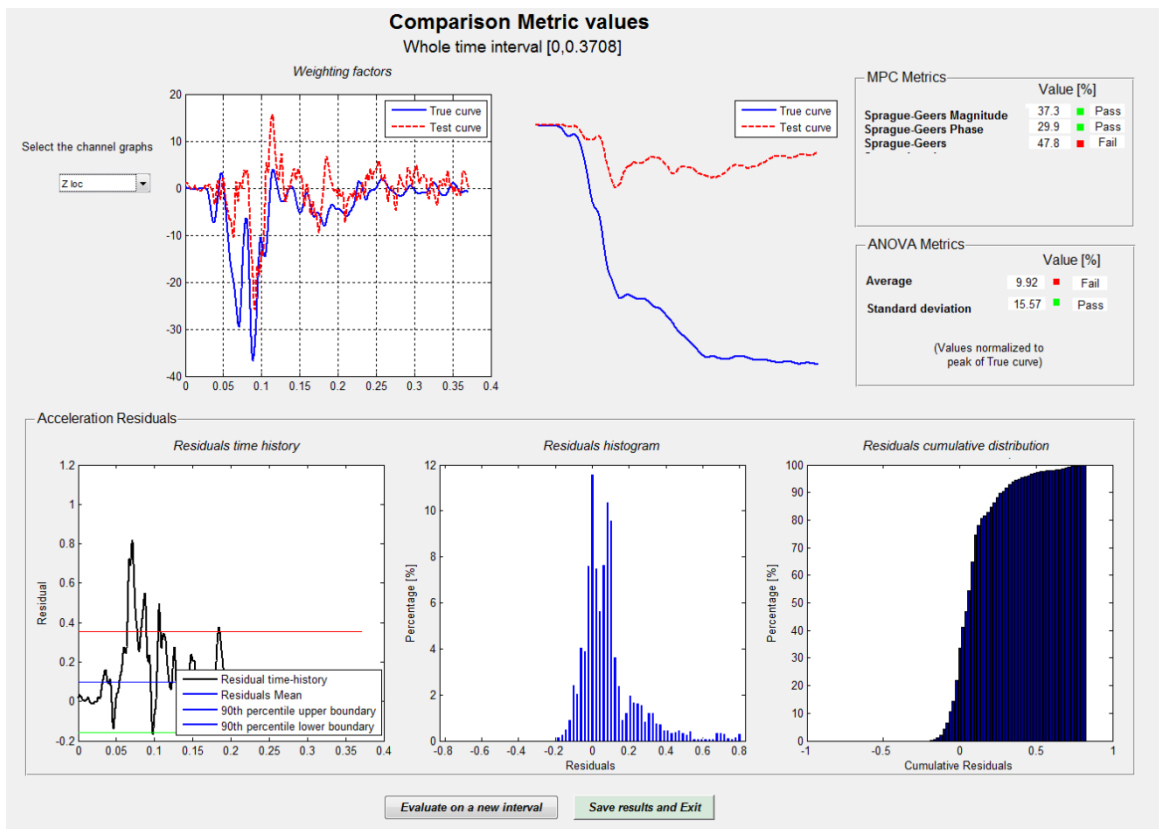
**Figure 2a: RSVVP Results – All Channels**



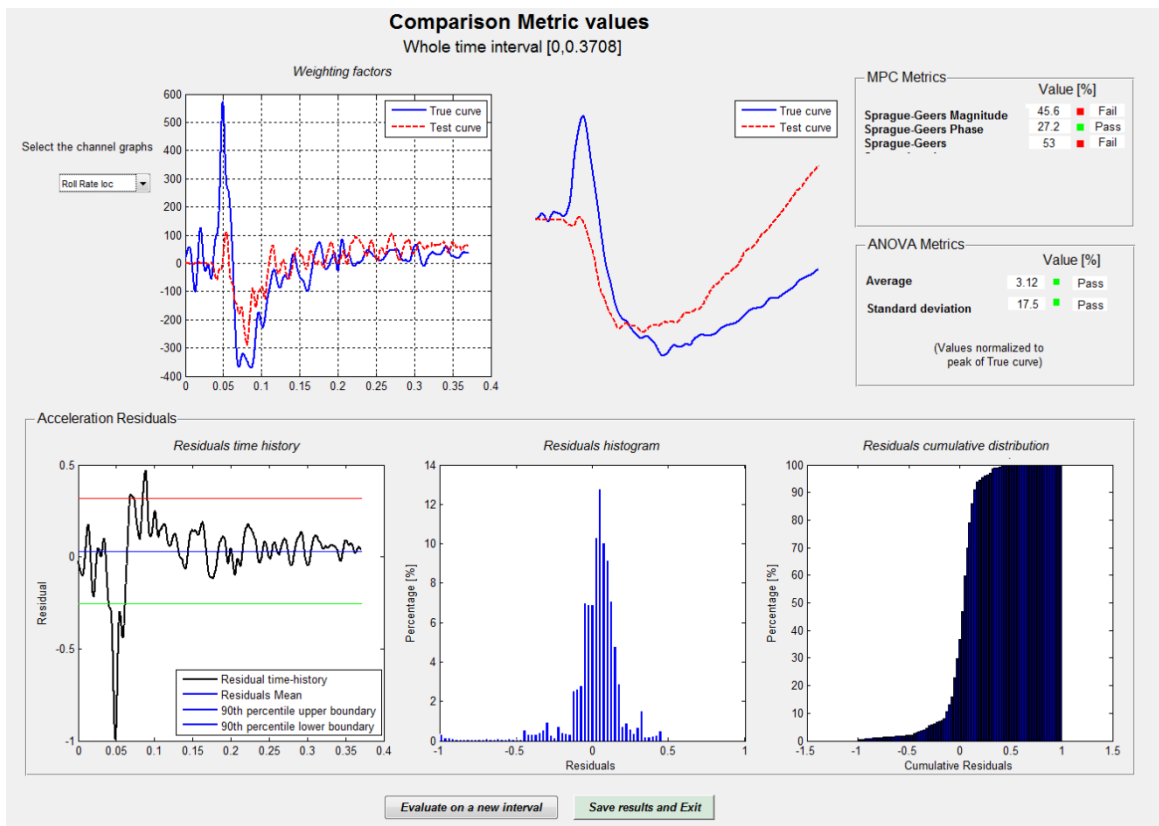
**Figure 2b: RSVVP Results – Longitudinal Acceleration**



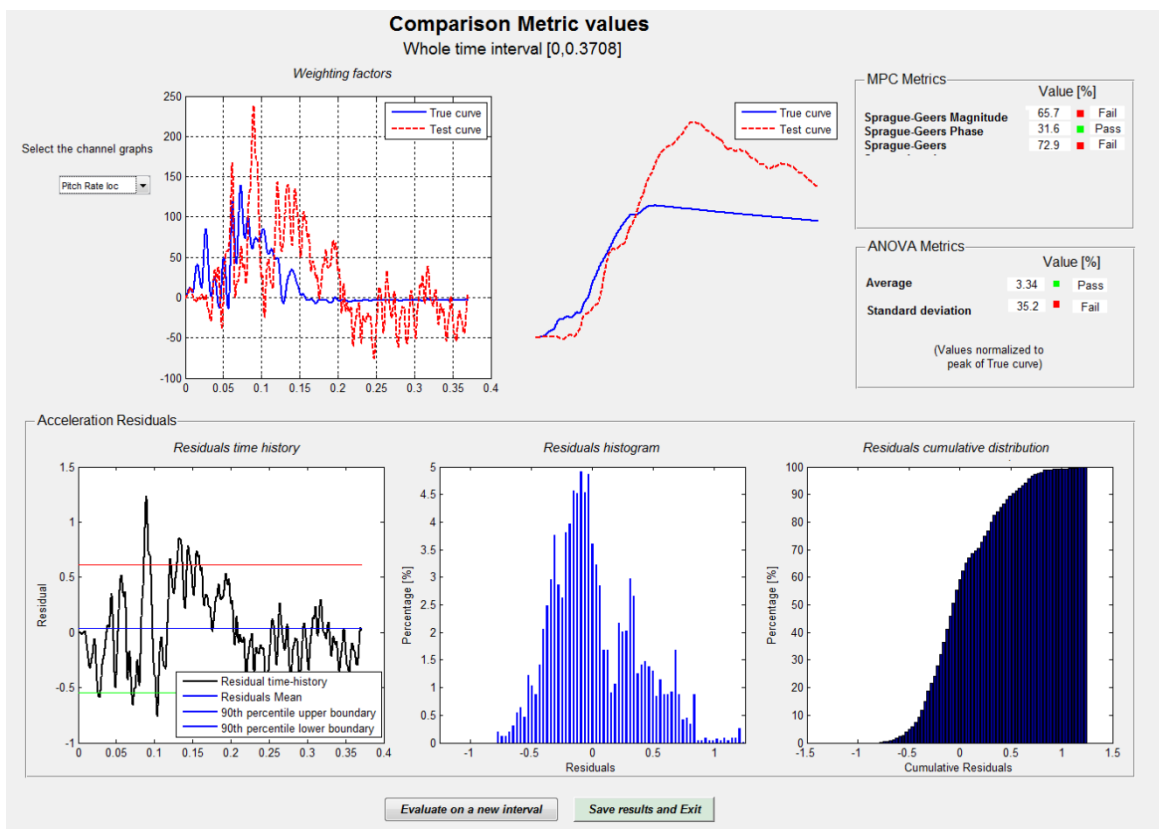
**Figure 2c: RSVVP Results – Lateral Acceleration**



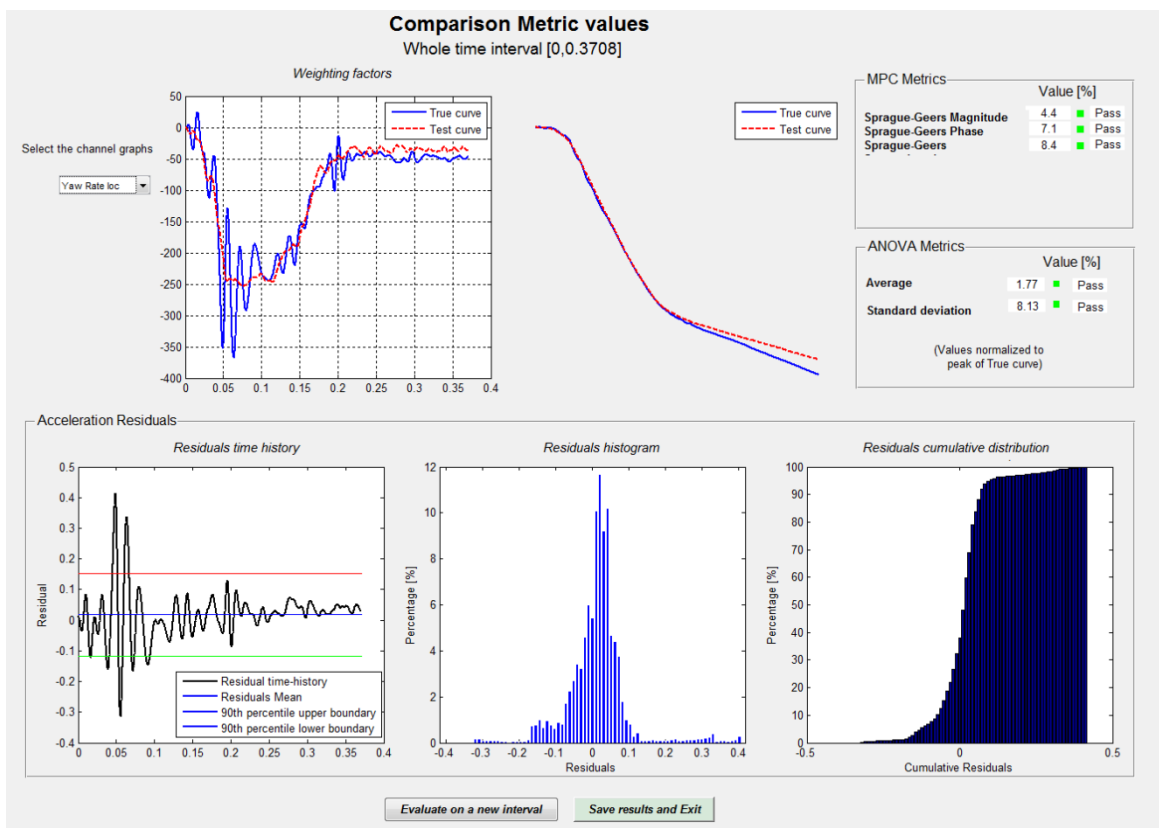
**Figure 2d: RSVVP Results – Vertical Acceleration**



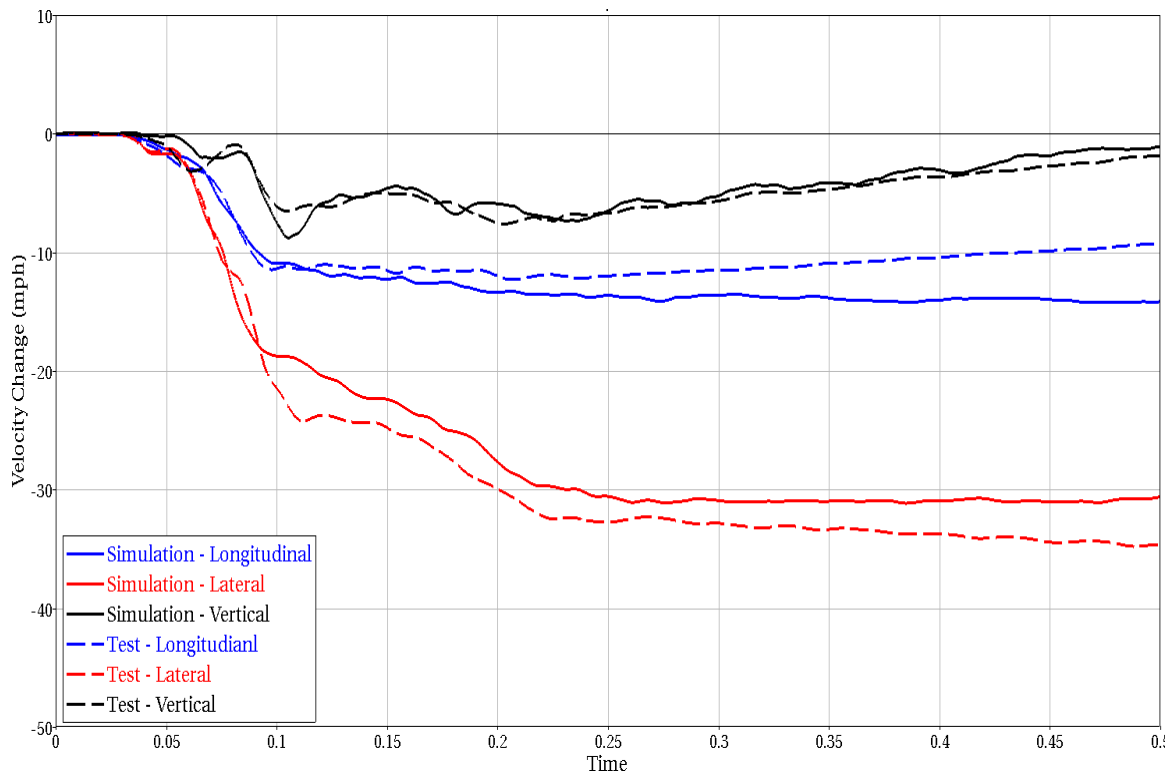
**Figure 2e: RSVVP Results – Roll Angle**



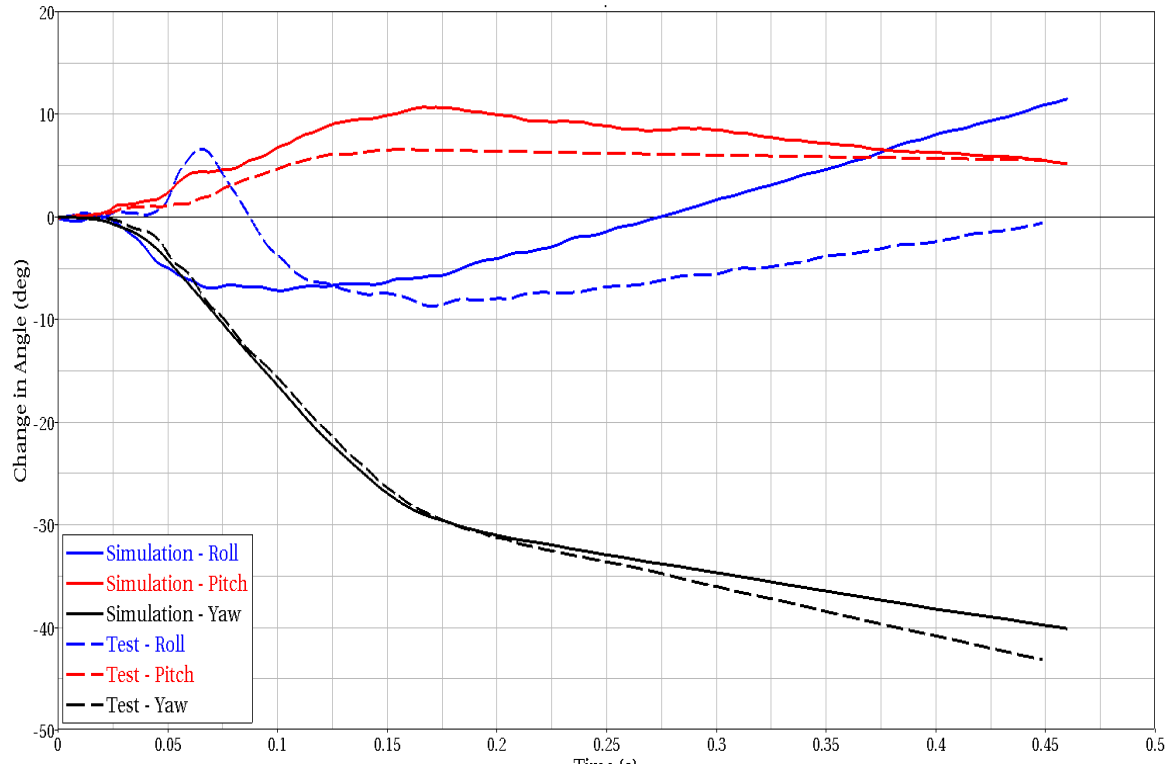
**Figure 2f: RSVVP Results – Pitch Angle**



**Figure 2g: RSVVP Results – Yaw Angle**



**Figure 3: Change in Vehicle Velocities**



**Figure 4: Change in Vehicle Angles**

# CCSA VALIDATION/VERIFICATION REPORT

**Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections**  
**Comparison Case: 1100C 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	A	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.	0.265 m	0.226 s	15	YES	
		A4	The relative difference in the number of broken or significantly bent posts is less than 20 percent.	Yes	Yes		YES	
		A5	Barrier did not fail (Answer Yes or No).	Yes	Yes		YES	
		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).	Yes	Yes		YES	
		A8	There was no significant snagging between vehicle body components and barrier elements (Answer Yes or No).	Yes	Yes		YES	
Occupant Risk	D	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	
		F	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 (.5s)	11 (.5s)	57% 4 deg	YES
			F3	Maximum vehicle pitch – relative difference is less than 20% or absolute difference is less than 5 deg.	10 (.5s)	7 (.5s)	30% 3 deg	YES
	F4		Maximum vehicle yaw – relative difference is less than 20% or absolute difference is less than 5 deg.	43 (.5s)	40 (.5s)	7% 3 deg	YES	
	H	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	
		H2	Longitudinal OIV (m/s) - Relative difference is less than 20% or absolute difference is less than 2 m/s	5.0	4.8	4% 0.2 m/s	YES	
		H3	Lateral OIV (m/s) - Relative difference is less than 20% or absolute difference is less than 2 m/s	10.7	8.7	19% 2 m/s	YES	
	I	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	5.5	2.5	55% 3 g	YES	
		I3	Lateral ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g’s	8.1	8.2	1% 0.1 g	YES	
	Vehicle Trajectory		The vehicle rebounded within the exit box. (Answer Yes or No)		Yes	Yes		YES

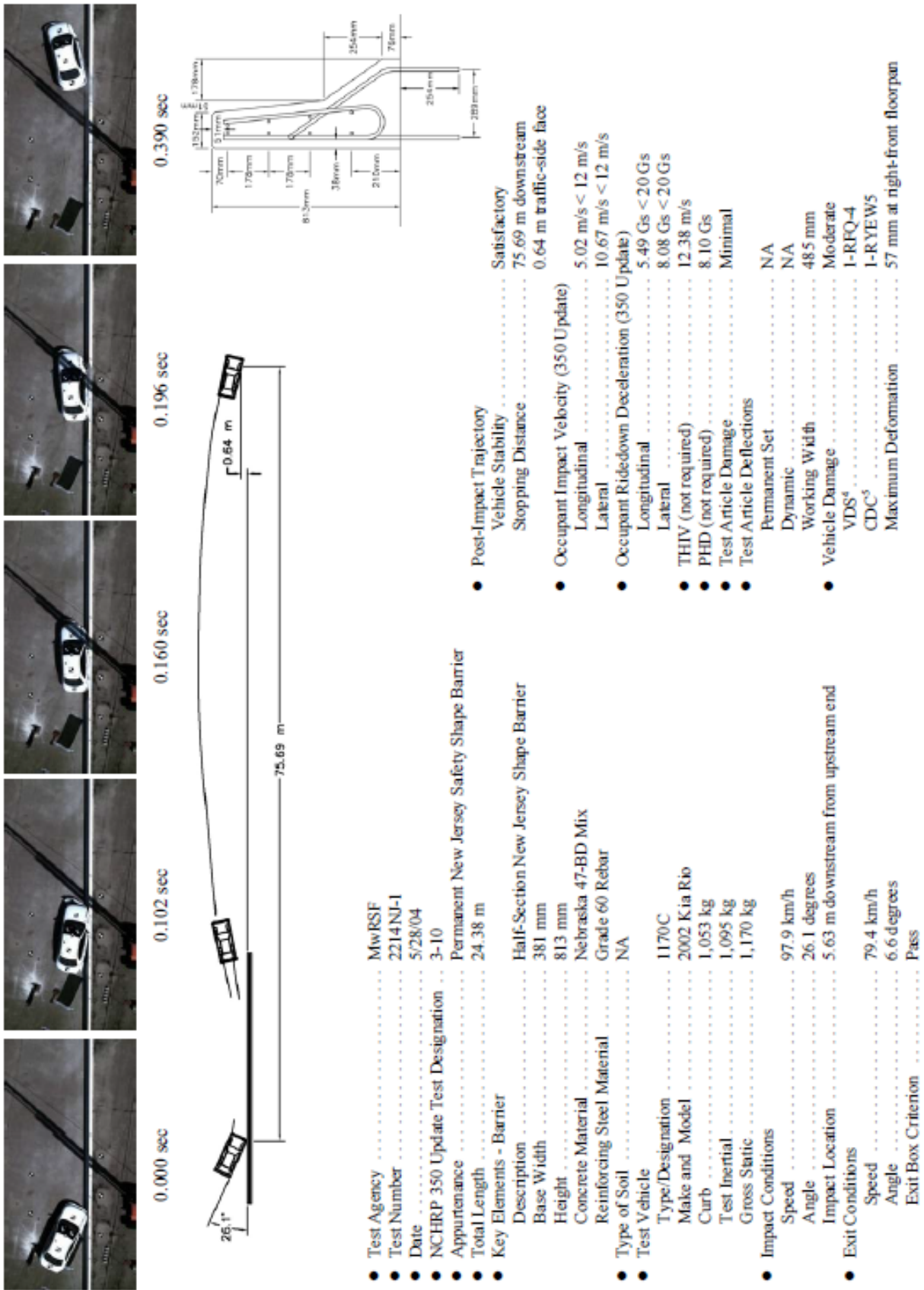


Figure 5: Full-Scale Test Summary





**Figure 6a: Sequential Comparisons – Front View**





**Figure 6b: Sequential Comparisons – Rear View**



Figure 6c: Sequential Comparisons – Top View

# CCSA VALIDATION/VERIFICATION REPORT

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

**Table F - Composite Verification and Validation Summary:**

List the Report MASH08 Test Number		
<b>Table C – Analysis Solution Verification</b>	Did all solution verification criteria in table pass?	<b>YES</b>
<b>Table D - RSVVP Results</b>	Do all the time history evaluation scores from the single channel factors result in a satisfactory comparison (i.e., the comparison passes the criterion)?	<b>NO</b>
	If all the values for Single Channel comparison did not pass, did the weighted procedure result in an acceptable comparison.	<b>YES</b>
<b>Table E - Roadside Safety Phenomena Importance Ranking Table</b>	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	<b>YES</b>
<b>Overall</b>	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.	<b>YES</b>

**NOTES:**  
 (none)

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

## CCSA VALIDATION/VERIFICATION REPORT

**Project:** CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections  
**Comparison Case:** 2270P 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	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
<b>Evaluation Method</b>	MASH (V1, 2009)	
<b>Hardware Type</b>	Longitudinal	
<b>Test Number</b>	3-11	
<b>Test Vehicle</b>	2270P	
<b>Criterion to be Applied</b>	<b>Structural Adequacy</b>	<b>A</b> - 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.
	<b>Occupant Risk</b>	<b>D</b> - 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.
		<b>F</b> - The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.
		<b>H</b> - 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.
		<b>I</b> - 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.
	<b>Vehicle Trajectory</b>	For redirective devices the vehicle shall exit within the prescribed box.

# CCSA VALIDATION/VERIFICATION REPORT

**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**

Single Channel Time History Comparison Results		Time interval [0 sec - 0.5 sec]		
O	<i>Sprague-Geer Metrics</i>	M	P	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
P	<i>ANOVA Metrics</i>	Mean	SD	Pass?
	X acceleration/Peak	1.32	29.37	YES
	Y acceleration/Peak	0.84	12.15	YES
	Z acceleration/Peak	0.66	44.94	NO
	Yaw rate	0.2	14.87	YES
	Roll rate	0.21	17.28	YES
	Pitch rate	10.86	53.95	NO
Multi-Channel Weighting Factors		Time interval [0 sec; 0.5 sec]		
Multi-Channel Weighting Method Peaks Area I Area II Inertial		X Channel	0.142263141	
		Y Channel	0.312496147	
		Z Channel	0.045240712	
		Yaw Channel	0.19476326	
		Roll Channel	0.200826808	
		Pitch Channel	0.104409933	
<i>Sprague-Geer Metrics</i>		M	P	Pass?
	All Channels (weighted)	21.4	23.1	YES
<i>ANOVA Metrics</i>		Mean	SD	Pass?
	All Channels (weighted)	1.5	22	YES

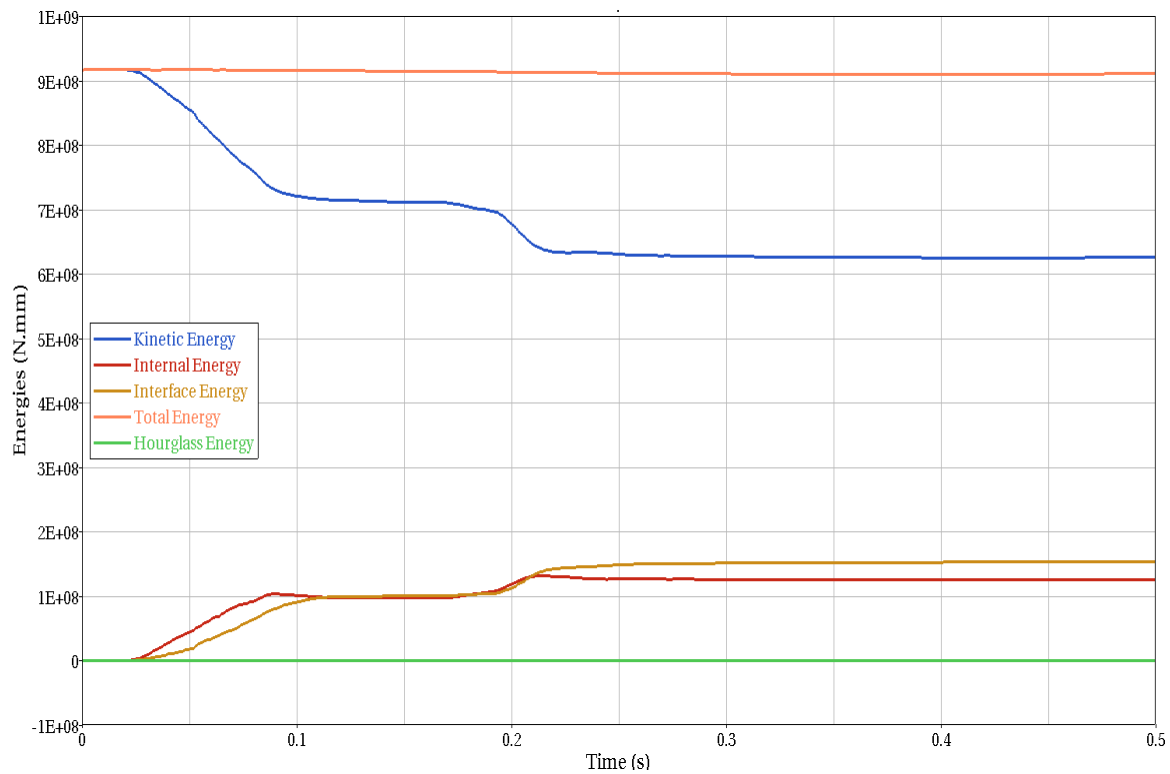


Figure 1: Simulations Energies

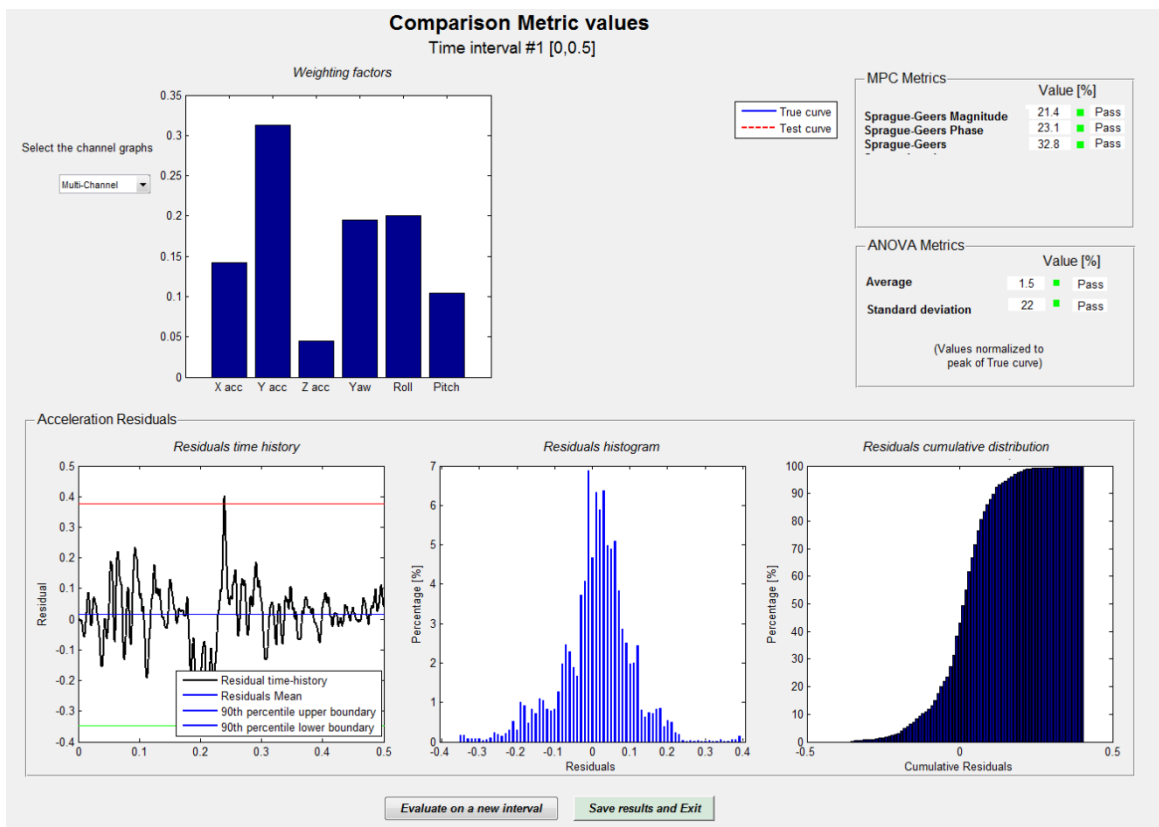
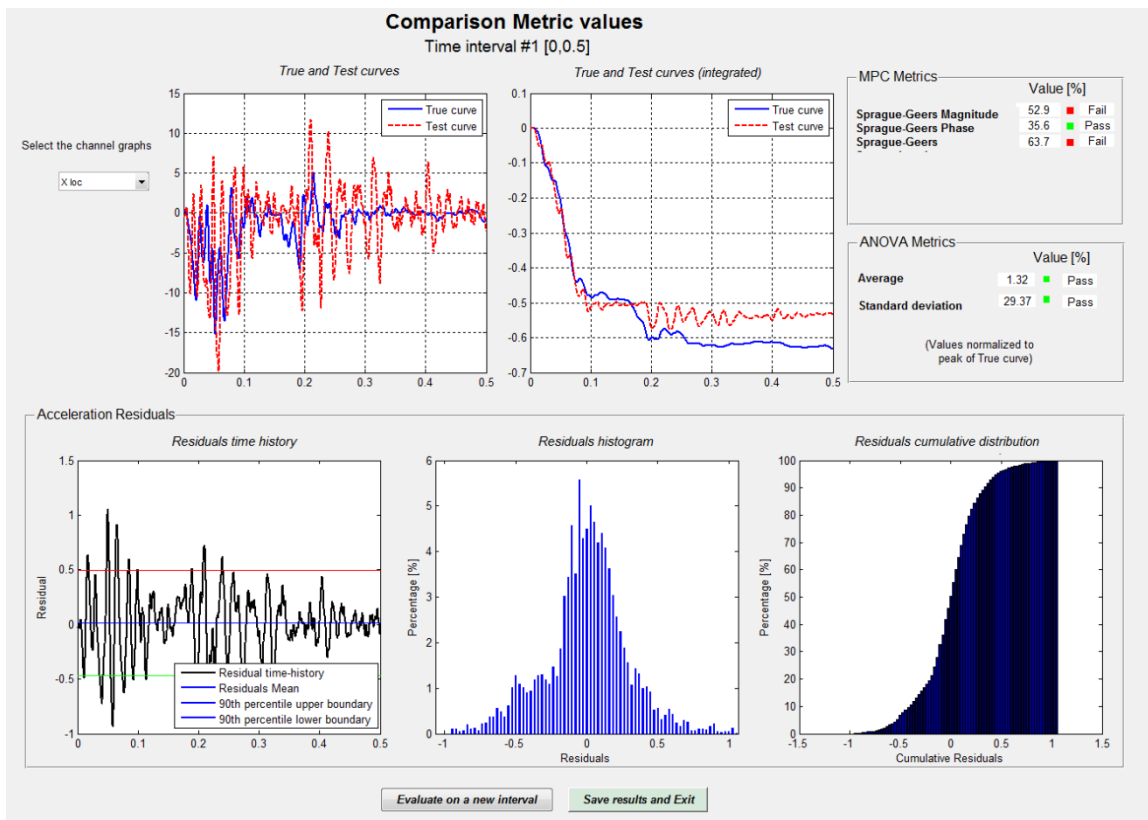
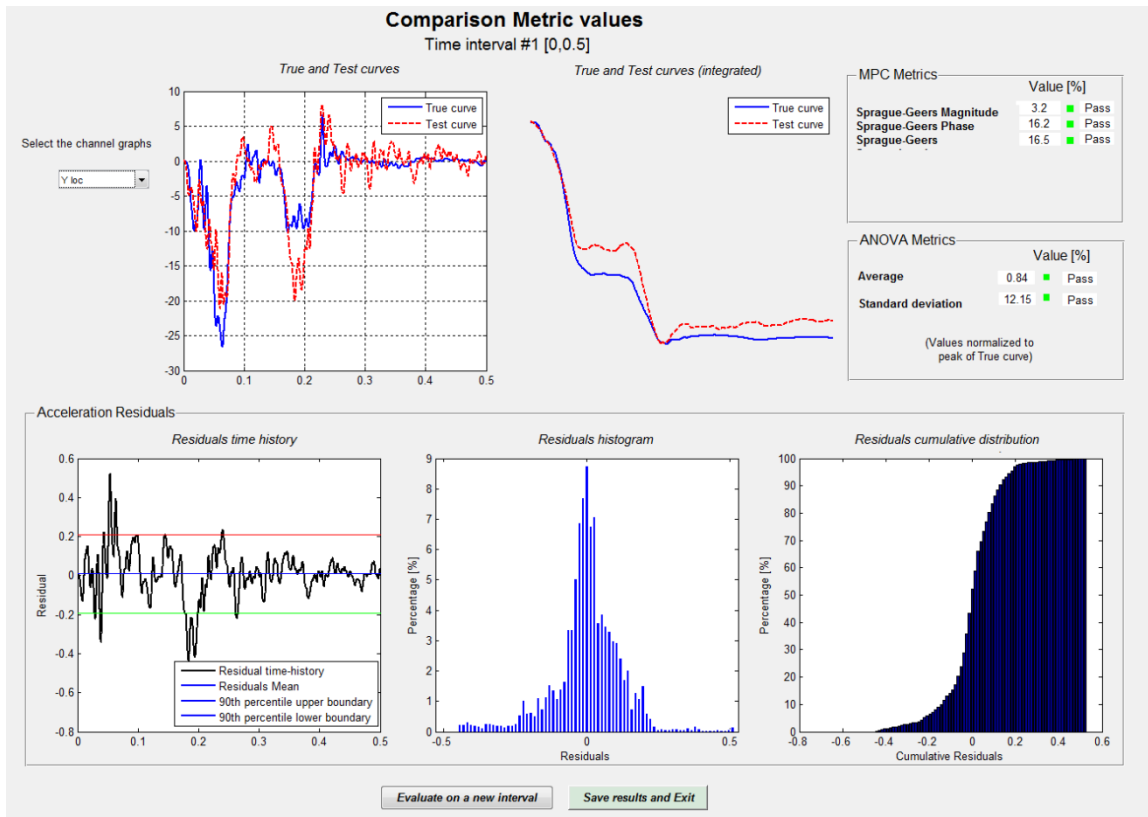


