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Integrated Seat Belt System Model Development

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16. Abstract

The National Highway Traffic Safety Administration (NHTSA) awarded a contract to select, acquire, tear down, test, and develop an LS-Dyna finite element (FE) model of a production automotive seat with an integrated seat belt (ISS). The results from this task order are the FE models of a 2019 Honda Odyssey second row seat. Static testing was conducted to validate the seat model. Dynamic sled tests were conducted using THOR-50M and BioRID-II anthropomorphic test devices (ATDs), each representing a 50th percentile male occupant.

The objective of this task order was to develop an FE model representing a seat with integrated seat belts from a recent model passenger vehicle. Static tests were conducted to evaluate seat deformation and potential failure mechanisms. Dynamic tests with appropriate ATDs were conducted to evaluate occupant kinematics and injury in high-severity front and rear impact crashes. All test data, along with seat tear down measurements and component testing, factored into the development and validation of the FE model. The data from these tests were used to validate the seat model. The requirements of this task order are:

1. The FE seat model demonstrates correlation with quasi-static rearward pull and forward pull test results. The kinematics of deformation and the result curves matched reasonably well.
2. The seat models were developed using LS-DYNA simulation code incorporating detailed FE modeling of components and assembly, such as:
    - Seat bottom and back frames
    - Seat track mechanism
    - Recliner mechanism
    - Seat bottom and back cushions
3. Representation of thickness and material properties of all seat components.
4. Dynamic tests with appropriate ATDs will be conducted to evaluate occupant kinematics and injury in high-severity front and rear impact crashes.
5. Perform five additional sled tests to evaluate the seat model in frontal and rear impacts with two different reclined seating angles.

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1 Executive Summary

The National Highway Traffic Safety Administration awarded a contract to select, acquire, tear down, test, and develop an LS-Dyna finite element (FE) model of a production automotive seat with an integrated seat belt (ISS). The results from this task order are the FE models of a 2019 Honda Odyssey second row seat. Static testing was conducted to validate the seat model. Dynamic sled tests were conducted using THOR-50M and BioRID-II anthropomorphic test devices (ATDs), each representing a 50th percentile male occupant.

The objective of this task order was to develop an FE model representing a seat with integrated seat belts from a recent model passenger vehicle. Static tests were conducted to evaluate seat deformation and potential failure mechanisms. Dynamic tests with appropriate ATDs were conducted to evaluate occupant kinematics and injury in high-severity front- and rear-impact crashes. All test data**,** along with seat tear down measurements and component testing, factored into the development and validation of the FE model. The data from these tests were used to validate the seat model. The requirements of this task order are as follows:

1. The FE seat model demonstrates correlation with quasi-static rearward pull and forward pull test results. The kinematics of deformation and the result curves matched reasonably well.
2. The seat models were developed using LS-DYNA simulation code incorporating detailed FE modeling of components and assembly, such as:
    - Seat bottom and back frames,
    - Seat track mechanism,
    - Recliner mechanism, and
    - Seat bottom and back cushions.
3. Representation of thickness and material properties of all seat components.
4. Dynamic tests with appropriate ATDs will be conducted to evaluate occupant kinematics and injury in high-severity front and rear-impact crashes.
5. Perform five additional sled tests to evaluate the seat model in frontal and rear impacts with two different reclined seating angles.

The FE model was developed using LS-DYNA software and dynamic crash simulations using appropriate ATD models. Static and dynamic testing was conducted to support validation of the resulting finite element model. The resulting FE model will be made publicly available upon completion of this task order.

2 Introduction and Scope of Work

2.1 Introduction

NHTSA proposed this study because autonomous vehicles are the near-future for the automotive industry. Autonomous vehicles open up the possibility of using ISS seats to allow drivers and occupants the option to ride in different recline and seat position orientations. NHTSA proposed this study to develop a detailed FEA model of an ISS seat for use in studies on autonomous vehicles. This study also explores and reviews the ATD responses for generic seat back angles.

The seat selection methodology criteria discussed in this report concluded in selection of the 2019 Honda Odyssey seat. The validated seat models were used to study the results of injury criteria for both the test procedures (FMVSS No. 208, Occupant crash protection Injury, and FMVSS No. 301, Fuel system integrity).

2.2 Program Tasks Summary

The objectives of this Task Order are as follows:

- Conduct an informal market survey to identify current production seats with an ISS that could be used for this study. Select an appropriate production vehicle seat for this model development task.
- Develop a test plan for static and dynamic testing of the selected seats and their constituent materials. The test plan shall include both static and dynamics testing for frontal- and rear-impact strength.
- Develop a baseline seat model using LS-DYNA finite element code and validate the model against static test results. Seat the appropriate ATD models and validate the models against the dynamic test results.
- The project objectives also include optional tasks of conducting sled tests for five different seat angles and update the report with test results and corresponding FE model updates.
- Deliver FE models of ISS seat.
    - LS-Dyna format
- Deliver test results and detailed report of destructive (static pull) and sled tests (dynamic impact) including videos, photographs, and raw data.
- Detailed project report including model development, test results correlation, FE analysis results such as seat deformation, occupant injury assessment.
    - CAE simulation animation videos with FE dummies.
    - Pictures and plots of occupant acceleration, injury criterion, etc.
    - Comparison of tests and simulations.

2.3 Program Test Matrix Summary

The test matrix below shows the load cases performed on the ISS seat.

Table 1: Load Case Summary

ISS Seat Performed Loadcases						
Sl No	**Load Case**	**Seat Back Angle(degrees)**	**ATD used**	**Load/Pulse/Speed**	**Physical Test**	**FE Simulation**
PHASE1 (FE Model Correlation Purpose)						
1	Forward Pull - Quasi Static	18	None	1335-13350 N (0 to 29 secs) - Torso & Lap Blocks 605-6050 N (o to 40 secs) - CG Bar	Done	Done
2	Rearward Pull - Quasi Static	18	None	93-935 N (0 to 5 secs)	Done	Done
3	FMVSS 301 - Rear Sled	18	BioRID	20g, 27kph	Done	Done
PHASE2 (FE Model Comparsion Purpose)						
4	FMVSS 301 - Rear Sled	18	THOR	20g, 27kph	Done	Done
5	FMVSS 301 - Rear Sled	45	THOR	20g, 27kph	Done	Done
6	Frontal Sled	18	THOR	28g, 40kph	Done	Done
7	Frontal Sled	45	THOR	28g, 40kph	Done	Done
8	Frontal Sled	18	THOR	38g, 56kph	Done	Done

2.4 Project Plan

The contractor developed a technical plan in phases for the acquisition, measurement, testing, model development, and validation of the selected seating system. The technical plan includes discussion of vehicle seat selection criteria, seat teardown, measurement procedures, material testing, static, dynamic test methods, model development, simulation, kinematic, and safety performance measures.

Phase 1 includes the acquisition, measurement, and testing of the ISS seat and FE seat model development to demonstrate acceptable correlation with quasi-static (rearward and forward pull) and rear-impact sled test with the BioRID-II dummy.

Phase 2 includes a test plan for five additional sled tests to evaluate forward and rear impacts at two different seats recline angles, using the THOR-50M dummy. The seat model from Phase1 was used to conduct simulations. The FE models were used to represent the additional sled tests and compare the results for further studies.

3 PHASE 1 – Baseline Seat Simulation

This section of the report explains the baseline FEA seat model validation and test simulations. The objective of this seat simulation was to compare the FE simulation results with data from the physical test and determine whether the FE seat model is a satisfactory representation of the physical seat.

3.1 Baseline Seat Choice

To aid in the selection of suitable seats, A2Mac1, the European automotive benchmark database,[1] was used. The selected seat for this task order was the 2019 Honda Odyssey second-row seat with ISS. The advantages of the Honda Odyssey were cost and availability of a complete assembled seat frame as a single part requiring limited assembly by the OEM parts department.

