Crash Test & Simulation Comparisons of a Pickup Truck & a Small Car Oblique Impacts Into a Concrete Barrier

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Abstract

Detailed finite element (FE) models of a 2270 kg Chevrolet Silverado and a 1100 kg Toyota Yaris are used as surrogates for barrier crashworthiness under the new Manual for Assessment of Safety Hardware (MASH). MASH requires assessment of barriers for both large and small vehicles, hence the use of 2270P and 1100P test vehicles. Impacts of these two vehicles into a New Jersey-shaped concrete median barrier were simulated and compared to full-scale crash tests. The objectives of this effort included (1) demonstrating the viability of the FE models for the new MASH crashworthiness evaluation, and (2) describing the application of the newly developed roadside verification and validation (V&V) procedures to compare simulation results and crash test data. Comparisons of the simulation results and data derived from crash tests using "traditional" methods suggested that the models provided viable results. Further comparisons using the new V&V procedures provided (1) a structured assessment across multiple factors reflected in PIRT tables and (2) statistical comparisons of the test and simulation results allowing a more robust validation than previous approaches. These comparisons further confirmed that the new vehicle models were able to effectively replicate impacts for MASH tests and that the V&V procedures provided useful insights and increased confidence in the models.

Introduction

Background

Over the years highway agencies have strived to improve highway safety through the testing of roadside hardware to assess its crashworthiness when impacted by an errant vehicle. Since the first barrier crashworthiness requirements were formulated in 1962, crash testing was necessary to determine whether the requirements were met. Over the years, the crash testing procedures as well as the protocols for ascertaining crashworthiness advanced to further enhance safety. The development of finite element (FE) models and crash simulation tools over the same period has provided an alternate method for determining crashworthiness. The current crashworthiness requirements are outlined in the Manual for Assessment of Safety Hardware (MASH) were adopted by The American Association of State Highway & Transportation Officials (AASHTO) in October 2009 [1].

The adoption of the new MASH requirements, however, often raises questions about whether previously approved hardware meets the new crashworthiness requirements. This becomes important when hardware has been damaged in a crash and a decision to repair or replace is needed. Given the number of deployed roadside safety devices that were accepted under previous requirements, the need exists for a crash testing alternative to evaluate the crashworthiness of existing hardware. Simulation approaches are believed to offer a viable means to determine crashworthiness under the new requirements without the high costs of testing. This paper describes an effort to determine whether New Jersey-shaped concrete barriers meet the higher crashworthiness requirements of MASH. This effort also demonstrates the enhanced confidence provided by the most recent crashworthiness requirements. Since MASH, like previous requirements, dictate that crashworthiness be demonstrated for both large and small vehicles, crash test results for impacts of a Chevrolet Silverado pick-up truck (2270 kg) and a Kia Rio (1100 kg) into a concrete barrier were undertaken. The crash test data are compared to simulations results for comparable vehicles using traditional and recently developed verification and validation procedures. The outcome of these efforts provided a clear indication that the previously developed concrete barrier design meets the latest crashworthiness requirements.

For more than 20 years, the FHWA has promoted the use of crash simulations based upon finite element (FE) models as a means to develop innovative designs and to evaluate their performance. To do so, requires finite element models of vehicles and the hardware. These models have been developed by the National Crash Analysis Center (NCAC) to describe the vehicle and test articles as a collection of elements that reflect the geometry of the items, the nature of connections to adjacent elements, the characteristics of the materials that comprise the element, and properties associated with the relationships between elements (e.g., joints, fracture mechanics). For vehicles, the FE model is developed by reverse engineering. For barrier hardware, the design geometries of the components are used to define elements and the associated material properties and connection details added to represent the item.

A detailed finite element model of the Chevrolet Silverado pick-up truck was developed for FHWA by the NCAC. This vehicle meets the requirements for the 2270P test vehicle prescribed by MASH. The model has been subjected to the traditional validation efforts, as well as a series of extended comparisons aimed at providing confidence in this detailed model. More recently, the NCAC developed a model for the 2010 Toyota Yaris which meets the requirements for a 1100 kg test vehicle. While the Yaris is not identical to the Kia Rio used in the test, it is considered an acceptable surrogate for crashworthiness analyses.

Objectives

The primary objective of this effort was to demonstrate the MASH crashworthiness of the New Jersey-shaped concrete barrier for the Chevrolet Silverado and Toyota Yaris by comparison of crash test data to simulation results. Secondary objectives included applying the recently developed procedures for verification and validation of simulation results and to gain additional insights on the performance of a commonly-used longitudinal barrier previously approved under the new MASH evaluation criteria.

Approach

This research effort used FE models of the 2007 Chevrolet Silverado pick-up truck and 2010 Toyota Yaris to simulate MASH crash tests 3-10 and 3-11 for impacts into a New Jersey-shaped concrete barrier. Crash tests were conducted by certified labs following the MASH protocols for oblique impacts with longitudinal barriers (i.e., impact angle 25 degrees, speed 100 km/h). Data and video from the crash tests were available for the comparisons. The simulations were set up to replicate the crash tests and to generate similar metrics for comparison. The comparisons followed traditional methods as well as recently recommended structured comparison and analytical methods.

Crash Test Descriptions

Silverado Test

A full-scale crash test of a 2007 Chevrolet Silverado quad-cab pick-up truck traveling at a speed of 101 km/h [62.6 mph] impacting a 813 mm [32-inch] concrete New Jersey-shaped barrier at an impact angle of 25.2 degrees was conducted at the Texas Transportation Institute on January 30, 2009 [2]. This test was conducted under NCHRP Project 22-14(3) "Evaluation of Existing Roadside Hardware Using Updated Criteria." According to the test report:

> *The 32-inch New Jersey shape barrier contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, override the installation. No measurable deflection of the barrier occurred. No detach elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present a hazard to other in the area. Maximum occupant compartment deformation was 50.8 mm [2.0 inches] at the right kick panel. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 29 and -16 degrees, respectively. Occupant risk factors were within the limits specified in MASH. The 2270P exited the barrier within the exit box. The 32-inch New Jersey-shaped barrier performed acceptably when impacted by the 2270P vehicle (2007 Chevrolet Silverado pick-up) and evaluated in accordance with the safety performance criteria presented in MASH.*

The details of this test are summarized in Figure 1. Based upon the above test observations, it was concluded that the New Jersey-shaped concrete barrier "passed" the MASH requirements for Test 3-11. Since it had passed the corresponding test under NCHRP Report 350 with a 2000P vehicle and these additional results were under more severe impact conditions (due to the greater mass of the 2270P vehicle), there was no doubt that its use could be continued.

