MODELING AND SIMULATION OF VAN FOR SIDE IMPACT SENSING TESTS

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Paper Number 07-0060

ABSTRACT

An extensive study on using non-linear finite element analyses to aid in calibrating a thorax or roof rail curtain airbag sensing system is presented. Modeling techniques and lessons learned from previously investigated frontal sensing finite element analyses were adopted in this side impact study. Modeling techniques that can be applied to the side impact simulations were identified and incorporated in a chosen van model. The van model was then used to simulate a set of no-deployment and deployment side impact calibration events. The simulation results were compared with available test data and side impact sensing algorithms were used to determine the airbag deployment time from the simulations. Airbag deployment times from the simulations are comparable to the test and it is strongly suggested from this study that a high fidelity vehicle model with a FEA-compatible sensing algorithm can greatly improve sensing simulation capability for side impacts.

INTRODUCTION

The use of math-based tools has reduced the need for hardware prototyping and testing, which in turn reduces a vehicle's development time and cost. However, there are still many tasks in the vehicle development process that math-based tools cannot do well. Of these, the task of calibrating a side airbag sensing system is a major task that has not been addressed. To obtain the required acceleration signals for sensing calibration, expensive prototype vehicles have been routinely crashed for vehicle development. A math-based side sensing calibration capability could significantly reduce prototyping and testing costs, as well as shorten the vehicle development time.

There have been a few papers published for the frontal sensing impact simulations [1,2,3,4,5] but none for the side impact sensing impact simulation. The major difference between the frontal impact and the side impact is that the latter generally requires a much earlier airbag deployment time, which, in turn, demands an even higher degree of model fidelity to ensure timely deployment. In these frontal sensing studies, the necessary modeling techniques to achieve high fidelity FEA models for simulating a suite of frontal sensing impact events have been documented. In this paper, study of the FEA-compatible sensing impact tests is extended to side impact sensing tests. The modeling techniques identified in previous studies are employed, if applicable, onto the side impact model and other necessary and unique side sensing impact modeling techniques are identified and studied so a high fidelity FEA-compatible side sensing impact vehicle model can be built to replace some of the tests and speed up the vehicle development process.

A van, shown in Figure 1, is selected for study in this paper. The following seven van vehicle side impact tests are available for correlation study: Side NCAP(New Car Assessment Program), FMVSS214 MDB (Moving Deformable Barrier) impact, IIHS (Insurance Institute for Highway Safety) side impact, front and rear door pole impacts, EEVC (European Enhanced Vehicle-safety Committee) barrier impact, and MDB no-deployment impact. The van side impact calibration crash matrix is shown in Table 1. Non destructive immunity tests, such as door slam, shopping cart/bicycle hits, etc., are not studied in this paper since they can be conducted more efficiently and economically in the test laboratories.

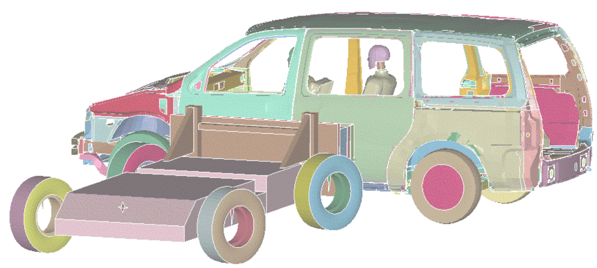

Figure 1. The van vehicle model.

Table 1.
Sensing calibration test matrix.

Tests
IIHS
Side NCAP
FMVSS214
Front Door Pole
Rear Door Pole
EEVC
MDB No-Deployment

MODELING TECHNIQUES CRUCIAL FOR CRASH TEST SIMULATIONS

Finite element simulations have been conducted routinely in the past decade to evaluate and improve crash and safety designs for specific high-speed impact conditions or regulations. Knowledge of fundamental modeling techniques had been accumulated for building a quality finite element model. These fundamental modeling techniques are:

- Reduce element size to about 10 mm in the crush zone to capture correct buckling modes
- Avoid initial penetration between parts
- Use joints, instead of rigid connection, to represent the door hinge and latch/striker system
- Use mass scaling option with caution
- Space the welding locations close to physical model and minimize the weld length
- Include gravitational force

All the analyses are completed using LS-DYNA version 960.1488[6]. The number of parts, elements and nodes of the model are summarized in Table 2. In what follows, we document the crucial modeling techniques, beyond what have been stated above, that are required for building a high fidelity side impact model for sensing calibration purpose.

Table 2.
Total number of parts, elements and nodes of the van FE model.