Figure 2a: RSVVP Results – All Channels

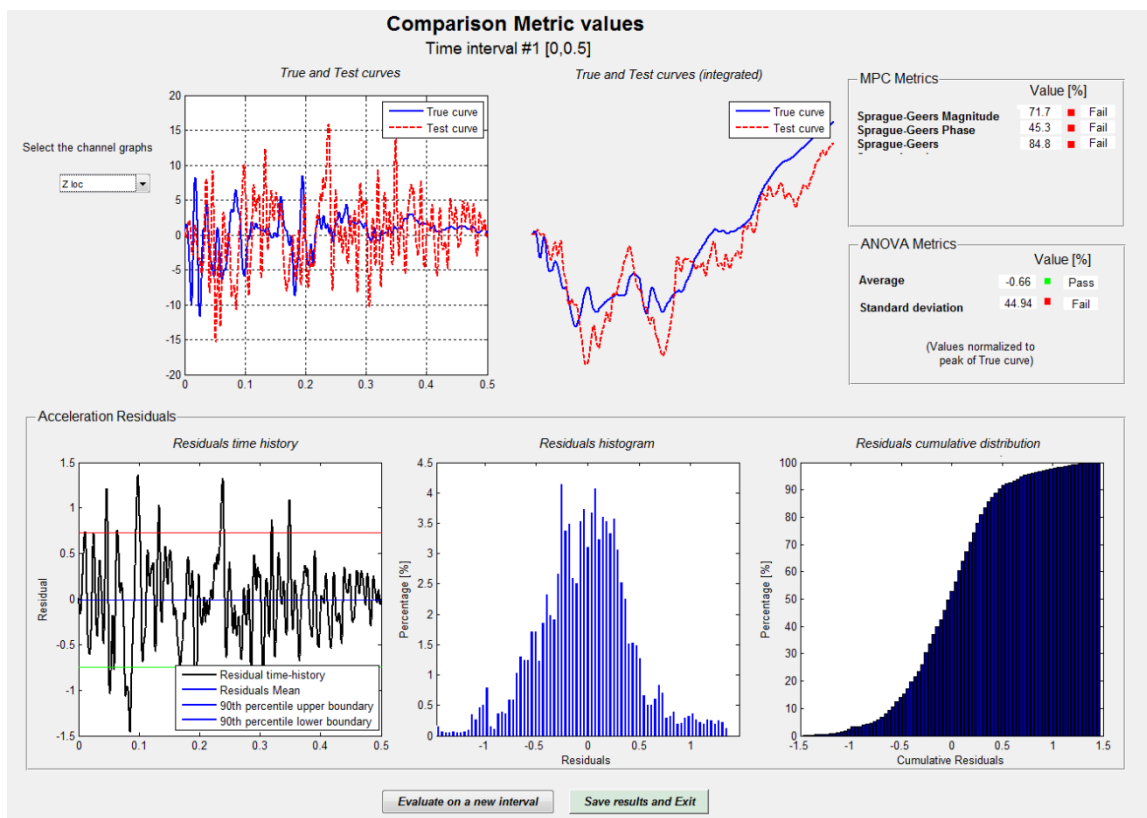




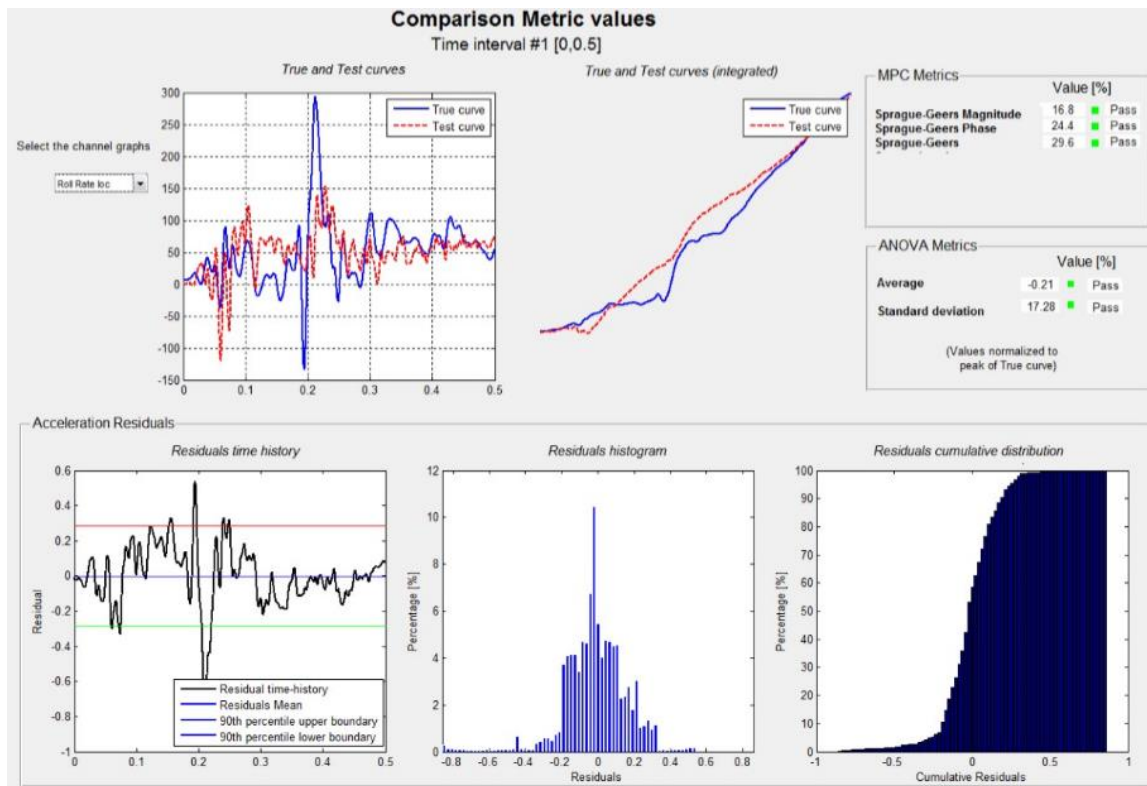
**Figure 2b: RSVVP Results – Longitudinal Acceleration**



**Figure 2c: RSVVP Results – Lateral Acceleration**

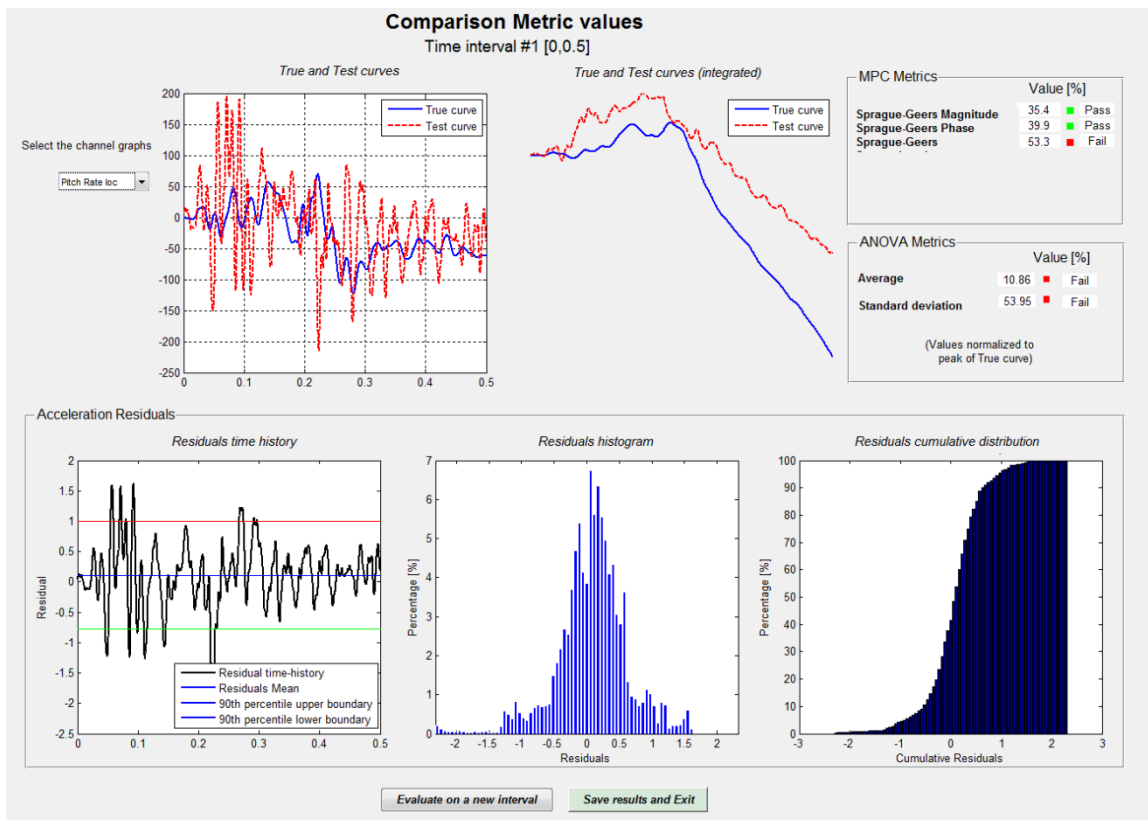


**Figure 2d: RSVVP Results – Vertical Acceleration**

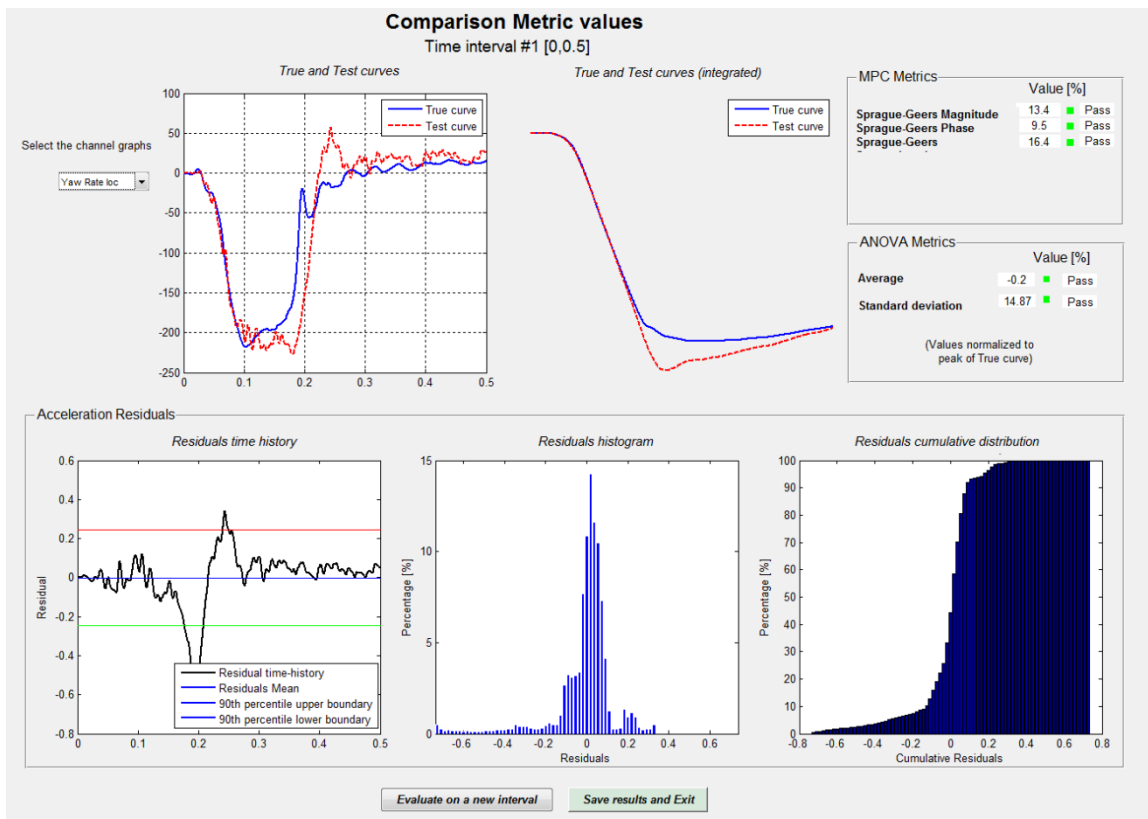


**Figure 2e: RSVVP Results – Roll Angle**

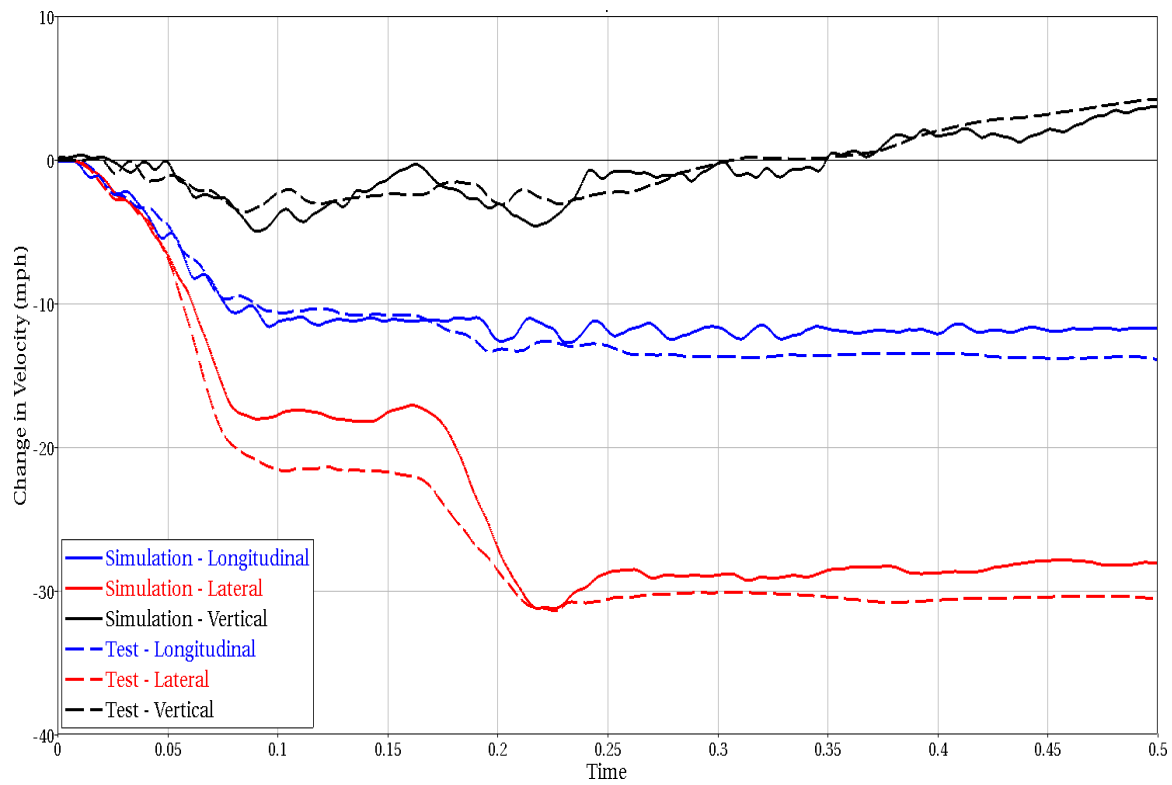




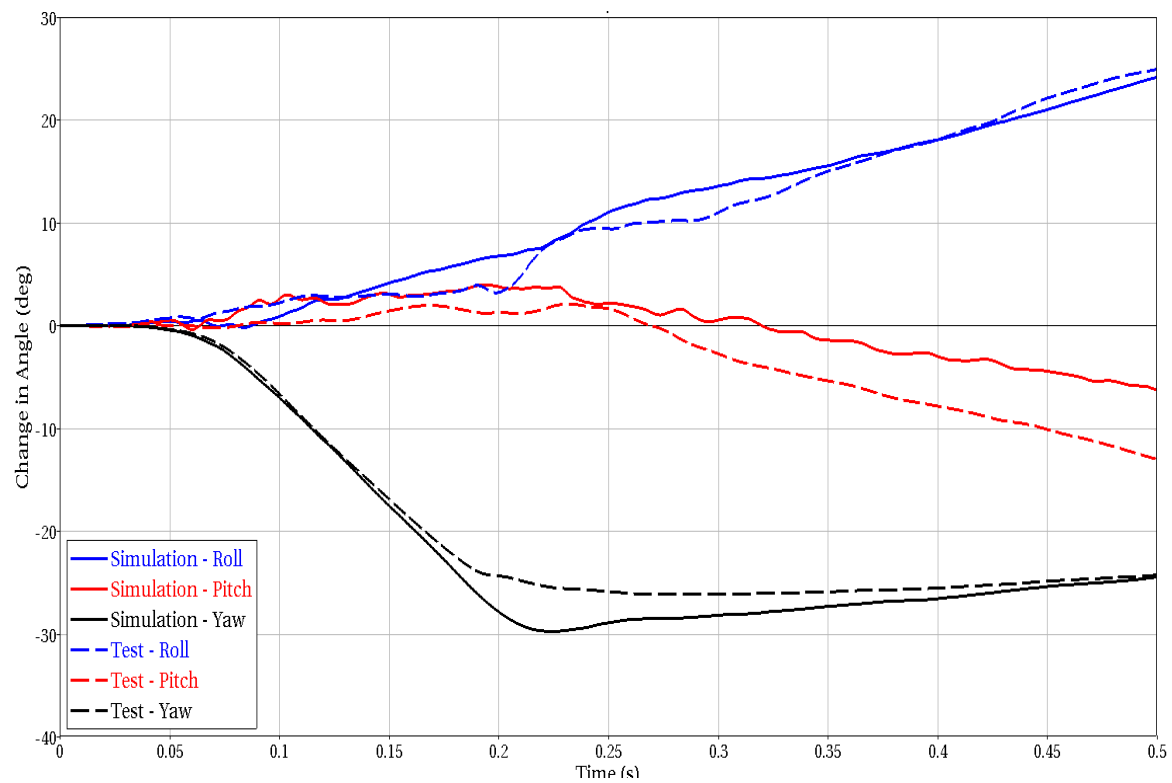
**Figure 2f: RSVVP Results – Pitch Angle**



**Figure 2g: RSVVP Results – Yaw Angle**



**Figure 3: Change in Vehicle Velocities**



**Figure 4: Change in Vehicle Angles**

# CCSA VALIDATION/VERIFICATION REPORT

## 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	1	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	
		A5	Barrier did not fail (Answer Yes or No).	Yes	Yes		YES	
		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).	Yes	Yes		YES	
		A8	There was no significant snagging between vehicle body components and barrier elements (Answer Yes or No).	Yes	Yes		YES	
Occupant Risk	2	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	
		3	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
			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
		4	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
			H2	Longitudinal OIV (m/s) - Relative difference is less than 20% 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
		5	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	

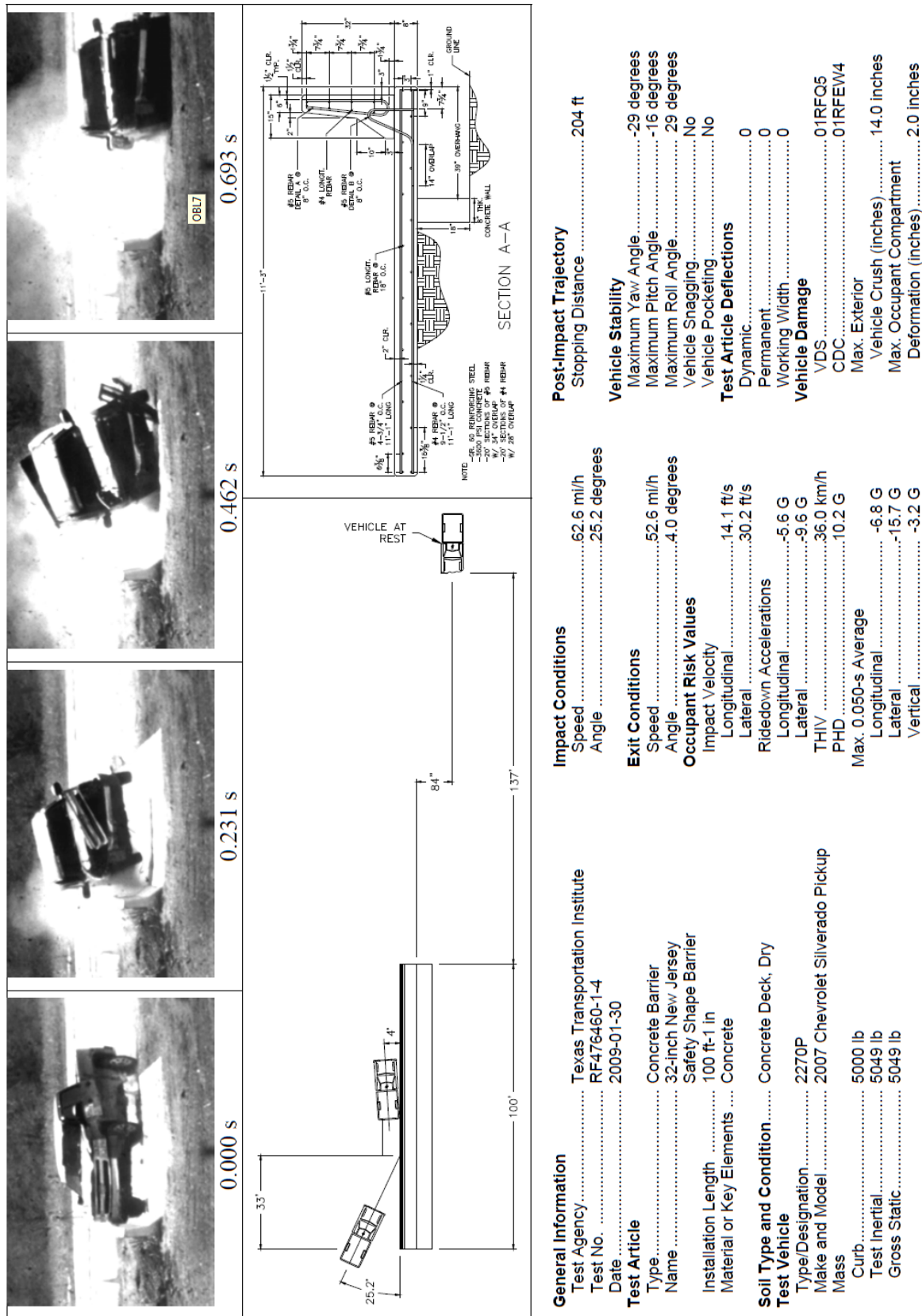


Figure 5: Full-Scale Test Summary

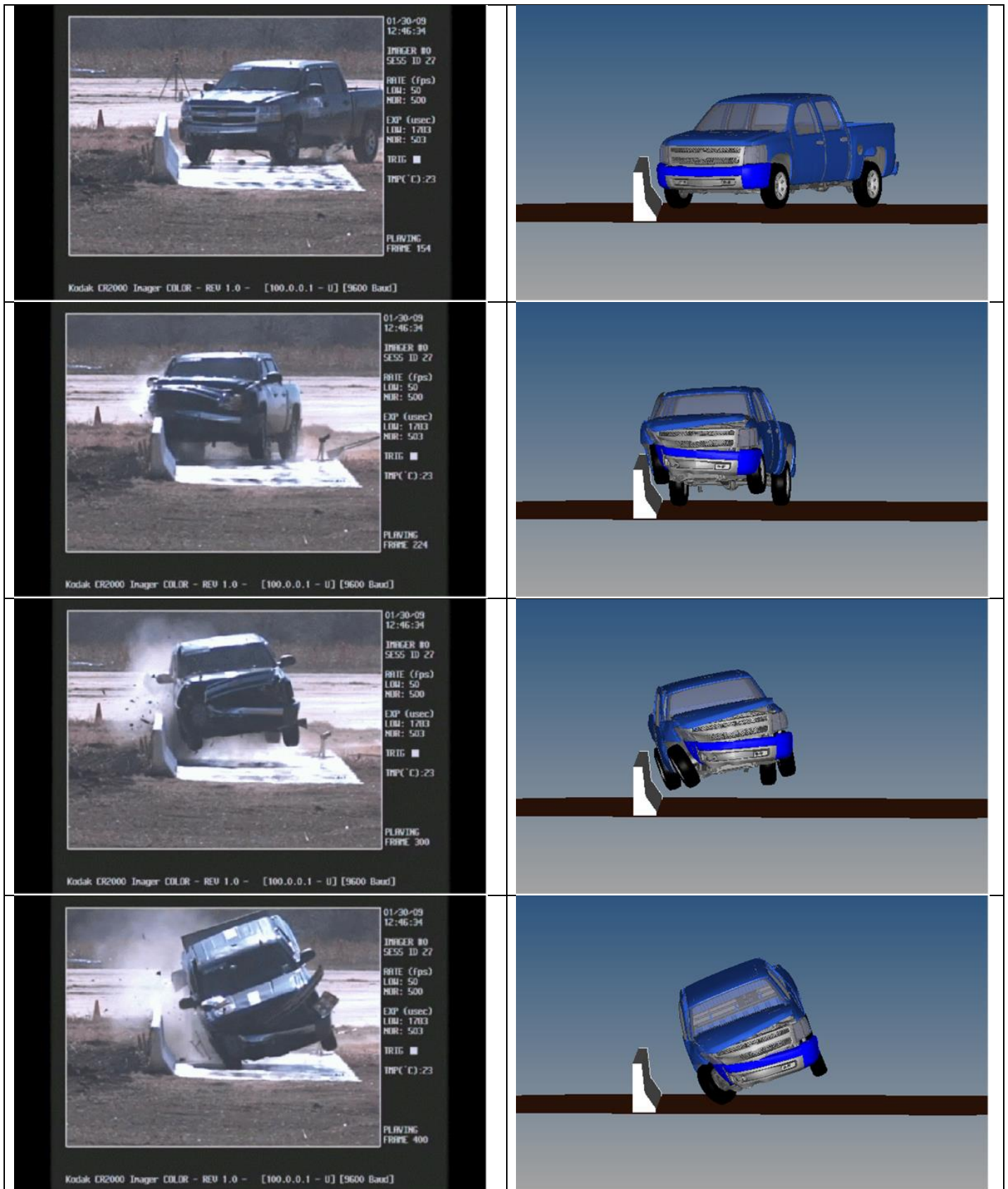


Figure 6a: Sequential Comparisons – Front View



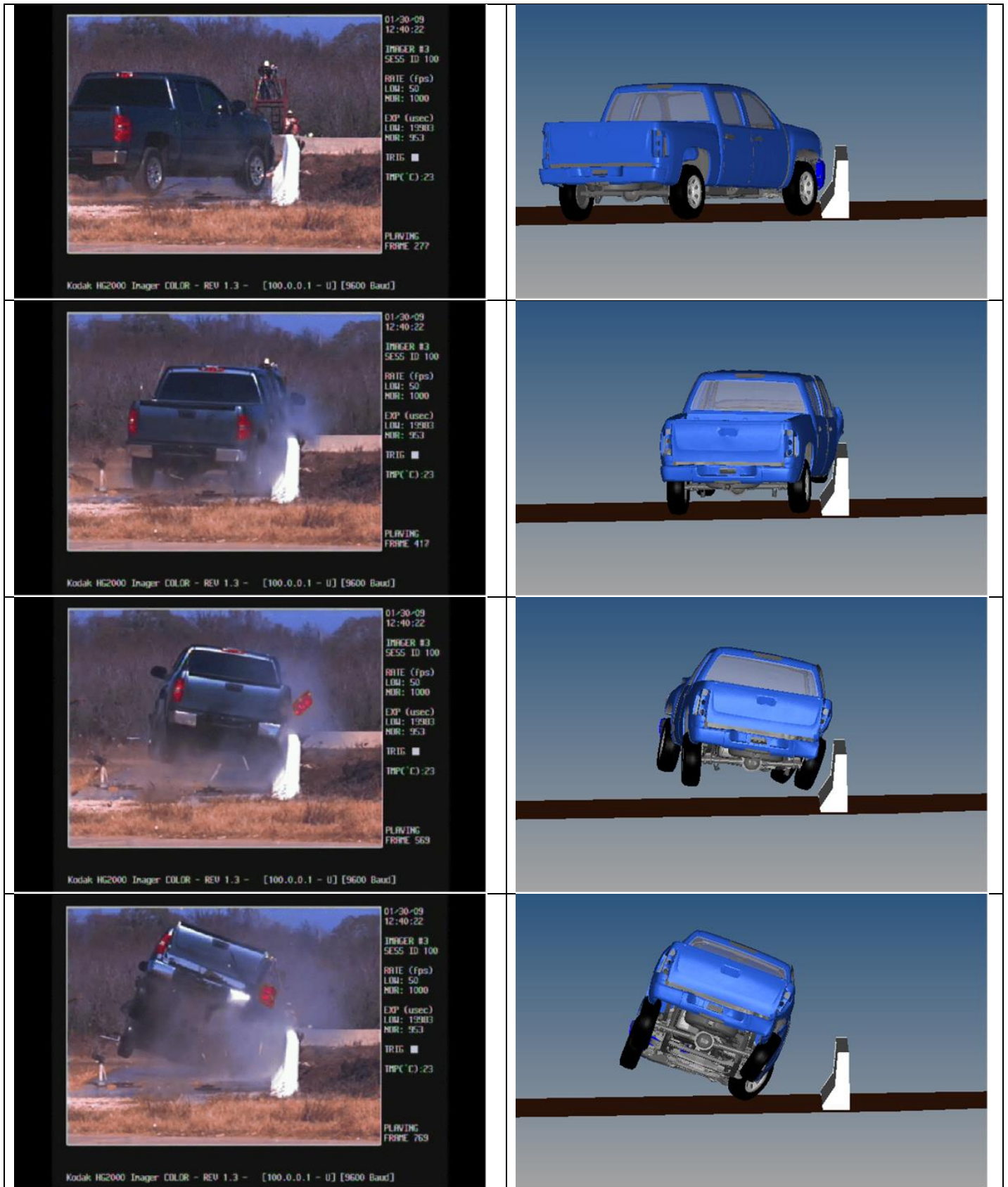


Figure 6b: Sequential Comparisons – Rear View



**Figure 6c: Sequential Comparisons – Top View**

## CCSA VALIDATION/VERIFICATION REPORT

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

**Table F - Composite Verification and Validation Summary:**

List the Report MASH08 Test Number		
<b>Table C – Analysis Solution Verification</b>	Did all solution verification criteria in table pass?	<b>YES</b>
<b>Table D - RSVVP Results</b>	Do all the time history evaluation scores from the single channel factors result in a satisfactory comparison (i.e., the comparison passes the criterion)?	<b>NO</b>
	If all the values for Single Channel comparison did not pass, did the weighted procedure result in an acceptable	<b>YES</b>
<b>Table E - Roadside Safety Phenomena Importance Ranking Table</b>	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	<b>YES</b>
<b>Overall</b>	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.	<b>YES</b>

**NOTES:**

(none)



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

## CCSA VALIDATION/VERIFICATION REPORT

**Project:** CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections  
**Comparison Case:** 2000P (Pickup Truck) with G41S Barrier  
**Impact Description:** 25.5-deg impact into barrier at 101.5 km/h (63.1 mph)  
**Governing Criteria:** NCHRP Report 350 TL-3  
**Report 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	<b>A</b> - 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	<b>D</b> - 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.
		<b>F</b> - The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.
		<b>L</b> - 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	<b>M</b> - 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

# CCSA VALIDATION/VERIFICATION REPORT

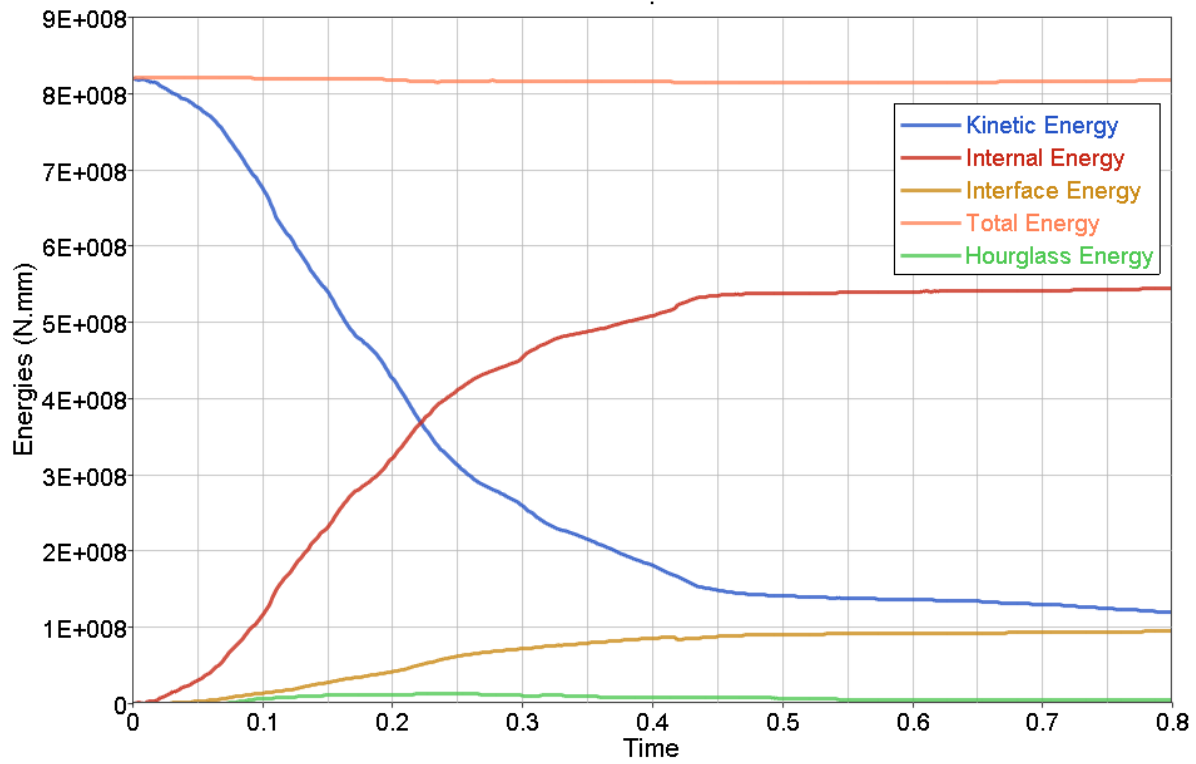
**Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections**  
**Comparison Case: 2000P (Pickup Truck) with G41S Barrier**