Kia Rio Test

A full-scale crash test of a 2002 Kia Rio passenger sedan traveling at a speed of 97.9 km/h [60.8 mph] impacting a 813 mm [32-inch] concrete New Jersey-shaped barrier at an impact angle of 26.1 degrees was conducted at the Midwest Roadside Safety Facility on May 28, 2004 [3]. This test was conducted under NCHRP Project 22-14 "Improvement of Procedures for the Safety Performance Evaluation of Roadside Features." According to the test report:

> *The 32-inch New Jersey shape barrier contained and redirected the 1100C vehicle. The barrier adequately contained and redirected the vehicle with controlled lateral displacements of the barrier system. There were no detached fragments which would suggest the potential for penetrating the occupant compartment and did not presented undue hazards to other traffic. The vehicle did not penetrate or ride over the concrete barrier system and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were noted, but they were deemed acceptable because they did not adversely affect occupant safety or cause rollover. The vehicle's trajectory revealed minimum intrusion into adjacent traffic lanes. In addition, the vehicle left the barrier within the exit box. Therefore, it was concluded that the New Jersey-shaped concrete barrier was acceptable at TL-3 for MASH requirements.*

The details of this test are summarized in Figure 2. Based upon the above test observations, it was concluded that the New Jersey-shaped concrete barrier "passed" the proposed MASH requirements for Test 3-10. Since it had passed the corresponding test under NCHRP Report 350 with a 820C vehicle and these additional results were under more severe impact conditions (due to the greater mass of the 1100C vehicle), there was no doubt that its use could be continued.

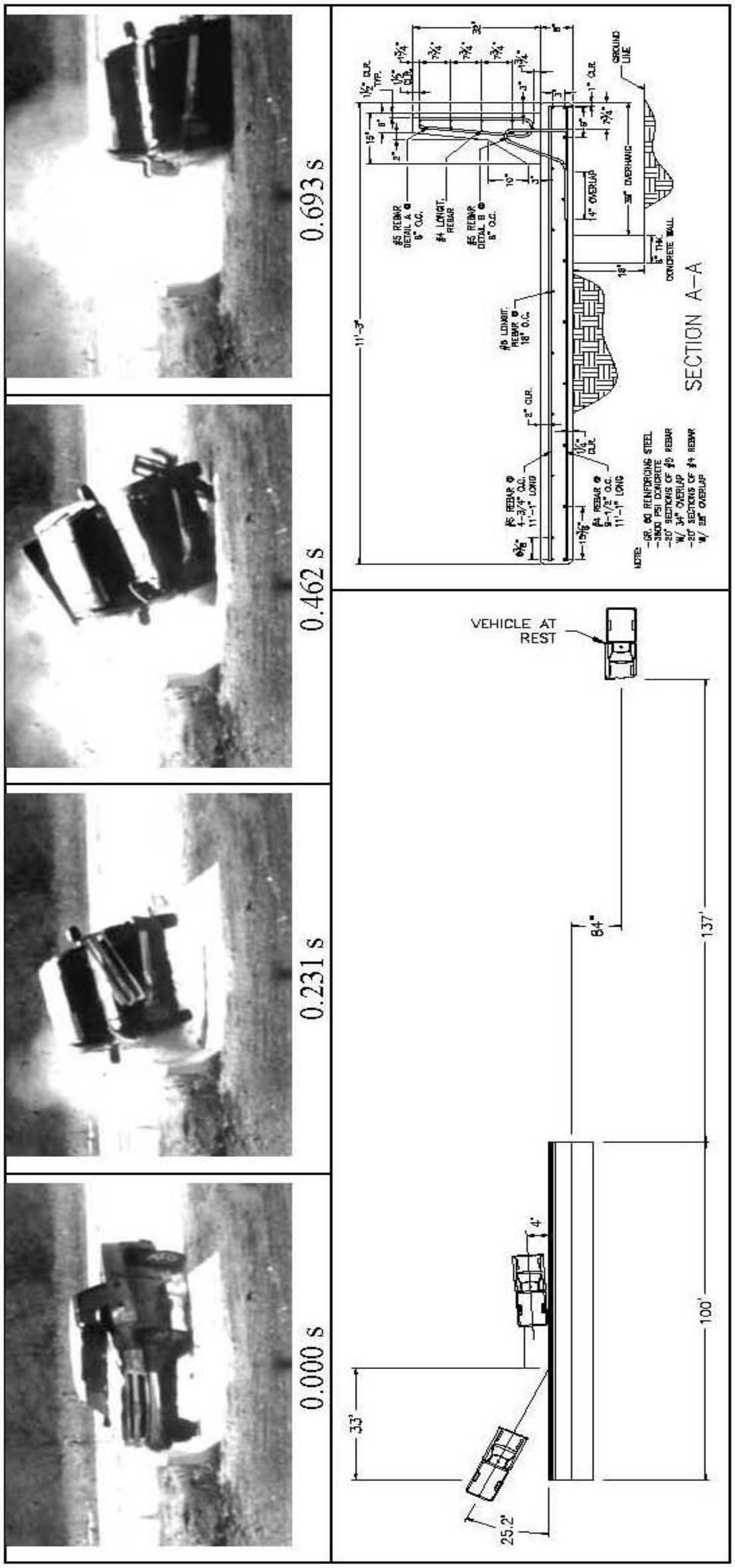

Figure 1: Full-Scale Test Summary for Pickup Truck Impacting the Concrete Barrier [2]