	Van FE Model
No. of Parts	246
No. of Nodes	232,959
No. of Shell Elements	227,223
No. of Solid Elements	829
No. of Beam Elements	28

Crucial Sensing Modeling Techniques For Side and Frontal Vehicles

Accelerometers -

Physical accelerometers measure the acceleration and deceleration in a fixed local frame, which translate and rotate with the component that the accelerometers are mounted on. Hence, the "ELEMENT_SEATBELT_ACCELEROMETER" card in LS-DYNA is used in our model to monitor the acceleration change in such a local coordinate frame. The FEA velocity curves shown in this paper are obtained by integrating the acceleration, filtered through SAE 180 class.

Six side impact sensor locations, the front door beam, BSIS (B-Pillar Side Impact Sensor), rear door beam, C-pillar at beltline, CSIS (C-Pillar Side Impact Sensor), and the SDM (Sensing Diagnostic Module) on the floor under the passenger's seat, shown in Figure 2, are used in this study for correlating crash pulses with available tests.

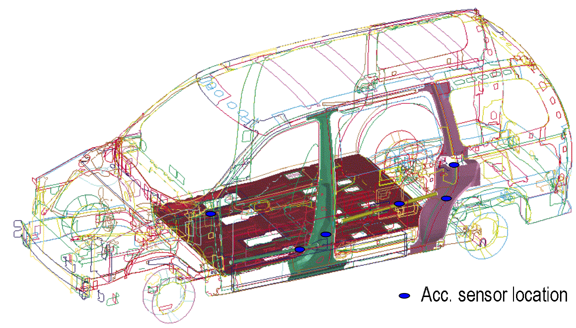

Figure 2. Monitored sensor locations: front door beam, BSIS, rear door beam, CSIS, C-pillar at beltline, and the SDM on the floor under the passenger's seat.

Strain Rate Effect

The strain rate effect of the materials was previously identified as the most crucial factor that must be incorporated in a frontal impact model to simulate a set of frontal impacts, high-speed deploy and low-speed no-deploy events [2,3,5,7]. In this side impact sensing study, the engineering properties of the metallic materials in the van FE model are updated to include strain rate sensitive material. A quasi-static stress-strain curve is substituted to study the results of the velocity changes in a high-speed FMVSS214 test and a low-speed MDB no-deployment impact test. The simulation setup for the FMVSS214 impact is shown in Figure 3. The differences of the velocity at the BSIS between the two simulations, shown in Figure 4, are insignificant before the side bags' required deployment time while the SDM velocity curve of the simulation using a quasi-static stress-strain curve exhibits a slightly softer response since softer material properties are used. For the lower speed MDB no-deployment impact, the differences of the simulations are less noticeable, as shown in Figure 5, with the quasi-static stress-strain material model showing a slightly softer response. The differences are not as significant as documented for the frontal impacts.

In the frontal impacts, the rails and cradle are loaded axially, and these major energy absorbing components can yield different crush modes when not employing the strain rate effect. This results in significant velocity deviation. The B-Pillar and the door beams, designed mainly for side impact protection, are designed to resist the bending force during the side impacts, and these components will not have dramatic differences in deformations if the material properties are modeled using a single quasi-static stress-strain curve; hence the deviation in the velocity curves is not as pronounced as the frontal impact events. However, significant differences might exist for vehicles, say, with a cross car beam design.

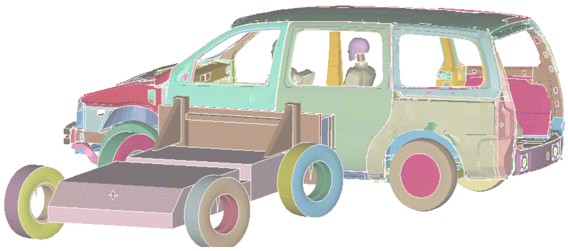

Figure 3. FMVSS 214 FEA model setup.

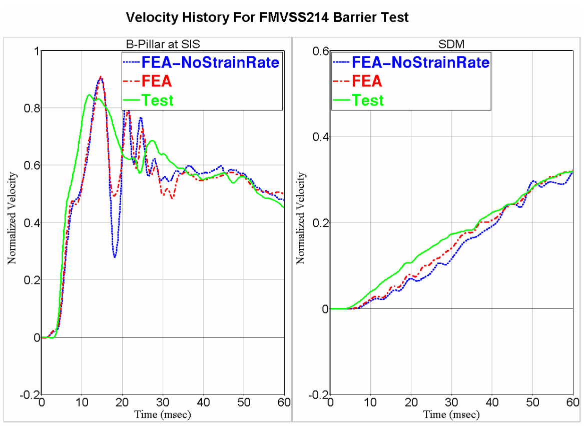

Figure 4. Comparing the FEA velocity curves with and without strain rate effect for FMVSS214 impact test.