**Table C – Analysis Solution Verification Summary**

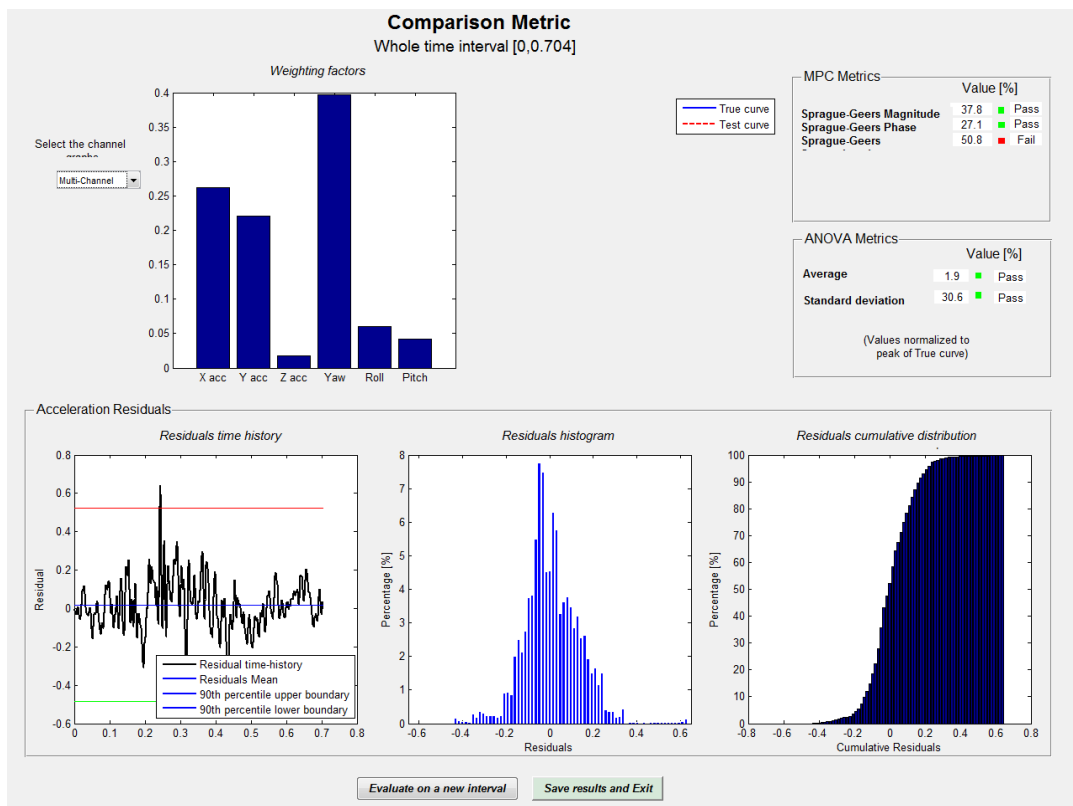
Verification Evaluation Criteria	Change (%)	Pass?
Total energy of the analysis solution (i.e., kinetic, potential, contact, etc.) must not vary more than 10 percent from the beginning of the run to the end of the run.	< 1%	YES
Hourglass Energy of the analysis solution at the end of the run is less than 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**

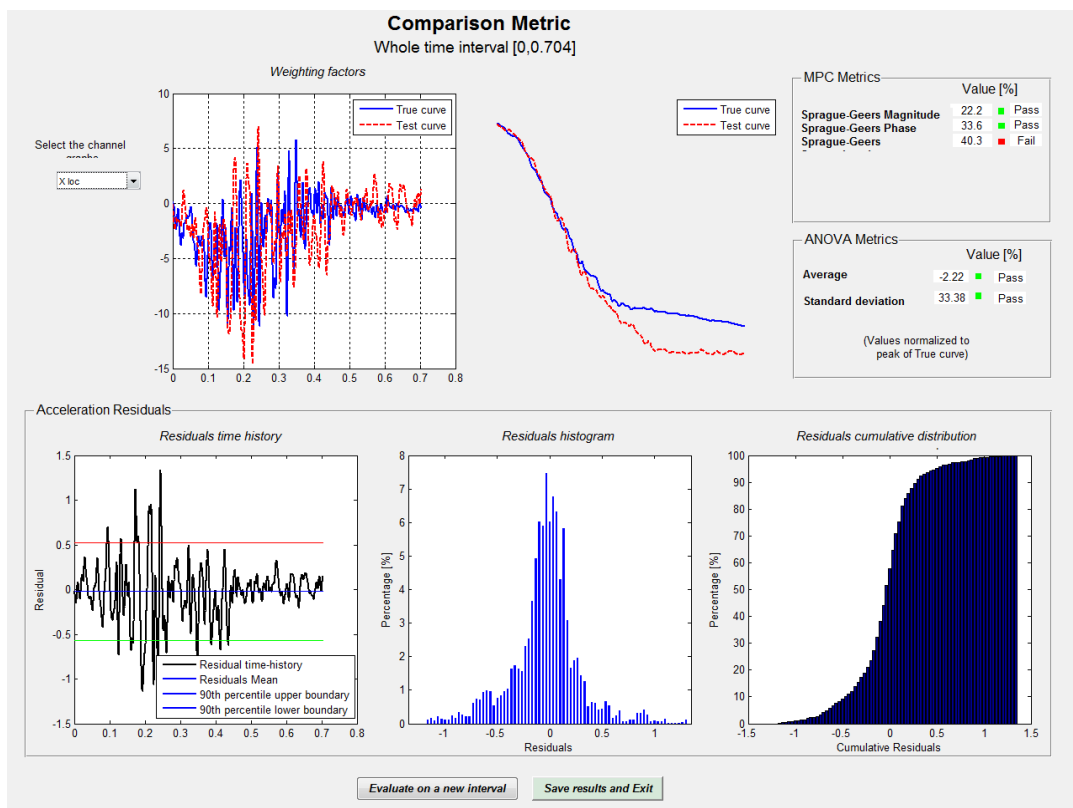
Single Channel Time History Comparison Results		Time interval [0 sec - 0.89 sec]		
O	<i>Sprague-Geer Metrics</i>	M	P	Pass?
	X acceleration	22.2	33.6	YES
	Y acceleration	42.9	33.2	NO
	Z acceleration	120.2	43.1	NO
	Yaw rate	0	12.2	YES
	Roll rate	235.5	46	NO
	Pitch rate	145.4	61.2	NO
P	<i>ANOVA Metrics</i>	Mean	SD	Pass?
	X acceleration/Peak	-2.22	33.38	YES
	Y acceleration/Peak	0.41	24.44	YES
	Z acceleration/Peak	-1.36	59.37	NO
	Yaw rate	-1.85	15.78	YES
	Roll rate	7.17	107.68	NO
	Pitch rate	63.57	62.77	NO
Multi-Channel Weighting Factors		Time interval [0 sec; 0.89 sec]		
Multi-Channel Weighting Method				
Peaks Area I Area II Inertial	X Channel	0.261526		
	Y Channel	0.220749		
	Z Channel	0.017725		
	Yaw Channel	0.397255		
	Roll Channel	0.060756		
	Pitch Channel	0.04199		
<i>Sprague-Geer Metrics</i>		M	P	Pass?
	All Channels (weighted)	37.8	27.1	YES
<i>ANOVA Metrics</i>		Mean	SD	Pass?
	All Channels (weighted)	1.9	30.6	YES



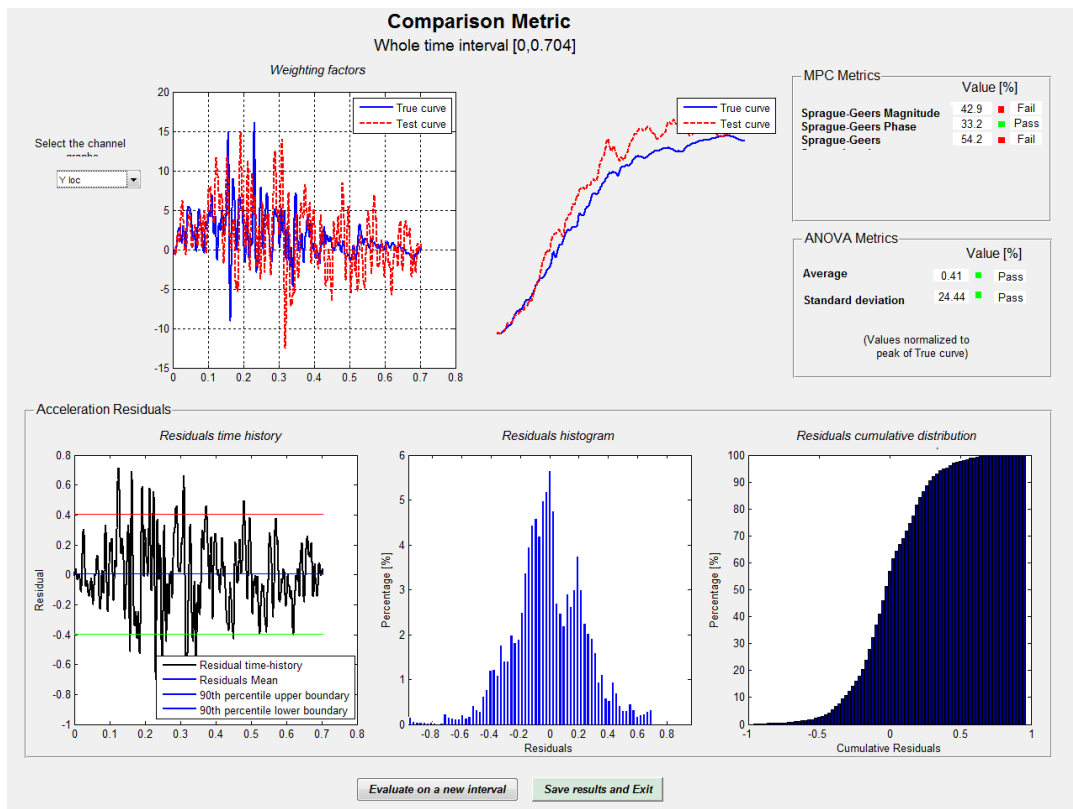
**Figure 1: Simulations Energies**



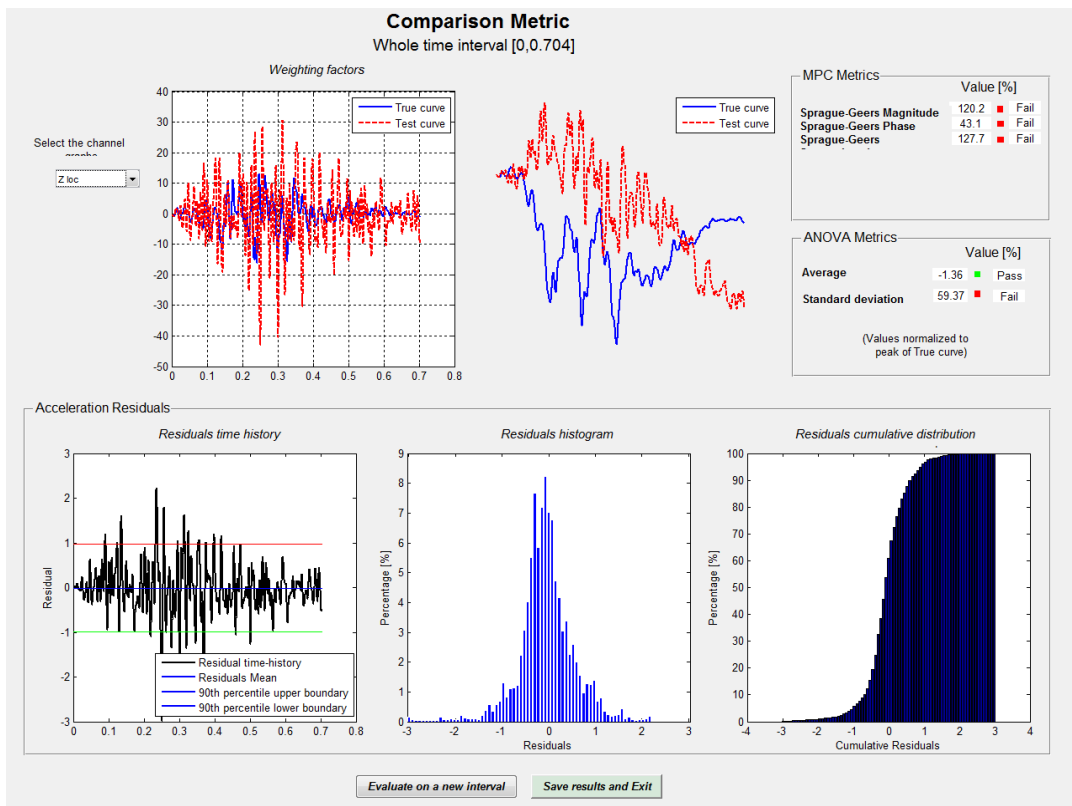
**Figure 2a: RSVVP Results – All Channels**



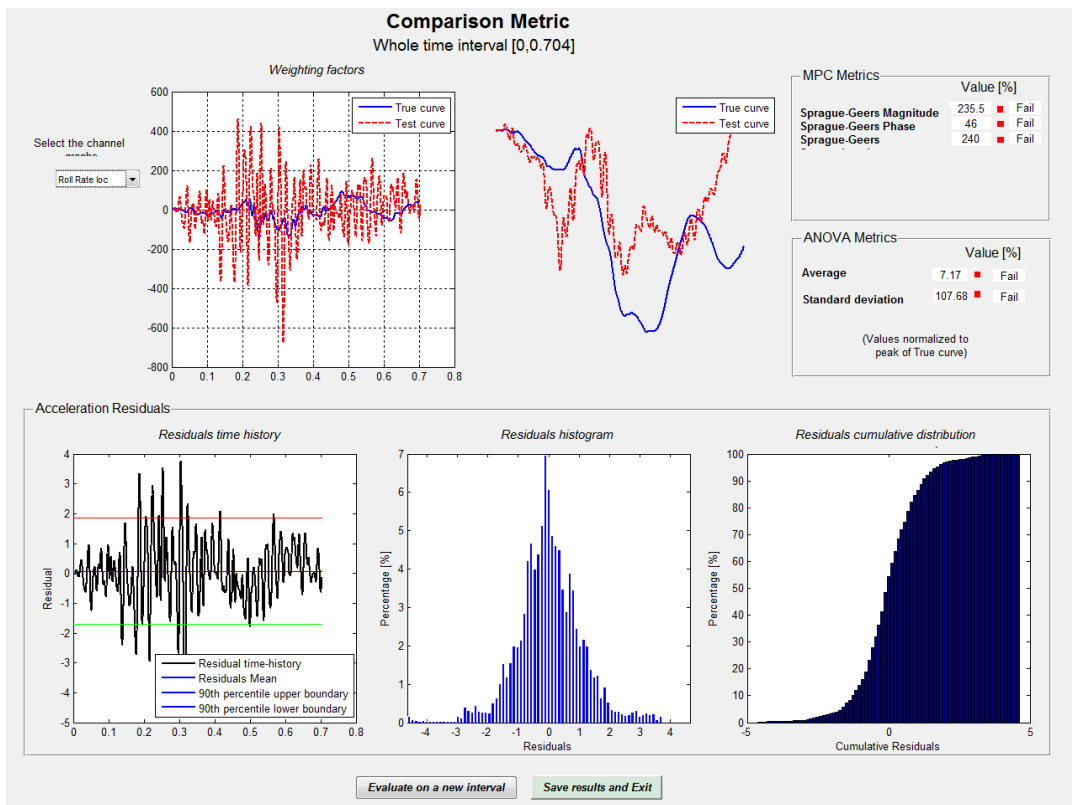
**Figure 2b: RSVVP Results – Longitudinal Acceleration**



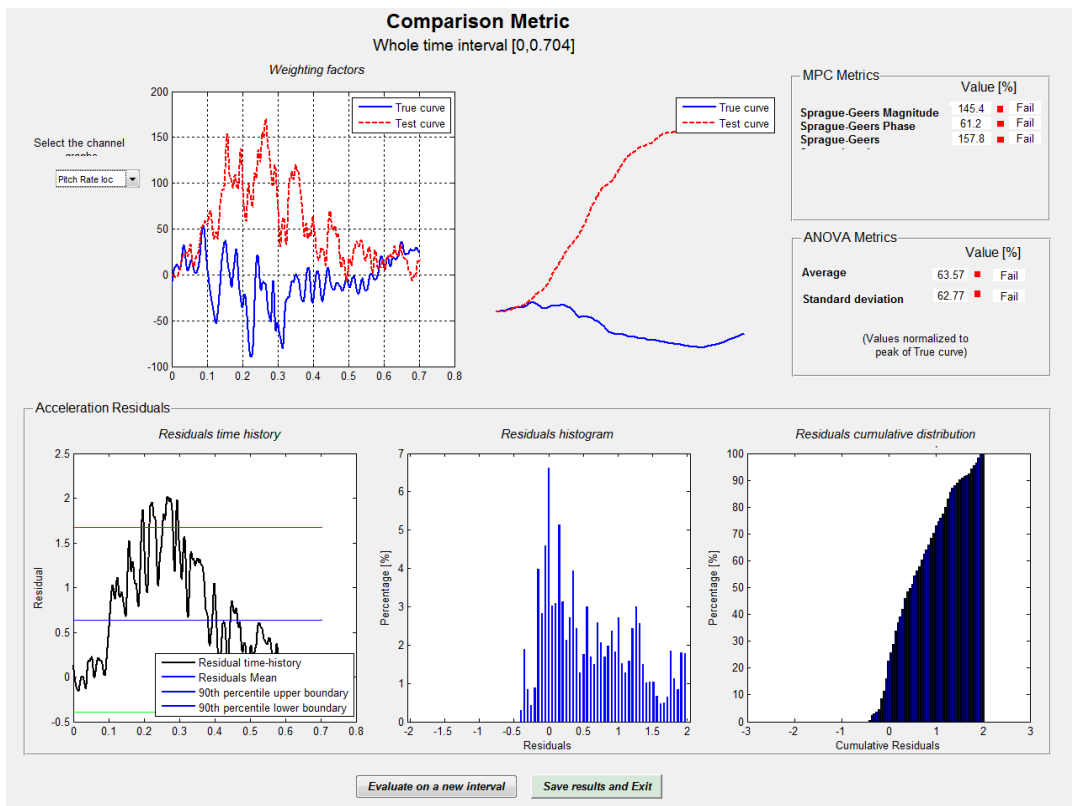
**Figure 2c: RSVVP Results – Lateral Acceleration**



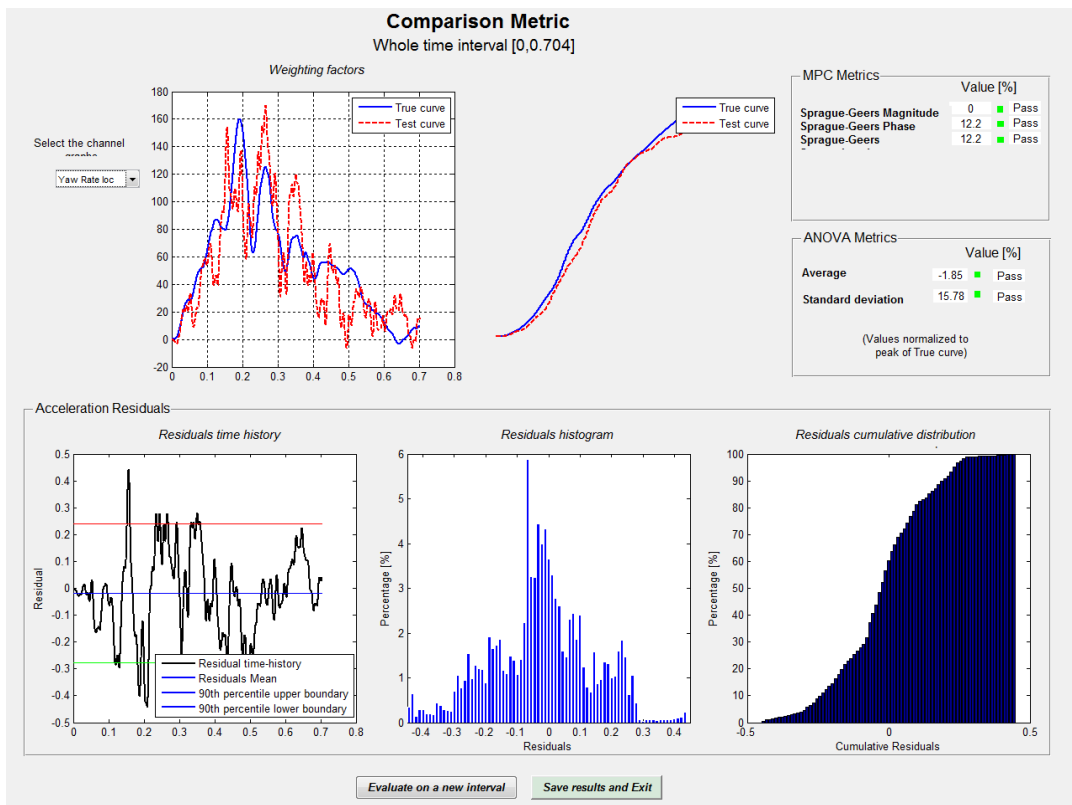
**Figure 2d: RSVVP Results – Vertical Acceleration**



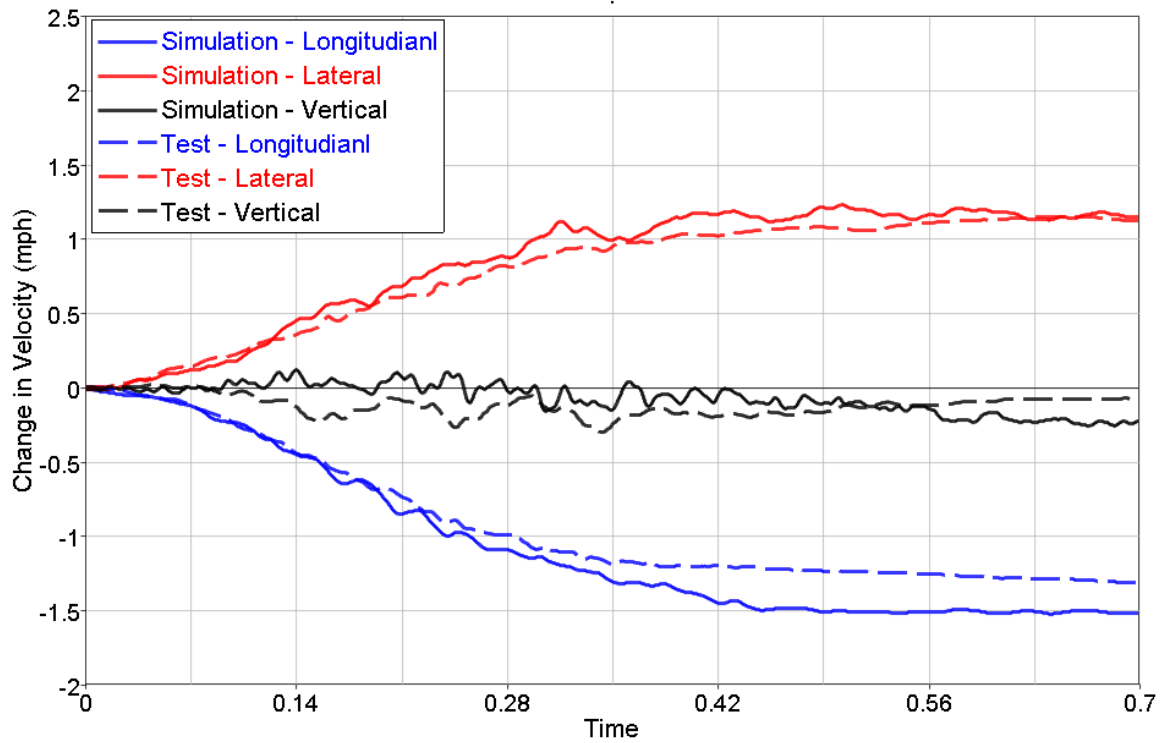
**Figure 2e: RSVVP Results – Roll Angle Rate**



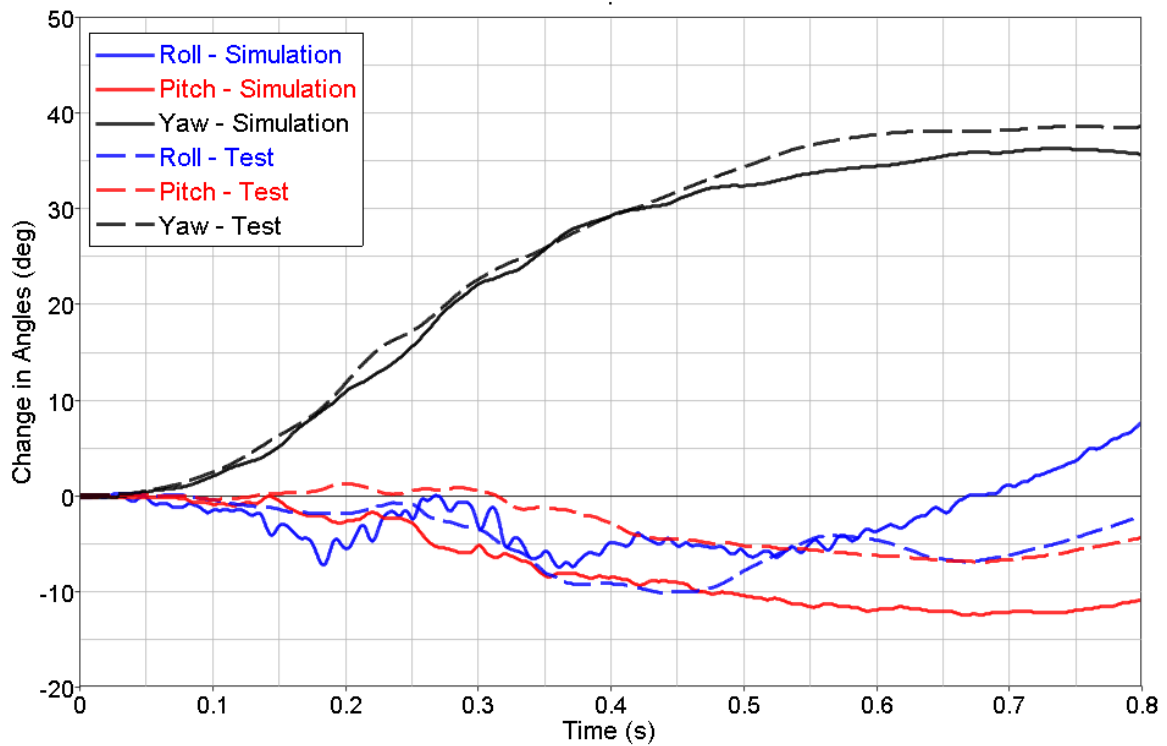
**Figure 2f: RSVVP Results – Pitch Angle Rate**



**Figure 2g: RSVVP Results – Yaw Angle Rate**



**Figure 3: Change in Vehicle Velocities**



**Figure 4: Change in Vehicle Angle**





# CCSA VALIDATION/VERIFICATION REPORT

**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?	
Structural Adequacy	A	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.	1. m	0.960 m	4.0 %	YES	
		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	
		A4	The relative difference in the number of broken or significantly bent posts is less than 20 percent.	4	4		YES	
		A5	Barrier did not fail (Answer Yes or No).	Yes	Yes		YES	
		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	
Occupant Risk	D		Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or personnel in a work zone (Answer Yes or No).	Yes	Yes		YES	
		F	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
			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
			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
	I	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	
		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	M	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	
		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	