The seat quantities required for the project were as follows:

Phase 1

1. Two second-row seats without cushions and plastic trims, manual adjustable.
2. Two second-row seats fully trimmed, with cushions and standard leather trim, manual adjustable.

Phase 2

1. Five second-row seats fully trimmed, with cushions and standard leather trim, manual adjustable.

Figure 1 shows seat assemblies purchased for testing and modeling purpose.

Figure 1. Seat Assembly

[1] A2Mac1 – Automotive Benchmarking, headquartered in Hary, France. https://portal.a2mac1.com/benchmarking-database/.

Seat assemblies 1 and 2 were used for seat back pull test and forward pull test. Seat assemblies 3 and 4 were used for FMVSS No. 301 rear-impact and frontal-impact sled tests.

3.2 Baseline Seat Quasi Static Tests

To develop a detailed seat model, the seat model was validated with physical test results. The overall seat was chosen as validation criteria to compare the FE seat model with physical test. The seat frame was used for the rearward pull and forward seat pull tests. The test was conducted with a similar loading method to that stated in FMVSS No. 207, Rearward pull, and FMVSS No. 210, Forward pull,[2] but the loads were applied until the seats collapsed.

For the rearward pull, the load was applied at the uppermost seatback as shown in Figure 2.

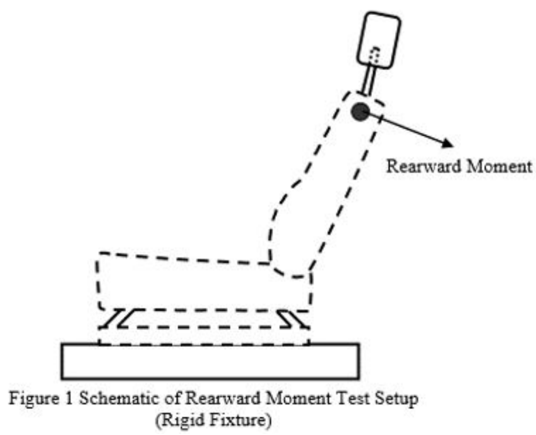

Figure 2. Schematic Diagram of the Seat Back Pull Loading

Fixturing of the sample consisted of attaching the sample to the fixture and then bolting the fixture to a T-slot plate. The weight and center of gravity dimensions were determined prior to testing. Production webbing was replaced with high strength webbing. Angle transducers were mounted to the seatback on each side for data purposes only. The rear seat mounts were welded directly to the fixture.

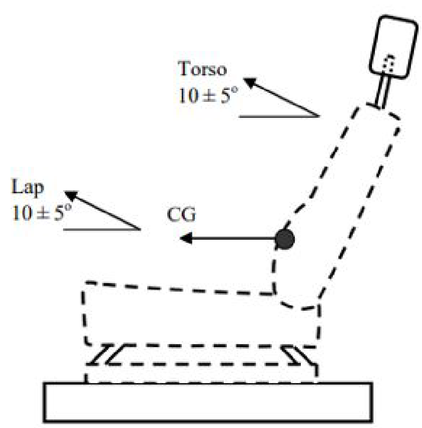

Figure 3. Schematic Diagram of the Seat Forward Pull Loading

[2] 49 CFR 571.207, S4.

3.2.1 Seat Rearward Pull Test

This test was conducted on the Honda Odyssey second-row seat without cushions and plastic trim in a quasi-static loading condition. The following load profile shown in Table 2 was used to pull the seat back. The necessary seat fixtures were fabricated to mount the seat using four seat bolts at the four corners of the seat base.

Table 2: Seat Back Pull Test Load Profile

Load Profile	
Time(s)	**Load (N)**
0	93
5	935
11	935
124	20,000

The seat back pull test setup of the seat is shown in Figure 4, and the test position of the seat is given in Table 3.

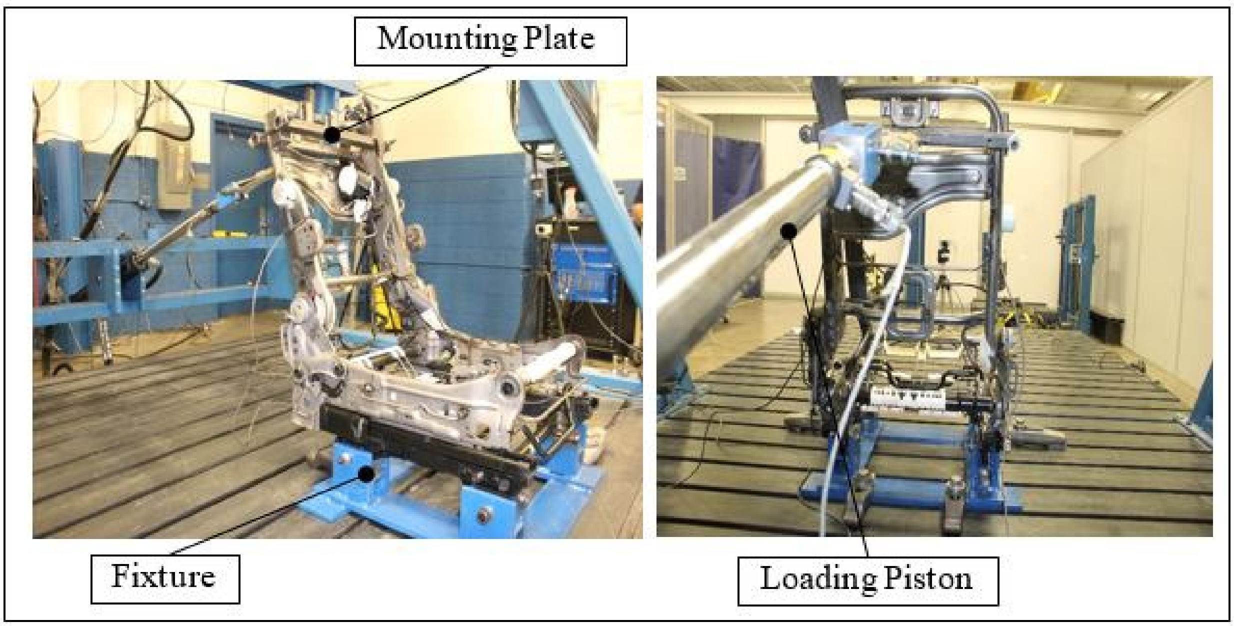

Figure 4. Seat Back Pull Test Seat Setup

Table 3: Seat Back Pull Test Seat Position

Seat Type: 2nd Row 4WM Seat(1st Row Driver Surrogate)	
Seat Function	**Test Position**
Track Position	Full Rearward
Vertical Position	N/A
Seat Back Angle (Measured at: Seat back)	18° (1st lock) (measured as 17°)
H-Point	228 mm above rear striker bolt
Moment Arm	399 mm
Temperature	73°F
Humidity	32%

The load was applied at the mounting plate on the top of the seat back frame in the rearward direction. A pull load was applied in the rearward direction from 93 N (newtons) at 0 seconds to 935 N at 5 seconds, and then the load was maintained for the next 6 seconds per the FMVSS No. 207 quasi static seat back strength test. The intent of this study was to observe the seat back strength for the maximum seat back rotation that might cause injury to the rear seat passenger by contact with the seat back. Therefore, after 11 seconds the pull load was increased further, until the seat back collapsed. It was found that the seat collapsed at 17,000 N. Images of deformed seat frames after the seat back pull test are shown in Figure 5 and Figure 6.