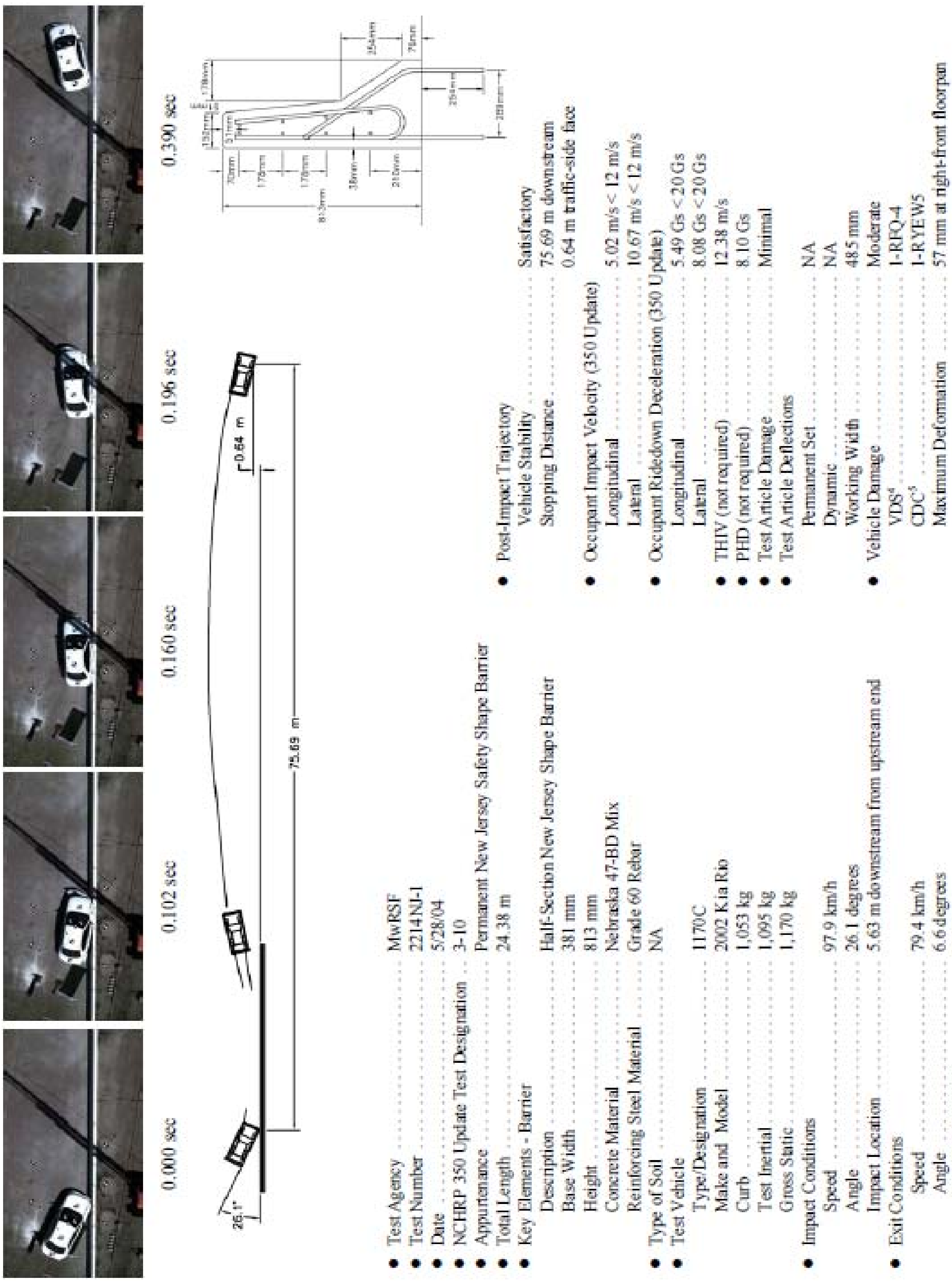

Figure 2: Full-Scale Test Summary for Small Car Impacting the Concrete Barrier [3]

Crash Simulation

Vehicle Models

The NCAC released a number of finite element (FE) vehicle models. Table 1 provides information on the features of the 2007 Chevrolet Silverado pick-up truck and the 20102 Toyota Yaris. These models were developed jointly by FHWA and NHTSA to serve multiple safety analysis purposes and advance vehicle and highway safety research. Reverse engineering methods were employed to build the FE model and the attention to detail was critical to making it suitable for application for different crash conditions.

The models were initially validated following traditional protocols for comparison of the data from the full frontal impact with a vertical wall required under the New Car Assessment Program (NCAP) administered by NHTSA and the simulated results for that test. In addition, the models were subjected to other NCAC-developed validation exercises including:

- Comparisons of actual and simulated inertial properties,
- Front suspension system component tests,
- Rear suspension system component tests, and
- Non-destructive bump and terrain tests.

Data from these tests was useful in enhancing the model and providing quantitative measures that increased confidence in the predictive capabilities for roadside barrier impacts. The results of the FE model validation efforts have been documented elsewhere [4, 5, 6, 7, 8]. The results are believed to indicate that the models will provide a sound basis for many types of crash simulation applications in the future.

The opportunity arose to take the validation efforts for the vehicle models one step further by collaboration with another project aimed at assessing the impact of the new crashworthiness criteria prescribed in the MASH. Under NCHRP project 22-14(3), seven tests of safety hardware previously approved under criteria outlined in NCHRP Report 350 were tested under MASH criteria [2]. This effort primarily involved using the larger pick-up truck (i.e., 2270 kg [5000 lbs] over 2000 kg [4400 lbs] pick-up truck) in the tests. In these tests a Chevrolet Silverado meeting the basic generic vehicle requirements was used. Subsequently, the Yaris model was created to provide the opportunity to evaluate the capabilities to evaluate the performance for a heavier small car (e.g., 1100 kg versus 820 kg). This paper focuses on the tests conducted with one of the seven barriers, the New Jersey-shaped concrete barrier. It was intended to provide further validation for the FE models and provide confidence in their fidelity usefulness to support the design and evaluation of roadside safety hardware to meet MASH requirements.

Barrier Hardware Model

An FE model of the New Jersey-shaped barrier developed by the NCAC was used for the simulation. The New Jersey barrier had a height of 813 mm [32 inches]. As concrete safety barriers do not deform or deflect even under severe crash conditions, all barrier models include only rigid shell elements. For the analysis, the length of barrier was extended to 41,222 mm [134 feet] to make sure the vehicle did not reach the end of the barrier before the end of the simulation. The barrier model mesh was refined to sizes between 50 and 93 mm [1.9 and 3.6

inches] to ensure optimum contact between the vehicle and barrier without excessive penetrations. The lower surface of the barrier was fixed to prevent any movement or deformation in the barrier during the crash simulation. Since the New Jersey-shaped barrier model had been extensively used in other simulation studies, a rigorous validation effort was not undertaken for this research [9, 10].

Table 1: NCAC Vehicle Models Representing NCHRP Report 350 and MASH Test Vehicles

Description	Vehicle Image
2010 Toyota Yaris • Weight – 1,100 kg (2,420 lbs) • CG 1004 mm rear, 569 mm high • Model Parameters Parts-771, Nodes - 998,218, Elements - 974,348 • Features: : FD, CD, SD, IM • Validations: FF, OF, MDB, SI, IP, SP, SC, ST, OT • Release Date: 12/02/2011	
2007 Chevrolet Silverado Pick-up Truck (Coarse) • Weight – 2,270 kg (5,000 lb) • CG 736mm (28.8 inches) • Model Parameters Parts-606, Nodes - 261,892, Elements - 251,241 • Features: : FD, CD, SD, IM • Validations: FF, IP, SP, SC, ST, OT • Original Release: 2/27/2009	
Validations Legend: • FF – NCAP Full Frontal • OF - Offset Frontal • SI – Side Impact • MDB – Modified Deformable Barrier • IP - Inertial Parameters • SP – Spring Response • SC – Suspension Components • ST – Suspension Tests (full-scale) • OT – Other	**Features Legend:** • FD – Fine Detail version • CD – Coarse Detail version • SD – Suspension Details • IM – Interior Modeled

Comparison of the Results

The validation efforts involved comparisons of the simulation results and the crash test data in three different ways with increasingly higher levels of rigor. Visual comparisons were first, followed by comparisons of traditional acceleration and rate metrics, and finally analytical comparisons.

Visual Comparisons for MASH Tests 3-11 (2270P Vehicle) and 3-10 (1100C Vehicle)

Figure 3 provides a visual comparison of the simulation versus actual test for the Silverado impact into a 813mm [32 inch] high New Jersey-shaped concrete barrier. This sequential view shows that there was similar behavior of the vehicle for each of the time steps shown. The nature of the interaction of the vehicle's bumper with the barrier and the degree of roll are similar in each case. The slightly greater amount of roll and pitch can be noted in the final view, but overall the visual comparison suggests good correlation.