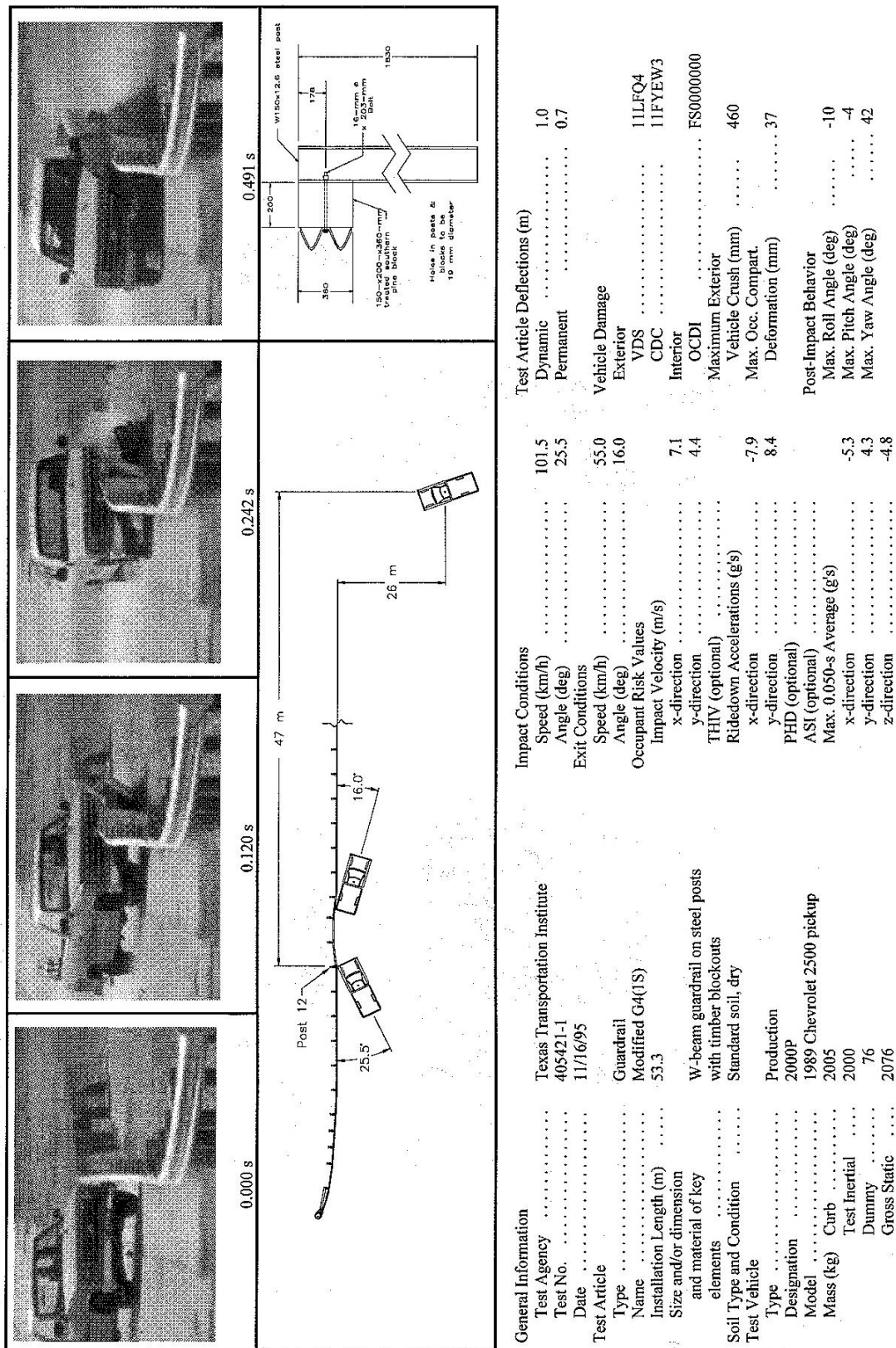


Figure 5: Full-Scale Test Summary

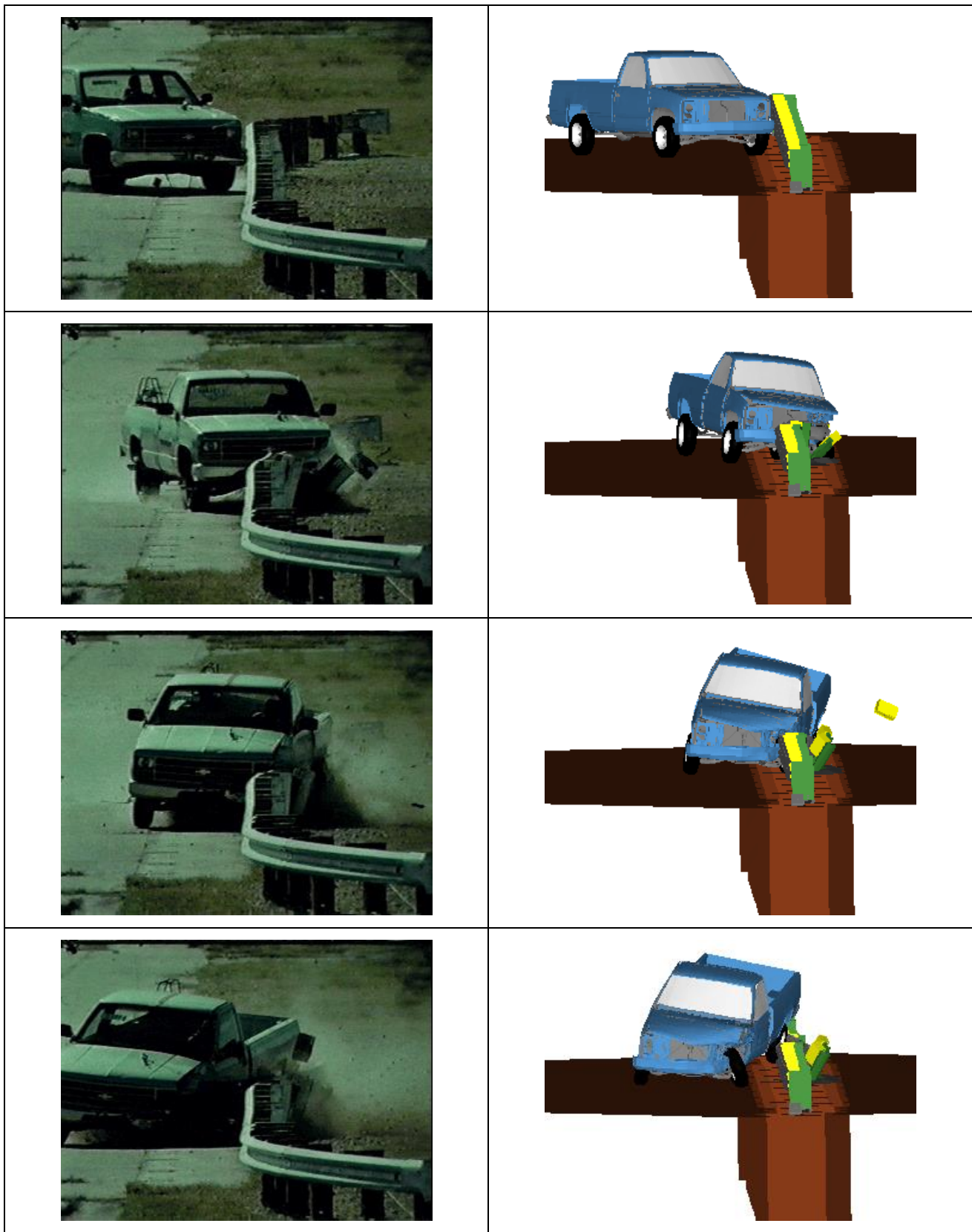
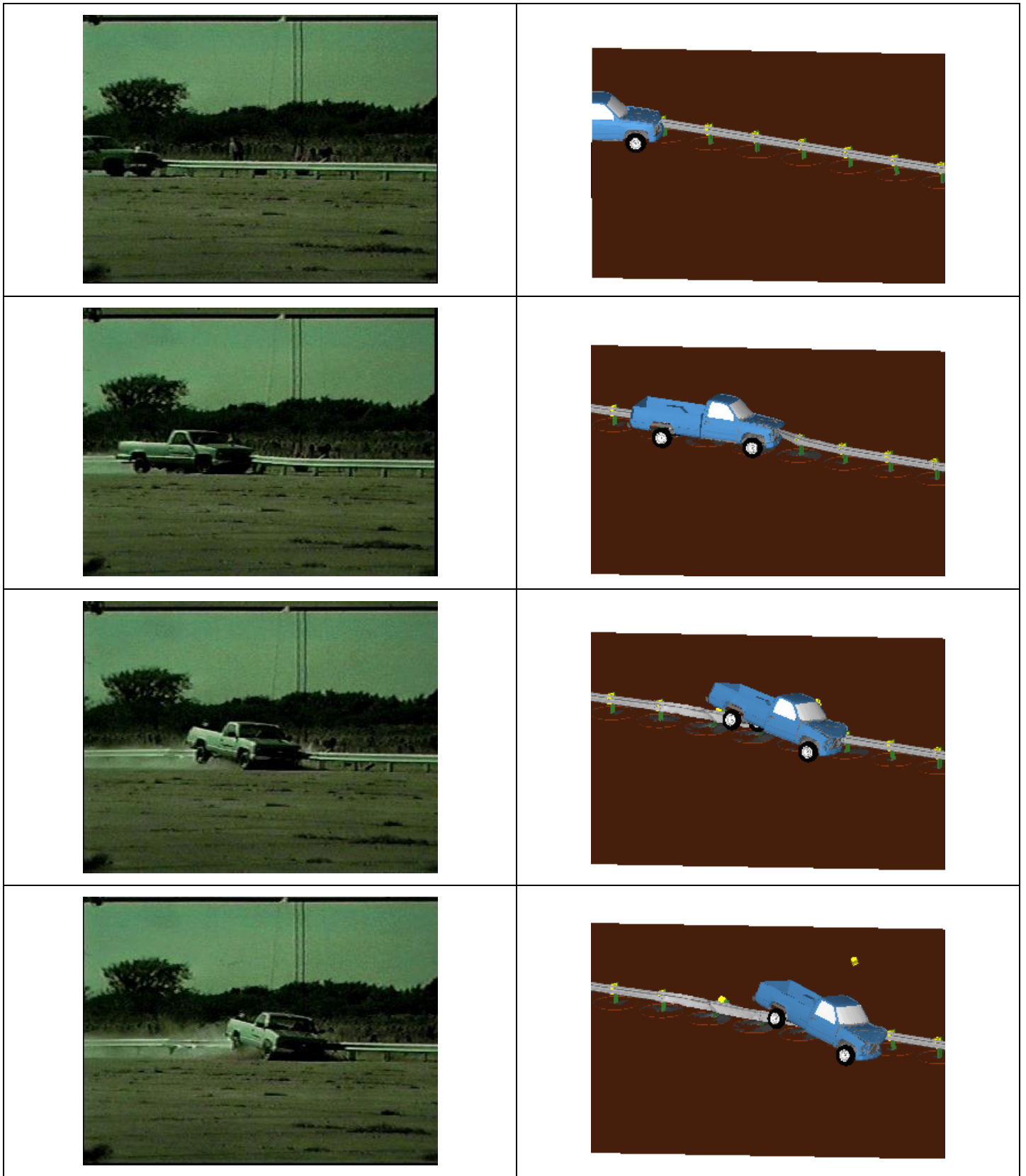
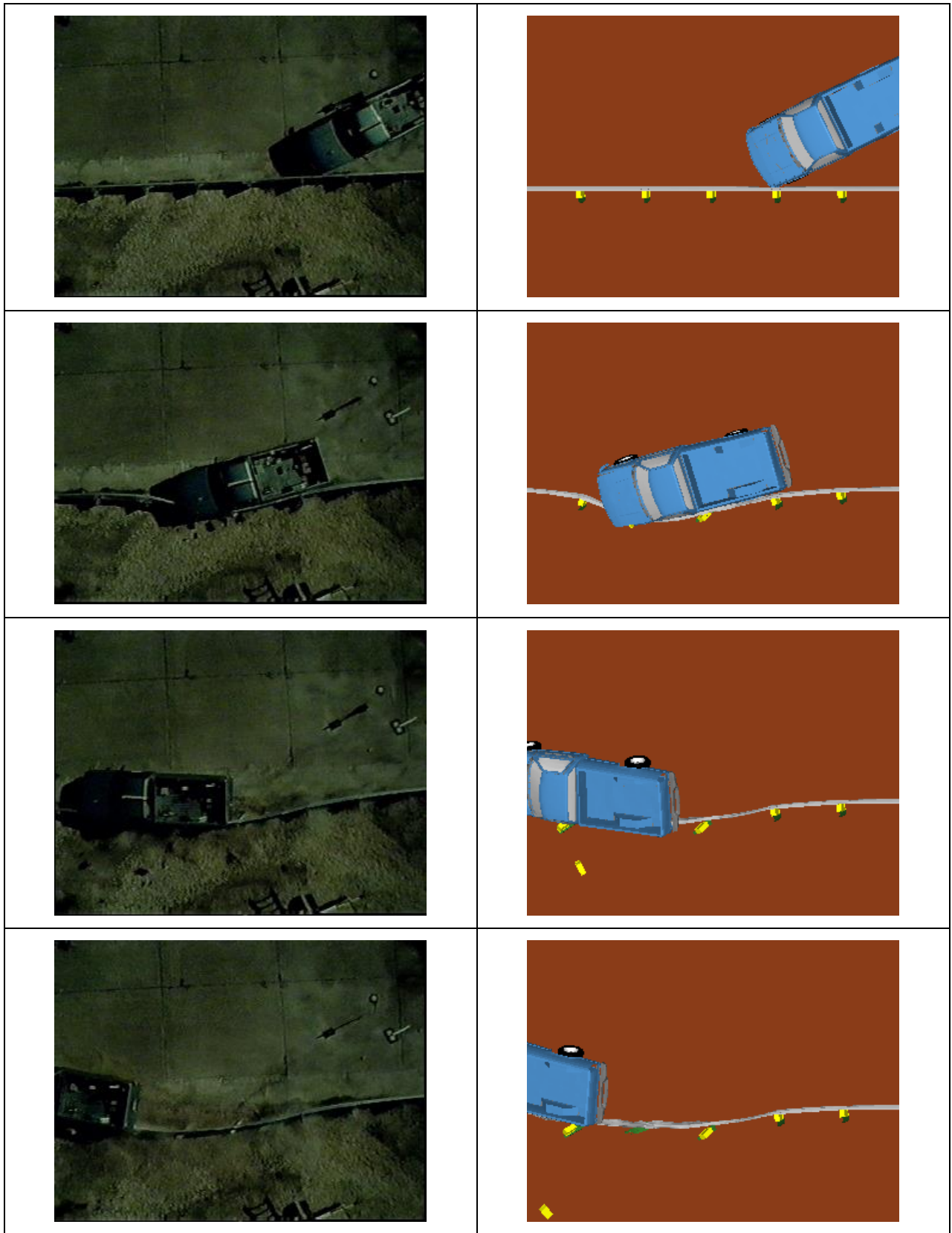


Figure 6a: Sequential Comparisons – Front View



**Figure 6b: Sequential Comparisons – Iso View**





**Figure 6c: Sequential Comparisons – Top View**

## CCSA VALIDATION/VERIFICATION REPORT

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

**Table F - Composite Verification and Validation Summary:**

List the Report MASH08 Test Number		
<b>Table C – Analysis Solution Verification</b>	Did all solution verification criteria in table pass?	<b>YES</b>
<b>Table D - RSVVP Results</b>	Do all the time history evaluation scores from the single channel factors result in a satisfactory comparison (i.e., the comparison passes the criterion)?	<b>NO</b>
	If all the values for Single Channel comparison did not pass, did the weighted procedure result in an acceptable comparison.	<b>YES</b>
<b>Table E - Roadside Safety Phenomena Importance Ranking Table</b>	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	<b>YES</b>
<b>Overall</b>	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.	<b>YES</b>

### NOTES:

(none)

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

## CCSA VALIDATION/VERIFICATION REPORT

**Project:** CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections  
**Comparison Case:** 2270P (Pickup Truck) with G41S Barrier  
**Impact Description:** 25.8-deg impact into barrier at 100.4 km/h (62.4 mph)  
**Governing Criteria:** MASH TL-3  
**Report 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
<b>Evaluation Method</b>	MASH (V1, 2009)	
<b>Hardware Type</b>	Longitudinal	
<b>Test Number</b>	3-11	
<b>Test Vehicle</b>	2270C	
<b>Criterion to be Applied</b>	<b>Structural Adequacy</b>	<b>A</b> - 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.
	<b>Occupant Risk</b>	<b>D</b> - 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.
		<b>F</b> - The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.
		<b>H</b> - 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.
		<b>I</b> - 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.
	<b>Vehicle Trajectory</b>	For redirective devices the vehicle shall exit within the prescribed box.



# CCSA VALIDATION/VERIFICATION REPORT

**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**

Single Channel Time History Comparison Results		Time interval [0 sec - 0.89 sec]		
O	<i>Sprague-Geer Metrics</i>	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)			
P	<i>ANOVA Metrics</i>	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)			
Multi-Channel Weighting Factors		Time interval [0 sec; 0.89 sec]		
Multi-Channel Weighting Method Peaks Area I Area II Inertial		X Channel	0.22878683	
		Y Channel	0.225135792	
		Z Channel	0.046077378	
		Yaw Channel	0.5	
		Roll Channel	(test data not available)	
		Pitch Channel	(test data not available)	
<i>Sprague-Geer Metrics</i>		M	P	Pass?
	All Channels (weighted)	36.7	24.6	YES
<i>ANOVA Metrics</i>		Mean	SD	Pass?
	All Channels (weighted)	-.02	29.6	YES

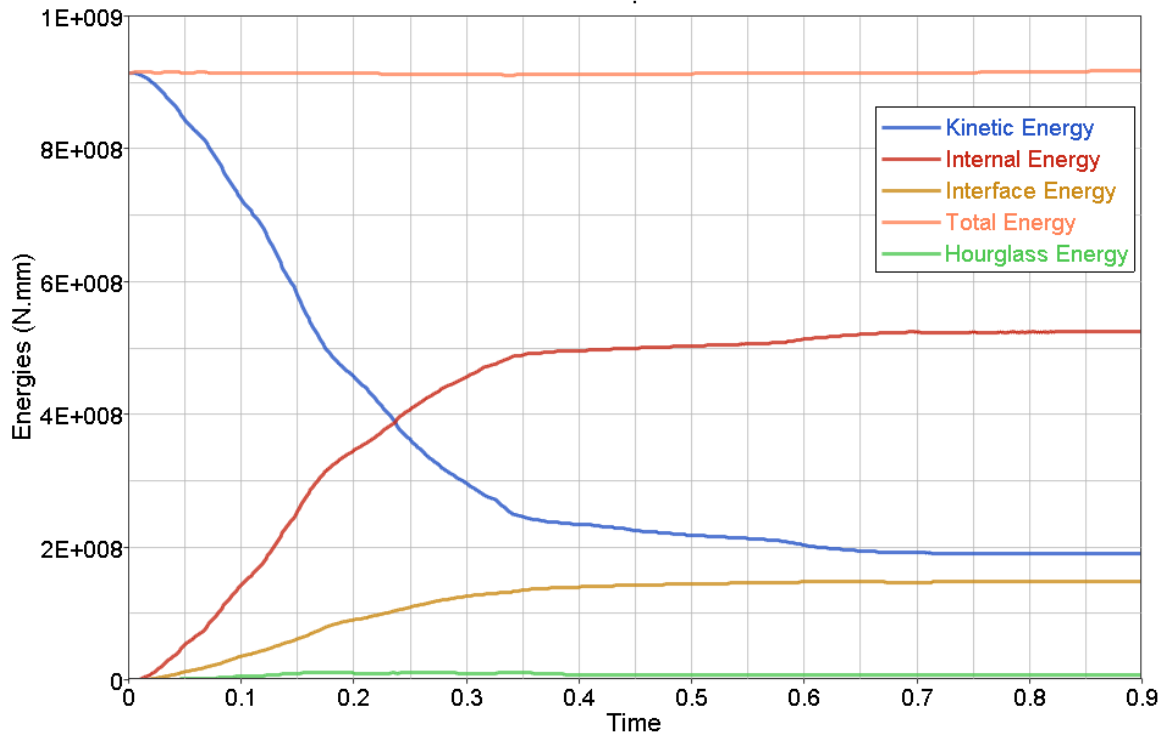


Figure 1: Simulations Energies

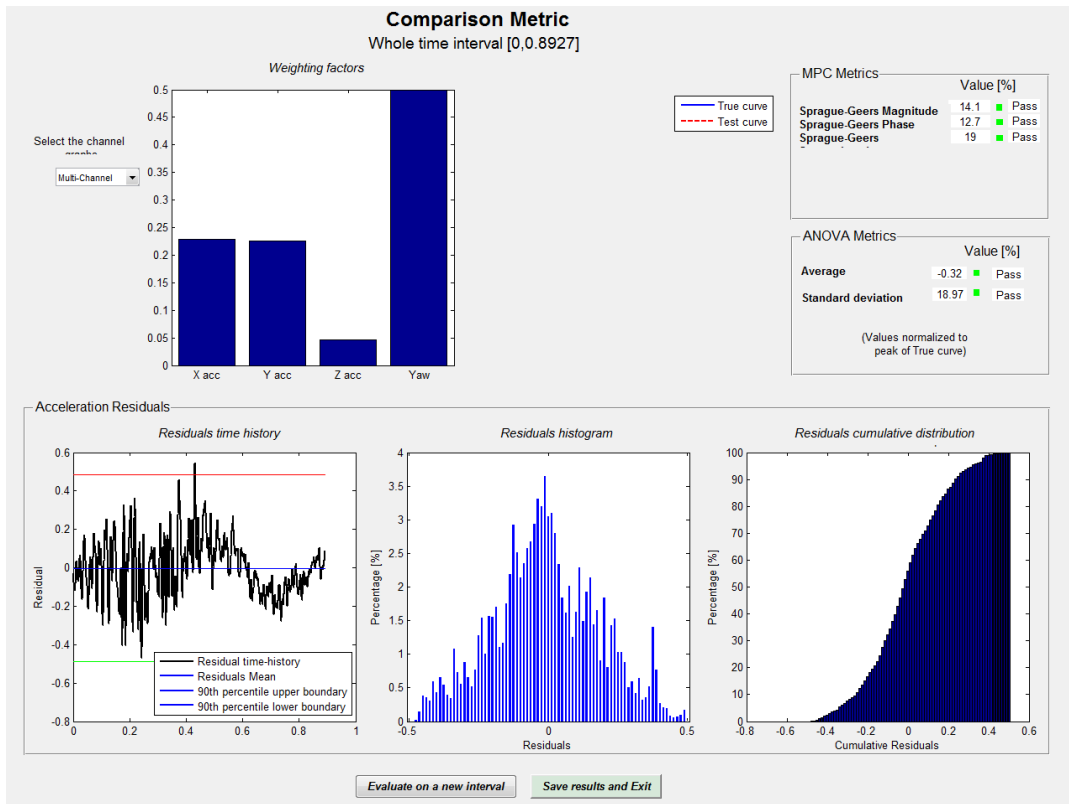
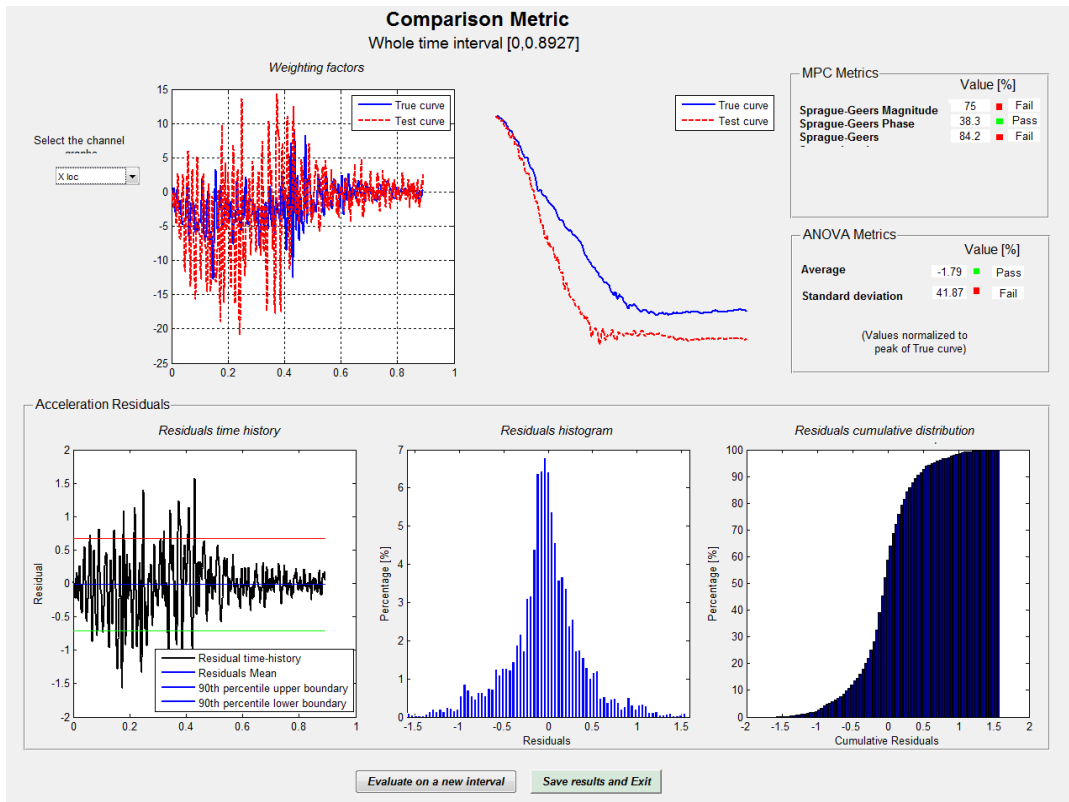
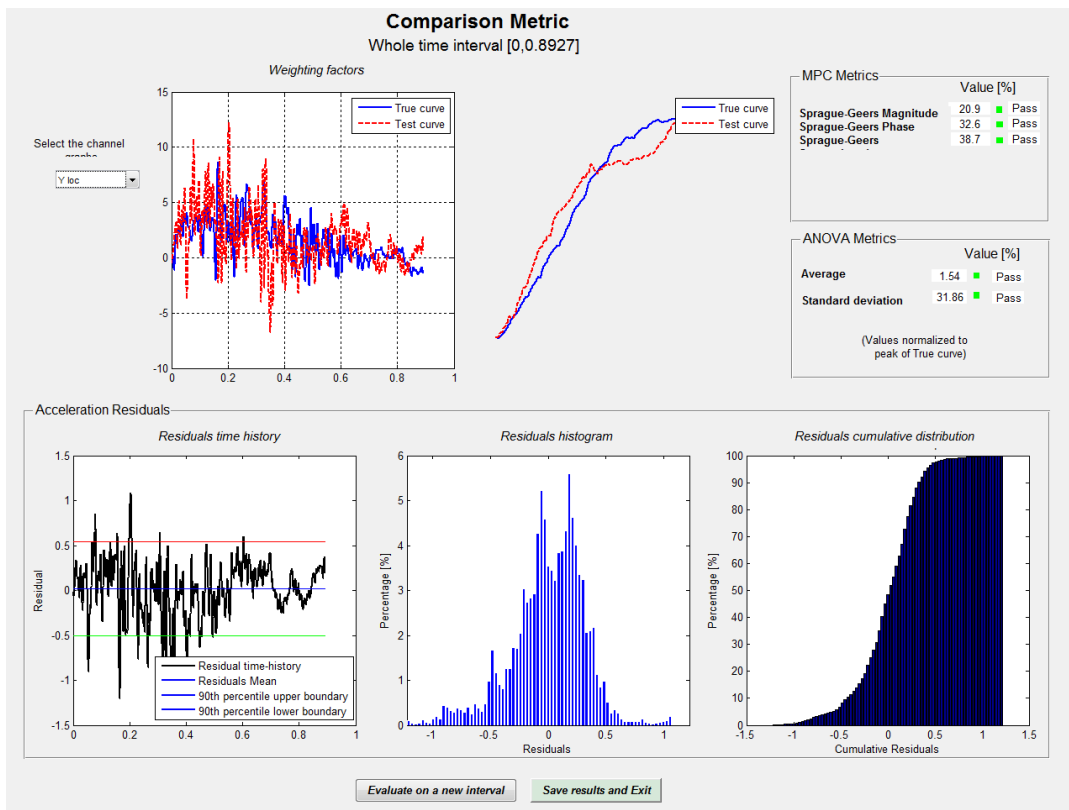


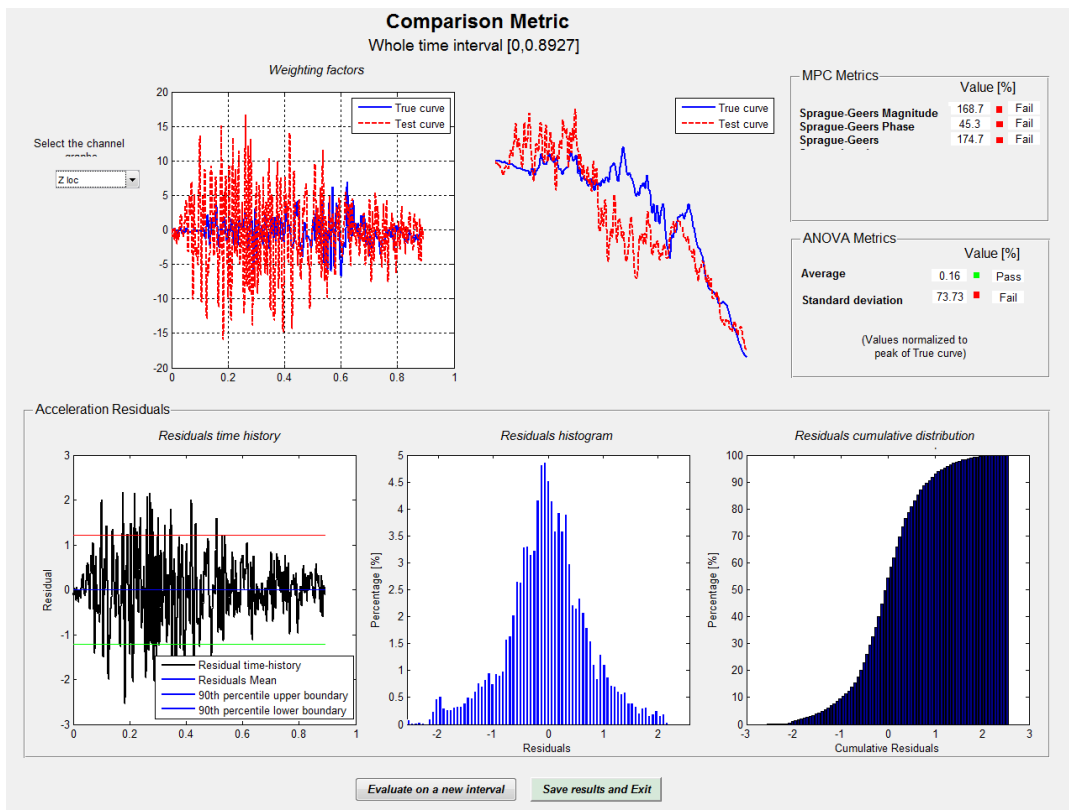
Figure 2a: RSVVP Results – All Channels



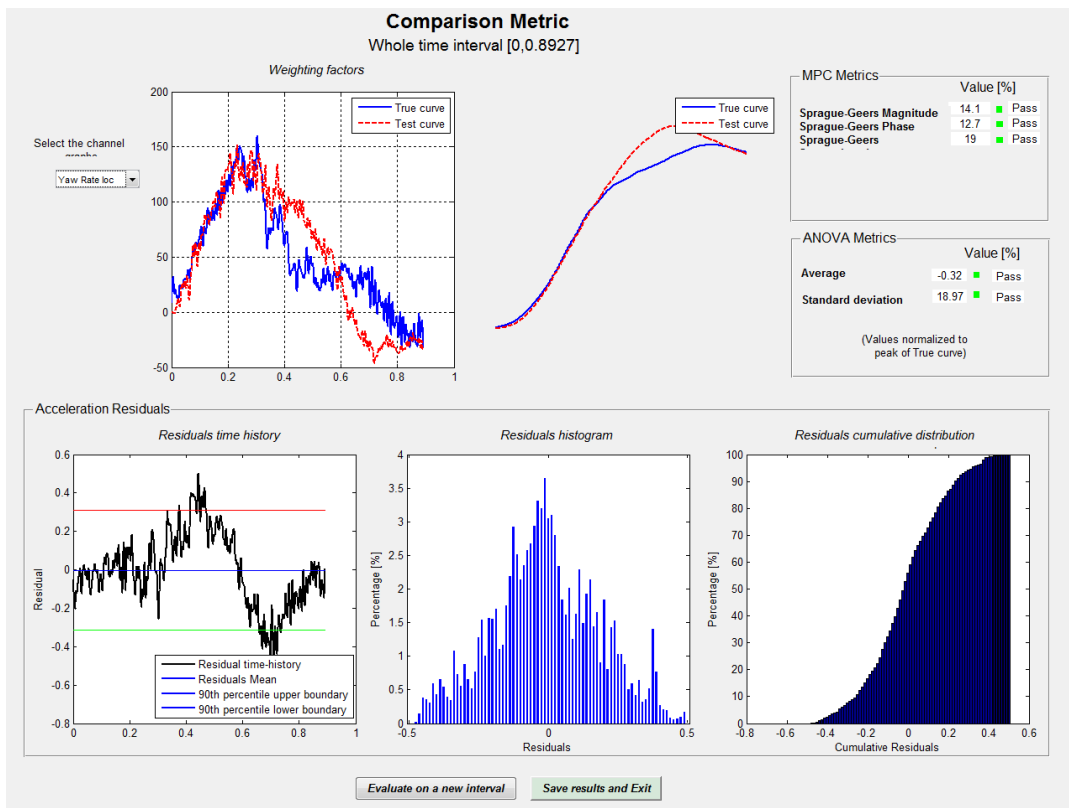
**Figure 2b: RSVVP Results – Longitudinal Acceleration**



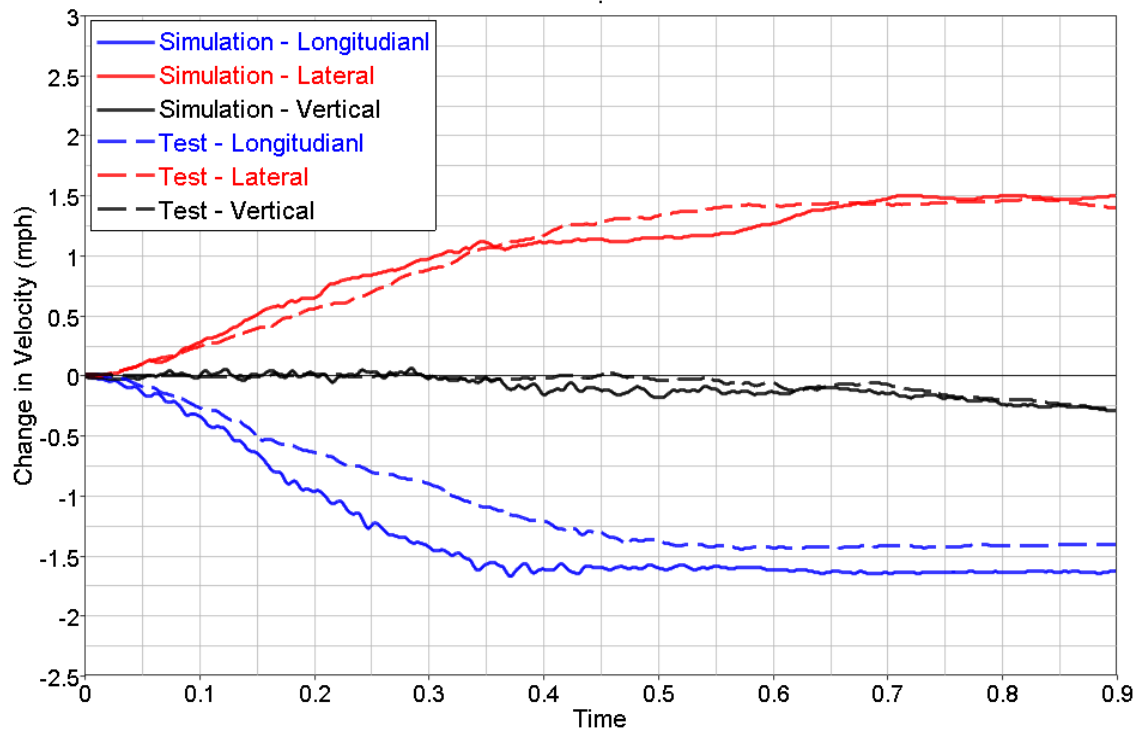
**Figure 2c: RSVVP Results – Lateral Acceleration**



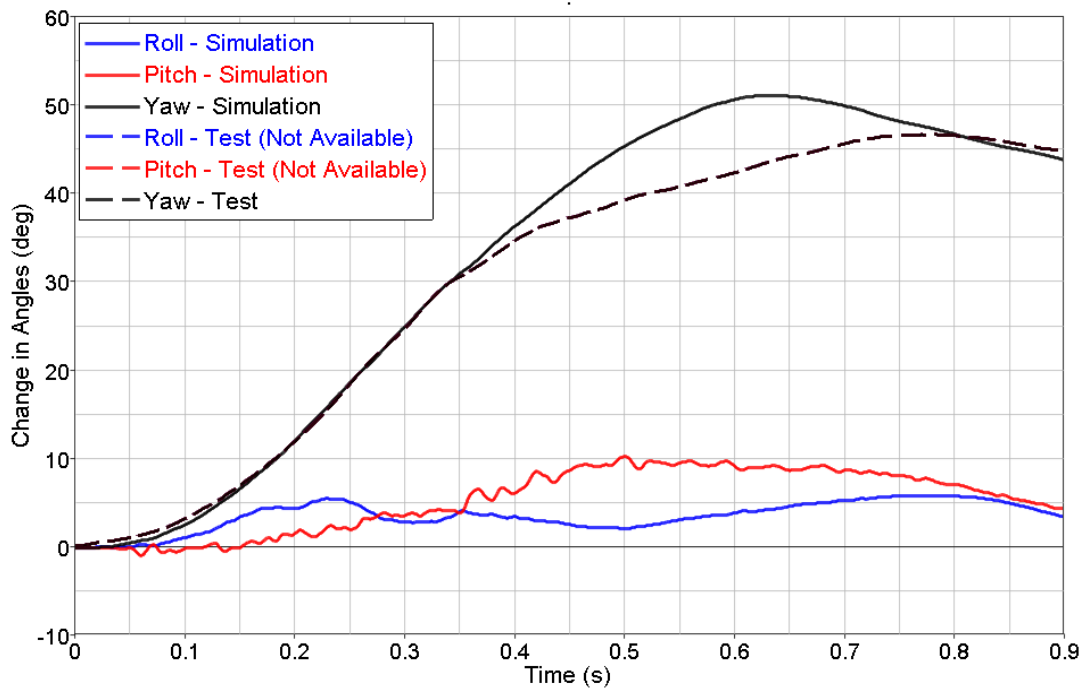
**Figure 2d: RSVVP Results – Vertical Acceleration**



**Figure 2e: RSVVP Results – Yaw Angle**



**Figure 3: Change in Vehicle Velocities**



**Figure 4: Change in Vehicle Angle**

# CCSA VALIDATION/VERIFICATION REPORT

**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?	
Structural Adequacy	A	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.	1.196 m	0.980 m	18.0 %	YES	
		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	
		A4	The relative difference in the number of broken or significantly bent posts is less than 20 percent.	3	3		YES	
		A5	Barrier did not fail (Answer Yes or No).	Yes	Yes		YES	
		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).	Yes	Yes		YES	
		A8	There was no significant snagging between vehicle body components and barrier elements (Answer Yes or No).	Yes	Yes		YES	
Occupant Risk	D	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	
		F	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	
	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	
	H	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	
		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	
	I	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

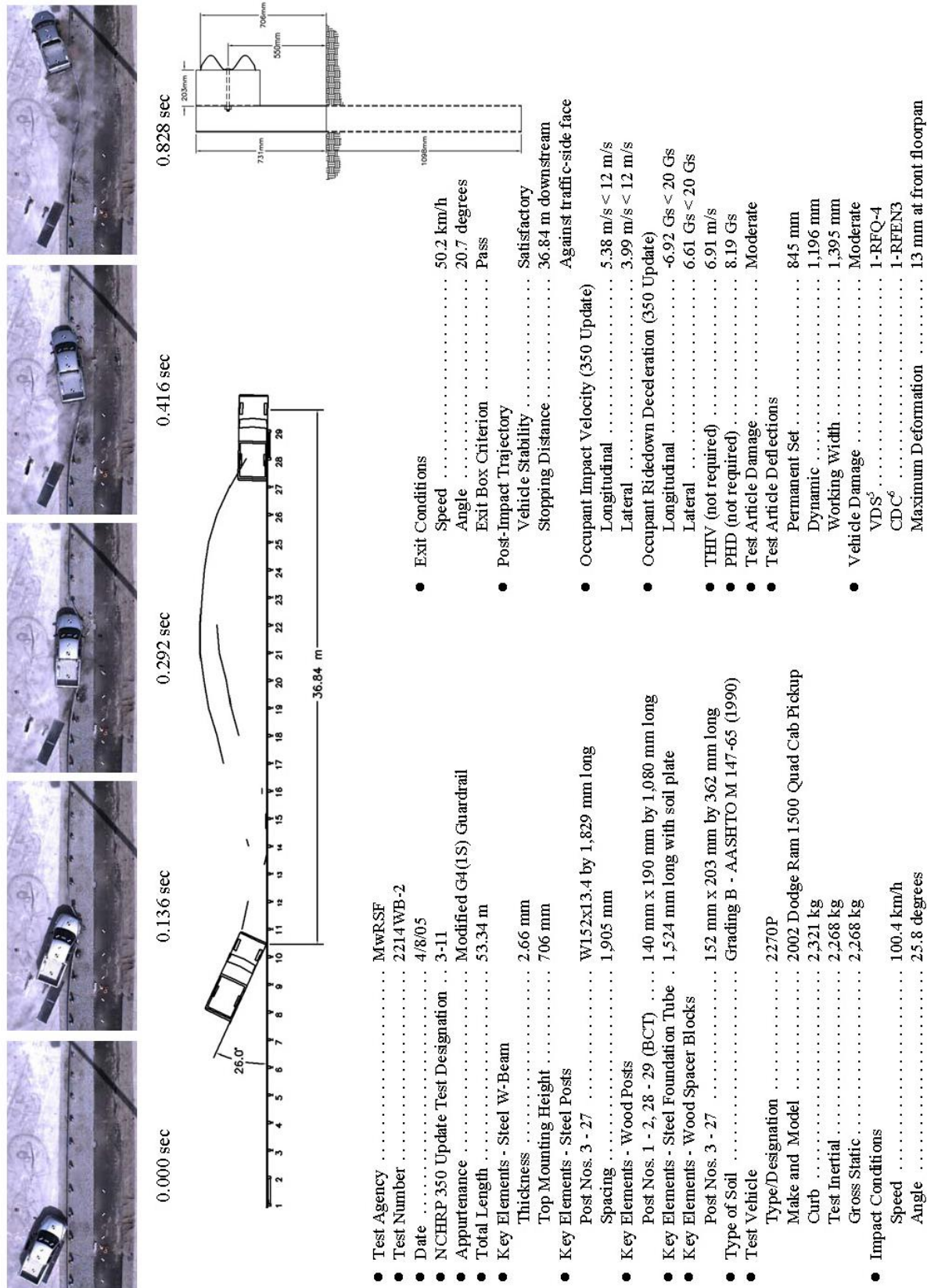
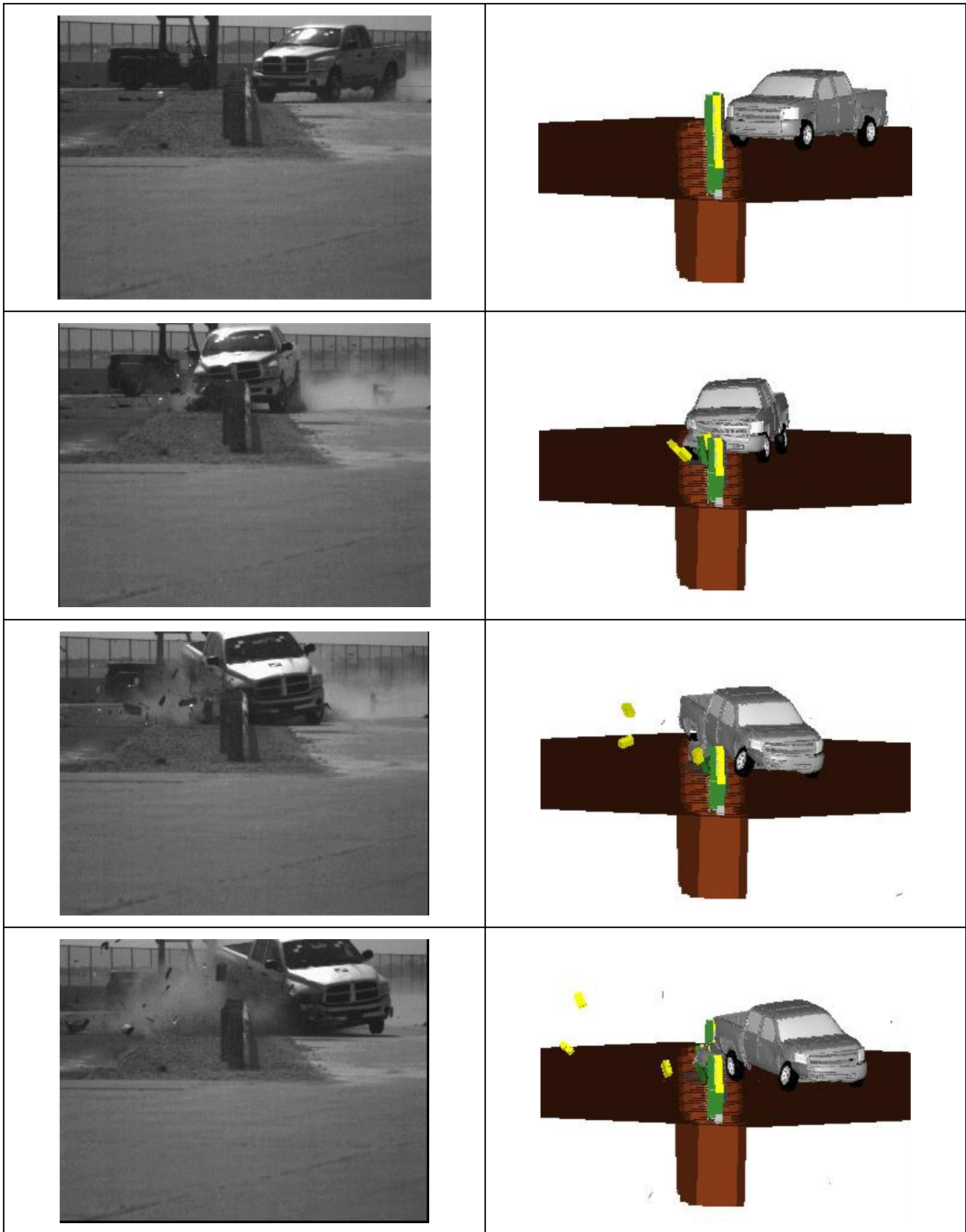