Figure 5. Seat Back Pull Test – Post-Test

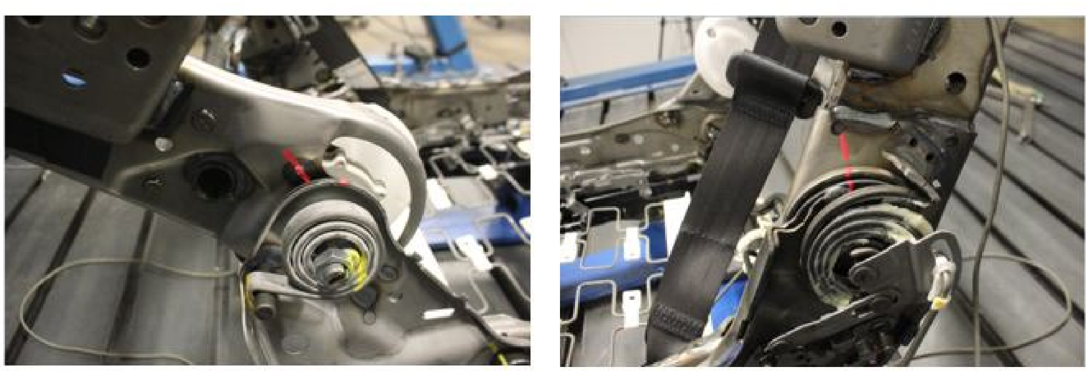

Figure 6. Seat Back Pull Test, Post-Test, Recliner Deformation

From the test results, we can observe that until 8 seconds there is no deformation or failure in the seat frame. After the test, significant deformation has been observed on the side frame parts, right recliner bracket and back tube. Also, right-hand side (RHS) seat frame deformed higher than the left-hand side (LHS) seat frame. There was significant amount of deformation observed on the recliner mechanism.

3.2.2 Forward Pull Test

Similar to the seat back pull, the test forward pull test was conducted on the Honda Odyssey second-row seat without cushions and plastic trim in the quasi-static loading condition. The following load profile shown in Table 4 is used to pull the seat back. The necessary seat fixtures were fabricated to mount the seat at four seat bolts, the same as done for the manual seat.

Table 4: Seat Forward Pull Test Load Profile

Load Profile			
Time (second)	Torso Load (N)	Lap Load (N)	CG Load (N)
0	1,335	1,335	605
29	13,350	13,350	6,050
40	13,350	13,350	6,050
80	30,000	30,000	13,560

The seat track was welded to the fixture to secure the seat coming off from the fixture. The seat forward pull test setup is shown in Figure 7.

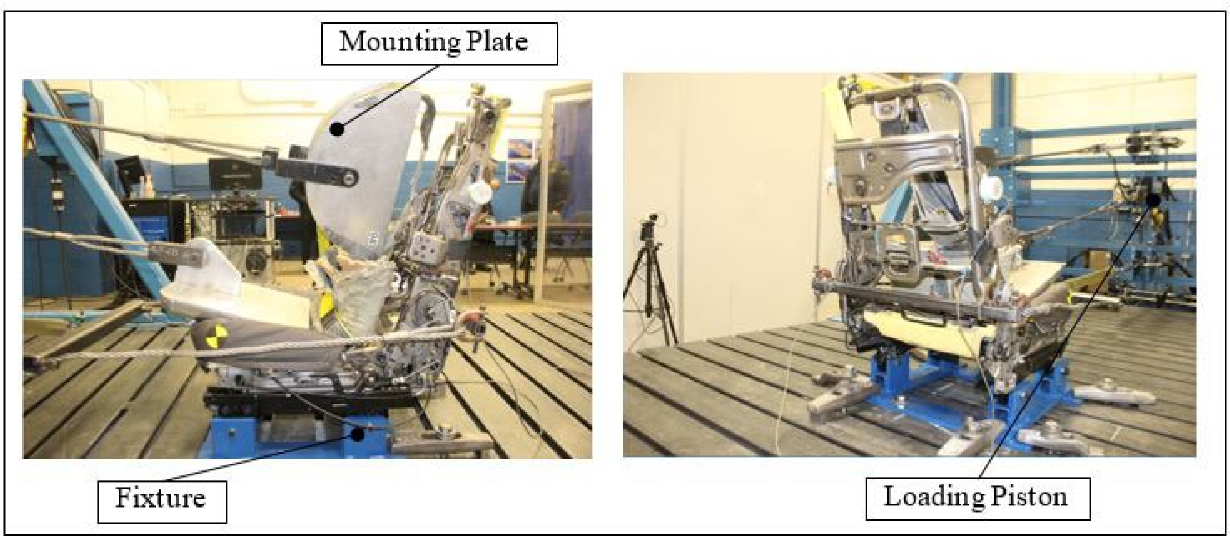

Figure 7. Seat Forward Pull Test, Pre-Test

The pull load was applied on the torso block, lap block, and CG bar in the forward direction with respective angles. For the torso and lap loading blocks started from 1,335 N (at 0 seconds) to 13,350 N (at 29 seconds), and then the load was maintained for 40 seconds after which the load was increased further until the seat frame collapsed. Similarly, for the CG bar the load started from 605 N (at 0 seconds) to 6,050 N (at 29 seconds), and then the load was maintained for 40 seconds after which the load was increased further until the seat frame collapsed.

Images of the deformed seat frames after the seat back pull test are shown in Figure 8 and Figure 9.

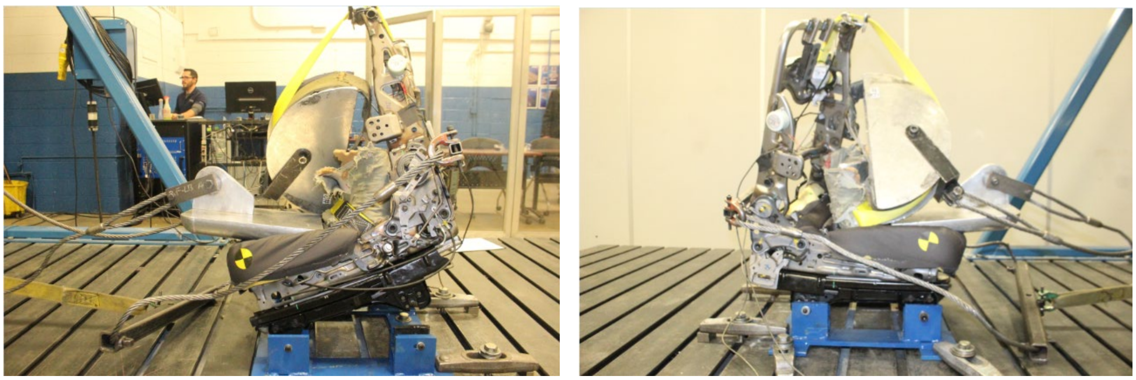

Figure 8. Seat Forward Pull Test, Post-Test

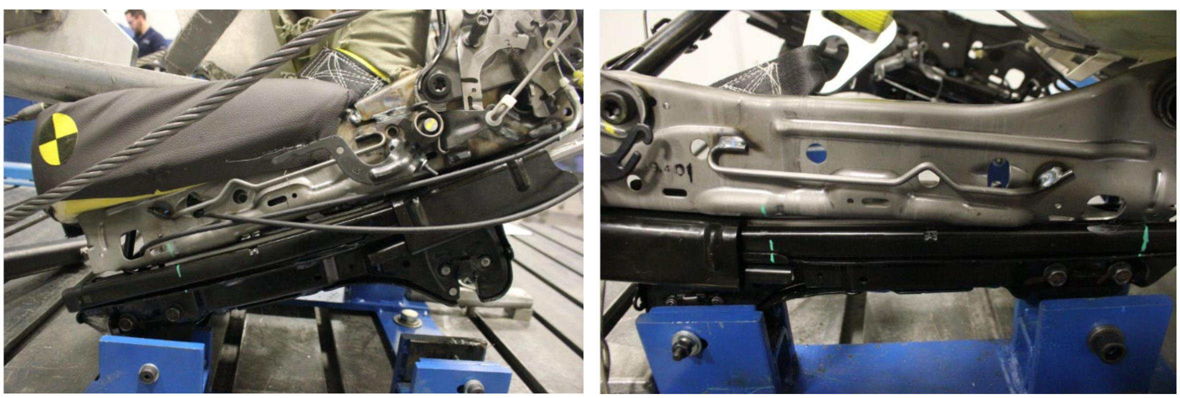

Figure 9. Seat Forward Pull Test, Post-Test, Seat Back Frame Deformation

There was no deformation or failures seen until 11 seconds. After the test, significant deformation was observed on the side frame parts and right recliner bracket. Also, there were no failures or deformation observed on the recliner mechanism.