The New Jersey-shaped barrier test with the small car demonstrated the crashworthiness at the other end of the spectrum. The Toyota Yaris FE model showed very similar impact behavior in front, rear, and overhead views of the test. Figure 4 provides a frontal visual comparison of the simulation versus actual test with the Kia Rio and the simulation of the Toyota Yaris for an impact into a 813mm [32 inch] high New Jersey-shaped concrete barrier. This sequential view shows that there was similar behavior of the vehicle for each of the time steps shown. The nature of the interaction of the vehicle's bumper with the barrier and the degree of roll are similar in each case.

Comparison of Traditional Metrics

The second level involved comparisons of the yaw, pitch, and roll measures for the vehicle between the simulation and the full-scale test. Figure 5 uses solid lines to represent the actual crash test data and dashed lines for the simulated results of the 2270P vehicle. The blue lines compare pitch angles and indicate similar behavior over the duration of the crash. There are less than 2 degrees of variation between these curves at any point in time. Similarly, the roll rates are compared by the red lines. These take similar tracks and also do not vary much more than 5 degrees at any time. Last, the comparison of the yaw rates is indicated by the green lines. They exhibit similar tracks and variation. This comparison of yaw, pitch, and roll data would suggest that the model is providing a good representation of the crash event. These further suggest a good correlation. Figure 6 shows the pitch, yaw, and roll metrics for the 1100C vehicle. In this figure the simulation data is represented by the solid lines and the crash test data the dashed lines. The lines indicate that the test and simulate had similar results for each metric. The greatest variation occurred for the roll metric which had a maximum variation of about 12 degrees which was within acceptable limits.

It is also possible to assess the validity of the model by analyzing the distribution of energy associated with the crash event. The laws of physics dictate that the total energy is balanced. Figures 7 and 8 provide the energy summaries for the Silverado and Yaris simulations. These indicate a relatively constant energy suggesting that there are no usual characterizations in the structure of the model that would be an unrealistic sink (point of dissipation) of the energy. The kinetic energy associated with the motion of the vehicle drops off as the velocity decreases during the crash. Further, there is an increase in internal energy as components of the vehicle absorb energy through deformation. Sliding energy, which is associated with the friction between the vehicle and barrier, also increases during the simulations. The sum of internal and sliding energy increase, as it would be expected, is equal to the reduction in kinetic energy.