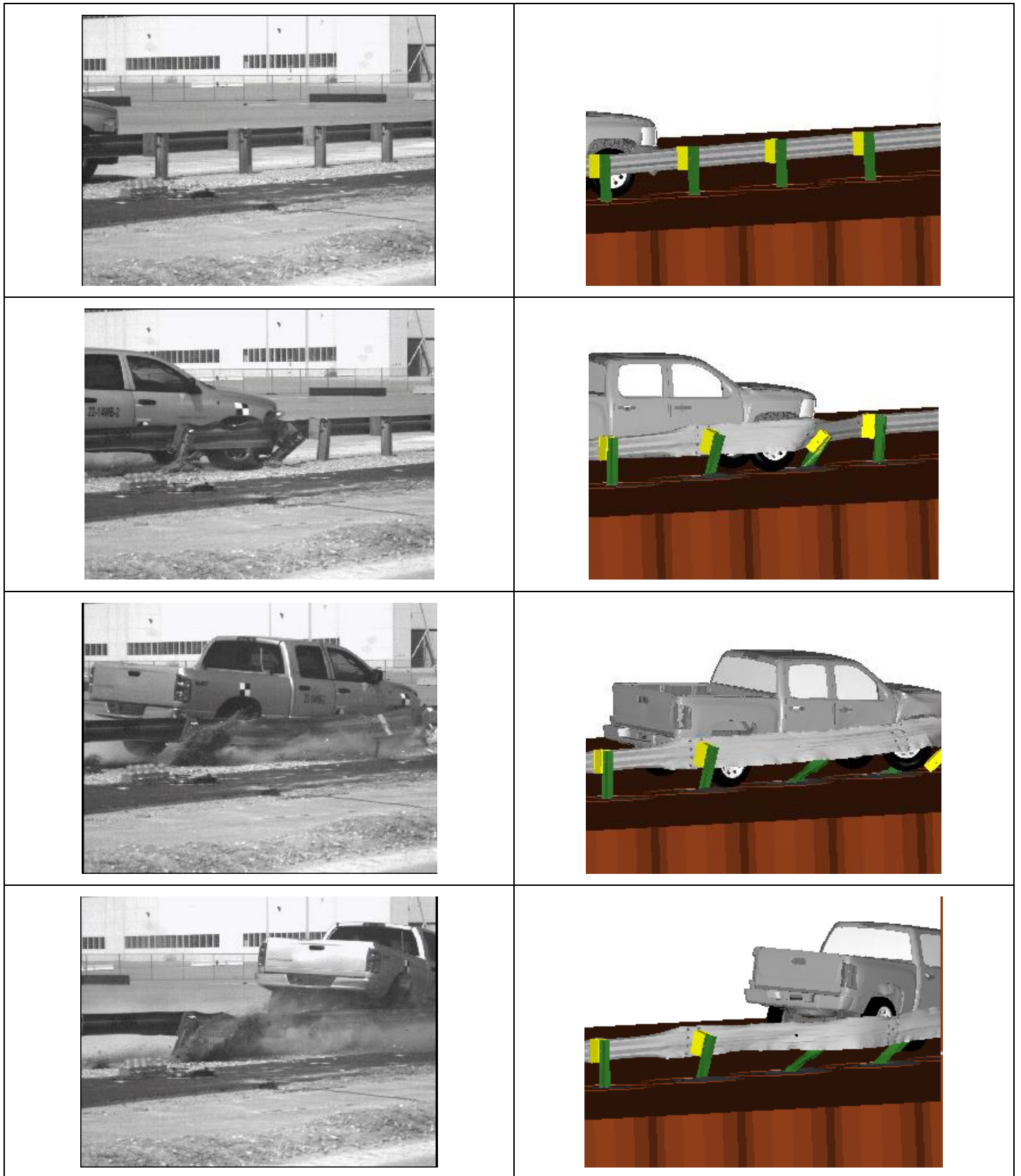
Figure 15. Summary of Test Results and Sequential Photographs, Test 2214WB-2

Figure 5: Full-Scale Test Summary

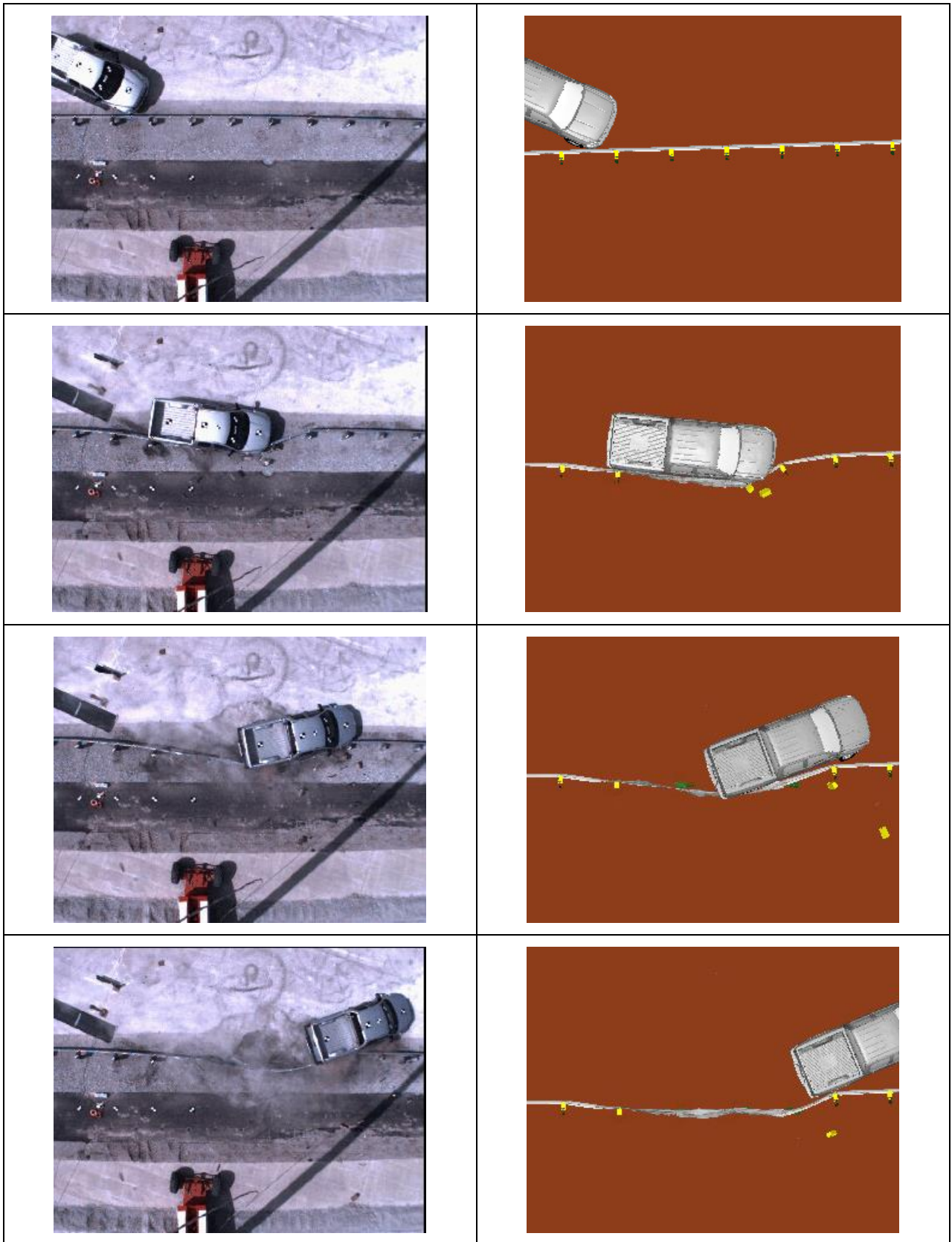




**Figure 6a: Sequential Comparisons – Front View**



**Figure 6b: Sequential Comparisons – Rear View**



**Figure 6c: Sequential Comparisons – Top View**

## CCSA VALIDATION/VERIFICATION REPORT

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

**Table F - Composite Verification and Validation Summary:**

List the Report MASH08 Test Number		
<b>Table C – Analysis Solution Verification</b>	Did all solution verification criteria in table pass?	<b>YES</b>
<b>Table D - RSVVP Results</b>	Do all the time history evaluation scores from the single channel factors result in a satisfactory comparison (i.e., the comparison passes the criterion)?	<b>NO</b>
	If all the values for Single Channel comparison did not pass, did the weighted procedure result in an acceptable comparison.	<b>YES</b>
<b>Table E - Roadside Safety Phenomena Importance Ranking Table</b>	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	<b>YES</b>
<b>Overall</b>	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.	<b>YES</b>

**NOTES:**

(none)

# Case-5: MGS Barrier Impact with 820C Vehicle

## CCSA VALIDATION/VERIFICATION REPORT

**Project:** CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections  
**Comparison Case:** 820C Vehicle with Midwest Guardrail Security Barrier  
**Impact Description:** 20-deg impact into barrier at 100 km/h (62 mph)  
**Governing Criteria:** Report 350 TL-3  
**Report 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
<b>Evaluation Method</b>	MASH (V1, 2009)	
<b>Hardware Type</b>	Longitudinal	
<b>Test Number</b>	3-10	
<b>Test Vehicle</b>	820C	
<b>Criterion to be Applied</b>	<b>Structural Adequacy</b>	<b>A</b> - 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.
	<b>Occupant Risk</b>	<b>D</b> - 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.
		<b>F</b> - The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.
		<b>H</b> - 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.
		<b>I</b> - 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.
	<b>Vehicle Trajectory</b>	For redirective devices the vehicle shall exit within the prescribed box.



# CCSA VALIDATION/VERIFICATION REPORT

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

Single Channel Time History Comparison Results		Time interval [0 sec - 0.5 sec]		
O	<i>Sprague-Geer Metrics</i>	M	P	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	<i>ANOVA Metrics</i>	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 interval [0 sec; 0.5 sec]		
Multi-Channel Weighting Method Peaks Area I Area II Inertial	X Channel	0.190111		
	Y Channel	0.362535		
	Z Channel	0.002645		
	Yaw Channel	0.362535		
	Roll Channel	0.072564		
	Pitch Channel	0.009609		
<i>Sprague-Geer Metrics</i>		M	P	Pass?
	All Channels (weighted)	16.5	21.4	YES
<i>ANOVA Metrics</i>		Mean	SD	Pass?
	All Channels (weighted)	-0.02	0.22	YES

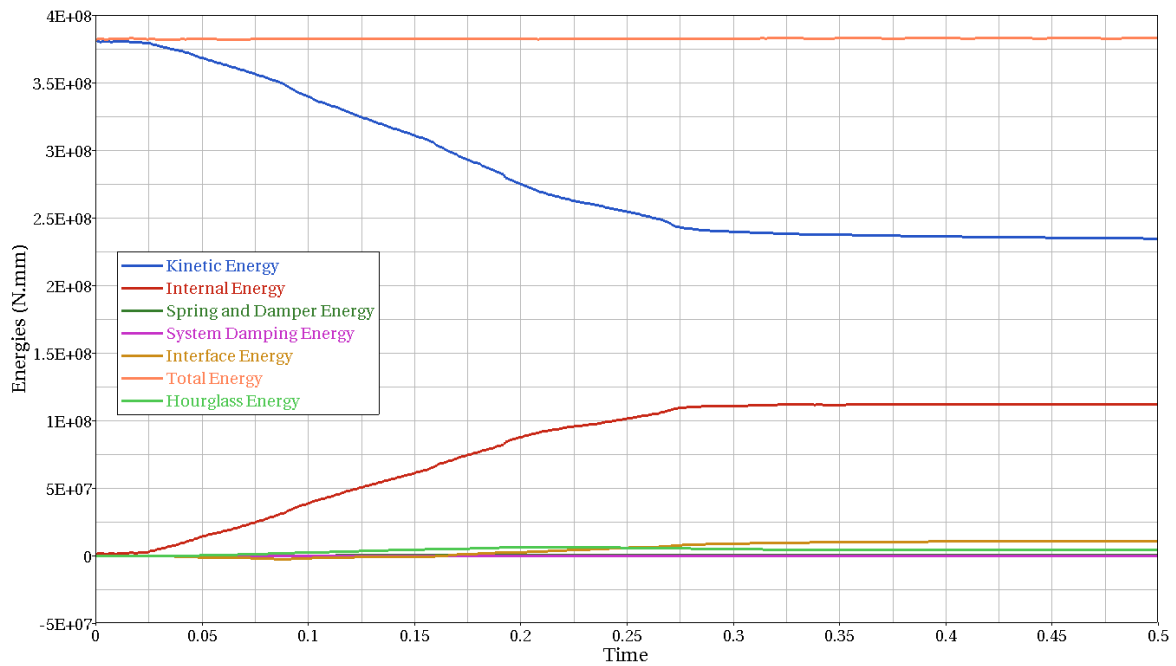


Figure 1: Simulations Energies

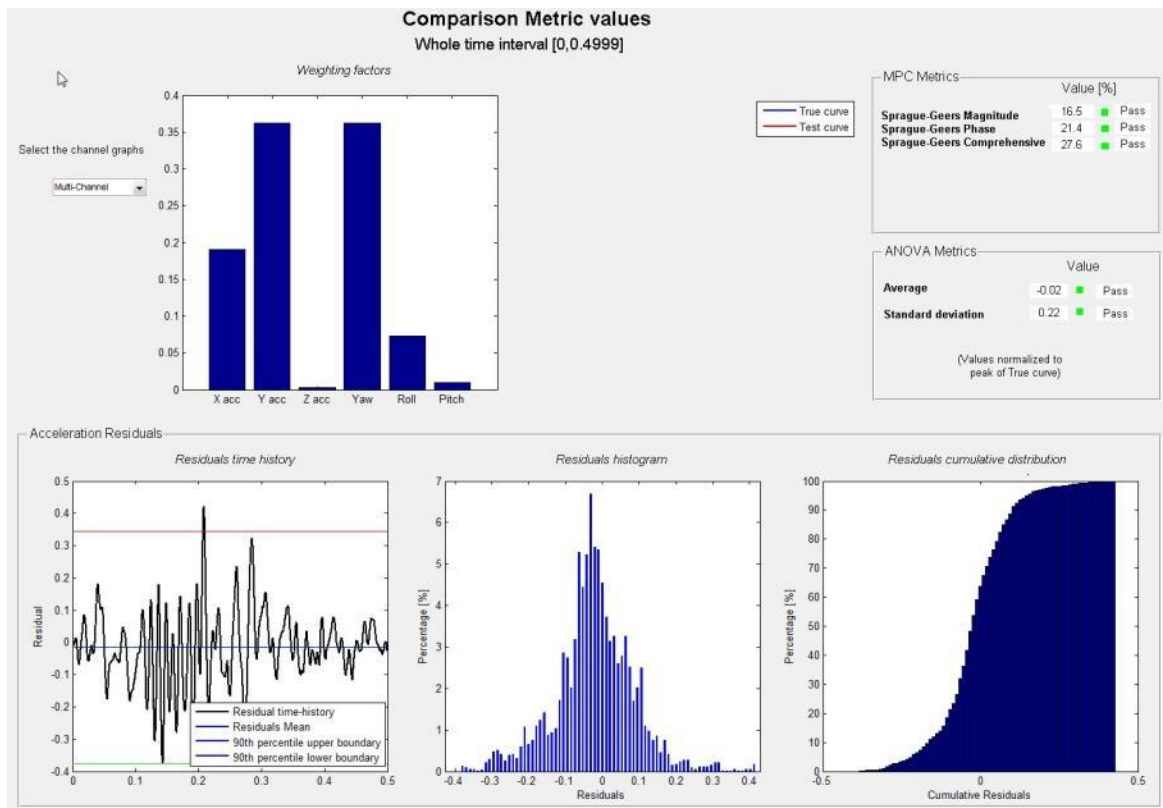
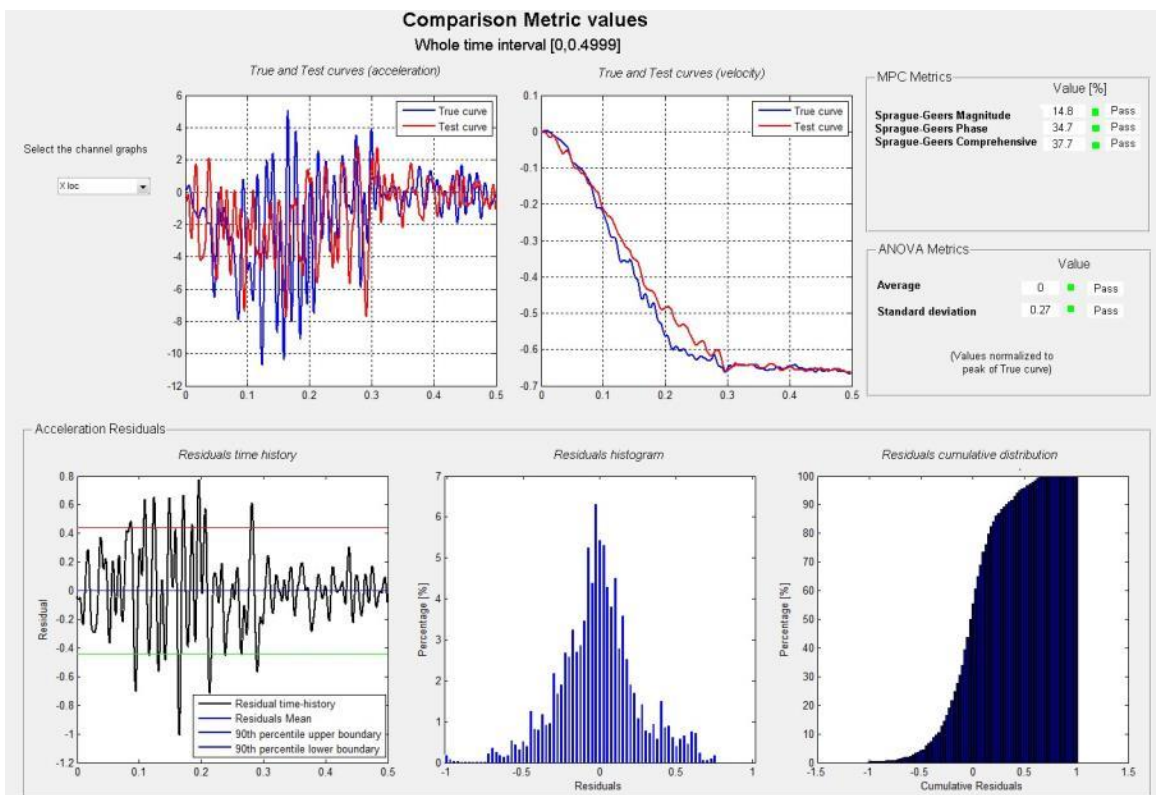
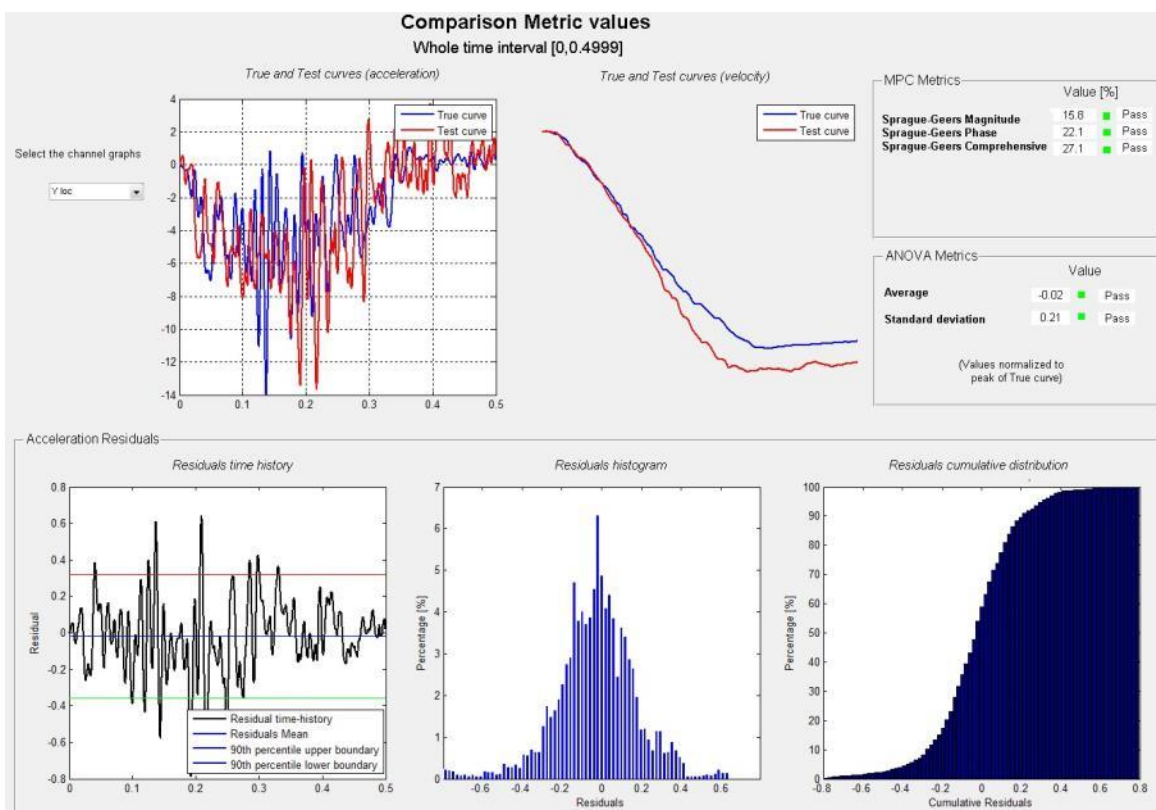


Figure 2a: RSVVP Results – All Channels

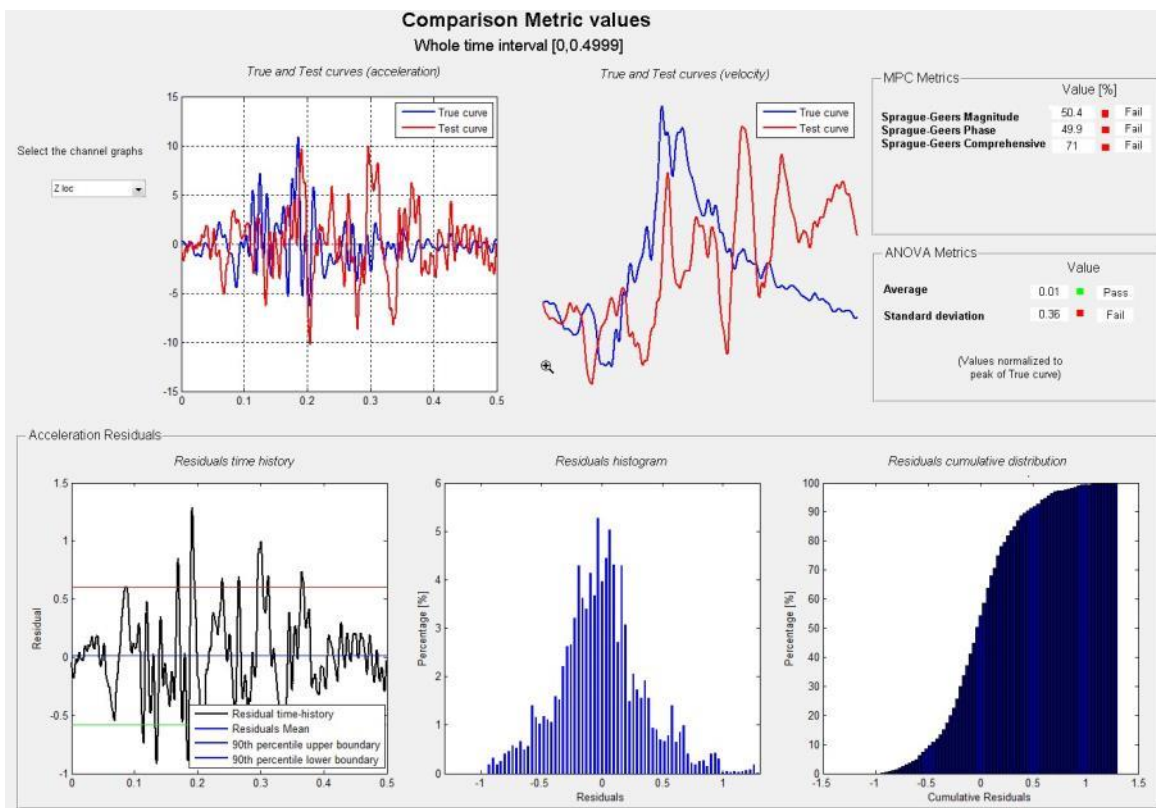




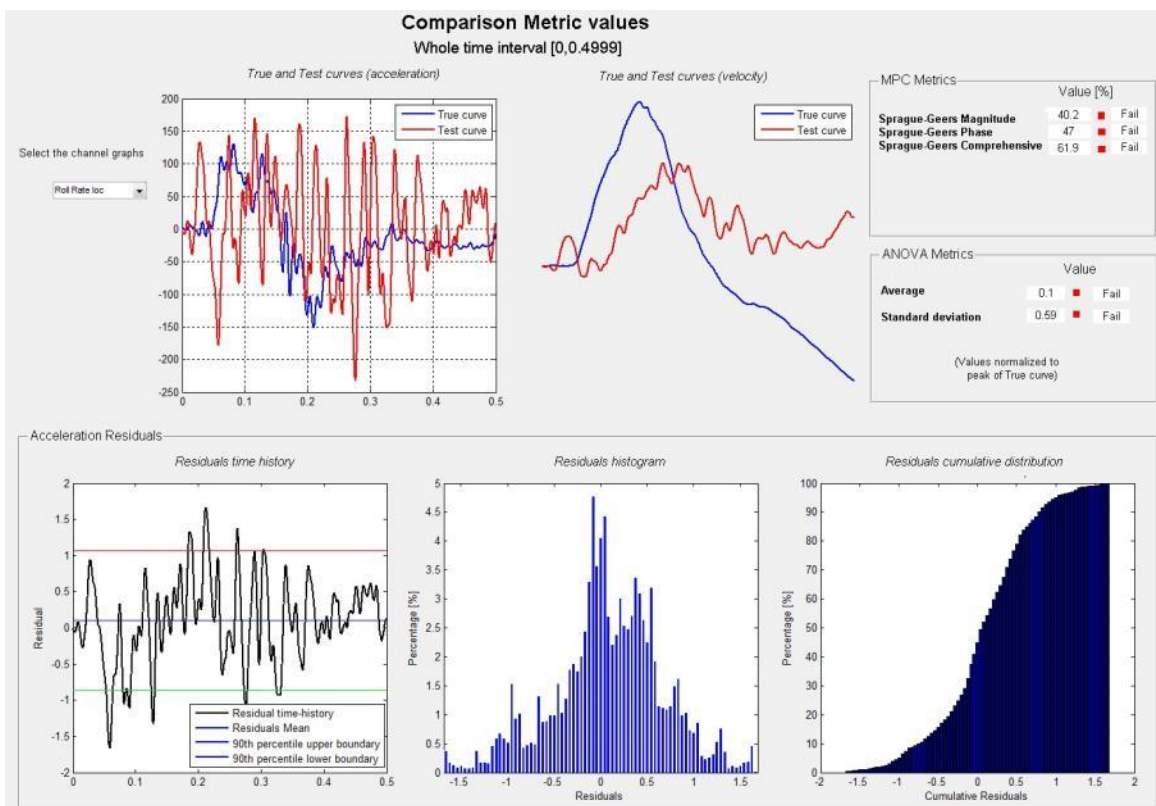
**Figure 2b: RSVVP Results – Longitudinal Acceleration**



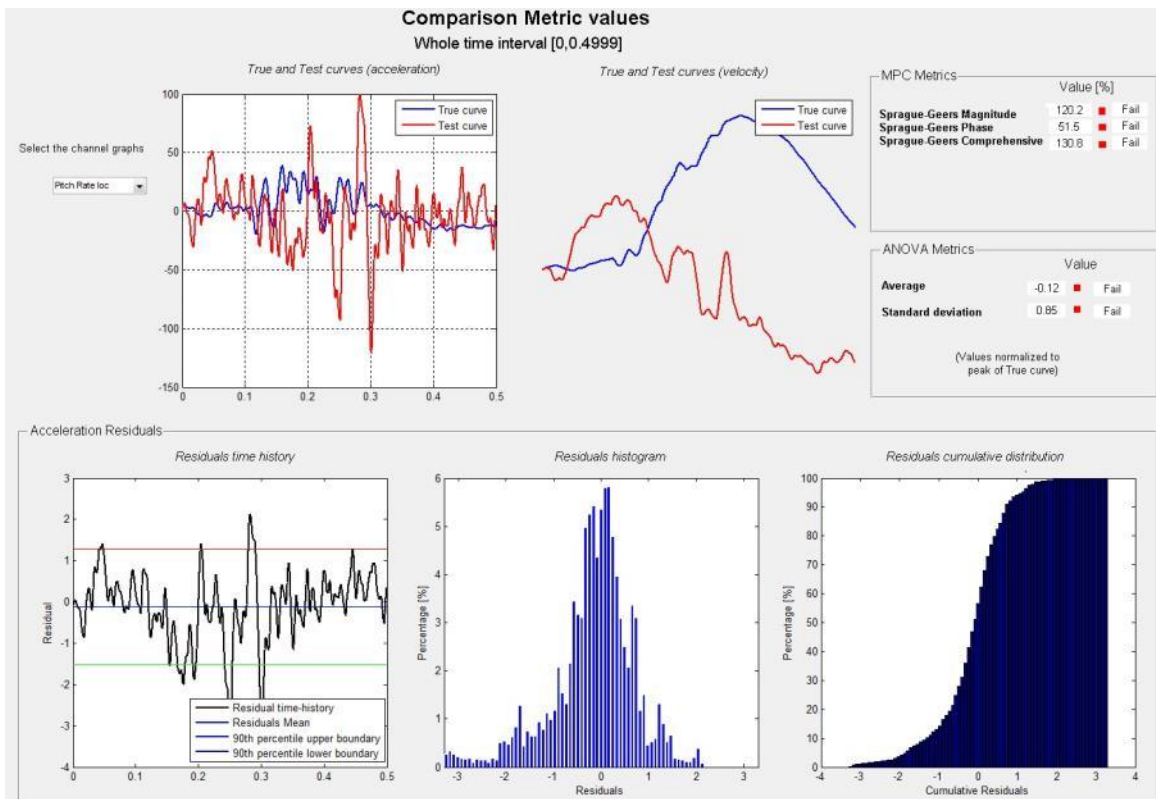
**Figure 2c: RSVVP Results – Lateral Acceleration**



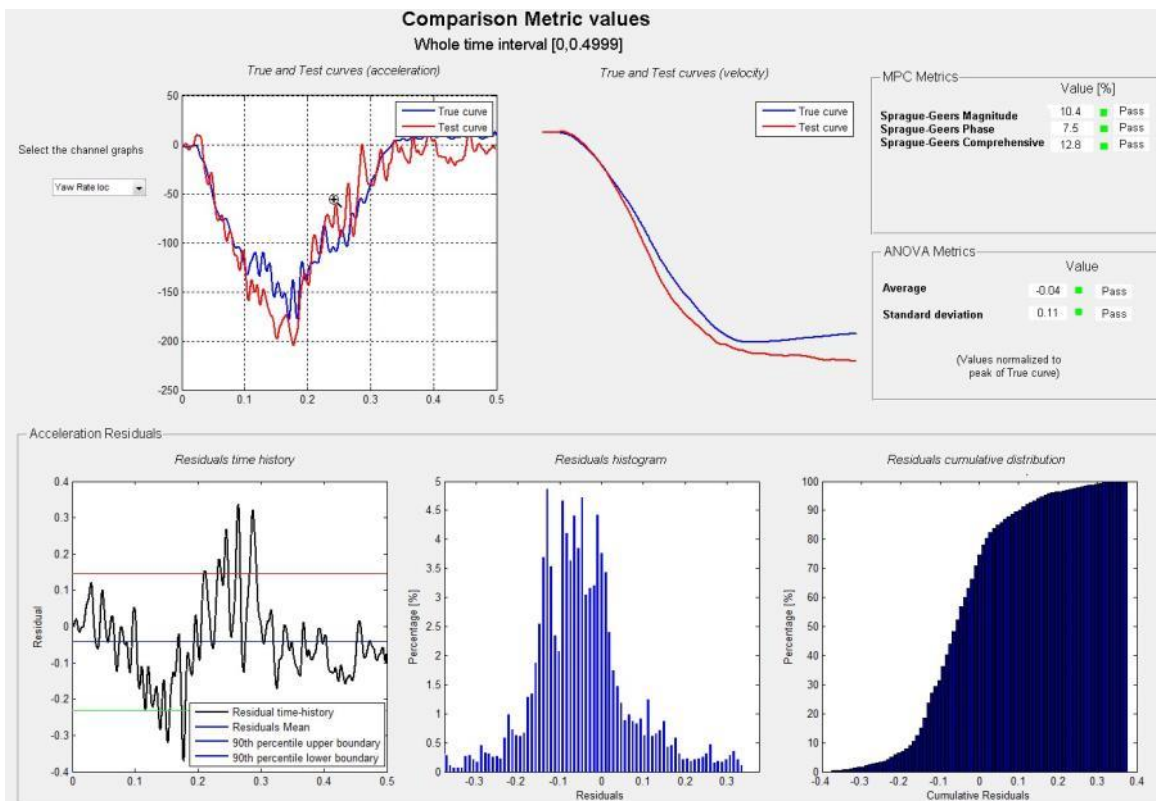
**Figure 2d: RSVVP Results – Vertical Acceleration**