3.2.3 Seat FE Model Development

The seat belt integrated seat models (in terms of design and assembling) were scanned and exported to stereolithographic digital format readable in computer aided design (CAD) tools. The thicknesses of the parts were recorded using vernier calipers. The material grades were estimated based on a hardness test. The scanned CAD data of the seat frame with cushion are shown in Figure 10.

Figure 10. Scanned Seat Models

The different parts from CAD data were then meshed in commercially available FE modeling tools. Most of the seat structure were made of stampings and tubes and modeled using shell elements. The latches, strikers, and seat cushions were modeled as solid elements. The recliner pivot joint is simulated by beam elements. Detailed seat models are shown in Figure 11.

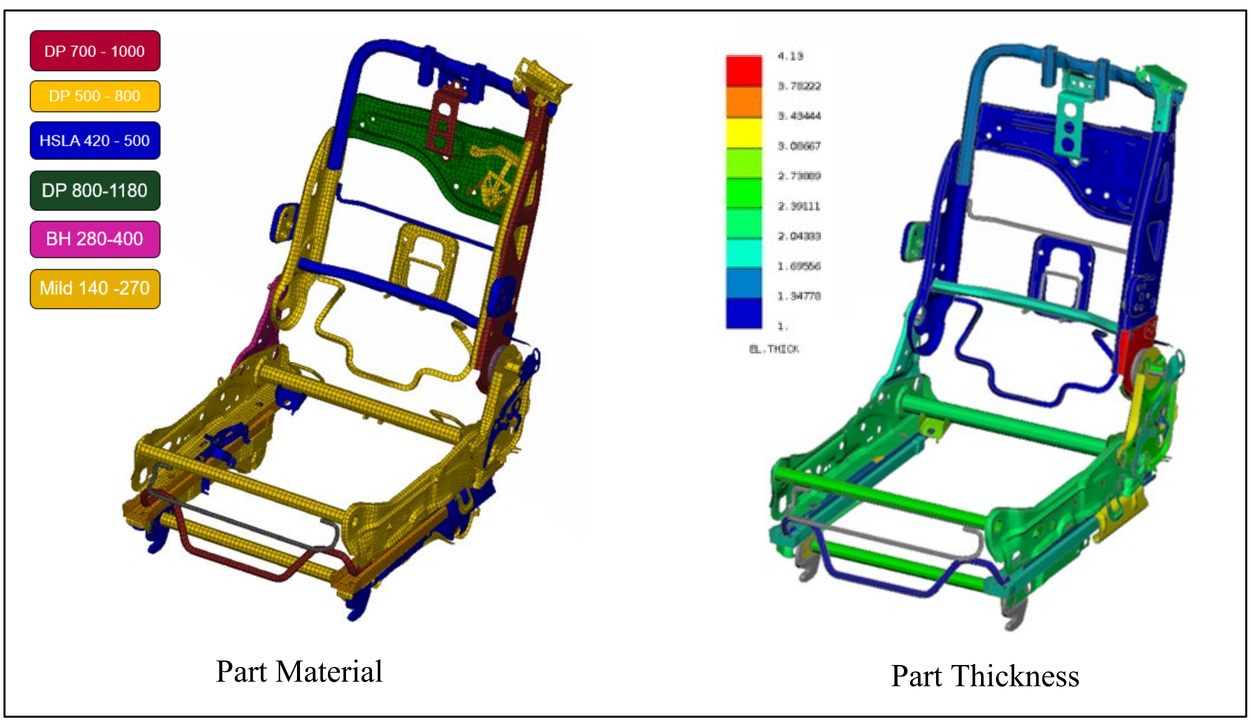

Figure 11. FE Model (Thickness and Material Information)

3.2.4 Seat Back Pull Test Correlation

The seat FE model was set up by positioning the seat to the full rear position. The seat back was rotated to 18 degrees rearward with respect to vertical plane. A rigid mounting plate was modeled and attached on the uppermost seatback member similar to the physical test. The load profile in terms of load curve (force versus time) was applied at the centre of the mounting plate at 90° angle with respect to the seat back. It was noted from the test that as the loading piston pulls the seat back rearward, the concentrated force rotates about global Y-axis at the point of application of load. The load was applied in the direction matching the loading piston displacement from the test. A local coordinate system was included in the model, at the centroid of the mounting plate to measure the seat back displacement along the loading direction. The load application and boundary conditions are shown in Figure 12 and Figure 13.