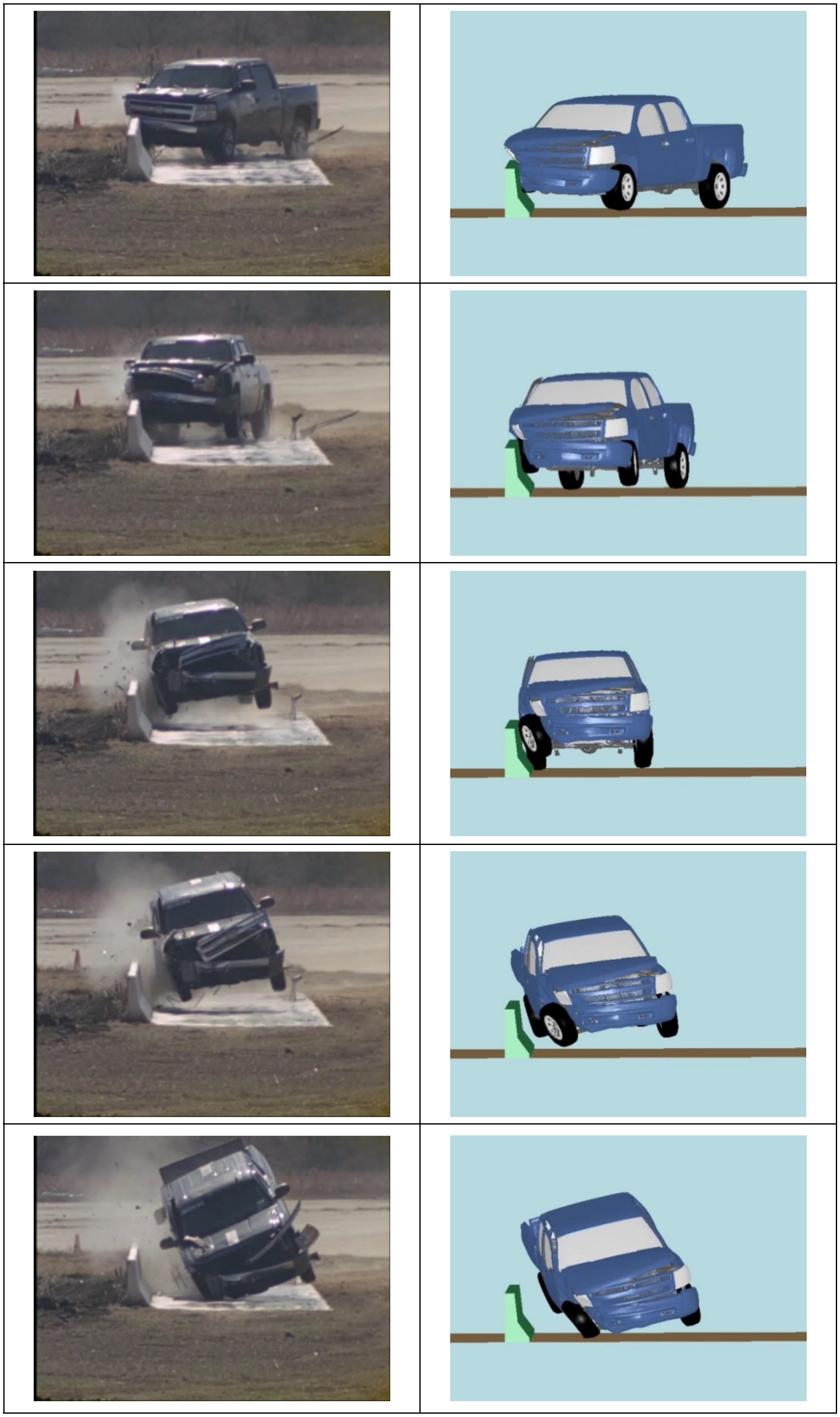

Figure 3: Sequential Views Comparing Crash Test to Simulation Results

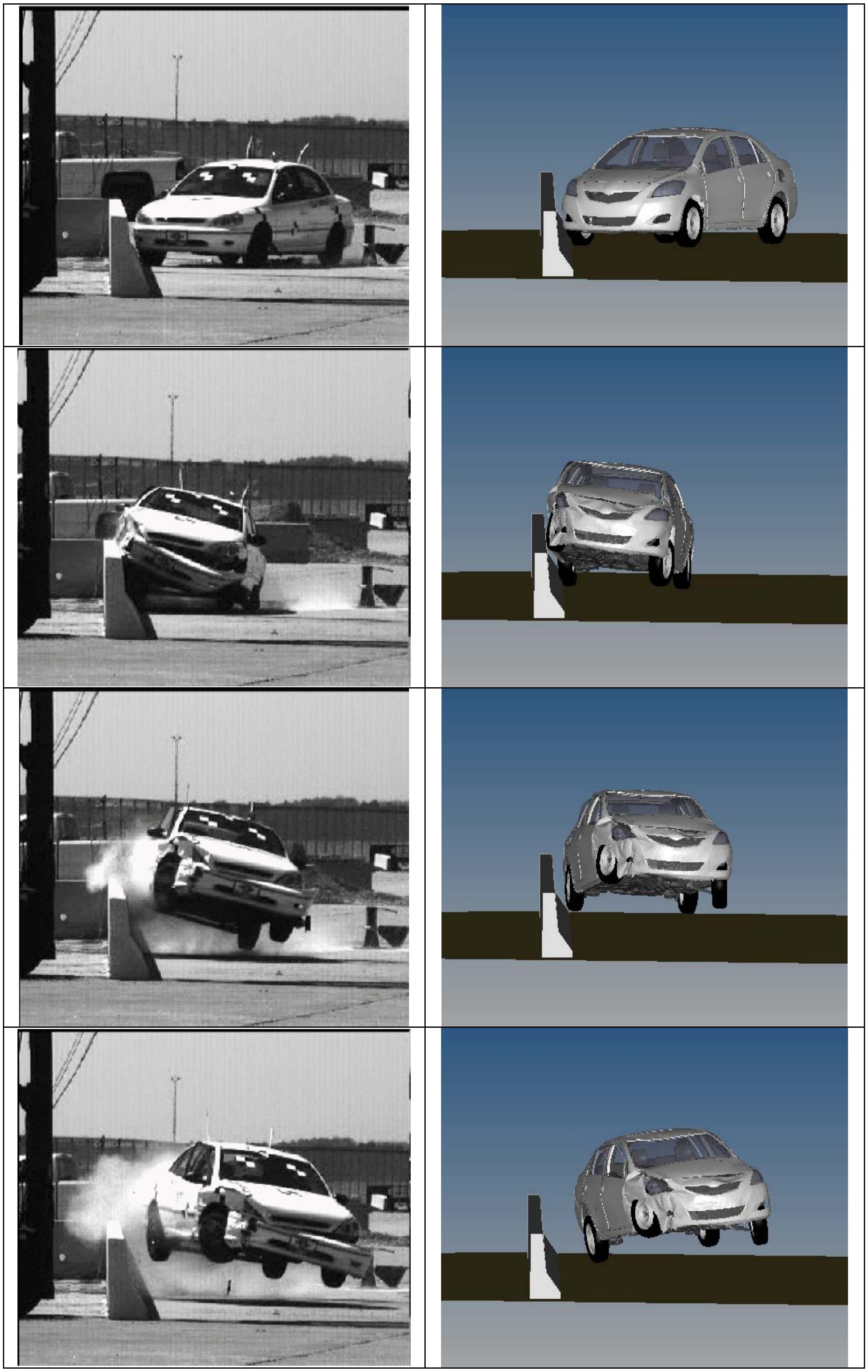

Figure 4: Sequential Visual Comparisons – Front View

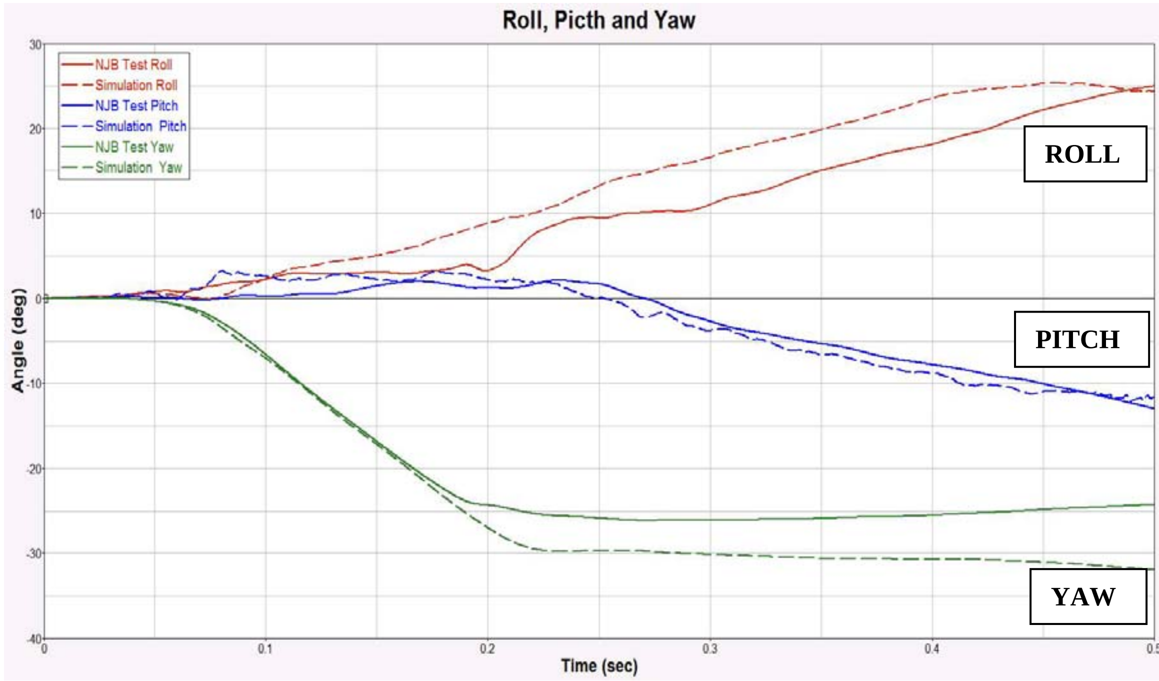

Figure 5: Comparison of Yaw, Pitch, and Roll Measures between Test and Simulation with Pickup Truck Vehicle