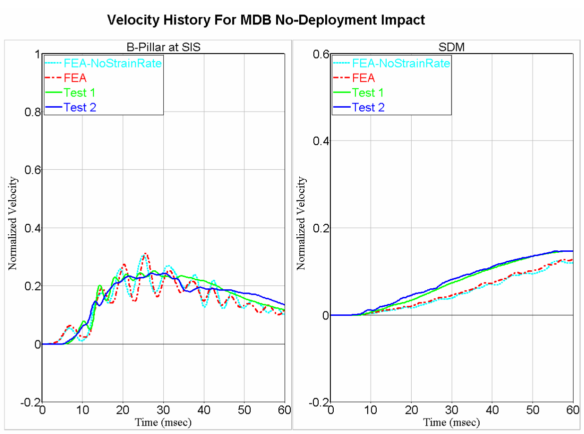

Figure 5. Comparing the FEA velocity curves with and without strain rate effect for MDB no-deployment impact test.

Segment-Based Contact

A full vehicle crash analysis involves interaction between all free surfaces, which includes contact at corners and edges. Correlation with the tests might be degraded significantly if the contacts are not defined properly. In one of the previous validation study [8], it was found that the velocity pulse correlation was improved by using the segment-based contact option in LS-DYNA. In this side impact study, however, the use of this option did not yield significant differences, as shown in Figure 6. To avoid any unrealized or unforeseen contact issues, it is still strongly recommended that the segment-based contact search parameter be considered when defining the contacts.

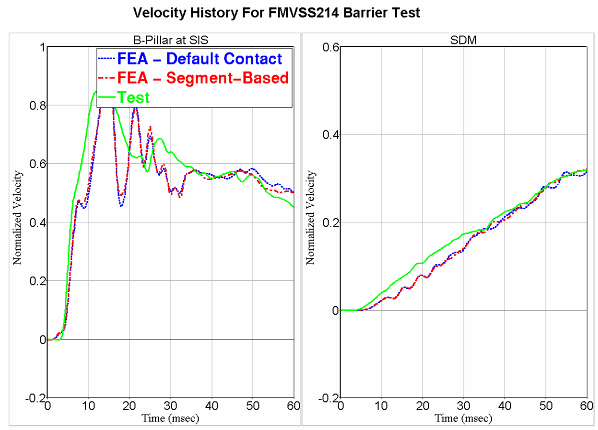

Figure 6. Comparing the FEA velocity curves with and without segment-based contact option for FMVSS214 impact test simulation.

Shell Element Type 16 and Type 2

Many shell element formulations are available to the users in LS-DYNA while formulation types 16 and 2 are the most commonly used. Use of the element formulation type 16 [6] significantly improves the overall SDM velocity correlation, depicted in Figure 7. The shell element formulation type 16, a fully integrated shell element, costs about 2.8 times more CPU-time than the default Belytschko-Tsay (BT) element (shell formulation type 2 in LS-DYNA). However, the BT shell element is very sensitive to element warping. Using the shell formulation type 2 tends to make a vehicle model softer, and the velocity response at the SDM showed this trend while the response at the BSIS did not.

For the lower speed MDB no-deployment impact, it has less effect on the SDM velocity, shown in Figure 8. It is observed that the velocity at the BSIS is less wavy when the shell formulation type 2 is used. When the shell formulation type 2 is used, accuracy of the analysis can be improved by turning on the warping stiffness control and updating the shell normal direction based on the nodal rotation available in the *CONTROL_SHELL card and using the stiffness form hourglass formulation. Use of those parameters for shell type 2 did not bring the SDM velocity of FMVSS 214 simulation closer to the test and match the result of shell type 16 as expected, shown in Figures 7 and 8.

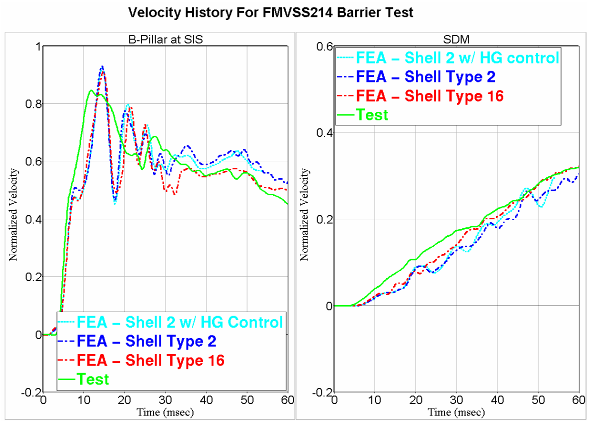

Figure 7. Comparing the FEA velocity curves with different shell element formulations, type 2 and type 16, for FMVSS214 impact.