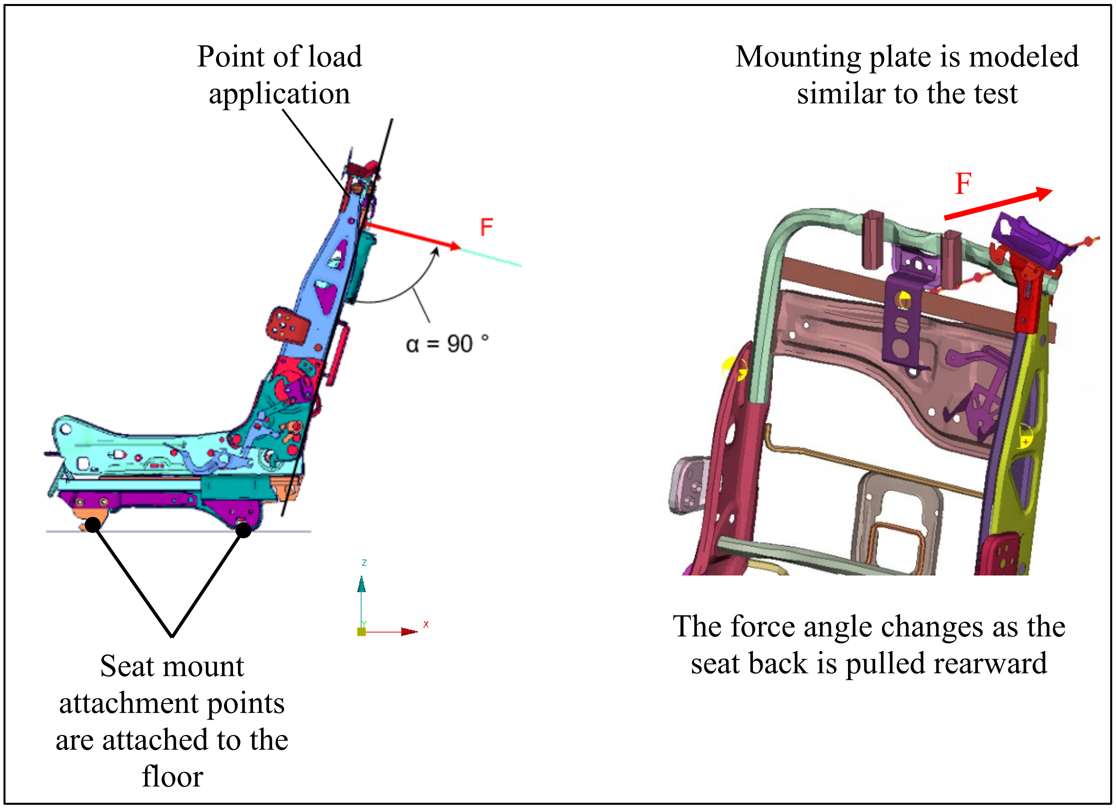

Figure 12. FE Model Setup, Loading, and Boundary Conditions

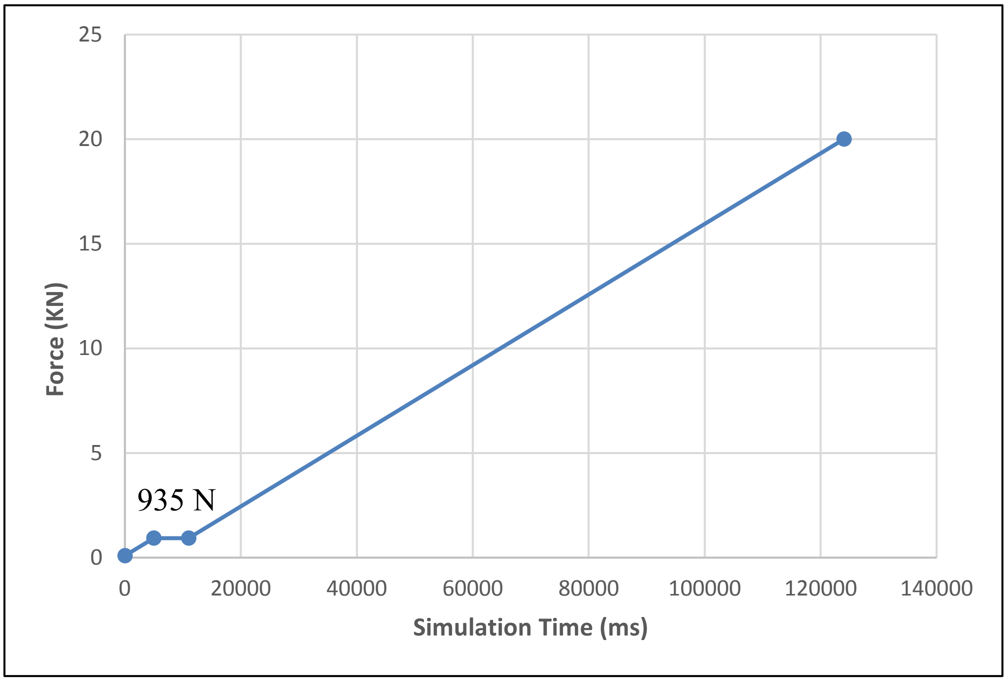

Figure 13. Loading Curve ─ Rearward Pull

A LS-DYNA simulation was run (LS-DYNA solver option to run quasi-static simulations) for 80 milliseconds. It should be noted that the material properties of FE parts were assumed with 0-strain rate stress-strain curve to run in quasi-static condition. FE simulation results of the seat back pull test were compared with the physical test. Figure 14 shows the comparison of FE model setup and test setup.

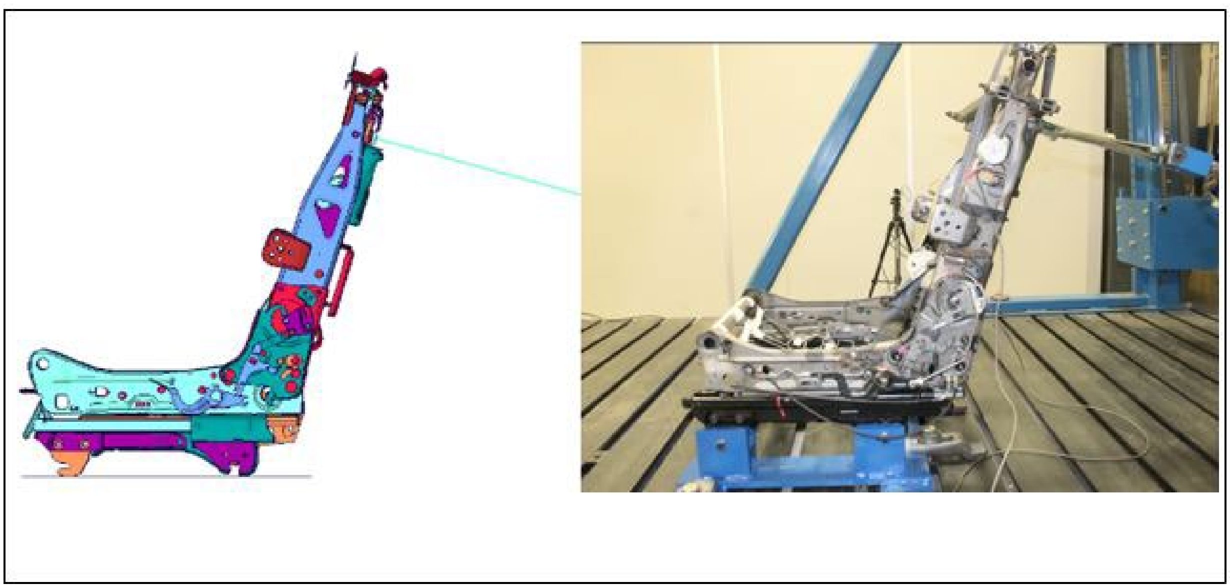

Figure 14. Model Setup Test Versus FEA

Figures 15, 16, and 17 show the deformation of the collapsed seat structure.