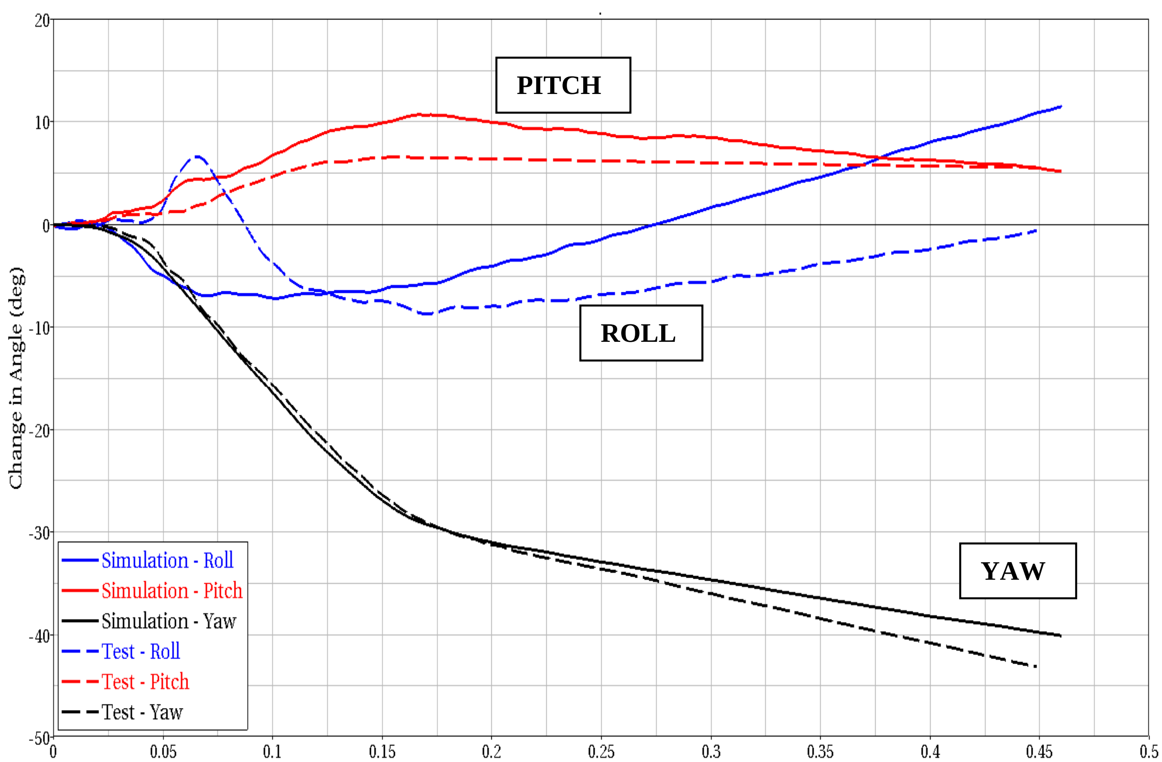

Figure 6: Comparison of Yaw, Pitch, and Roll Measures between Test and Simulation with Small Car Vehicle

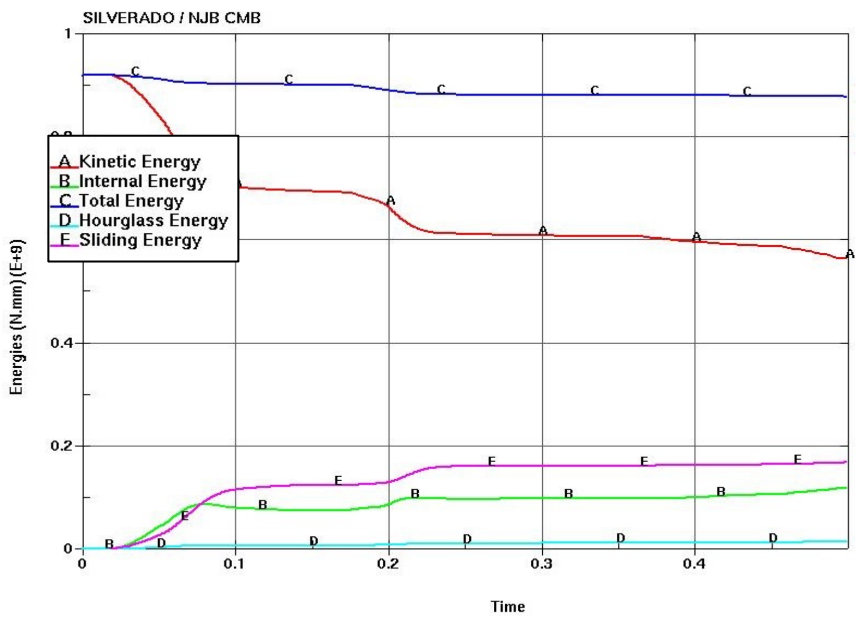

Figure 7: Energy Balance Diagram for Silverado Simulation

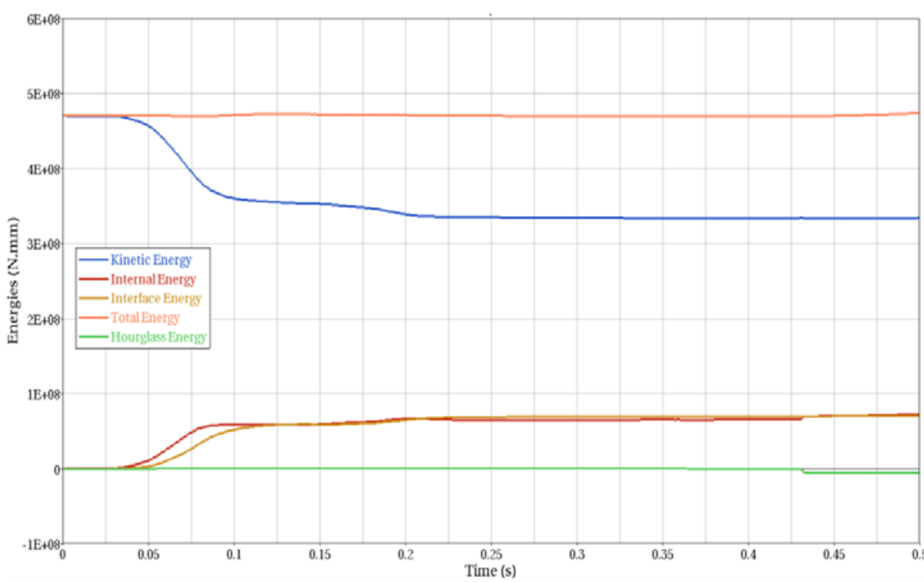

Figure 8: Energy Balance Diagram for Yaris Simulation

Analytical Comparisons

The verification and validation procedure recommended by NCHRP Project 22-24 "Guidelines for Verification and Validation of Crash Simulations Used in Roadside Safety Applications" was used to compare the results of the crash against the computer simulation at a third level [11]. The V&V procedure involves the use of the RSVVP software package, which compares paired sets of time-based data and undertakes the necessary data adjustments, and then applies a series of statistical tests to the data to determine how well it compares. The software allows various types of data to be used including the common crash test and simulation data, as follows:

- X-acceleration – Acceleration in the longitudinal direction of the vehicle
- Y-acceleration – Acceleration in the lateral direction of travel of the vehicle
- Z-acceleration – Acceleration in the vertical direction of travel of the vehicle
- Yaw rate – Rate of angle change of the vehicle relative to its vertical axis
- Roll rate – Rate of angle change of vehicle relative to its longitudinal axis
- Pitch rate – Rate of angle change of the vehicle relative to its lateral axis

The software allows single- and multi-channel comparisons of the above types of data that are typically captured by the instrumentation used in crash tests and the metrics that can be generated by the simulation software. Figure 9 is a typical output of the RSVVP software that summarizes the statistical evaluation of the longitudinal (X-axis) acceleration data between the test and the simulation for the test involving the Silverado pick-up truck and New Jersey-shaped barrier. The RSVVP output graphs provide information about the relative differences in the data in multiple ways and provide statistical comparisons using the Sprague-Geers and ANOVA methods. The output also indicates whether the results pass or fail to meet the acceptance criteria. The software produces a graph for each of the six acceleration and rate factors.