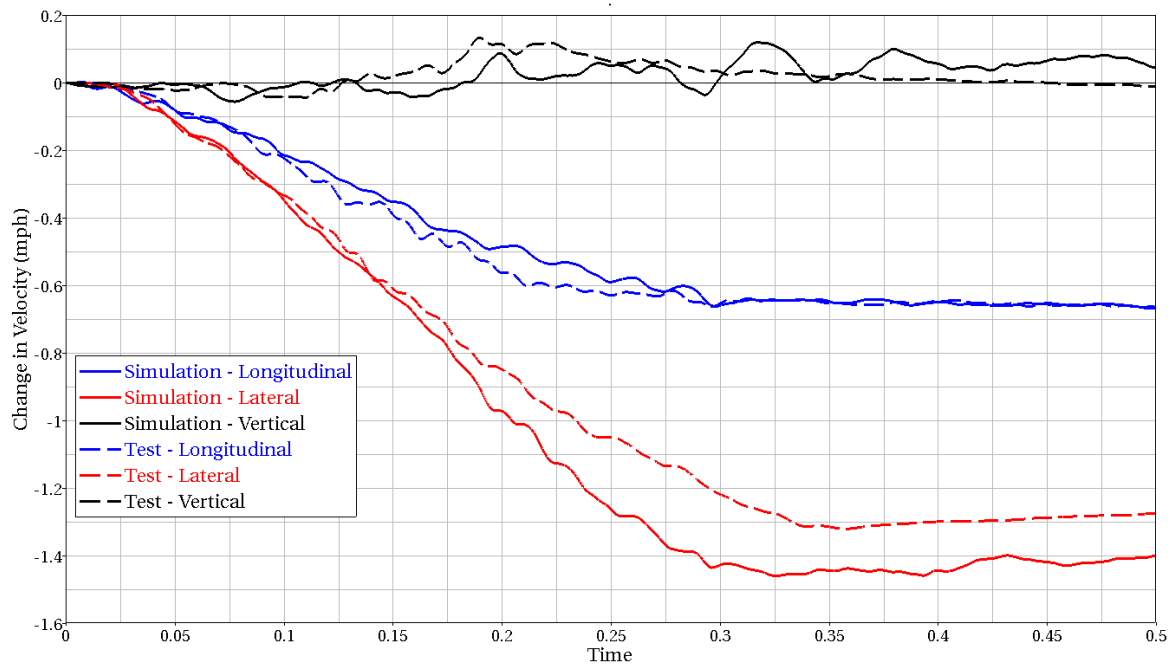
**Figure 2e: RSVVP Results – Roll Angle**



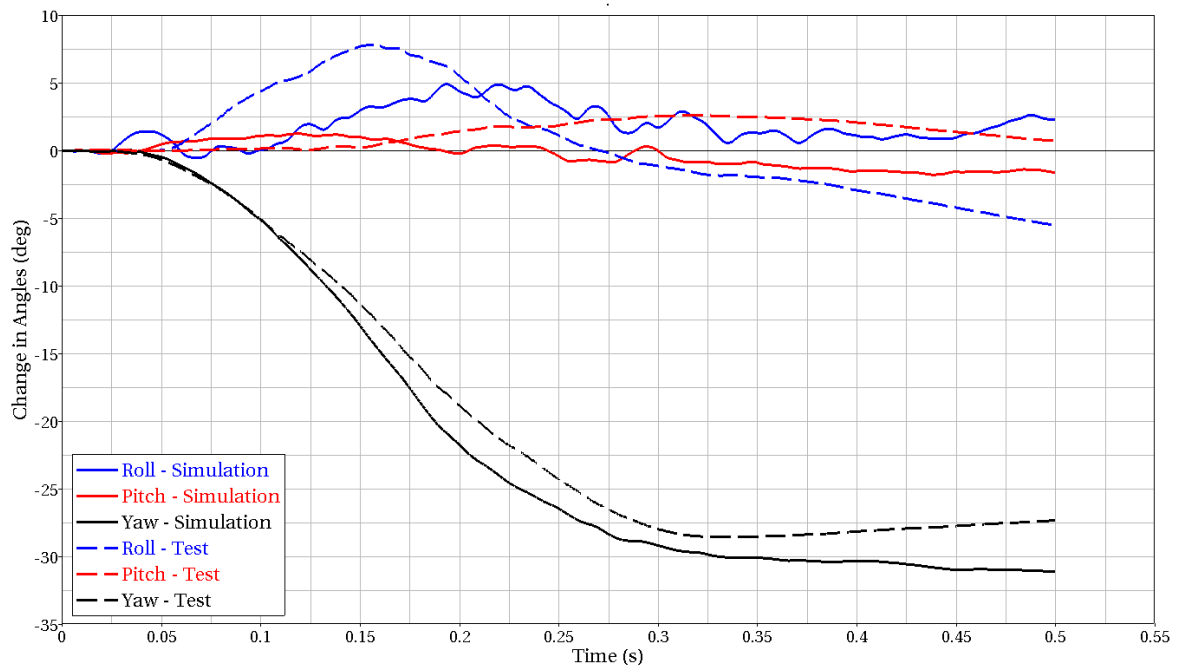
**Figure 2f: RSVVP Results – Pitch Angle**



**Figure 2g: RSVVP Results – Yaw Angle**



**Figure 3: Change in Vehicle Velocities**



**Figure 4: Change in Vehicle Angles**

# CCSA VALIDATION/VERIFICATION REPORT

**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	A	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	
		A3	The relative difference in the time of vehicle-barrier contact is less than 20 percent.	s	0.36 s	15	YES	
		A4	The relative difference in the number of broken or significantly bent posts is less than 20 percent.	Yes	Yes		YES	
		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	Yes		NO	
		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	
Occupant Risk	D	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	
		F	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
			F3	Maximum vehicle pitch – relative difference is less than 20% or absolute difference is less than 5 deg.	2.6 0(.31s)	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.	28.5 (0.33s)	31.0 (0.5s)	8% 2.5 deg	YES	
	H	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	
		H2	Longitudinal OIV (m/s) - Relative difference is less than 20% 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	
	I	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	
	Vehicle Trajectory			The vehicle rebounded within the exit box. (Answer Yes or No)	Yes	Yes		YES



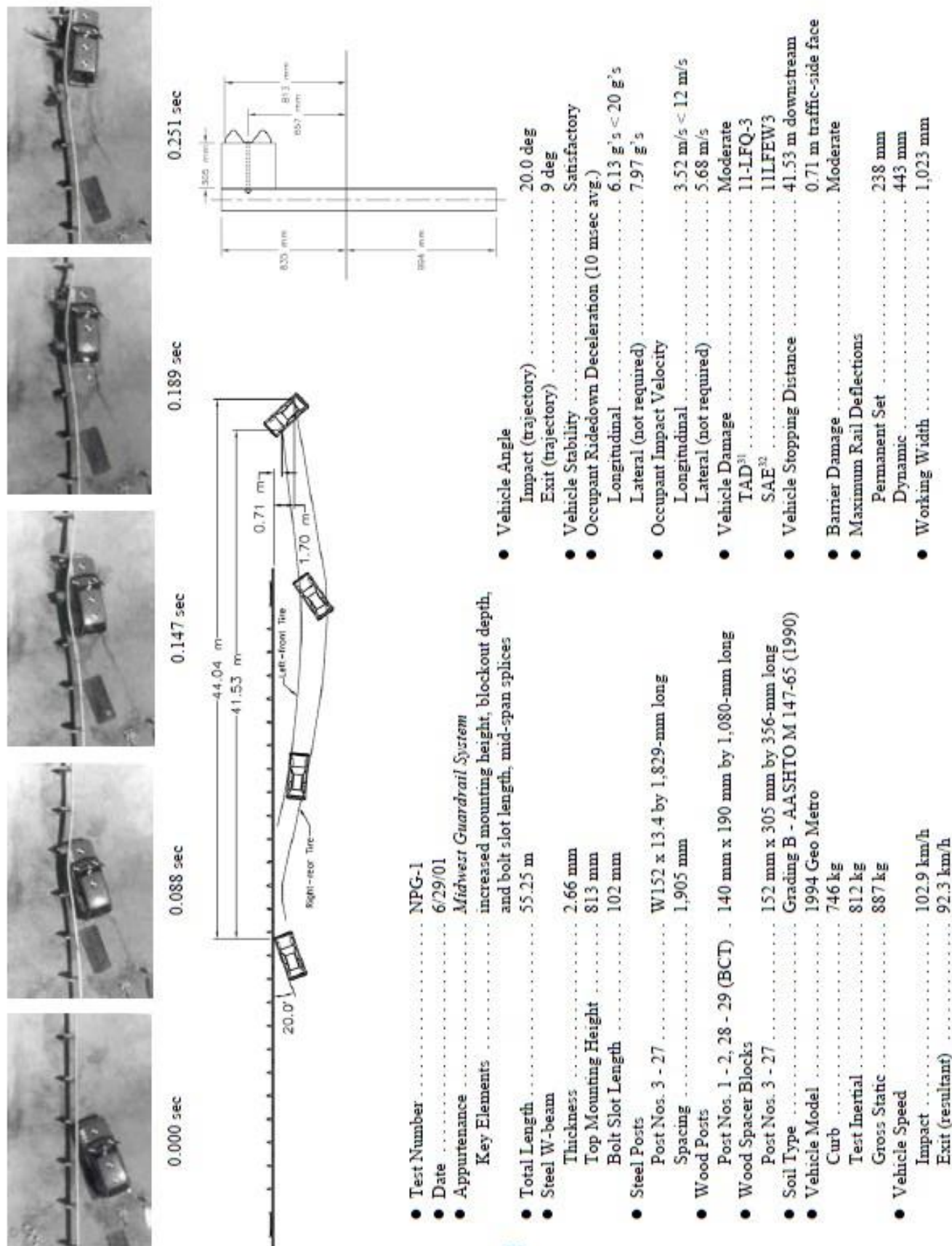
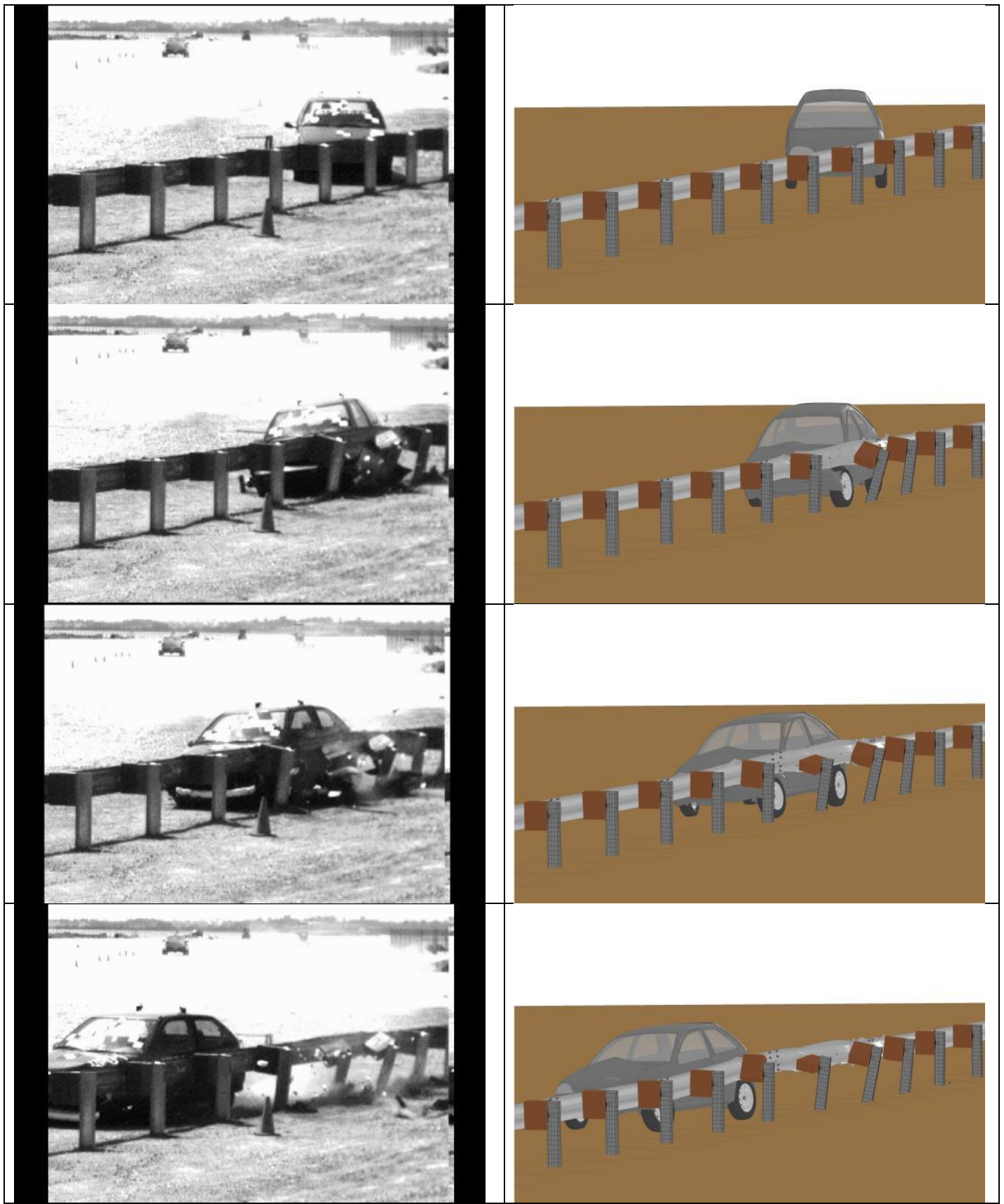
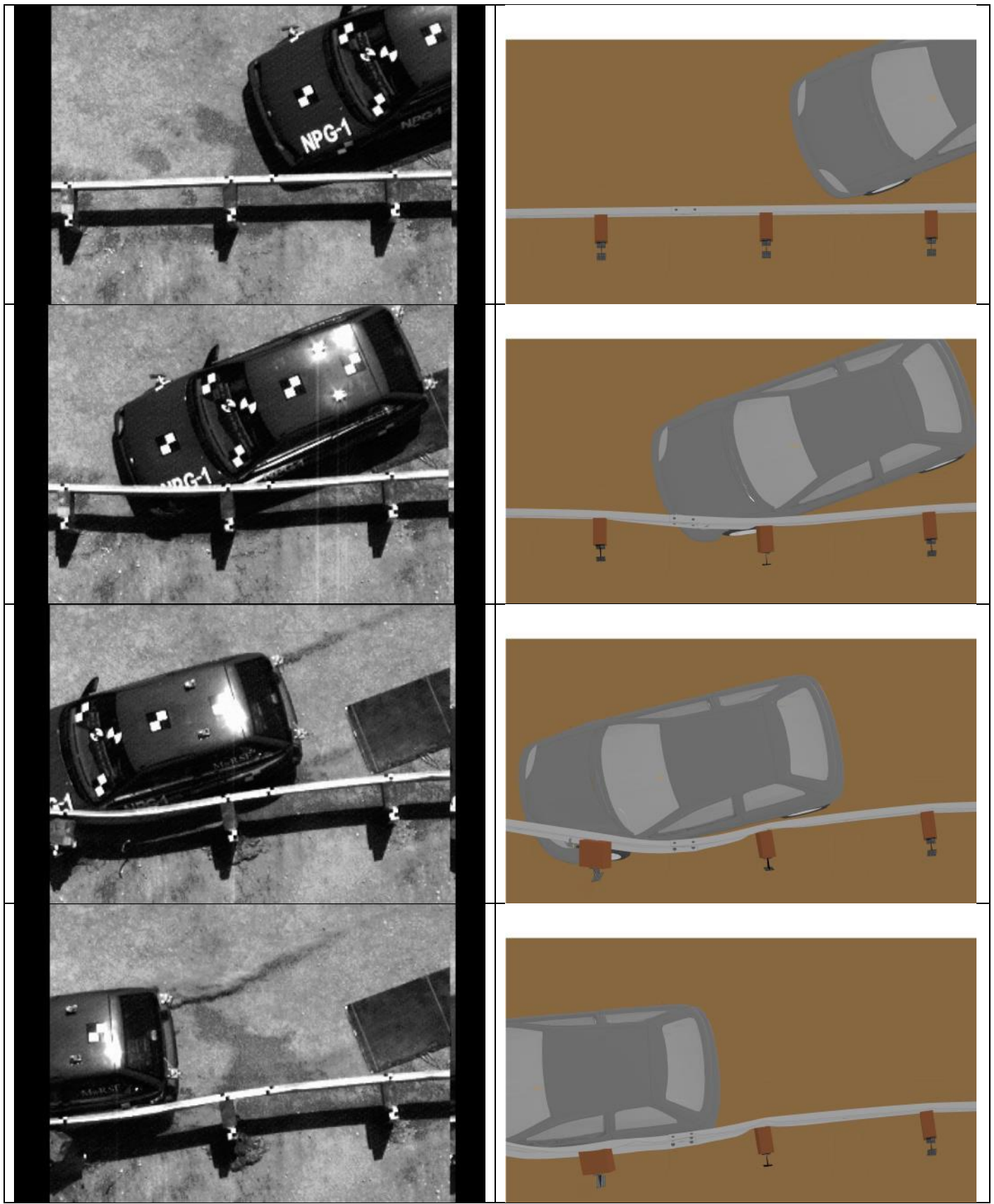


Figure 5 – Full Scale Test Summary



**Figure 6a: Sequential Comparisons – Front View**





**Figure 6b: Sequential Comparisons – Top View**

## CCSA VALIDATION/VERIFICATION REPORT

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

**Table F - Composite Verification and Validation Summary:**

<b>List the Report MASH08 Test Number</b>		
<b>Table C – Analysis Solution Verification</b>	Did all solution verification criteria in table pass?	<b>YES</b>
<b>Table D - RSVVP Results</b>	Do all the time history evaluation scores from the single channel factors result in a satisfactory comparison (i.e., the comparison passes the criterion)?	<b>NO</b>
	If all the values for Single Channel comparison did not pass, did the weighted procedure result in an acceptable comparison.	<b>YES</b>
<b>Table E - Roadside Safety Phenomena Importance Ranking Table</b>	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	<b>YES</b>
<b>Overall</b>	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.	<b>YES</b>

**NOTES:**

(none)

# Case-6: MGS Barrier Impact with 1100C Vehicle

## CCSA VALIDATION/VERIFICATION REPORT

**Project:** CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections  
**Comparison Case:** 1100C Vehicle with MGS Barrier  
**Impact Description:** 25.4-deg impact into barrier at 97.8 km/h (60.8 mph)  
**Governing Criteria:** MASH TL-3  
**Report 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:**

Category	Subset	Values
<b>Evaluation Method</b>	MASH (V1, 2009)	
<b>Hardware Type</b>	Longitudinal	
<b>Test Number</b>	3-10	
<b>Test Vehicle</b>	1100C	
<b>Criterion to be Applied</b>	<b>Structural Adequacy</b>	<b>A</b> - 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.
	<b>Occupant Risk</b>	<b>D</b> - 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.
		<b>F</b> - The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.
		<b>H</b> - 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.
		<b>I</b> - 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.
	<b>Vehicle Trajectory</b>	For redirective devices the vehicle shall exit within the prescribed box.

# CCSA VALIDATION/VERIFICATION REPORT

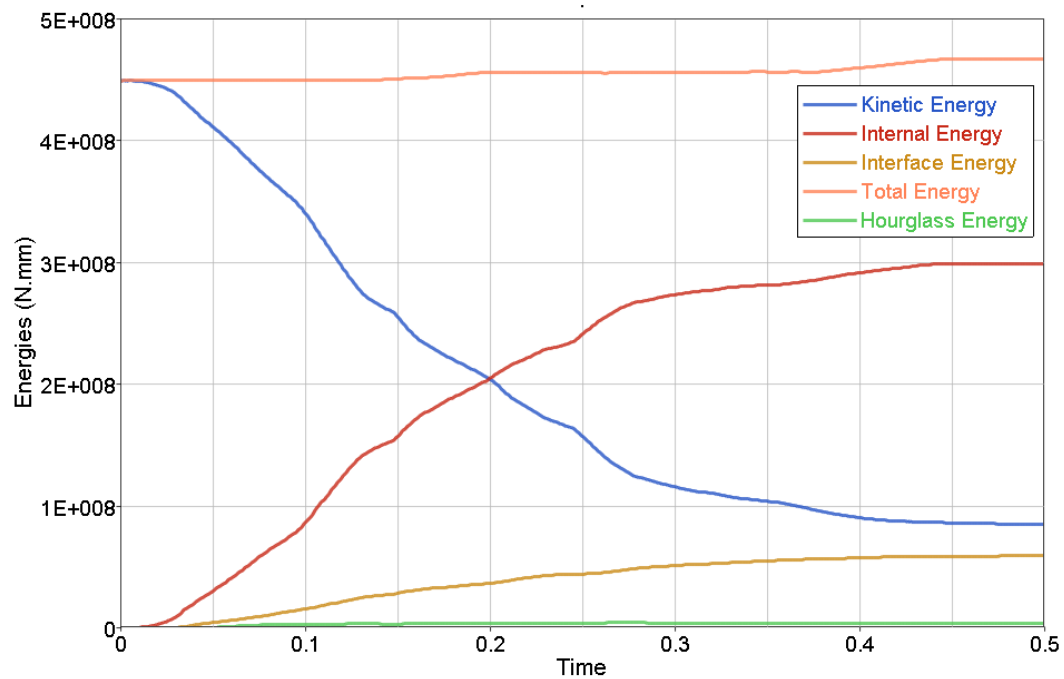
**Project: CCSA Longitudinal Barriers on Curved, Superelevated Roadway Sections**  
**Comparison Case: 1100C Vehicle with MGS Barrier**

**Table C – Analysis Solution Verification Summary**

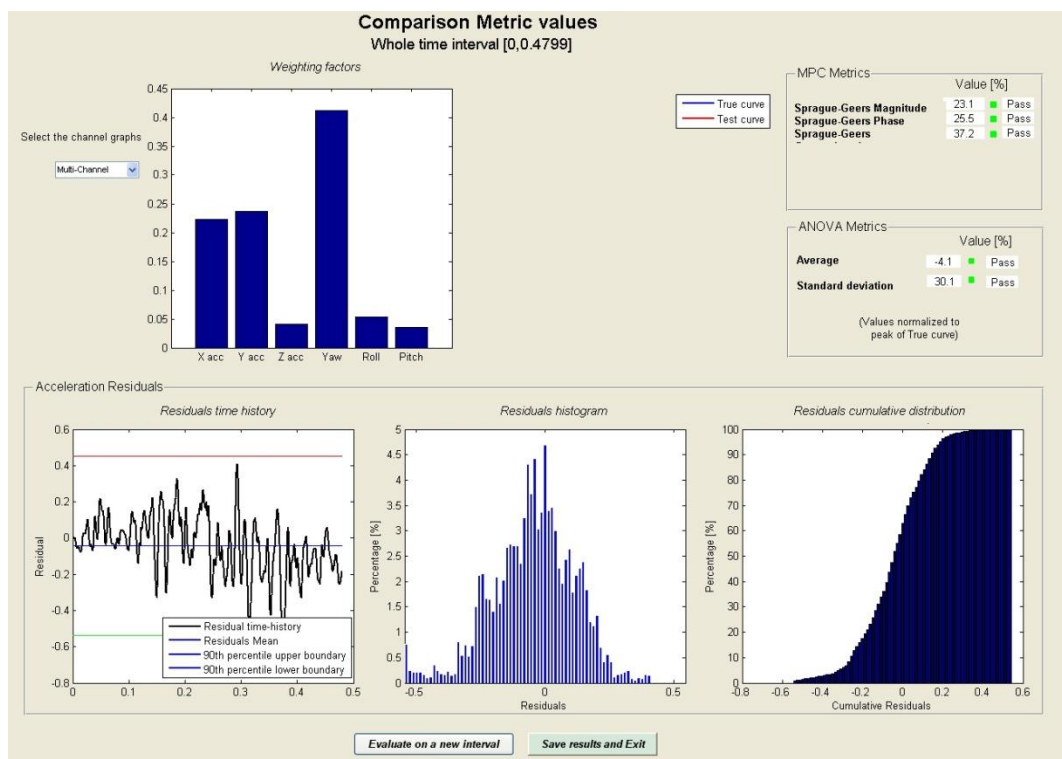
Verification Evaluation Criteria	Change (%)	Pass?
Total energy of the analysis solution (i.e., kinetic, potential, contact, etc.) must not vary more than 10 percent from the beginning of the run to the end of the run.	2.64	YES
Hourglass Energy of the analysis solution at the end of the run is less than 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**

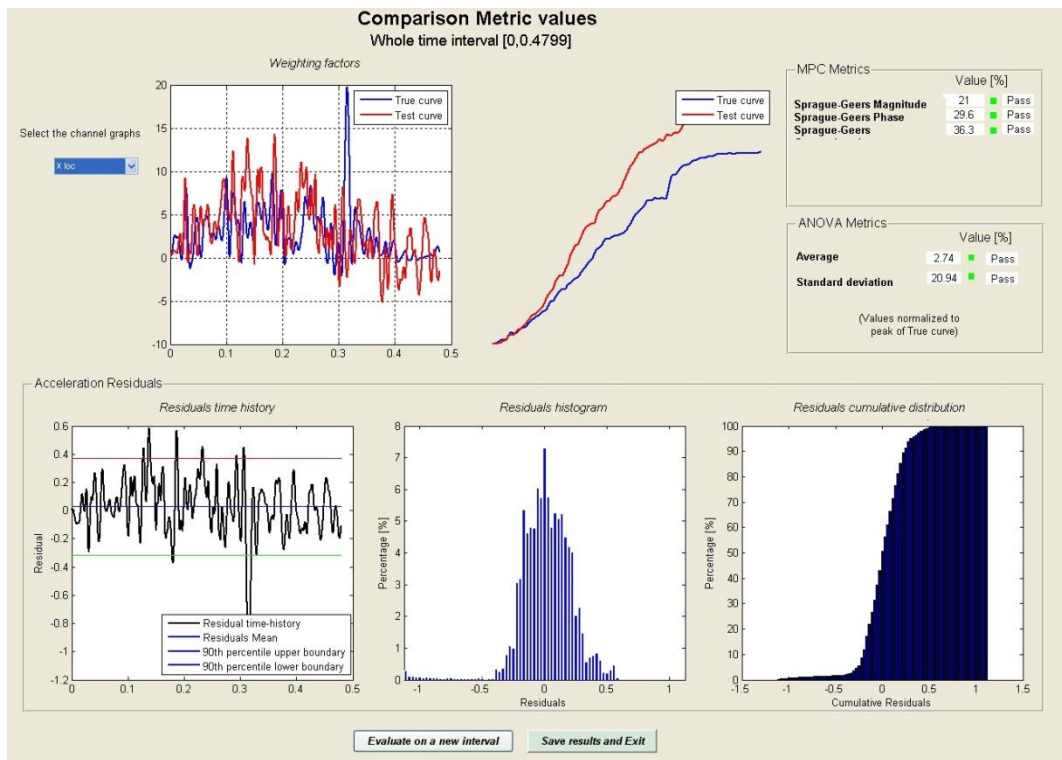
Single Channel Time History Comparison Results		Time interval [0 sec - 0.5 sec]		
O	<b><i>Sprague-Geer Metrics</i></b>	<b>M</b>	<b>P</b>	<b>Pass?</b>
	X acceleration	21	29.6	YES
	Y acceleration	42.6	30.4	NO
	Z acceleration	110.2	43.5	NO
	Yaw rate	1.8	16.6	YES
	Roll rate	1.5	29.9	YES
	Pitch rate	85.7	43.6	NO
P	<b><i>ANOVA Metrics</i></b>	<b>Mean</b>	<b>SD</b>	<b>Pass?</b>
	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
<b>Multi-Channel Weighting Factors</b>		<b>Time interval [0 sec; 0.5 sec]</b>		
<b>Multi-Channel Weighting Method</b> <b>Peaks Area I</b> <b>Area II Inertial</b>	<b>X Channel</b>	0.222365		
	<b>Y Channel</b>	0.236344		
	<b>Z Channel</b>	0.041289		
	<b>Yaw Channel</b>	0.412014		
	<b>Roll Channel</b>	0.052883		
	<b>Pitch Channel</b>	0.035101		
<b><i>Sprague-Geer Metrics</i></b>		<b>M</b>	<b>P</b>	<b>Pass?</b>
	All Channels (weighted)	23.1	25.5	YES
<b><i>ANOVA Metrics</i></b>		<b>Mean</b>	<b>SD</b>	<b>Pass?</b>
	All Channels (weighted)	-4.1	30.1	YES