Figure 15. Global Deformation of the Seat Frame

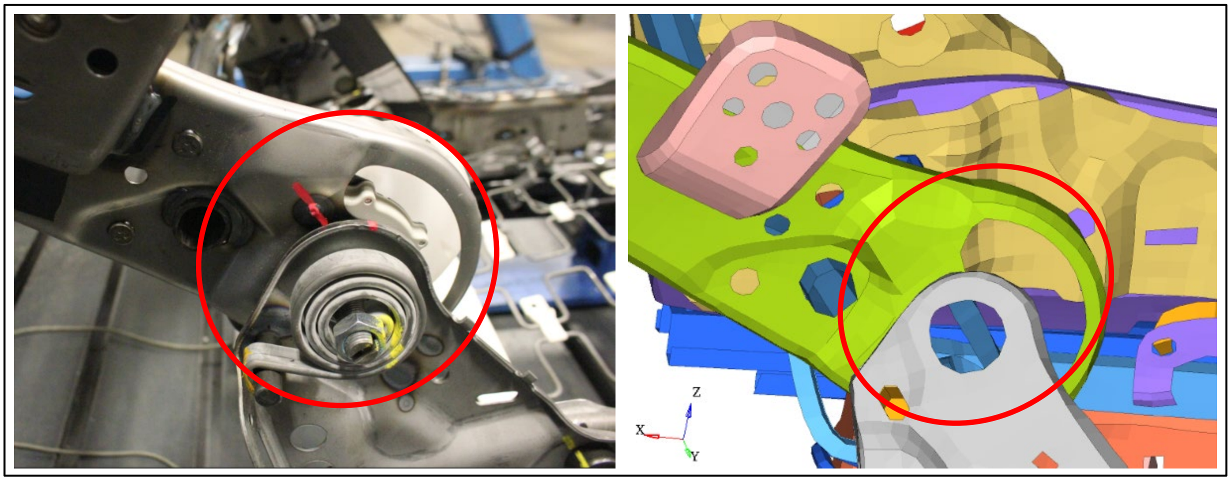

Figure 16. Similar Deformation of RHS Recliner Mechanism Test Versus FEA

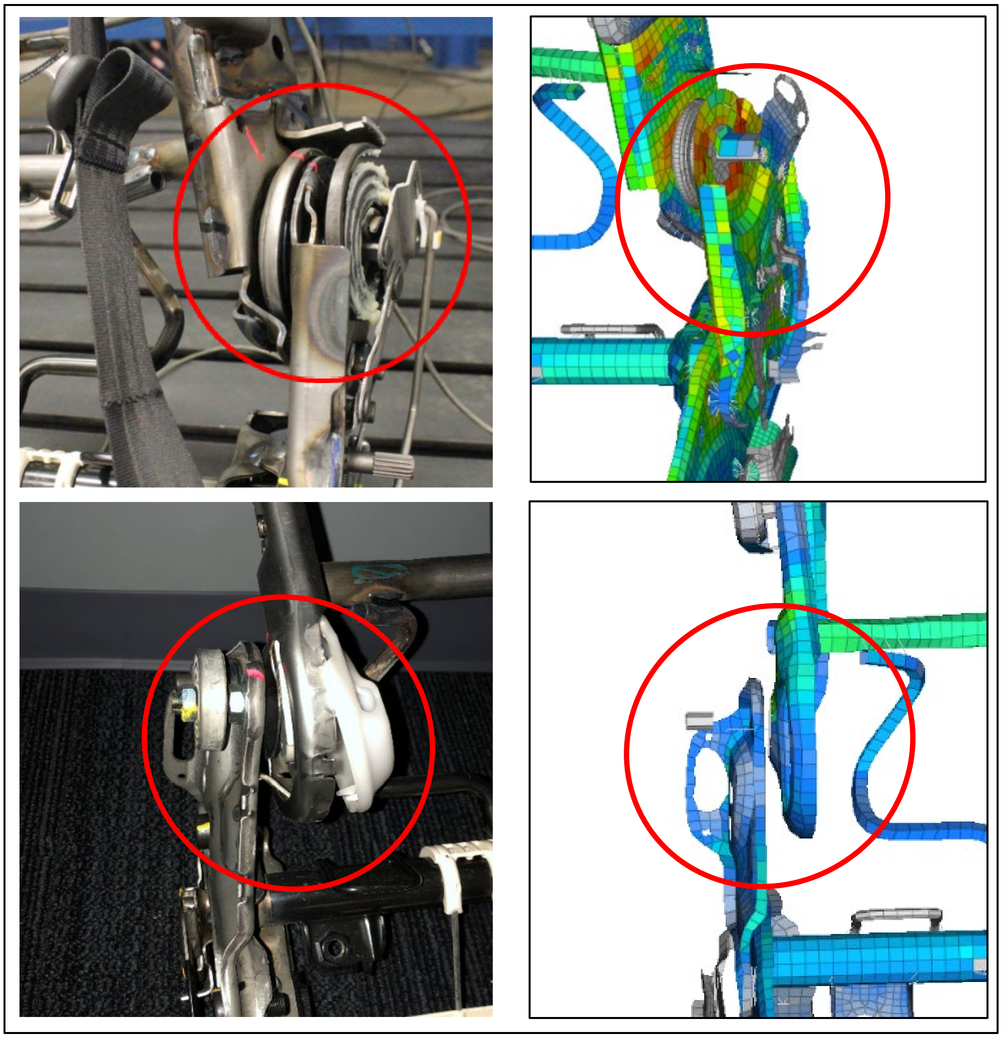

Figure 17. Seat Deformation at Failure Area Similar to Test

The seat back frame parts and the side tube have shown deformation in both Test and FEA. In addition to the frame deformation, the seat back strength was compared in terms of stiffness using force versus displacement (FD) plots. The displacement of the seat back, which represents the piston displacement in the physical test, was measured and plotted against the applied load profile. The comparison of FD curves from the FE simulation with the physical test data is shown in Figure 18.

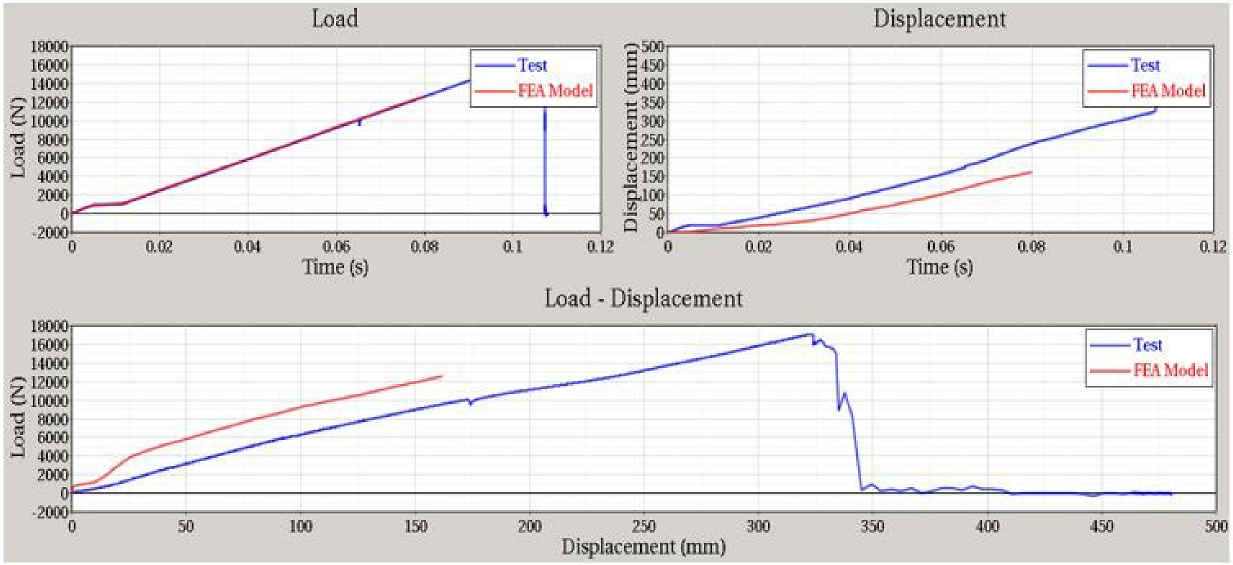

Figure 18. Force Versus Displacement Curves

A commercially available curve comparison tool called CORA[3] compared the CAE and test FD curves. The FD curve shows a correlation rating of about 82 percent, which is a generally acceptable rating for such curves as good correlation.

From the above comparisons of result curves, it shows that the ISS seat correlated closely enough with the physical test. This shows that FE seat was modeled with acceptable detail and accuracy in this test condition.

3.2.5 Seat Forward Pull Test Correlation

The seat FE model was set up by positioning the seat to the full rear position by adjusting the seat position mechanism. The seat back was rotated to 18 degrees rearward with respect to the vertical plane. Forward pull (FMVSS No.210) analysis consists of body blocks, which are modeled using shell elements, and a rigid material property. The part of the seat belt that wraps around the body blocks (forward pull) and the dummy (sled simulation) was modeled using 2-D shell elements, and the rest of the seat belt was modeled using 1-D seat belt elements. Pull chains were also modeled as 1-D elements. The load profile (force versus time) was applied to the pull chain similar to the cylinder load in the test. The loading curves used are shown in Figure 19.

[3] Partnership for Dummy Technology and Biomechanics. (n.d.) CORA [**COR**relation and **A**nalysis], Release 3.6 Users Manual. Gaimersheim, Germany. CORA 3.6.1 has a release date of October 2, 2012. CORAplus 4.0.4 has a release date of June 21, 2017.