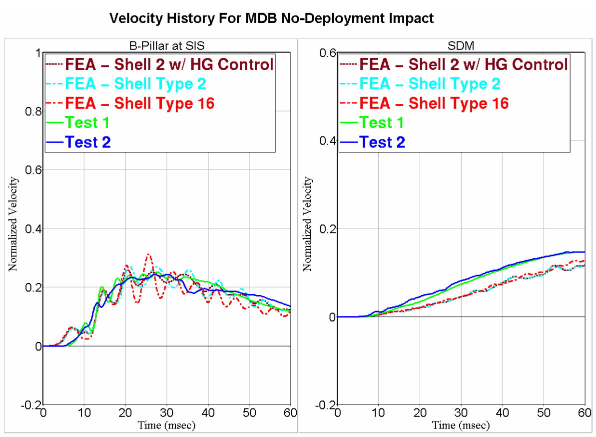

Figure 8. Comparing the FEA velocity curves with different shell element formulations, type 2 and type 16, for MDB no-deployment impact.

Crucial Modeling Techniques For side impact vehicles ONLY

Modeling of Door Striker

In simulating the FMVSS214 quasi-static test, the inclusion of a detailed modeling of door striker and latch system can improve the correlation of the resistance force. The improvement is from the small relative displacement between the striker and the latch system. In our dynamic crash study, this system is modeled as a joint to allow the realistic relative displacement and rotation between the door and B-Pillar. When the joint is replaced by a rigid connection, it does not result in significant difference in the overall SDM response as shown in Figure 9 and it shows a slightly stiffer response in the BSIS at airbag deployment time.

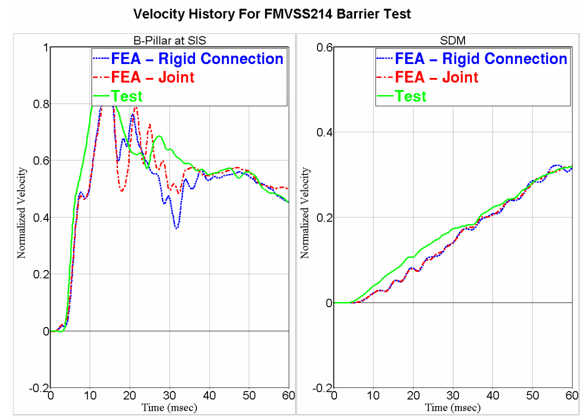

Figure 9. Comparing the FEA velocity curves for the modeling of striker and hinge system for FMVSS214 impact.

Friction Coefficient Between Barrier and Vehicle

The friction coefficient between the moving deformable barrier and the vehicle in the crash test is also studied so that a proper coefficient can be established. The friction coefficient values of 0.0, 0.2, and 0.4 are used to study their effects on the SDM velocity. As a higher friction coefficient is used, the vehicle has a slightly stiffer response at the SDM, i.e., greater velocity change, shown in Figure 10, while the response change at the BSIS is less noticeable. It is concluded from this study that a friction coefficient of 0.2 can achieve better correlation.

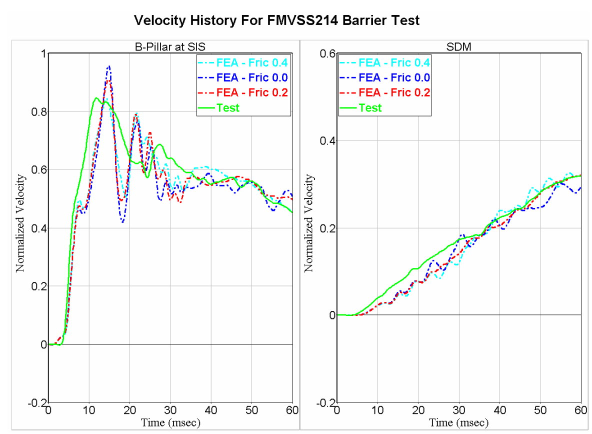

Figure 10. Different friction coefficients between the barrier and the vehicle for FMVSS 214 simulation.

SIMULATION RESULTS

Comparison Between the Tests and Simulations

Using the enhanced model by employing the modeling techniques described above, we simulated seven side crash tests listed in Table 1 using a consistent vehicle model. FEA accelerations at the target locations are first extracted from the simulations and then integrated to obtain the velocity histories. The complete velocity time histories for the seven side impact tests are shown in the Appendix. For the Side-NCAP and EEVC impact conditions, only the velocity curves at the SDM and BSIS for the tests are shown for comparisons, since there is no data available for the other locations.