The meaning of the various graphs is noted below (moving from upper left to lower right):

- Time history plot – The red line indicted the simulated data and the blue line the test data that was captured during the crash event. Each data point is a measure of the acceleration recorded.
- Plot of integrated time histories – Integrating the change of acceleration data allows the changes in velocity to be plotted. A general decrease in velocity is noted, as expected, although there is some deviation between the test and the simulation after the impact.
- MPC Metrics – One of the metrics used to compare the simulation curve to the test. This metric is based on the Geers approach. This statistical metric provides a measure of “goodness of fit” between the two curves. Three parameters are used for the evaluation: the magnitude (M), phase (P), and comprehensive (C, combined magnitude and phase). A value of less than 40 for M, P, and C is considered passing the criteria. In this example, the metric meets the M and P values but does not meet the C values and hence the box for C is labeled “fail.”
- ANOVA Metrics – A second metric used to compare the test and simulation curves. The “goodness of fit” is assessed using the Analysis of Variance approach. Two parameters are used for the comparison: the average residual between the two curves and the standard deviation of the residuals. Values of less than 5% for the average residual and 35% for the standard deviation are considered passing the criteria. In this example, the metric meets the criteria and hence the “pass” labels.
- Residuals Plots (time history, histogram, and cumulative) – These plots show the residual (i.e. difference between the two curves in different forms). In the first plot, time history, the residual is shown versus time. In the second, the residual is shown in a histogram format where the percentage of the residual is plotted against the percentage of its occurrence. In the third plot, the cumulative of the residual (sum of all residuals up to that point in time) is plotted versus time.

Since not all measurements have the same importance in the tests, (e.g. in some tests little roll, pitch, X-acceleration, etc. are observed), these low magnitude channels could fail the evaluation metrics even if the simulation is valid. To overcome this problem, a multichannel comparison, where each channel is given a weighting factor based on magnitude, is incorporated in the validation process. A summary of the multi-channel output is shown in Figure 10. The figure indicates that the simulation passes all comparison metrics. The relative weights are indicated in the bar graph in the upper left corner.

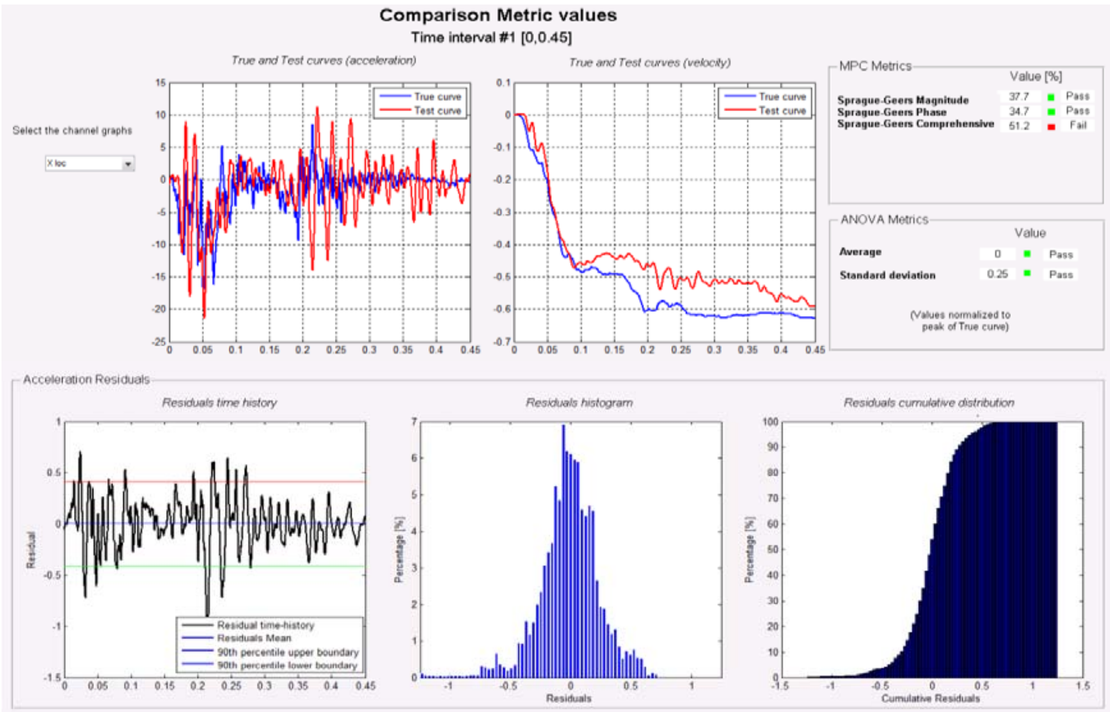

Figure 9: Typical RSVVP Longitudinal Acceleration Comparisons

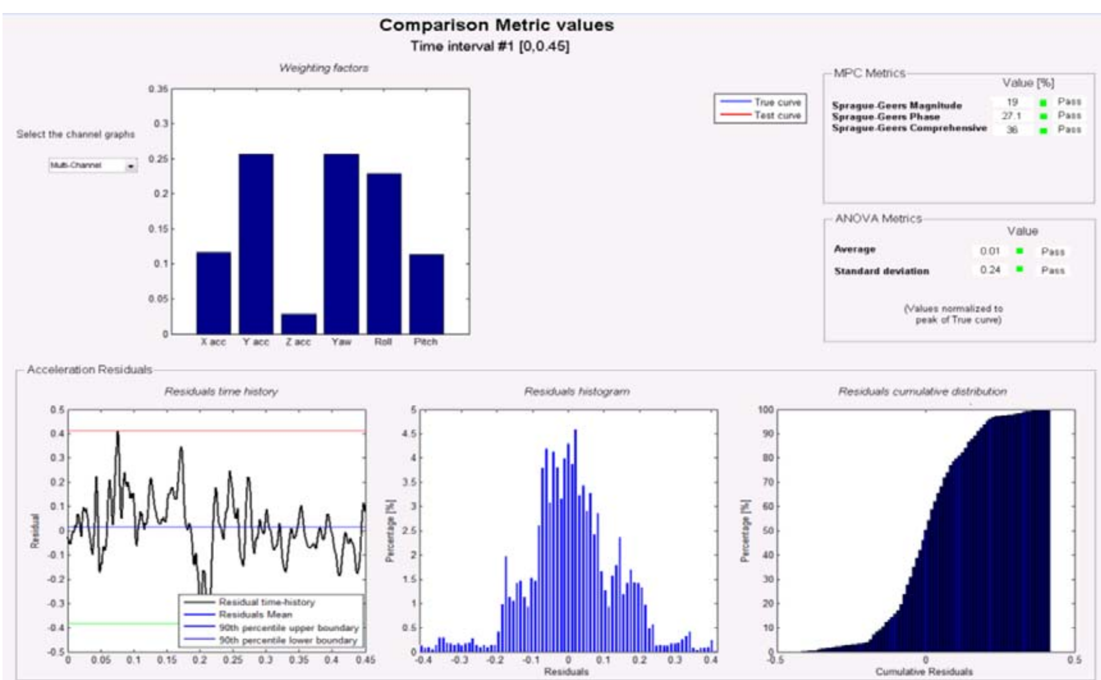

Figure 10: Typical RSVVP Weighted Multi-Channel Comparisons

Phenomena Importance Rank Comparisons

In addition to comparing the time history from the transducers mounted on the vehicle, the verification and validation procedure calls for additional evaluations that can be adjusted to reflect the type of barrier being evaluated. The expected performance of longitudinal barriers under MASH served as the basis for the “Phenomena Importance Ranking Table (PIRT)” comparisons. A set of MASH structural adequacy, occupant risk, and vehicle trajectory factors have been defined. The test and simulation results for each factor must all be with prescribed bounds for the model to be considered valid under PIRT assessments. These also involve checking the simulation results to ensure that there are discrepancies in simulations such as in the energies (kinetic, internal, hourglass, total, etc.) and mass of the components.