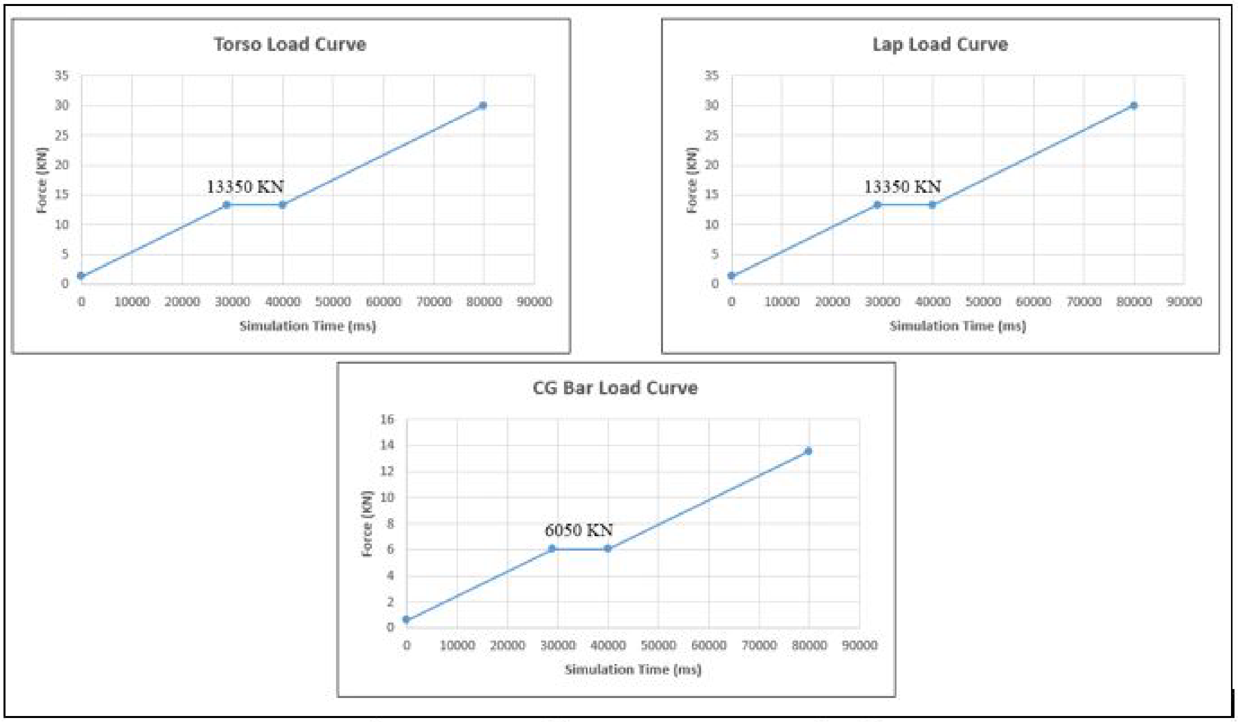

Figure 19. Loading Curve – Forward Pull

FE simulation results of the seat forward pull test were compared with the physical test. Figure 20 shows the comparison of the deformed shape of the seat.

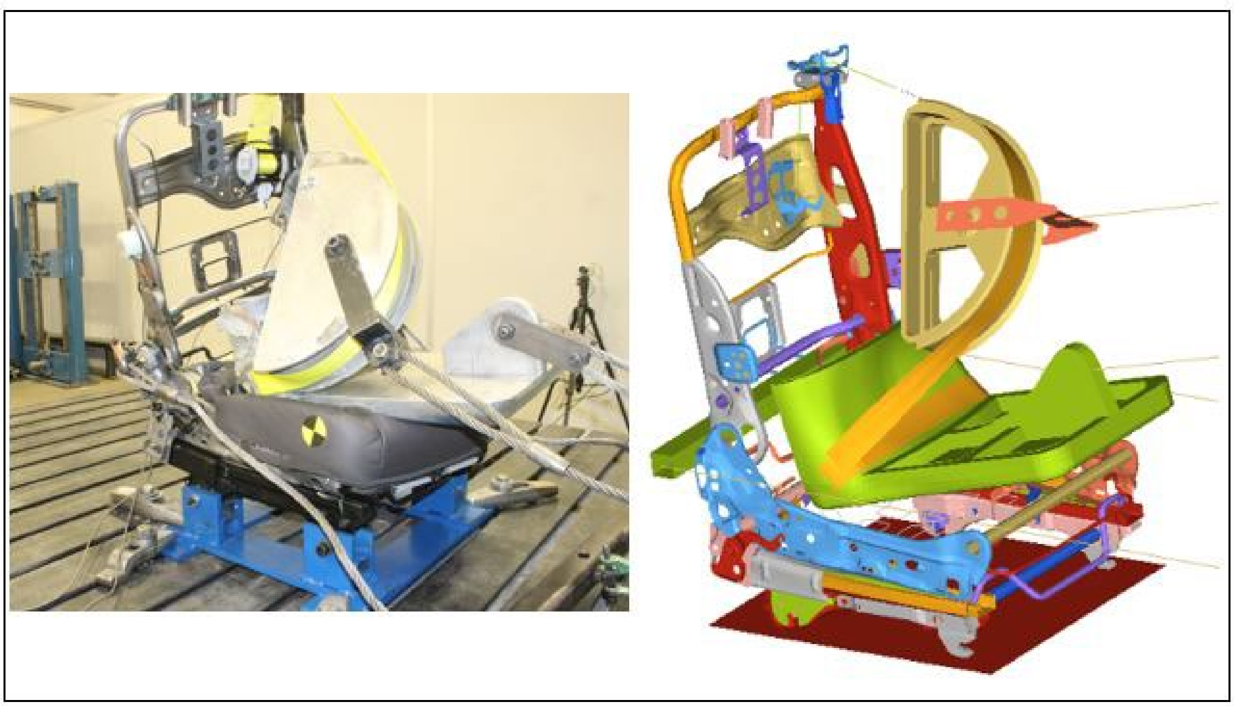

Figure 20. Deformation of RHS Seat – Test Versus FEA

Figures 21, 22, and 23 show the deformation of the collapsed seat structure.