In this section, the IIHS side impact simulation results are selected to compare with the test. Deformation of the vehicle model after the impact is shown in Figure 11. Correlations of the velocity history at selected locations are shown in Figure 12. The front door beam sensor signal was prematurely terminated before 3 msec into this test. Comparing the velocity change at the BSIS, shown in Figure 12, between the simulation and the test, good agreement was observed upto 7 msec into the crash event. Efforts were focused on improving the velocity at the BSIS, and it indeed results in a good correlation. For the rear door beam and C-pillar sensors, FEA velocity curves show a 2 ~3 msec earlier rise than the test, but they do have similar velocity characteristics. The velocity curve at SDM for the IIHS impact simulation is lagging behind the test, which indicates that the FEA model has a softer overall response than that of the vehicle. Among all the simulated impacts events, MDB no-deployment impact, FMVSS214, EEVC, and front door side pole impacts have good SDM velocity correlation with the available tests, while the Side-NCAP, IIHS, and rear door side pole impacts show softer response, as shown in the Appendix.

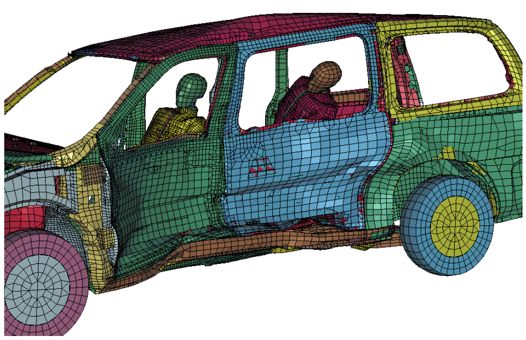

Figure 11. FEA model after the IIHS impact test.

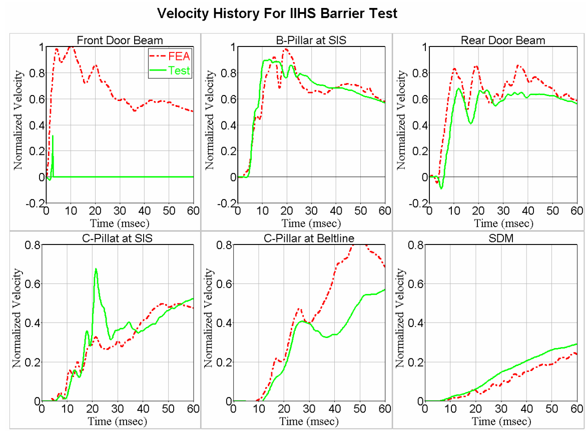

Figure 12. Velocity histories for IIHS side impact at the targeted locations for both simulation and test.

FEA-COMPATIBLE PARAMETERS

One of the objectives of this study is to identify what output parameters from finite element analysis generally correlate well with test data. These parameters are termed the FEA-compatible parameters, which are ideally suited for crash sensing algorithms if crash simulations will be used in place of crash tests for sensing algorithm calibration.

Figures 13 and 14 depict the correlations between the simulated and the measured accelerations of the FMVSS214 vehicle test at the BSIS and SDM. The acceleration data shown in the two figures is filtered through a different SAE filtering class, class 60 and class 180. Acceleration correlations before the first 7 msec at the two locations are fair, and the acceleration data can potentially be used for safing purpose, if the required airbag deployment time for FMVSS 214 is within 7 msec. The entire histories of the FEA accelerations, however, do not correlate well with the test.

Velocity, shown in Figure 15, at both SDM and BSIS shows reasonable agreement with the test, and the displacements, plotted in Figure 16, shows good agreement. It is clearly indicated from the figures that the acceleration is not a FEA-compatible measure. A similar trend is observed from other types of crash events. Complete velocity pulses for other impact tests and sensor locations are shown in the Appendix.

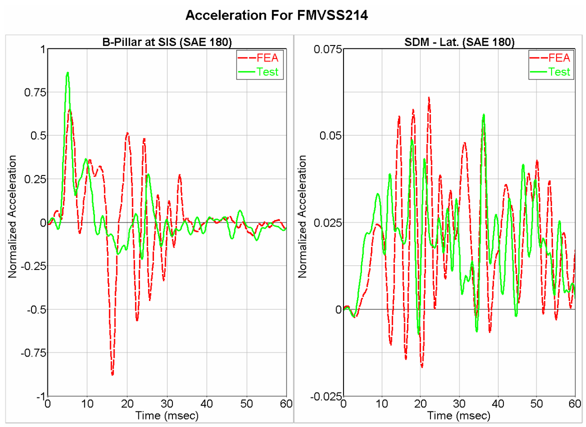

Figure 13. Acceleration histories, filter with SAE 180, for FMVSS214 side impact at the BSIS and SDM.