Table 2 provides the verification and validation results from crash test data and the simulation results relative to Tests 3-11 and 3-10 for impacts into a New Jersey-shaped barrier. For each vehicle, the metrics or responses relative to the structural adequacy, occupant risk, and vehicle trajectories are noted in adjacent columns (labeled “test” and “sim”). It can be noted that the comparison values or responses are all similar. (Detailed versions of this table indicate the actual degree of variation.)

The Verification and Validation procedures provide a structured series of comparisons to document and statistically assess the time-based data sets that are derived from tests and simulations. The procedures provide for:

- Fundamental documentation of the test and simulation datasets that are being compared,
- Tabular summaries of the results of the comparisons,
- Statistical measures for comparison of multi- or single-channel data, and
- Composite score.

The procedure does not lead to a singular rating of any case analyzed, but it does lead to a systematic assessment of the similarities and differences associated with the measured versus analytical solution for any set of time-based impact performance data.

The RSVVP summary in Table 3 shows the values computed by the Sprague-Geers or ANOVA methods and the Pass/Fail outcome of the statistical comparisons. The weighted, multi-channel comparisons shown in the table are considered the more important metric as it accounts for varying importance of the factors all “passed” for both methods. The results indicate that “statistically” the simulation and crash test results for the oblique impacts by the large and small vehicles are similar.

Table 2: MASH PIRTs Evaluation Summary for the New Jersey-shaped Concrete Barrier

		Barrier:	**New Jersey CMB**			
		Test Reference:	MwRSF		TTI	
		Vehicle:	Small Car		Pickup	
		Impact:	100 kph - 25°		100kph - 25°	
Structural Adequacy			Test	Sim.	Test	Sim.
A1	Test article should contain & redirect the vehicle; vehicle should not …		Y	Y	Y	Y
A2	Relative diff. in the max. dynamic deflection is less than 20%. (m)		0	0	0	0
A3	Relative diff. in time of vehicle-barrier contact is less than 20%. (sec)		0.26	0.23	0.24	0.25
A4	Relative diff. in number of broken or significantly bent posts is less than 20%.		NA	NA	NA	NA
A5	Barrier did not fail		Y	Y	Y	Y
A6	There were no failures of connector elements		Y	Y	Y	Y
A7	There was no significant snagging between vehicle wheels & barrier elements		Y	Y	Y	Y
A8	There was no significant snagging between vehicle body and barrier elements		Y	Y	Y	Y
Occupant Risk						
D1	Detached elements, fragments, or other debris should not penetrate or …		Y	Y	Y	Y
F1	The vehicle should remain upright during and after the collision …		Y	Y	Y	Y
F2	Diff. in max. Roll should be less than 20 %.or abs. diff. should be less than 5°		7	11	25	26
F3	Diff. in max. Pitch should be less than 20 %.or abs. diff. should be less than 5°		10	7	14	14
F4	Diff. in max. Yaw should be less than 20 %.or abs. diff. should be less than 5°		43	40	12	7
H1	Long. & lateral occupant impact velocities (OIV) should be less 12m/s …		Y	Y	Y	Y
H2	Long. OIV - Relative diff. is less than 20% or abs. value less than 2 m/s		5.0	4.8	4.3	4.7
H3	Lat. OIV - Relative diff. is less than 20% or abs. value is less than 2 m/s		10.7	8.7	9.2	7.9
I1	Long. & lat. Occup. ridedown accelerations (ORA) should be less than 20 g		Y	Y	Y	Y
I2	Long. ORA diff. should less than 20 % or abs. diff. is less than 4g		5.5	2.5	5.6	7.6
I3	Lat. ORA - Relative diff. is less than 20% or abs. diff. less than 4g		8.1	8.2	9.6	12.9
Vehicle Trajectory						
	Vehicle rebounded within the exit box		Y	Y	Y	Y

Table 3: RSVVP Multi-Channel Evaluation Summary for New Jersey-shaped Concrete Barriers

	Barrier:	**New Jersey CMB**			
	Test Reference:	MwRSF		MwRSF	
	Vehicle:	Small Car		Small Car	
	Impact:	100 kph - 25°		100 kph - 25°	
Multiple Channel Results			Pass?		Pass?
Sprauge-Geer Metrics	Magnitude	18.2	Yes	21.4	Yes
	Phase	17.3		23.1	
ANOVA Metrics	Magnitude	3.2	Yes	1.5	Yes
	Phase	12.8		22.0	

Summary and Conclusions

This effort successfully applied the finite element models of the Chevrolet Silverado pick-up truck and Toyota Yaris passenger sedan in the simulations of MASH tests 3-11 and 3-10 for oblique impacts into a New Jersey-shaped barrier. The effort led to the following conclusions:

- The detailed FE models were stable and displayed no unusual behavior in barrier impact simulations.
- Visual comparison of the test and the simulation (best compared by viewing the video and animation) showed that there was very similar behavior at all time steps in the crash event.
- The traditional comparison of graphs of roll, pitch, and yaw measures reflected good correlations between the crash test data and simulation results suggesting that both models are valid.
- The analytical validation efforts indicated that both simulations provide a good representation of the MASH tests for impacts with the New Jersey-shaped barrier.

The new verification and validation procedures were also assessed in this exercise. It was noted:

- The RSVVP software is a useful tool for comparing sets of time-based data and various summaries of data variations were made available. It includes features that facilitate time correlation of the data. These metrics, however, are limited to typical acceleration and angular rate change metrics.
- The PIRT assessment provides a structured approach to comparing the various metrics or aspects between the crash test and simulation. MASH-related metrics allow the comparisons to reflect the requirements of current crashworthiness standards.
- The pass/fail thresholds seem appropriate but analysis of individual results over many tests will be necessary to detect patterns that might suggest whether the current criteria are too loose or too stringent.

Further refinements or efforts that might be considered useful include:

- An increased focus on the metrics compared between the test and simulation. There may be other metrics unique to a type of impact that should get attention. Simulation can generate many additional metrics over the impact event as well as outcomes.
- There is a need to confirm that the pass/fail criteria are appropriate. This may only be possible when many more comparisons have been completed.
- It may be appropriate to make provisions to include reviews of the data and residual distributions to note anomalies that or deviations that may question “passing” results.

Acknowledgements

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