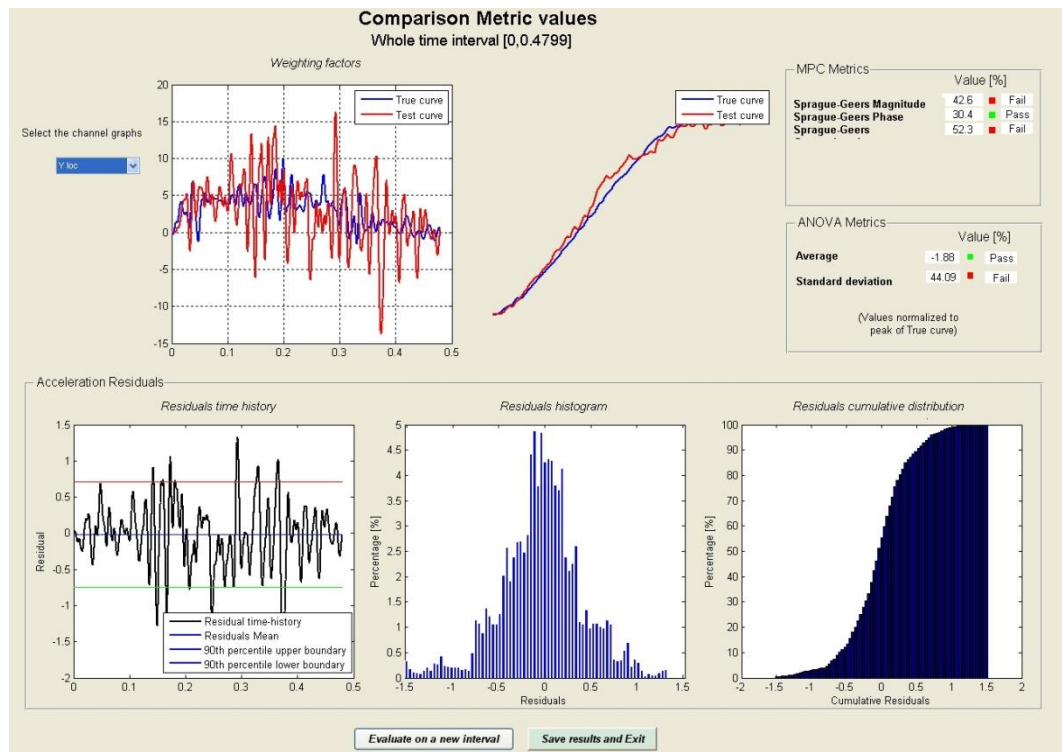
**Figure 1: Simulations Energies**



**Figure 2a: RSVVP Results – All Channels**

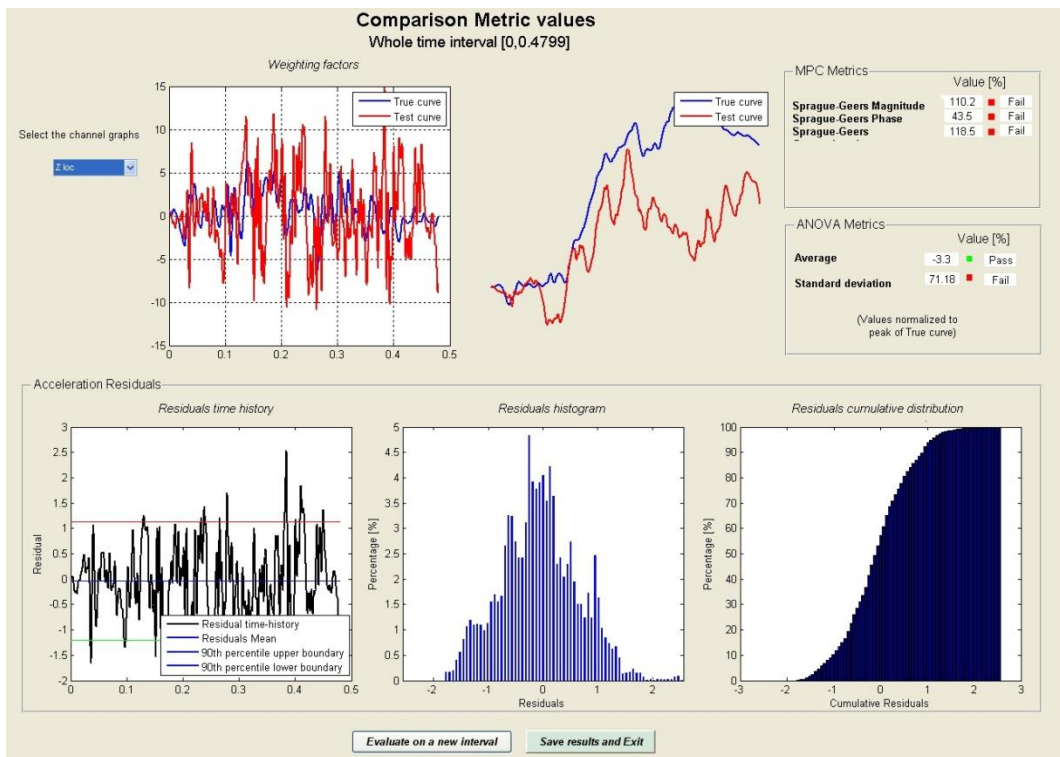


**Figure 2b: RSVVP Results – Longitudinal Acceleration**

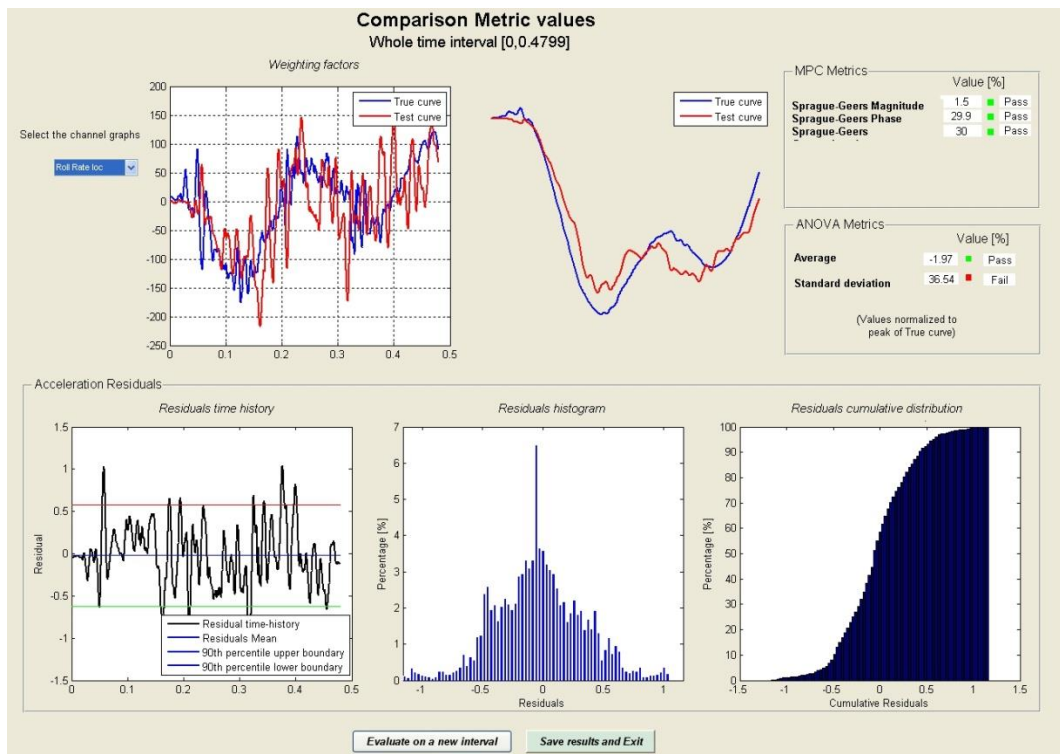


**Figure 2c: RSVVP Results – Lateral Acceleration**

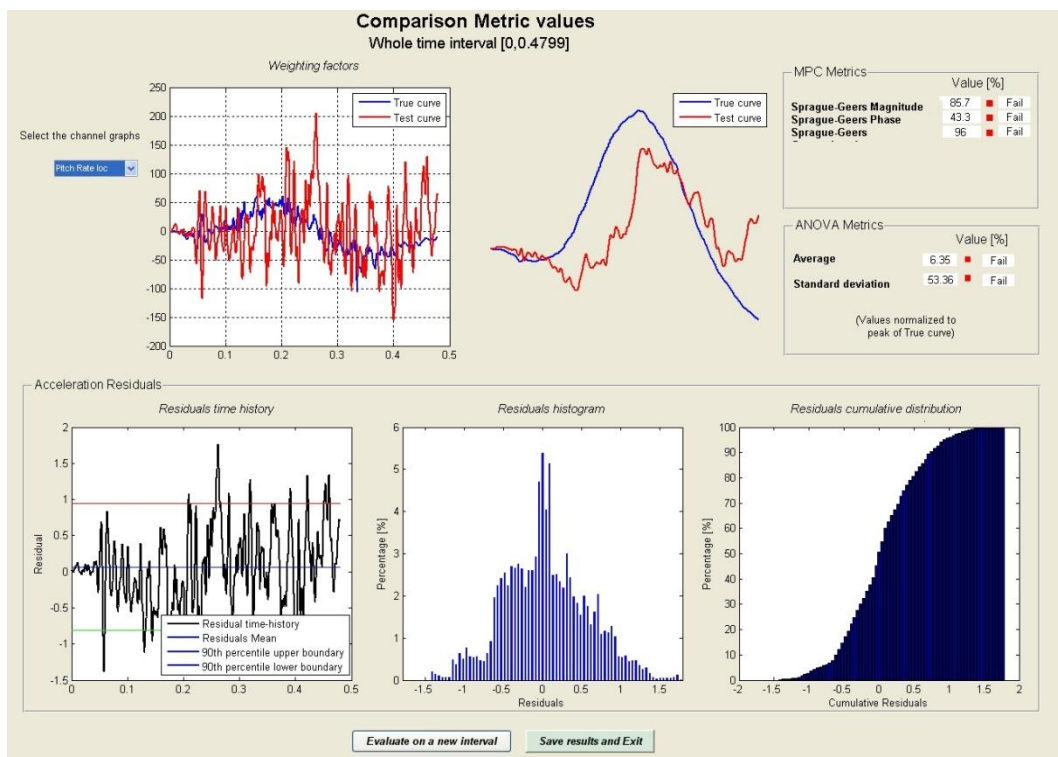




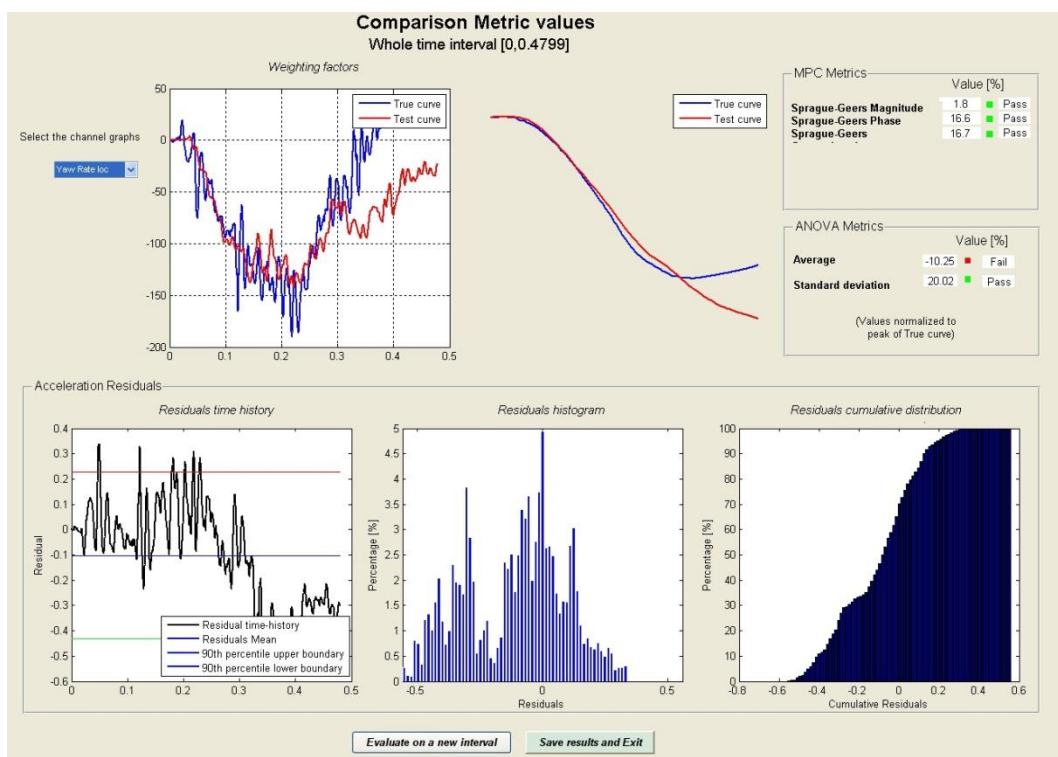
**Figure 2d: RSVVP Results – Vertical Acceleration**



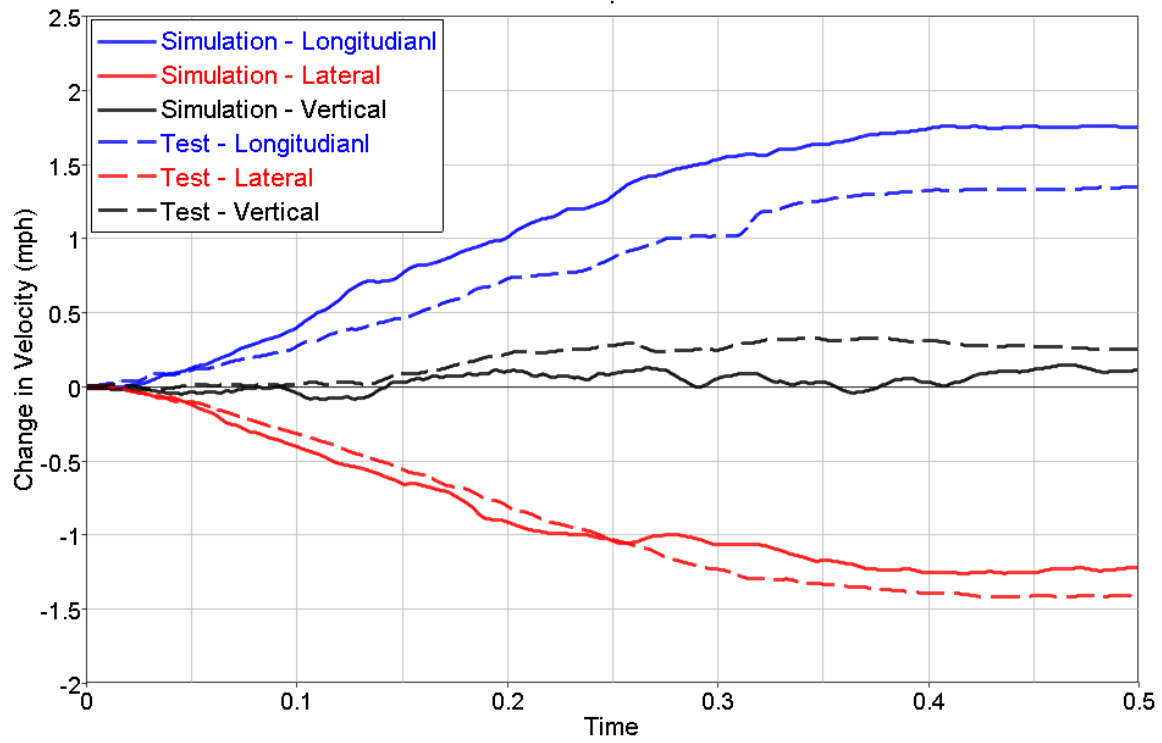
**Figure 2e: RSVVP Results – Roll Angle**



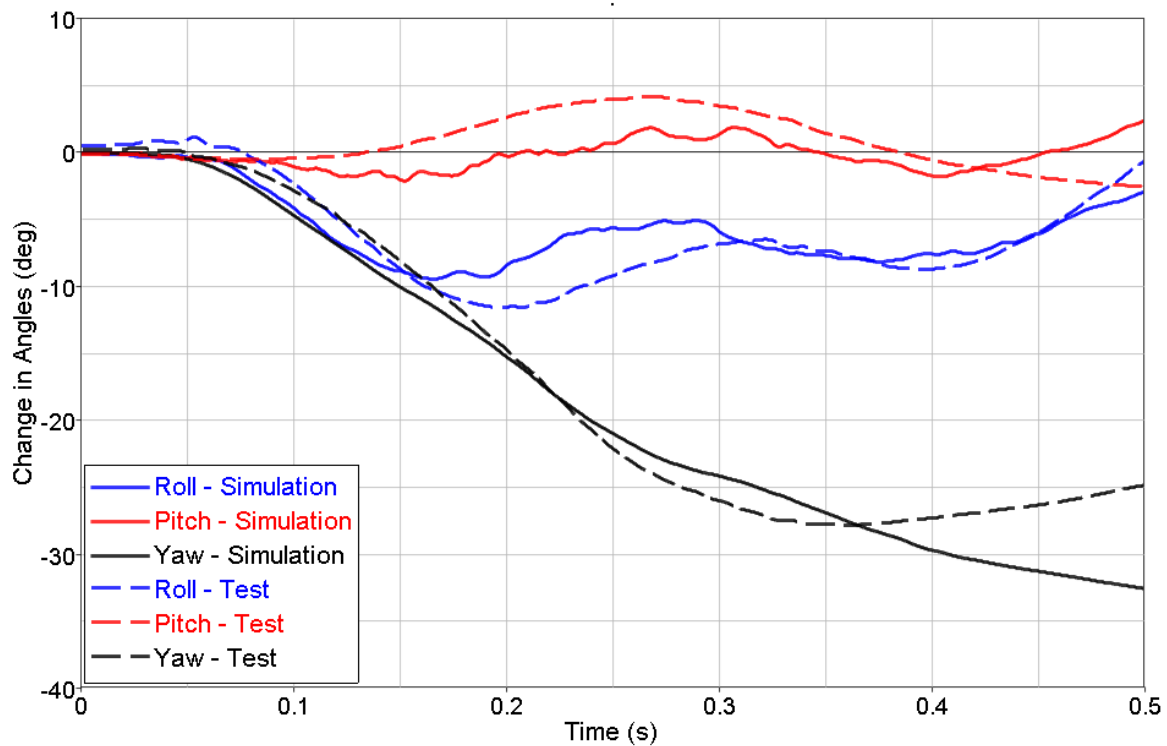
**Figure 2f: RSVVP Results – Pitch Angle**



**Figure 2g: RSVVP Results – Yaw Angle**



**Figure 3: Change in Vehicle Velocities**



**Figure 4: Change in Vehicle Angle**

# CCSA VALIDATION/VERIFICATION REPORT

**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	B	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	
		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	
Occupant Risk	B	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	
		F	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
			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
	H	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	
		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	
	I	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	



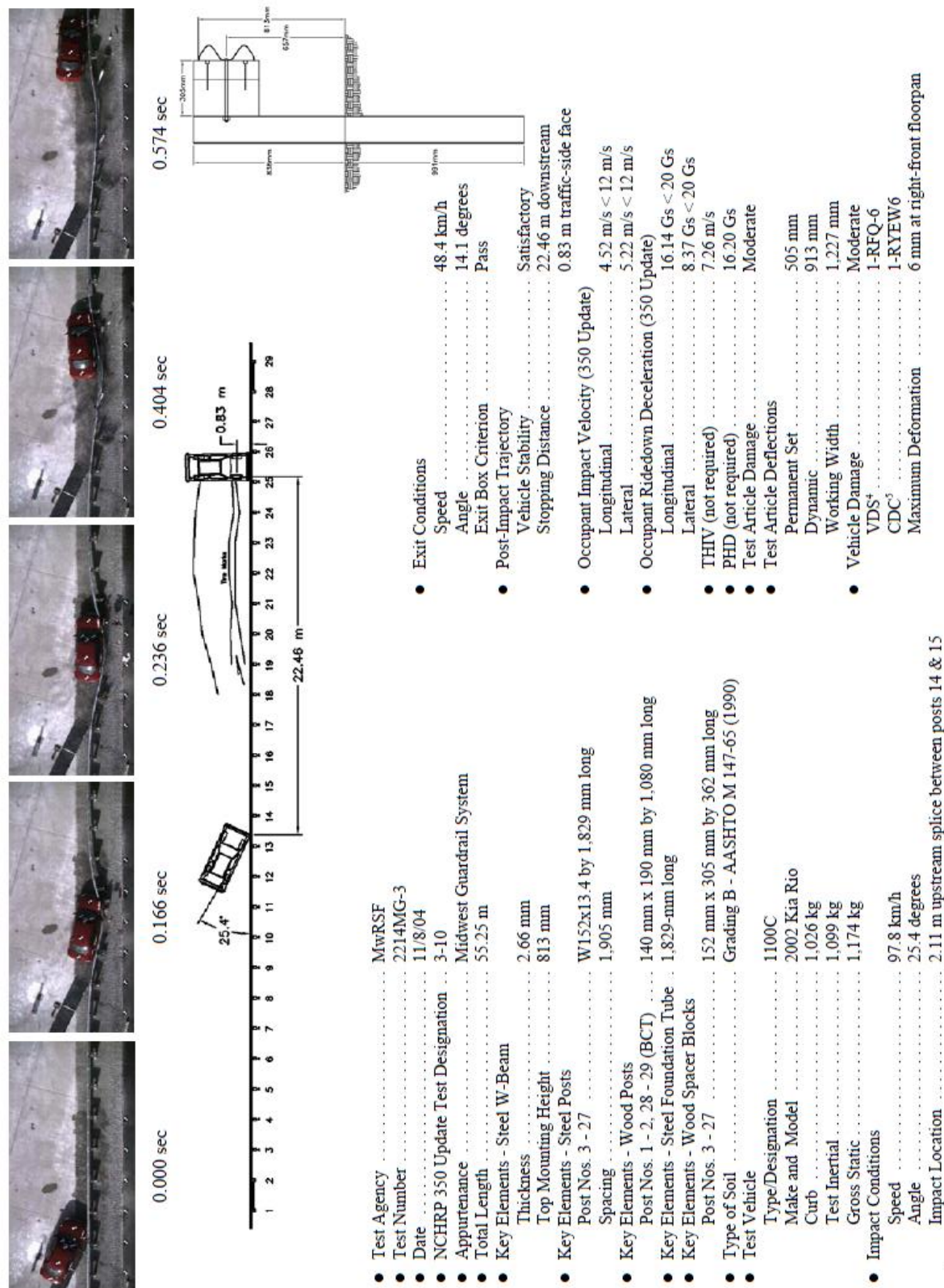
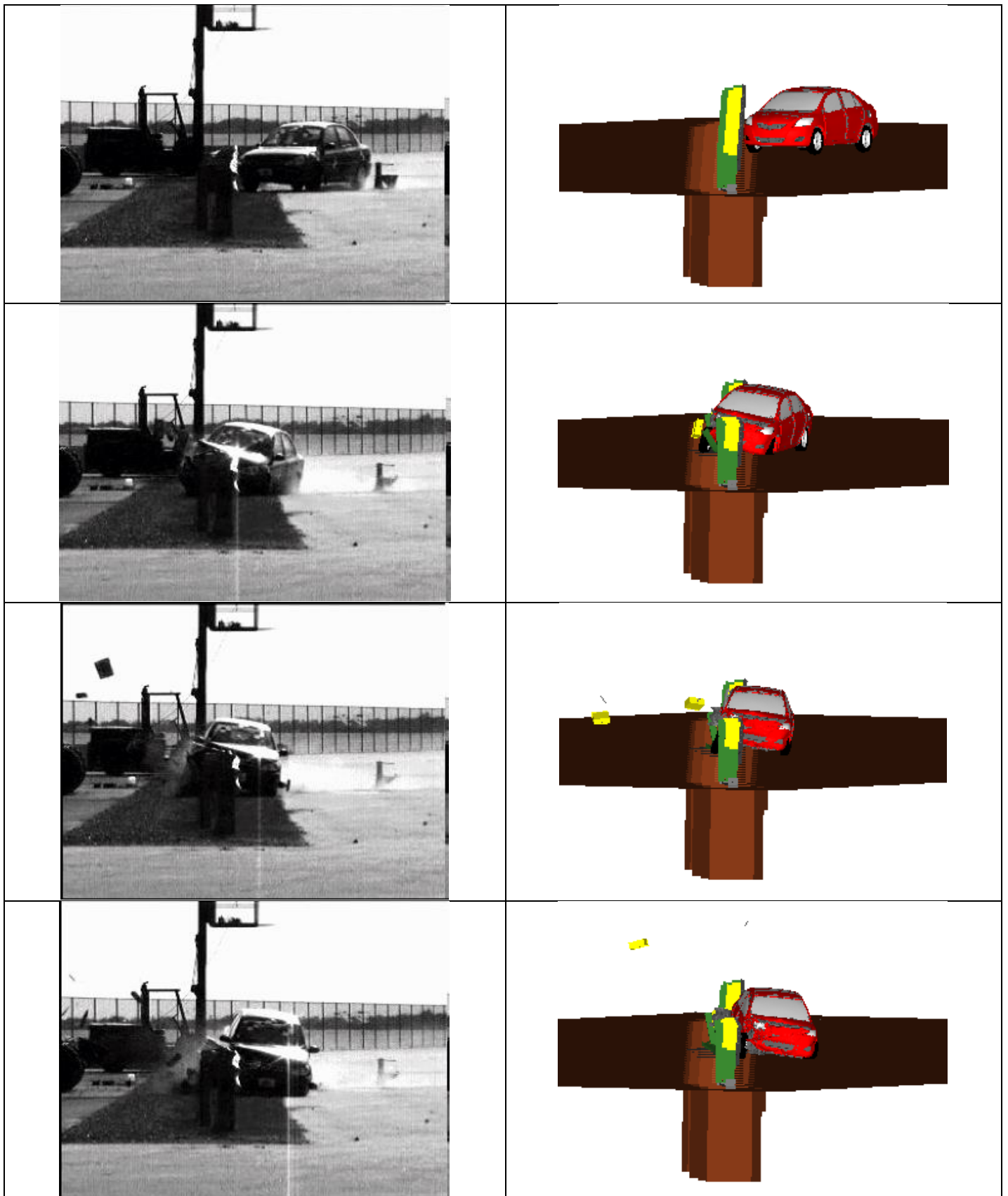


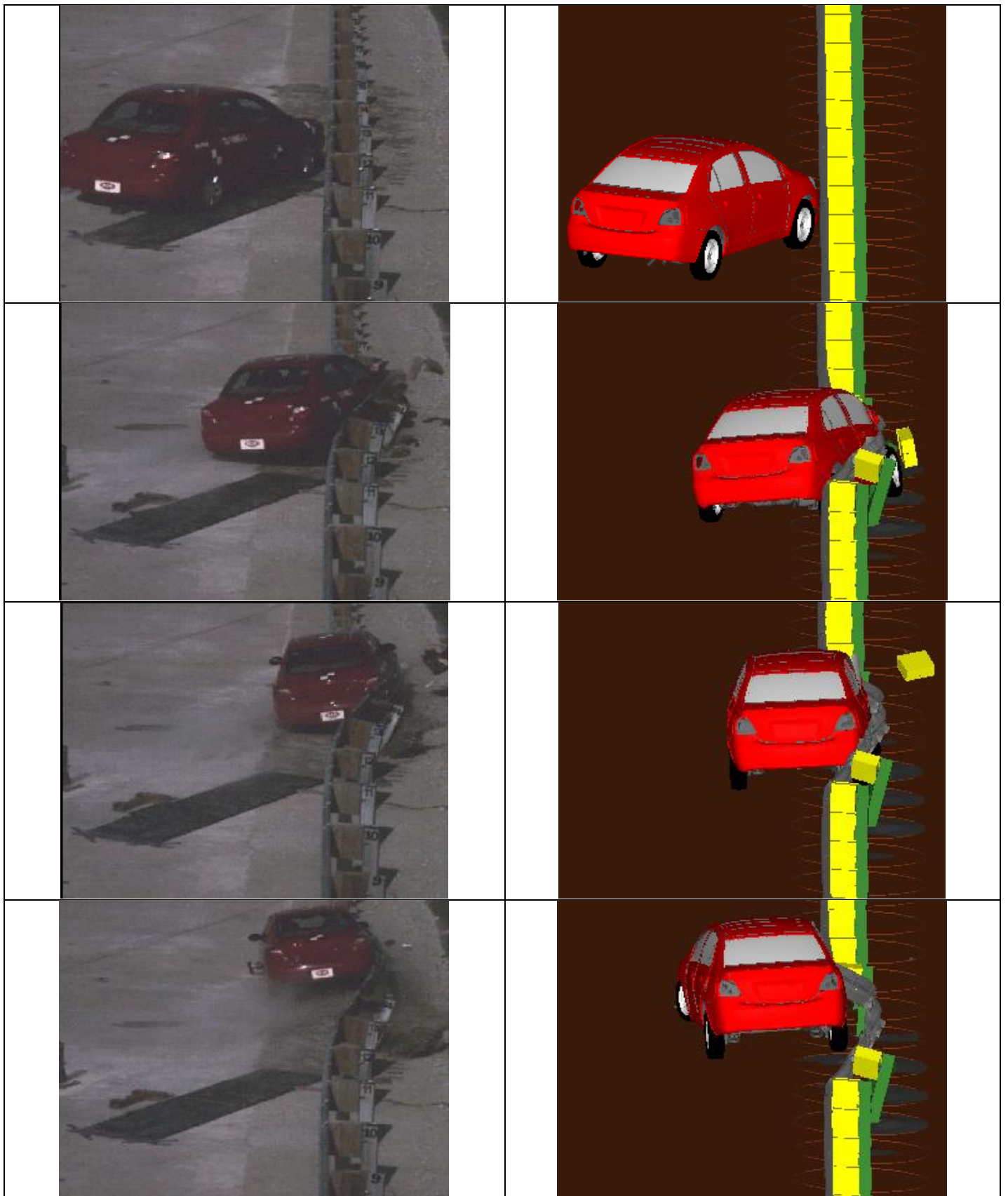
Figure 13. Summary of Test Results and Sequential Photographs, Test 2214MG-3

Figure 5: Full-Scale Test Summary

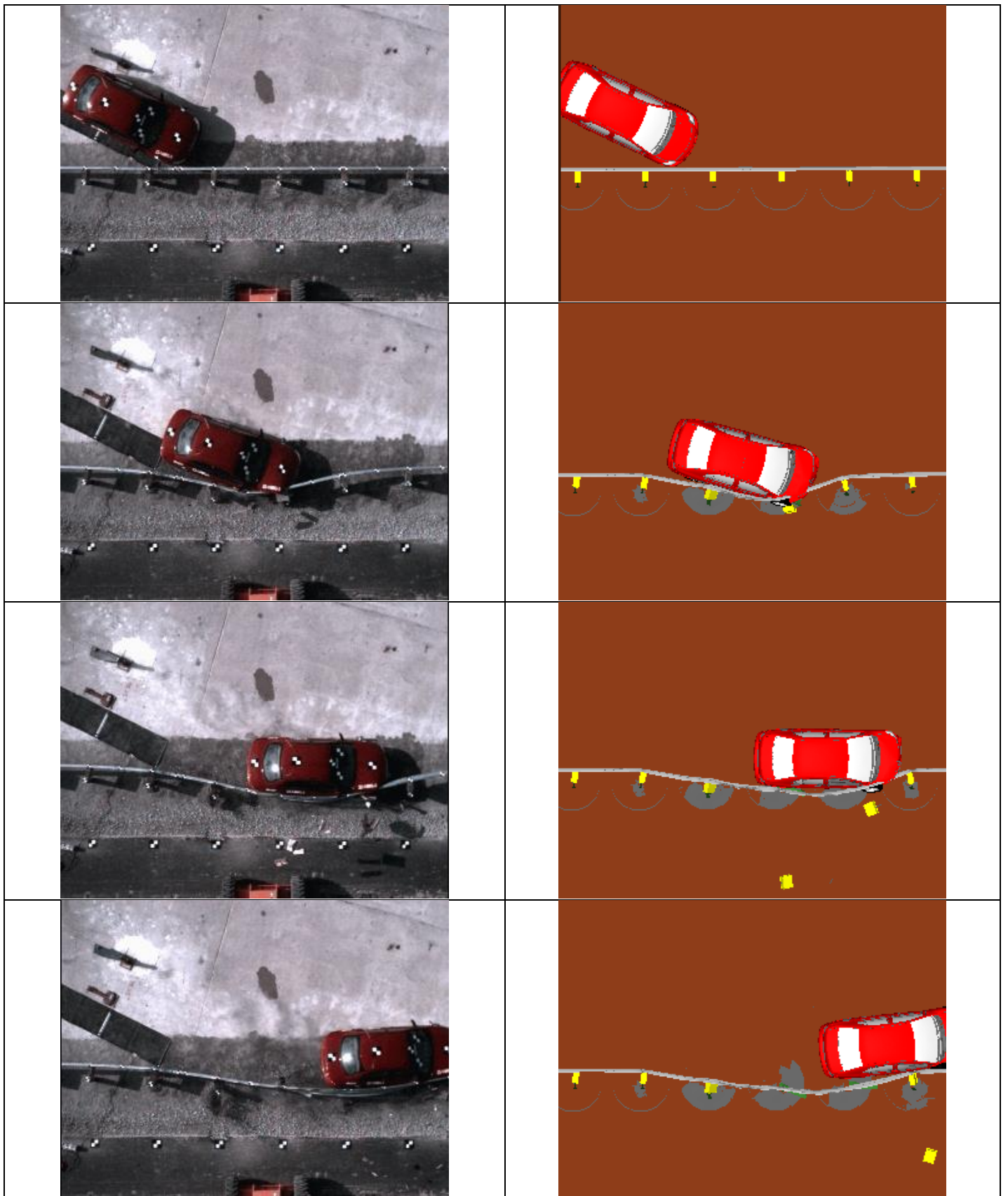


**Figure 6a: Sequential Comparisons – Front View**





**Figure 6b: Sequential Comparisons – Rear View**



**Figure 6c: Sequential Comparisons – Top View**

## CCSA VALIDATION/VERIFICATION REPORT

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

**Table F - Composite Verification and Validation Summary:**

List the Report MASH08 Test Number		
<b>Table C – Analysis Solution Verification</b>	Did all solution verification criteria in table pass?	<b>YES</b>
<b>Table D - RSVVP Results</b>	Do all the time history evaluation scores from the single channel factors result in a satisfactory comparison (i.e., the comparison passes the criterion)?	<b>NO</b>
	If all the values for Single Channel comparison did not pass, did the weighted procedure result in an acceptable comparison.	<b>YES</b>
<b>Table E - Roadside Safety Phenomena Importance Ranking Table</b>	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	<b>NO</b>
<b>Overall</b>	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.	<b>NO</b>

### 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 Sections  
**Comparison Case:** 2270P (Pickup Truck) with MGS Barrier  
**Impact Description:** 25.5-deg impact into barrier at 101.1 km/h (62.82 mph)  
**Governing Criteria:** MASH TL-3  
**Report 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
<b>Evaluation Method</b>	MASH (V1, 2009)	
<b>Hardware Type</b>	Longitudinal	
<b>Test Number</b>	3-11	
<b>Test Vehicle</b>	2270C	
<b>Criterion to be Applied</b>	<b>Structural Adequacy</b>	<b>A</b> - 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.
	<b>Occupant Risk</b>	<b>D</b> - 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.
		<b>F</b> - The vehicle should remain upright during and after the collision although moderate roll, pitching and yawing are acceptable.
		<b>H</b> - 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.
		<b>I</b> - 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.
	<b>Vehicle Trajectory</b>	For redirective devices the vehicle shall exit within the prescribed box.

# CCSA VALIDATION/VERIFICATION REPORT

**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**

Single Channel Time History Comparison Results		Time interval [0 sec - 0.67 sec]		
O	<i>Sprague-Geer Metrics</i>	M	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
P	<i>ANOVA Metrics</i>	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
Multi-Channel Weighting Factors		Time interval [0 sec; 0.67 sec]		
Multi-Channel Weighting Method		X Channel	0.206777873	
Peaks Area I		Y Channel	0.275396472	
Area II Inertial		Z Channel	0.017825655	
		Yaw Channel	0.441018937	
		Roll Channel	0.032383125	
		Pitch Channel	0.026597937	
<i>Sprague-Geer Metrics</i>		M	P	Pass?
	All Channels (weighted)	28.5	24.8	YES
<i>ANOVA Metrics</i>		Mean	SD	Pass?
	All Channels (weighted)	1.9	33.2	YES

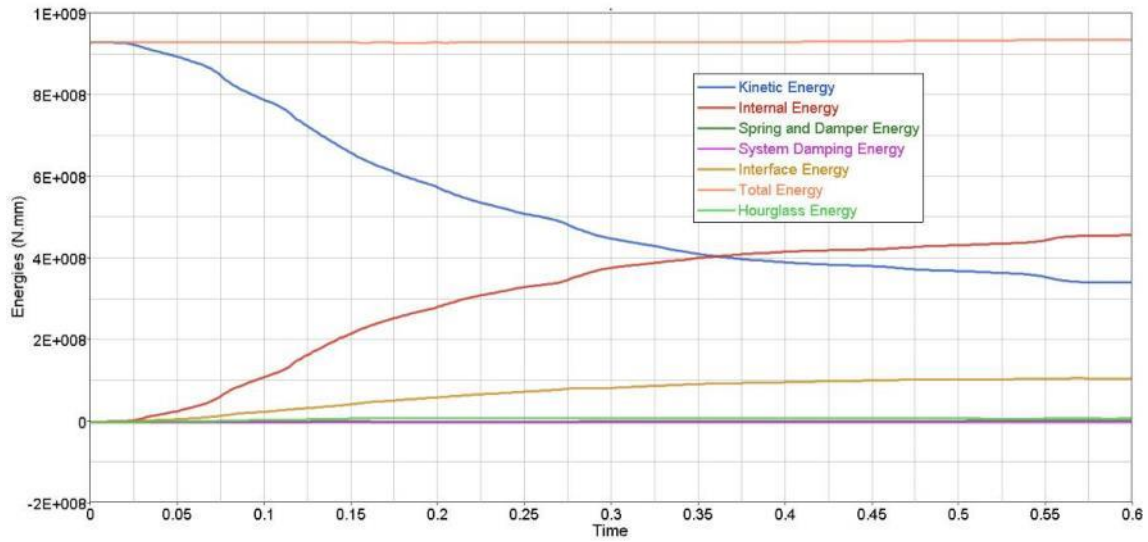


Figure 1: Simulations Energies

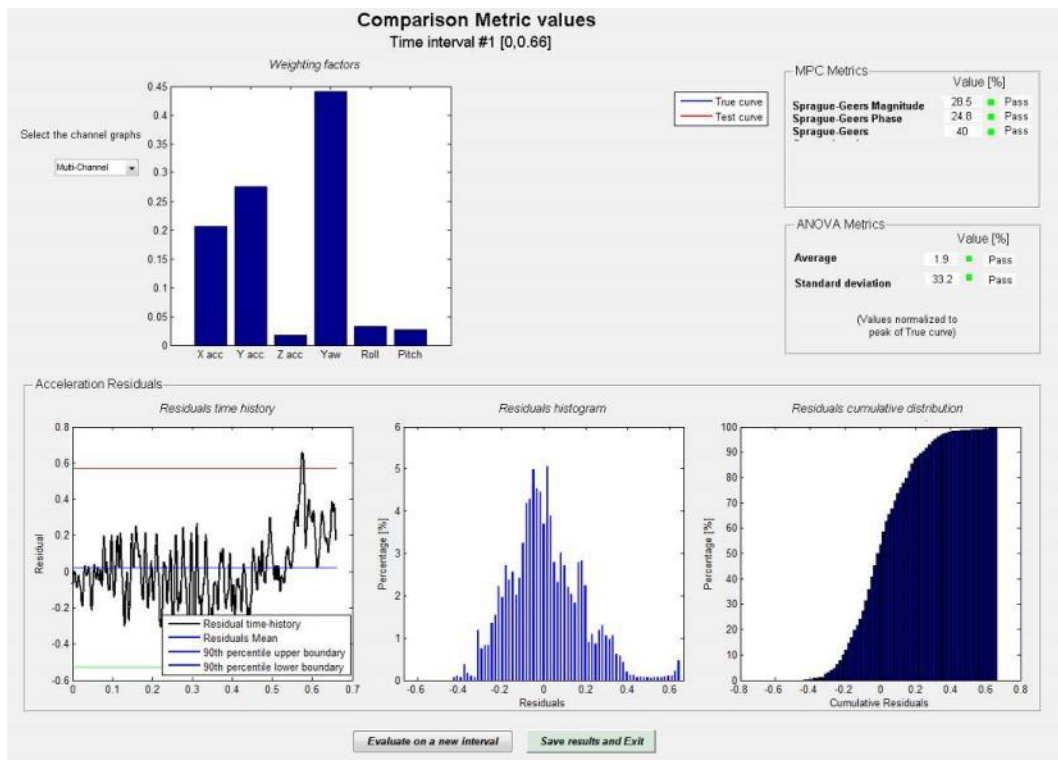
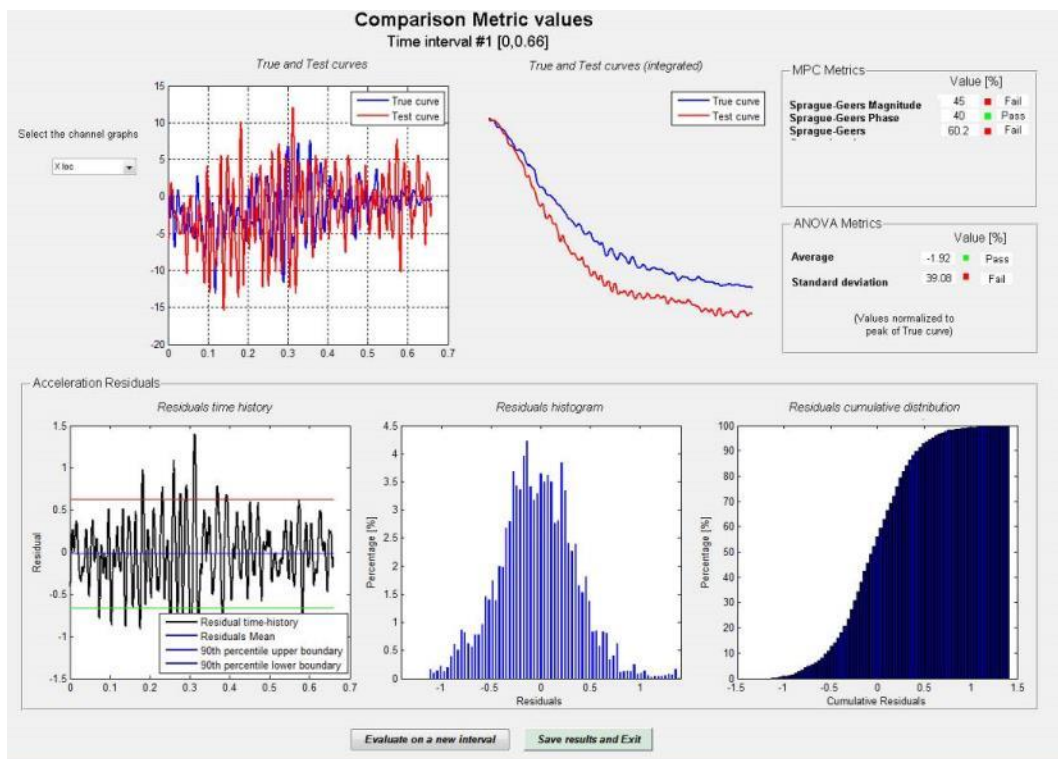
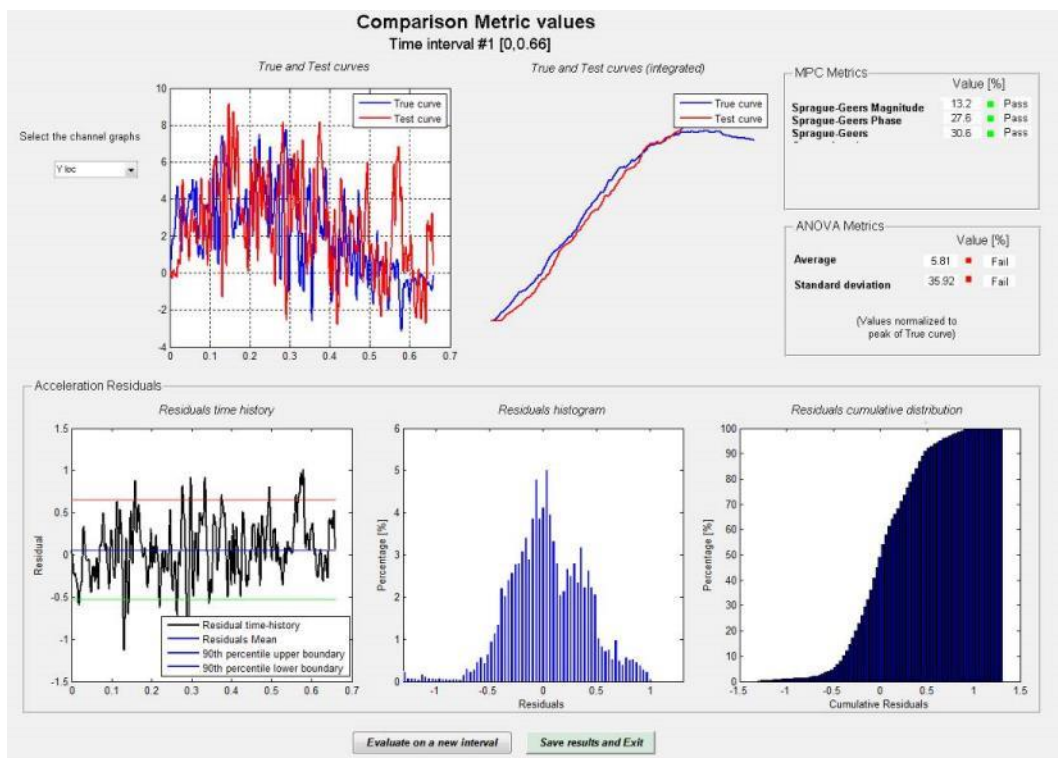