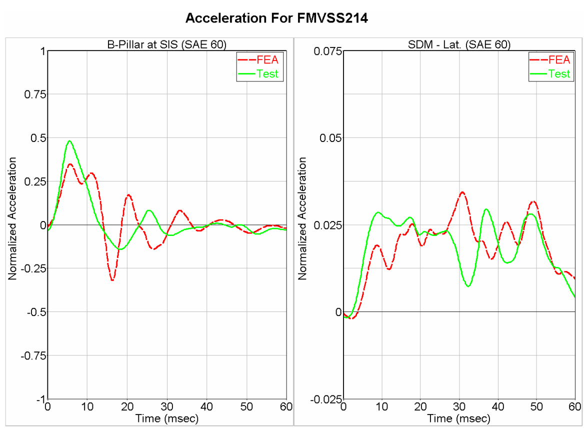

Figure 14. Acceleration histories, filter with SAE 60, for FMVSS214 side impact at the BSIS and SDM.

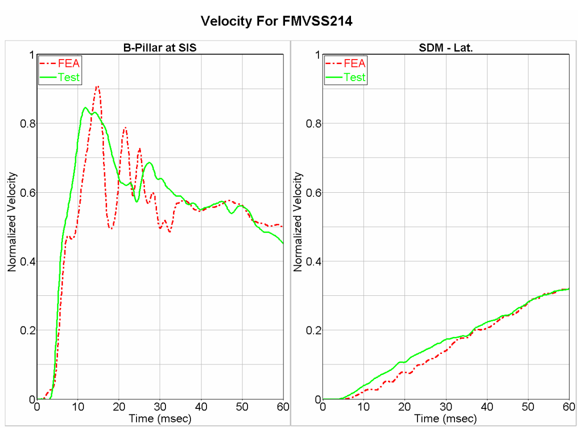

Figure 15. Velocity histories for FMVSS214 side impact at the BSIS and SDM.

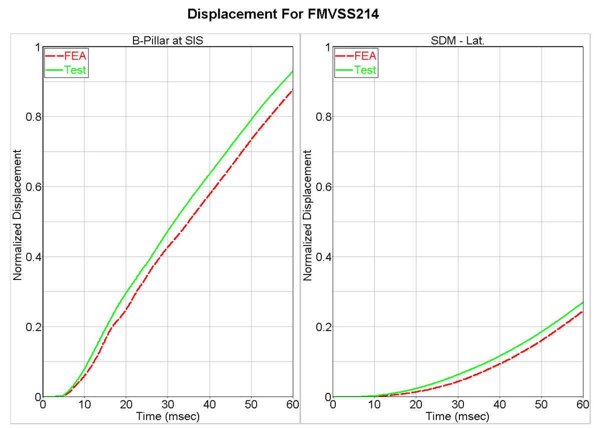

Figure 16. Displacement histories for FMVSS214 side impact at the BSIS and SDM.

We summarized our observations on the FEA compatibility of each measurement in Table 3. Those parameters rated as “fair” or “good” are ideally suited for building FEA-compatible crash sensing algorithms.

Table 3.
FEA compatibility.

Parameters	FEA-Compatibility
Jerk at SDM and Satellite Sensors	Poor
Acceleration at SDM (Entire Duration)	Poor
Acceleration at Satellite Sensors (Entire Duration)	Poor
Acceleration at SDM (Before Airbag Deployment)	Fair
Acceleration at Satellite Sensors (Before Airbag Deployment)	Fair
Velocity at SDM	Fair
Velocity at Front Sensors	Fair
Displacement at SDM	Good
Displacement at Front Sensors	Good

FEA PERFORMANCE USING EXISTING ALGORITHM AND CALIBRATION

Simulations inherently have a higher frequency content than the tests. An example of these accelerations and their frequency content at the front door beam for front door side pole impact is plotted in Figure 17. Satellite sensor signals received by SDM are also constrained by the sensor resolution and frequency of the communication. These constraints result in different clipped signals between the tests and the simulations. The filtered acceleration magnitude of the un-clipped FEA acceleration, shown in Figure 18, is higher than the test, while the magnitude of the clipped FEA data is smaller. This signal clipping and filtering may produce different sensing performances between the test and the simulation, even though the FEA velocity correlates well with the test.

Acceleration signals from the tests were first calibrated to meet the airbag deployment target times using the test data. Algorithms were then used to determine the airbag deployment times of the simulations without changing the existing algorithms and the thresholds. It was observed from this exercise that the FEA side sensing system performance was comparable with the tests and the development of a FEA-compatible side impact sensing algorithm becomes more favorable for side impacts sensing system.

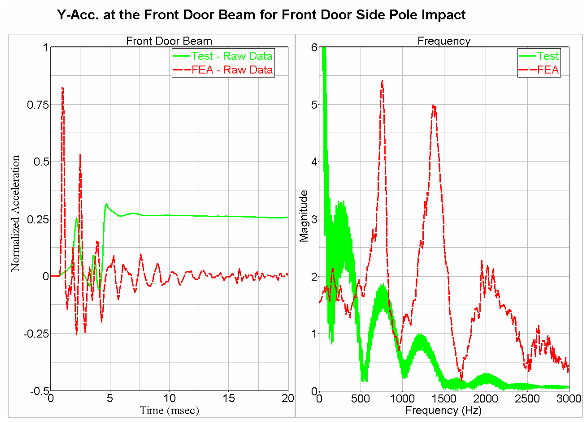

Figure 17. Test and FEA accelerations and frequency contents at the front door beam for the front door side pole impact.

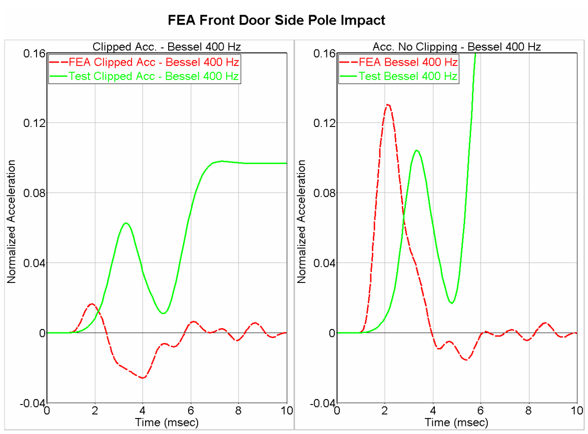

Figure 18. Test and FEA front door beam accelerations of the original and the clipped signals filtered through 4-Pole Bessel filter for the front door side pole impact.

SUMMARY

We identified and applied the critical modeling techniques and guidelines for building a high fidelity side impact finite element model for the van vehicle that could be used to simulate a suite of side impact tests for crash sensing calibration purposes. Using this enhanced model, we simulated seven different side crash events. Acceleration signals from the tests along with corresponding simulation results were calibrated to determine the side airbag deployment times without changing the existing sensing algorithms calibrated based on the tests. It was observed that the FEA side sensing system performance was comparable with the tests.

From the velocity correlations and calibration results, it is strongly suggested that the acceleration data and the calculated vehicle velocity and displacement at both satellite sensors and SDM can be subsequently used in the development of a FEA-compatible sensing algorithm.

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APPENDIX

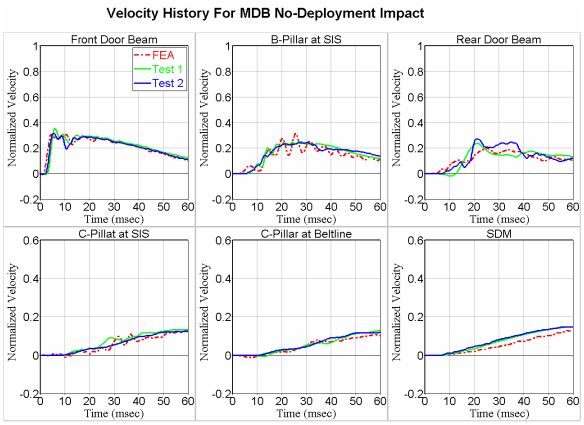

Figure A1. Velocity histories for the MDB no-deployment impact.

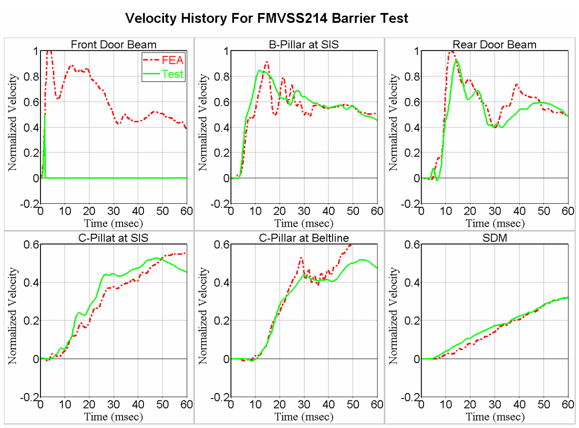

Figure A2. Velocity histories for the FMVSS214 impact.