Figure 2a: RSVVP Results – All Channels

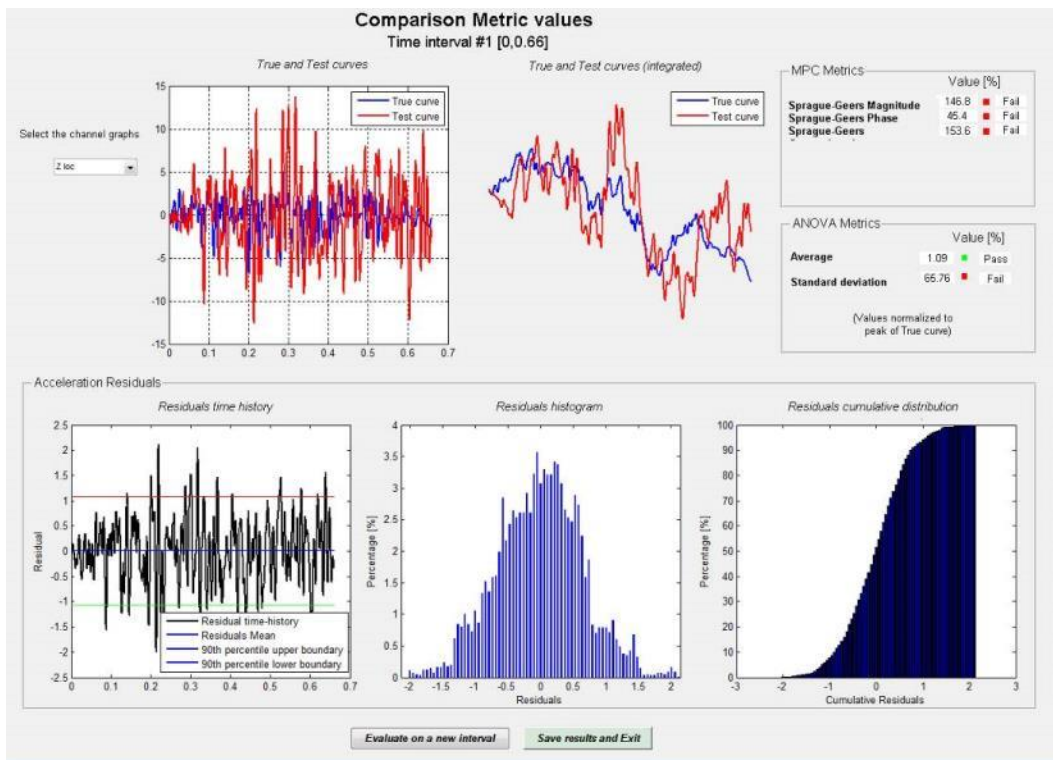




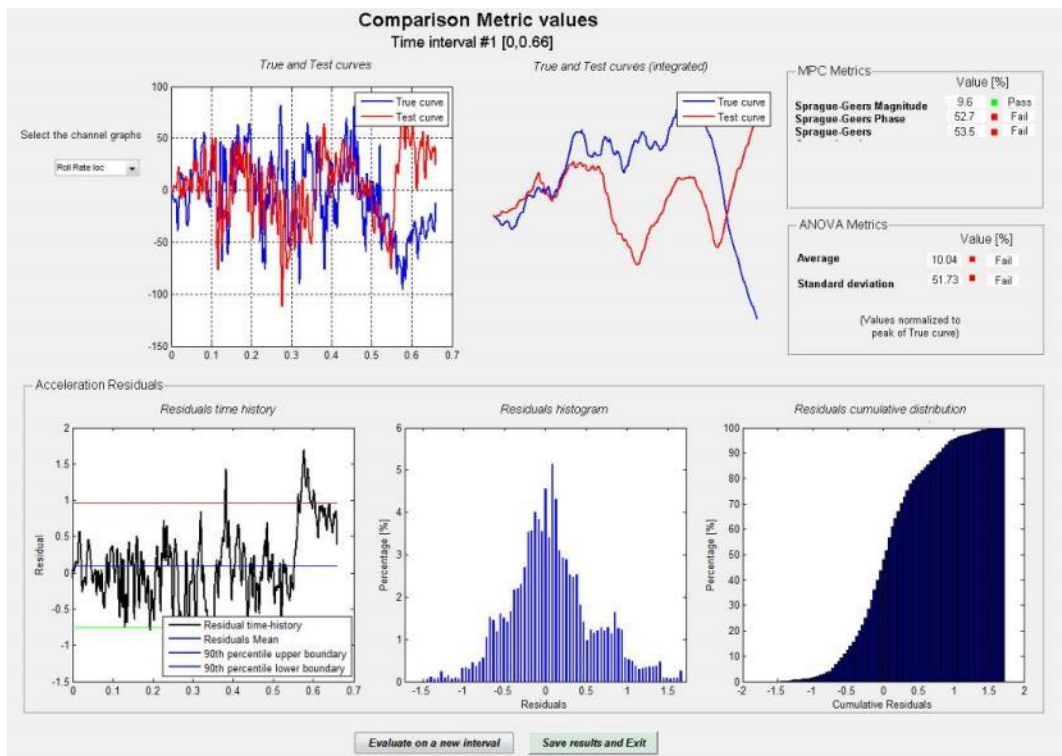
**Figure 2b: RSVVP Results – Longitudinal Acceleration**



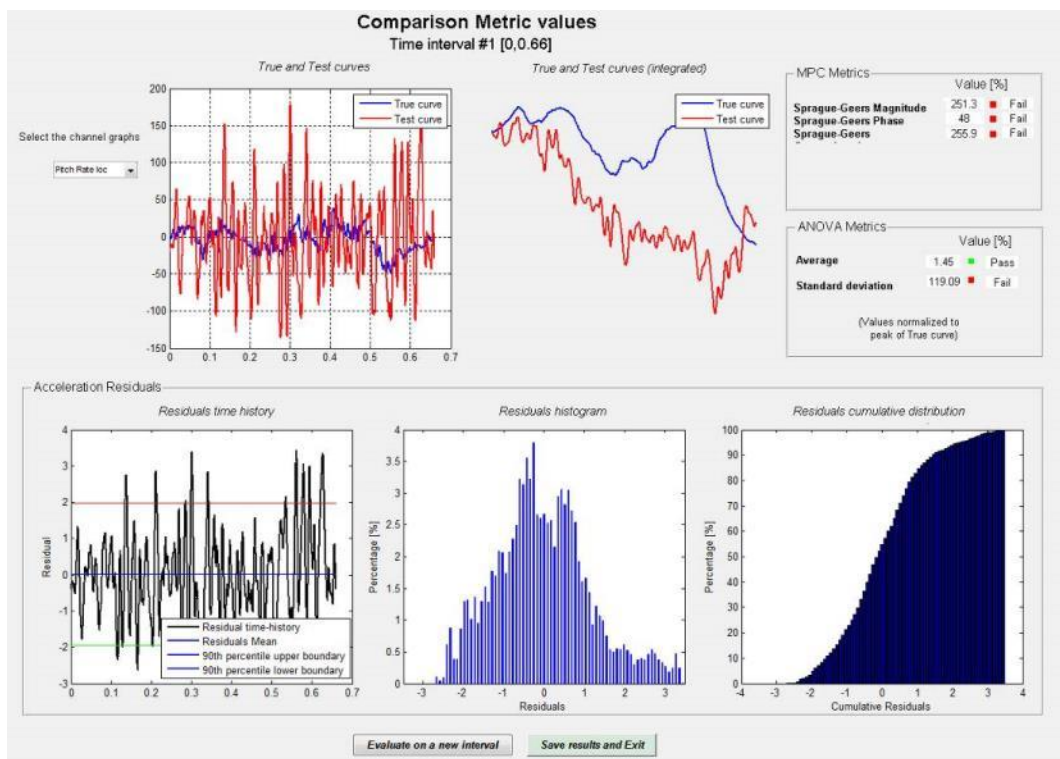
**Figure 2c: RSVVP Results – Lateral Acceleration**



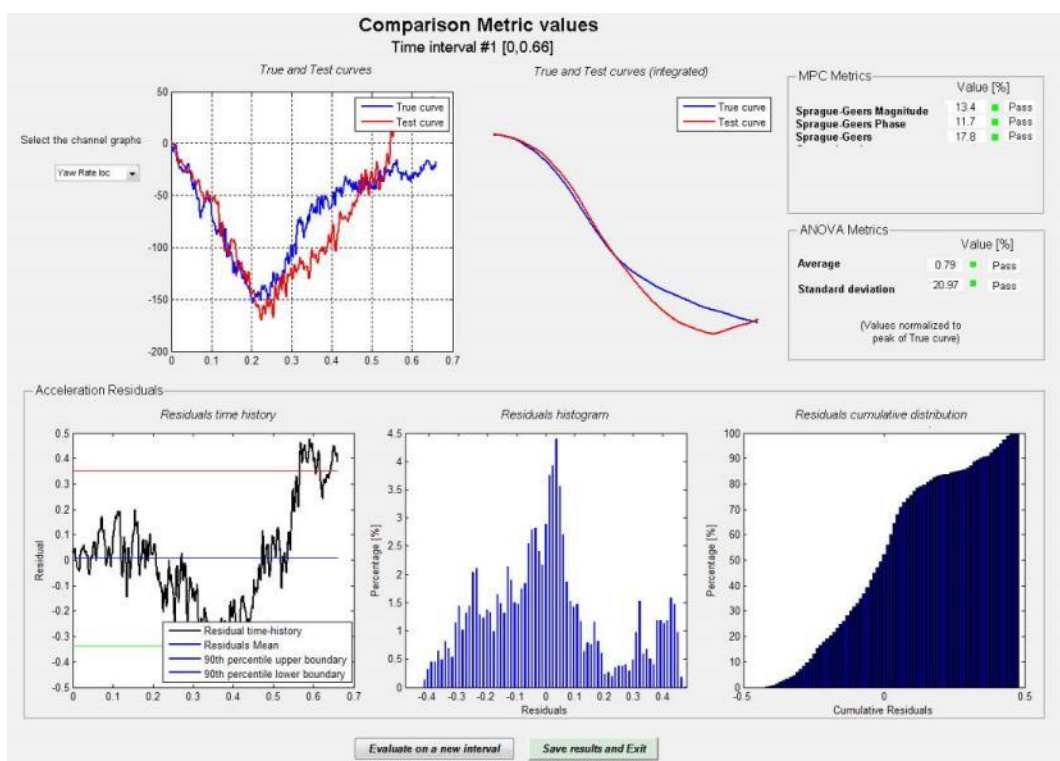
**Figure 2d: RSVVP Results – Vertical Acceleration**



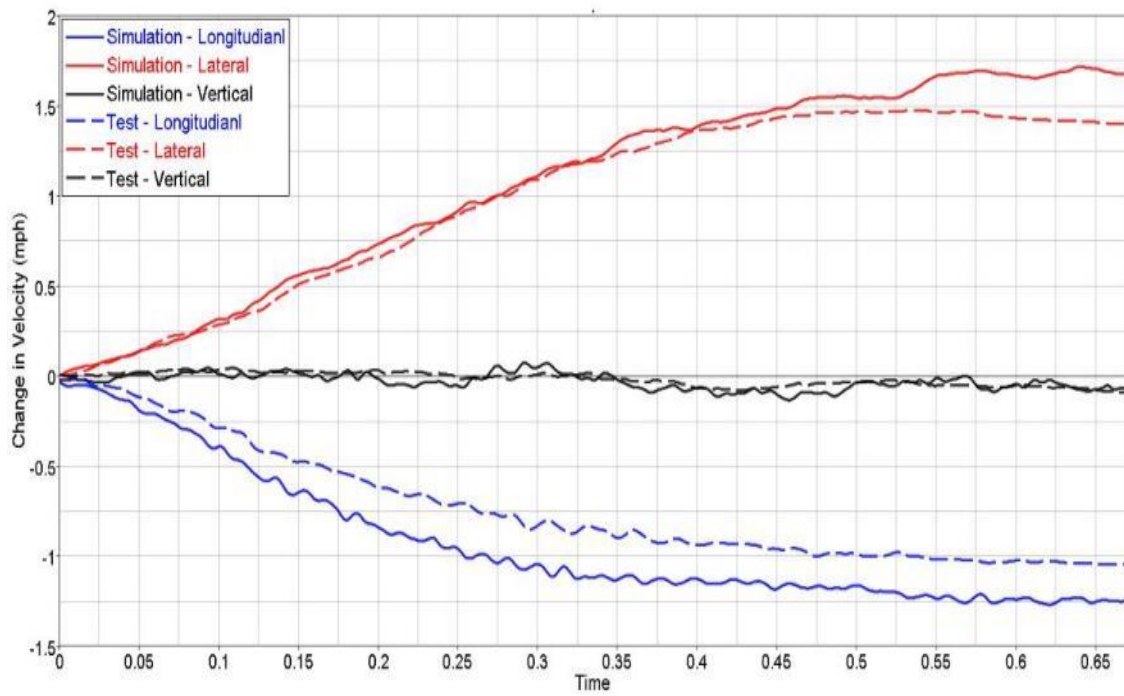
**Figure 2e: RSVVP Results – Roll Angle**



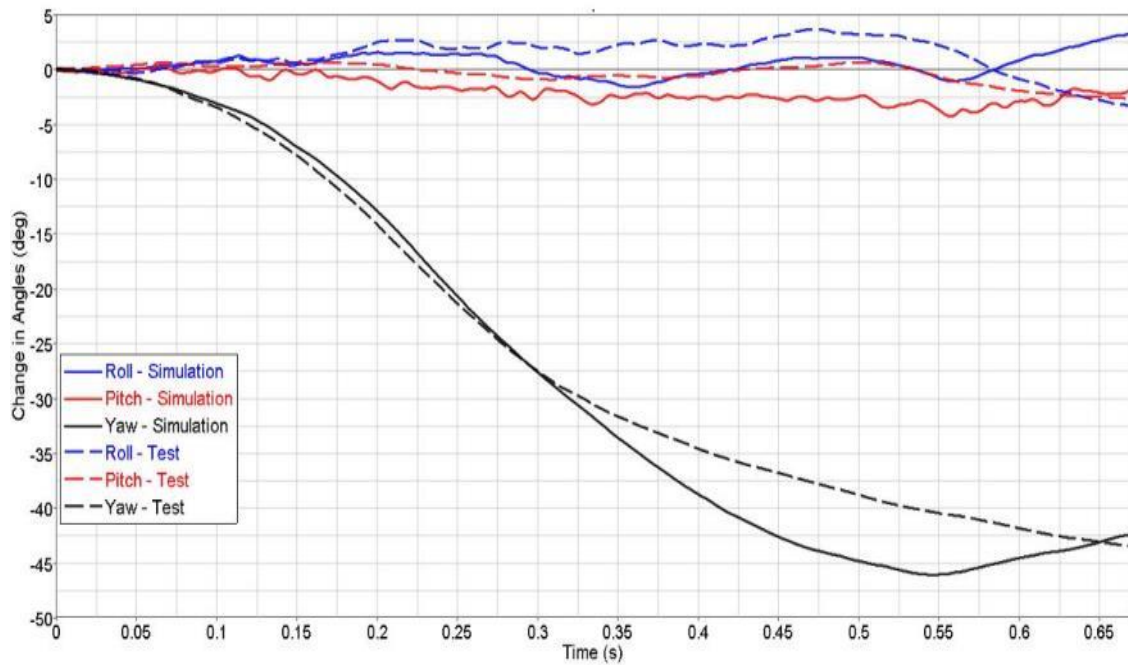
**Figure 2f: RSVVP Results – Pitch Angle**



**Figure 2g: RSVVP Results – Yaw Angle**



**Figure 3: Change in Vehicle Velocities**



**Figure 4: Change in Vehicle Angle**



# CCSA VALIDATION/VERIFICATION REPORT

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

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

Evaluation Criteria				Known Result	Analysis Result	Relative Diff. (%)	Agree?	
Structural Adequacy	I	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.	1.11 m	1.03 m	7%	YES	
		A3	The relative difference in the time of vehicle-barrier contact is less than 20 percent.	0.72 s	0.63 s	12%		
		A4	The relative difference in the number of broken or significantly bent posts is less than 20 percent.	3	3		YES	
		A5	Barrier did not fail (Answer Yes or No).	Yes	Yes		YES	
		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).	Yes	Yes		YES	
		A8	There was no significant snagging between vehicle body components and barrier elements (Answer Yes or No).	Yes	Yes		YES	
Occupant Risk	I	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	
		F	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.	3.58 (.68s)	3.49 (.68s)	3% 0.09 deg	YES
			F3	Maximum vehicle pitch – relative difference is less than 20% or absolute difference is less than 5 deg.	2.86 (.68s)	4.17 (.68s)	31.4% 1.31 deg	YES
			F4	Maximum vehicle yaw – relative difference is less than 20% or absolute difference is less than 5 deg.	43.74 (.68s)	46.01 (.68s)	4.9% 2.27 deg	YES
	H	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	
		H2	Longitudinal OIV (m/s) - Relative difference is less than 20% or absolute difference is less than 2 m/s	4.67	5.59	16.4% 0.92 m/s	YES	
		H3	Lateral OIV (m/s) - Relative difference is less than 20% or absolute difference is less than 2 m/s	4.76	5.09	6.5% 0.33 m/s	YES	
	I	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	8.23	12.10	31.9% 3.87 g	YES	
		I3	Lateral ORA (g) - Relative difference is less than 20% or absolute difference is less than 4 g’s	6.93	9.68	28.4% 2.75 g	YES	
	Vehicle Trajectory			The vehicle rebounded within the exit box. (Answer Yes or No)	Yes	Yes		YES

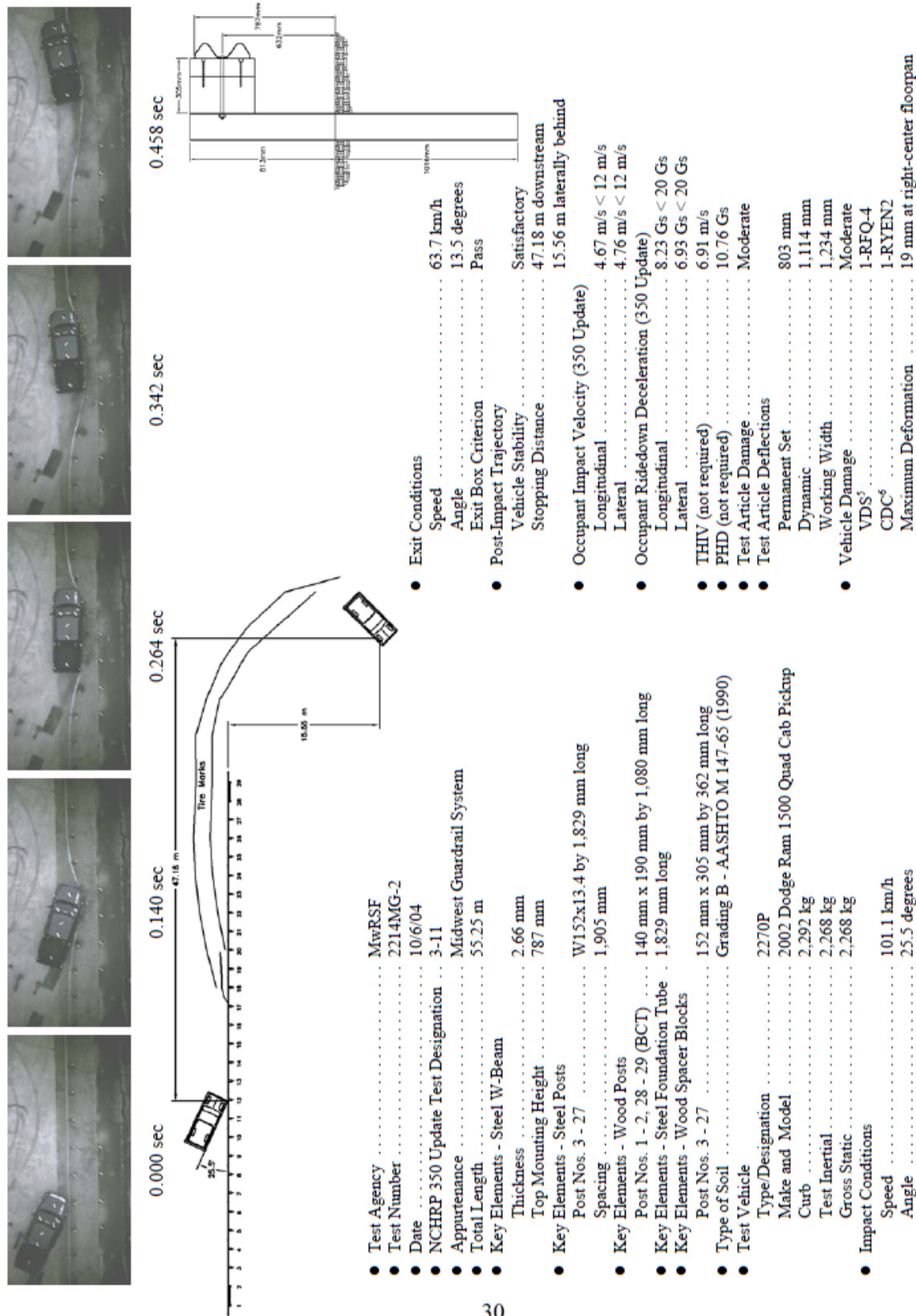
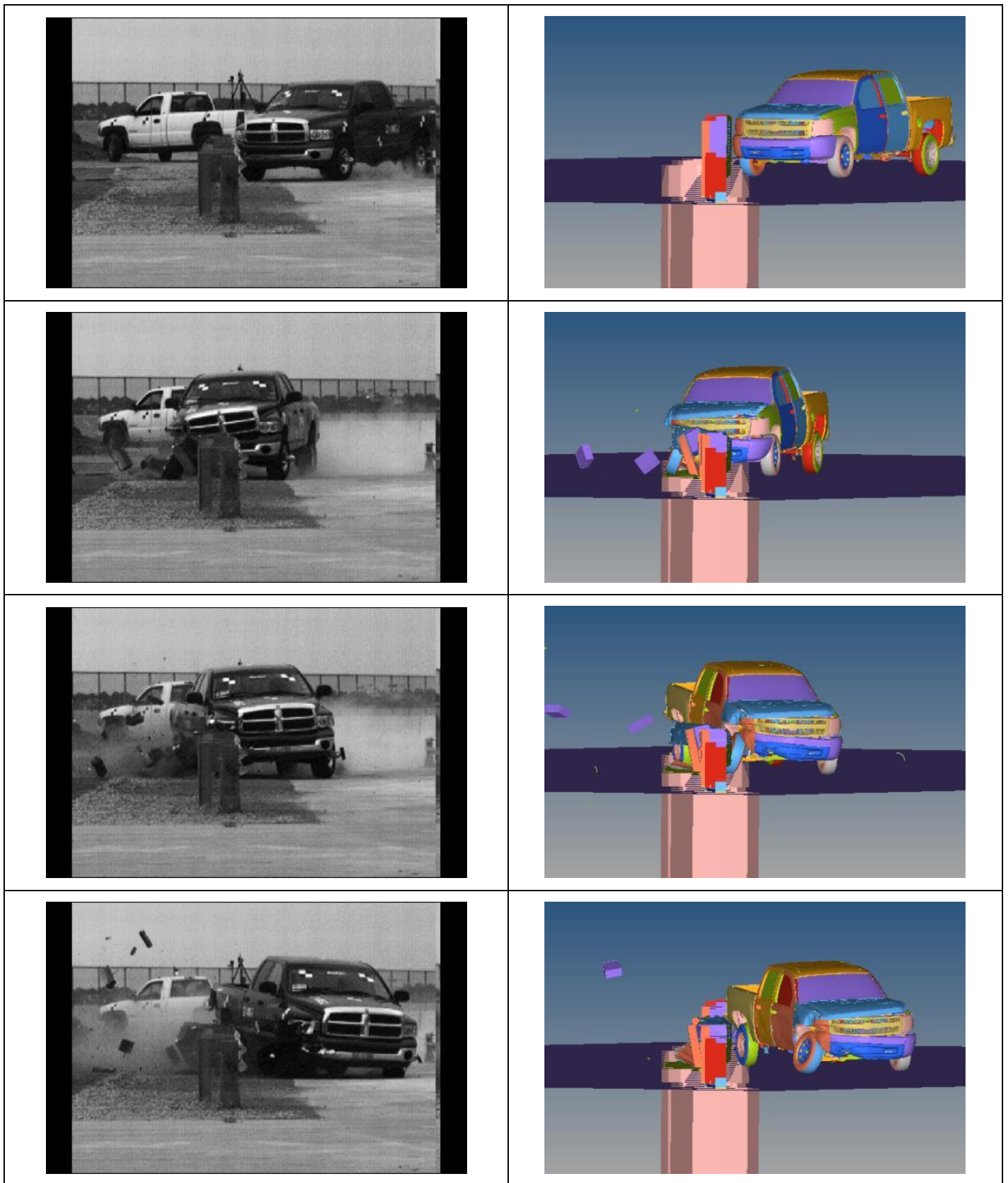


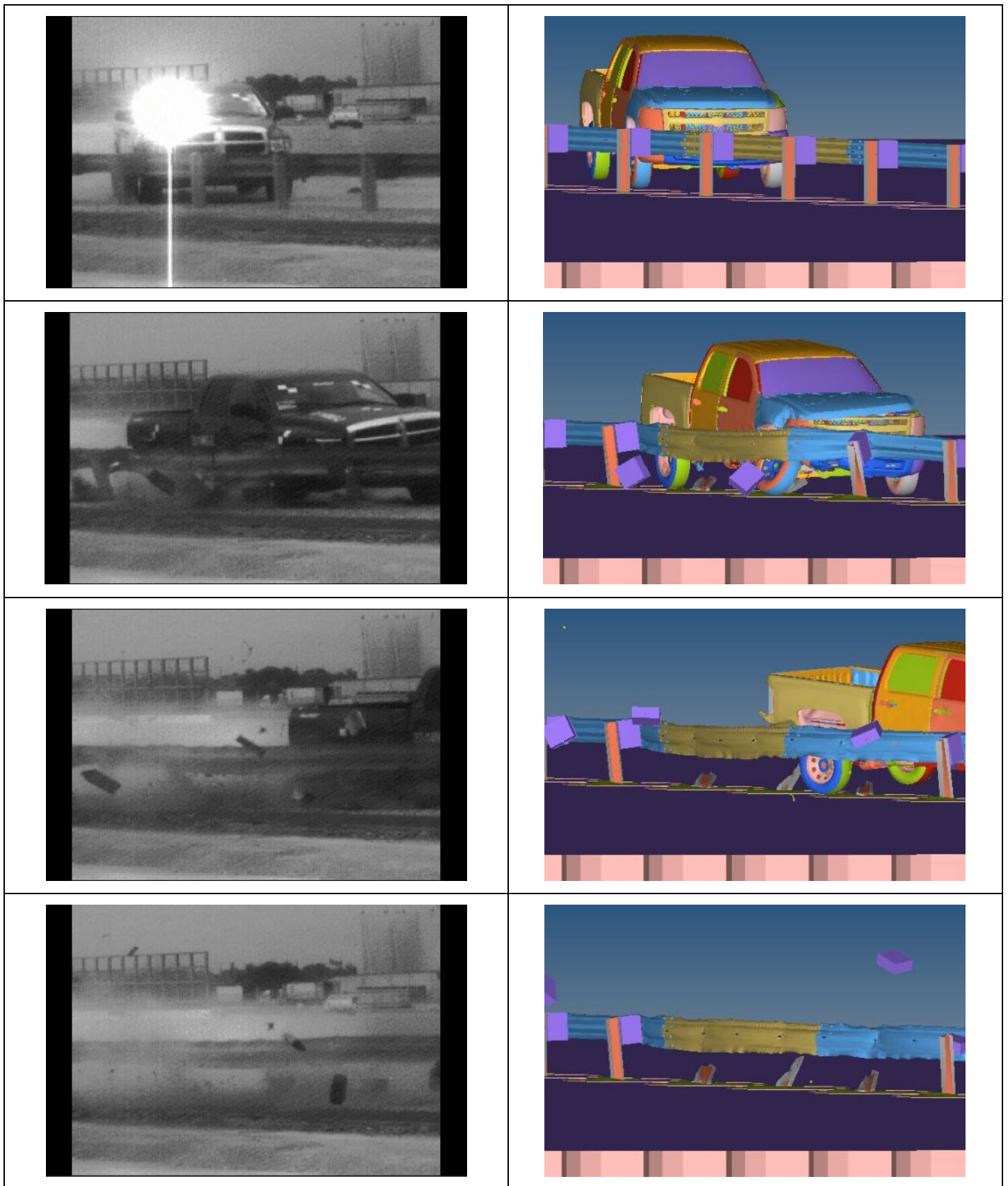
Figure 14. Summary of Test Results and Sequential Photographs, Test 2214MG-2

Figure 5: Full-Scale Test Summary

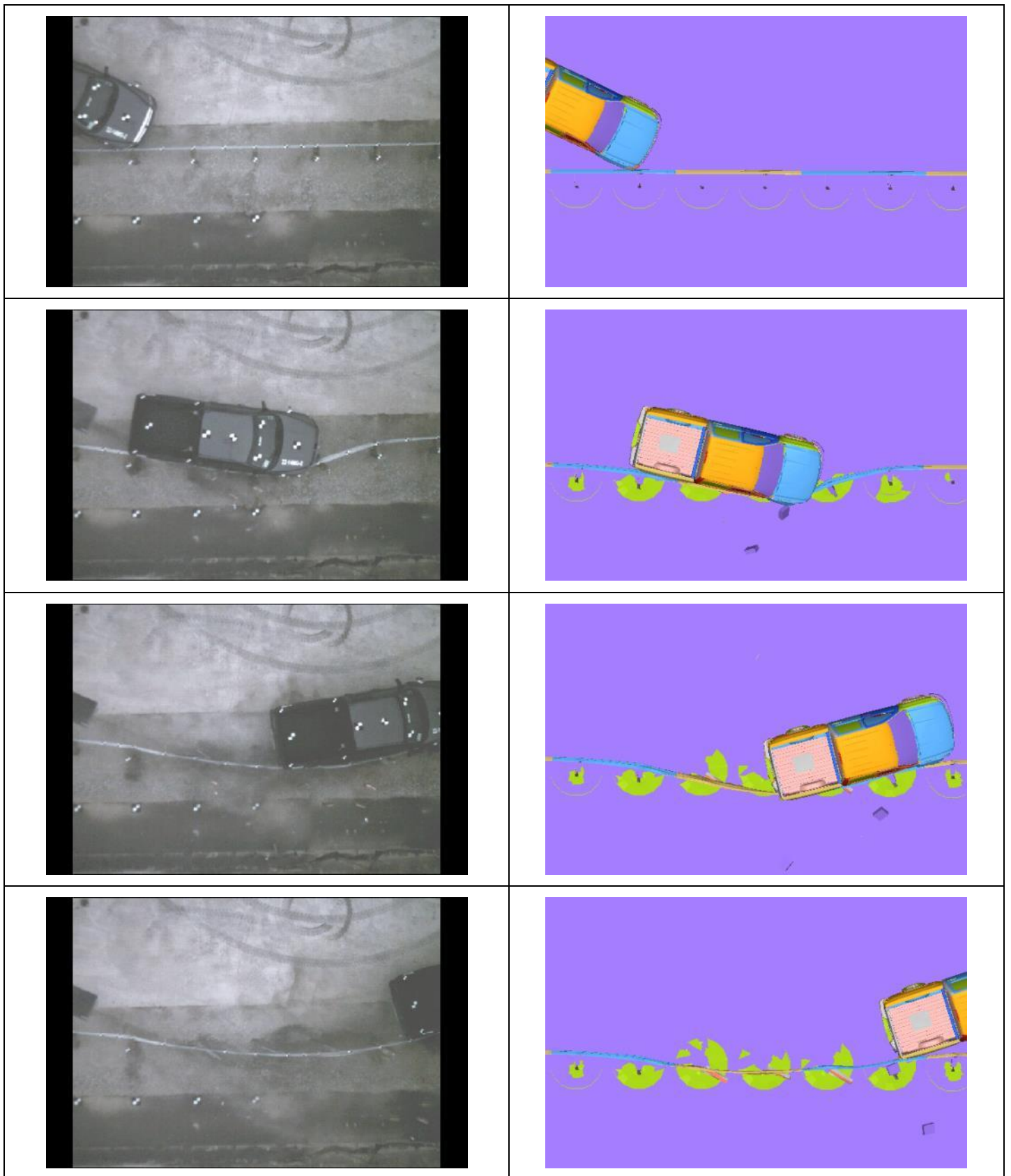




**Figure 6a: Sequential Comparisons – Front View**



**Figure 6b: Sequential Comparisons – Rear View**



**Figure 6c: Sequential Comparisons – Top View**

# CCSA VALIDATION/VERIFICATION REPORT

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

**Table F - Composite Verification and Validation Summary:**

List the Report MASH08 Test Number		
<b>Table C – Analysis Solution Verification Summary</b>	Did all solution verification criteria in table pass?	<b>YES</b>
<b>Table D - RSVVP Results</b>	Do all the time history evaluation scores from the single channel factors result in a satisfactory comparison (i.e., the comparison passes the criterion)?	<b>NO</b>
	If all the values for Single Channel comparison did not pass, did the weighted procedure result in an acceptable comparison.	<b>YES</b>
<b>Table E - Roadside Safety Phenomena Importance Ranking Table</b>	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	<b>YES</b>
<b>Overall</b>	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.	<b>YES</b>

## NOTES:

(none)