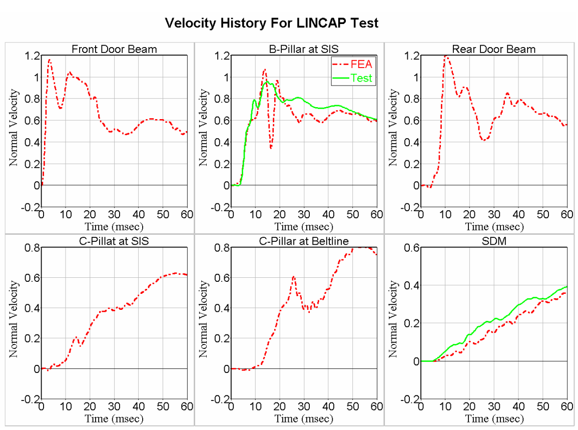

Figure A3. Velocity histories for the Side NCAP impact.

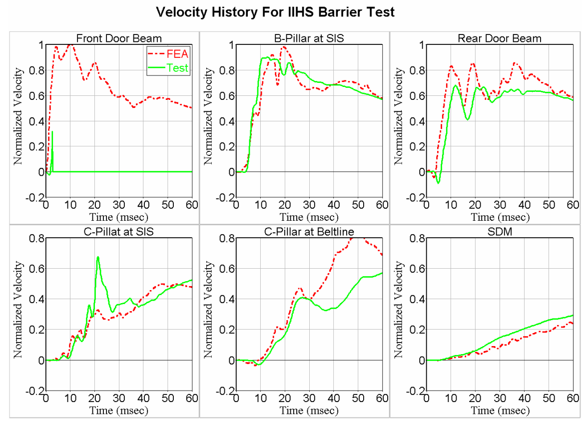

Figure A4. Velocity histories for the IIHS impact.

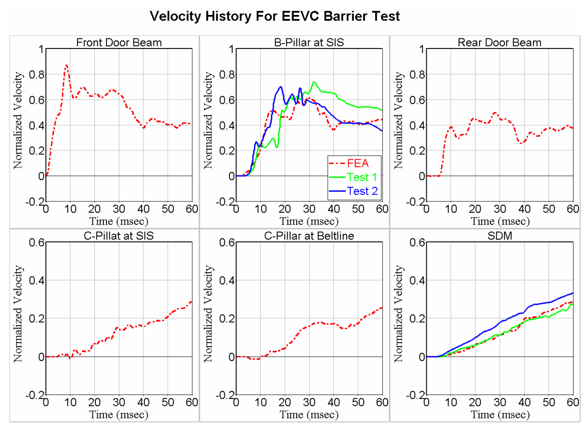

Figure A5. Velocity histories for the EEVC impact.

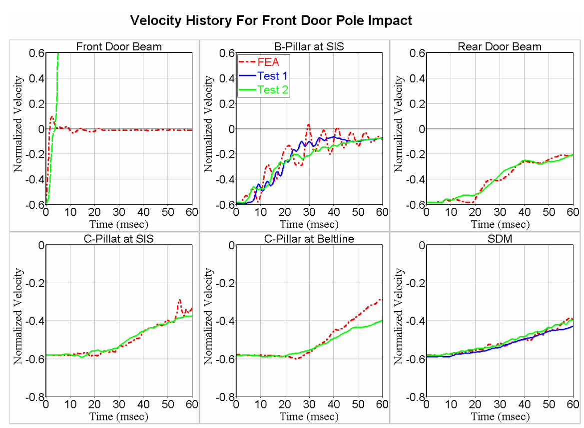

Figure A6. Velocity histories for the front door pole impact.

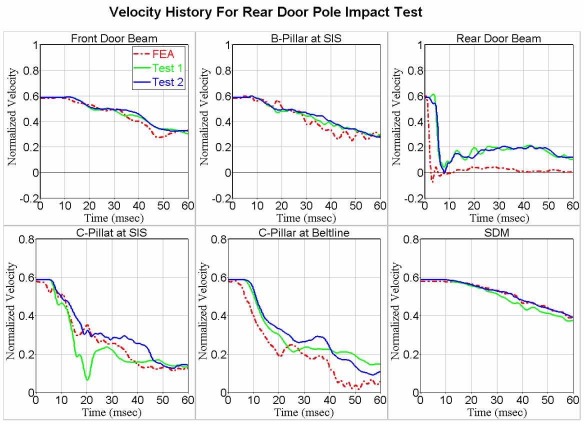

Figure A7. Velocity histories for the rear door pole impact.