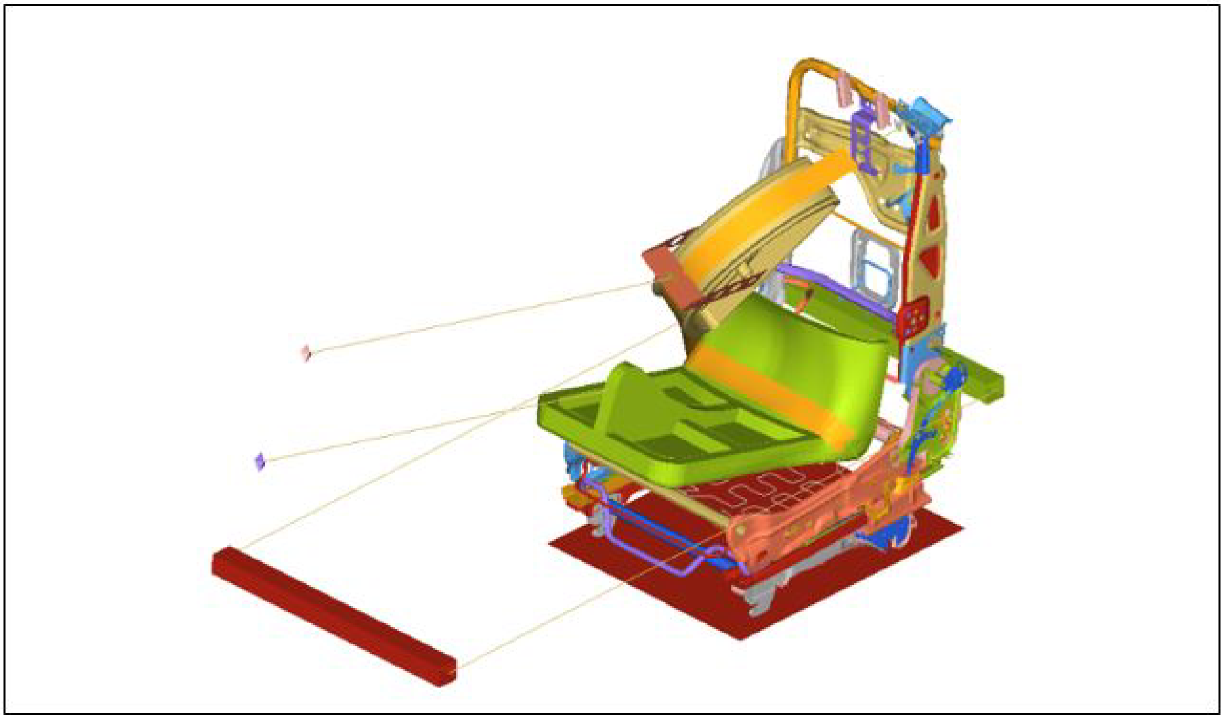

Figure 21. Global Deformation of the Seat Frame

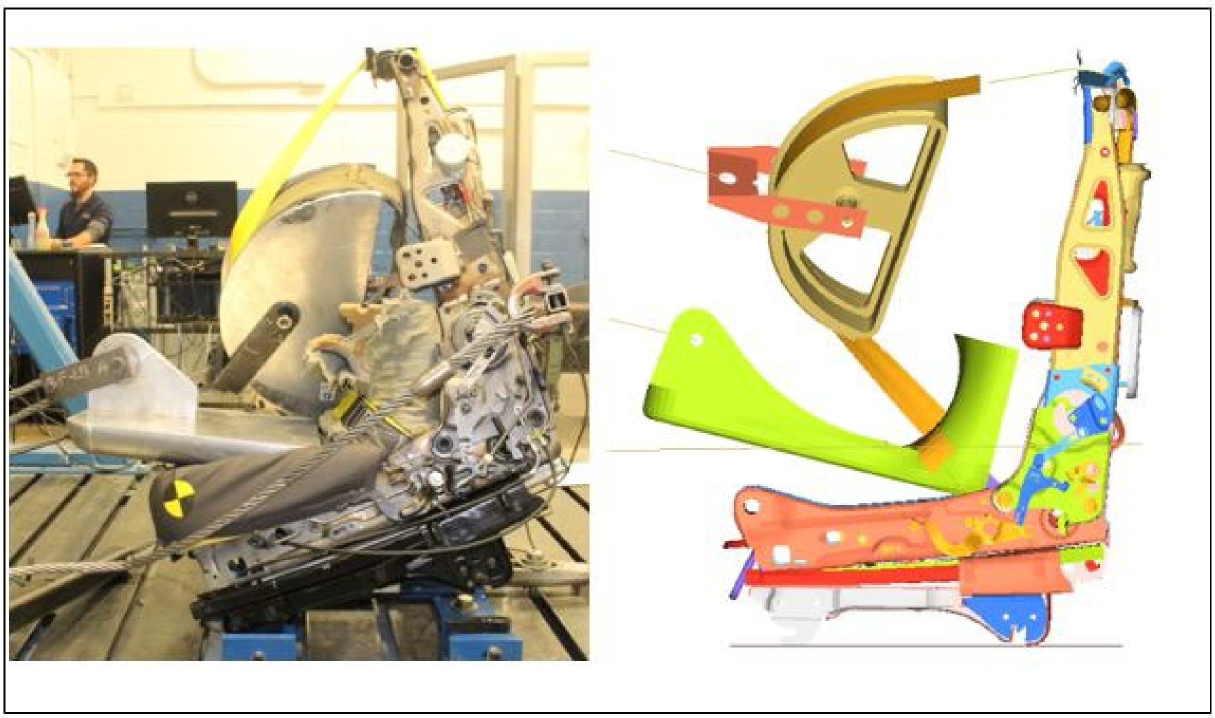

Figure 22. Deformation of LHS Seat – Test Versus FEA

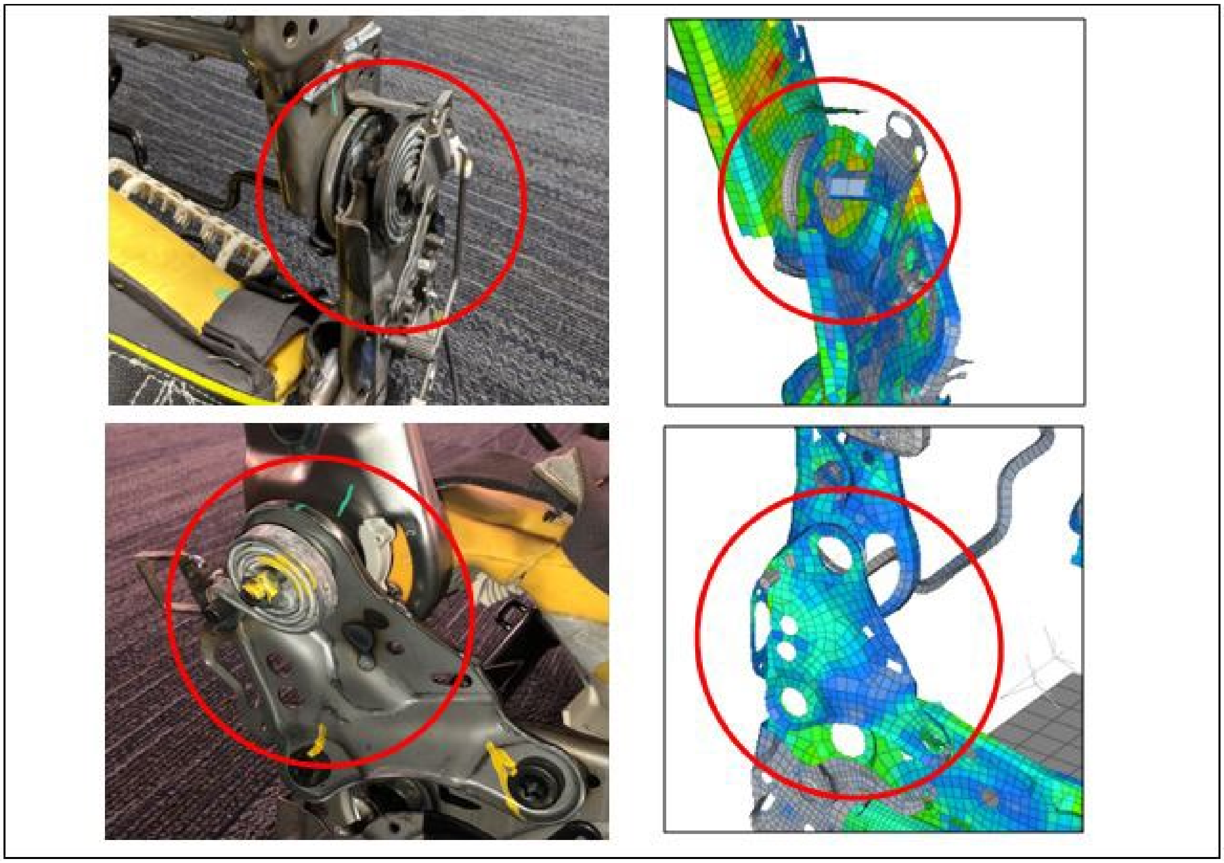

Figure 23. Seat Deformation at Failure Area Similar to Test

In addition to the frame deformation, the seat back strength was compared in terms of force versus time and displacement versus time plots. The displacement of the seat back, which represents the piston displacement in the physical test was measured and plotted. The comparison of force and displacement curves of FE simulation and physical test are shown in Figures 24, 25, and 26 for torso, lap, and CG bar, respectively.

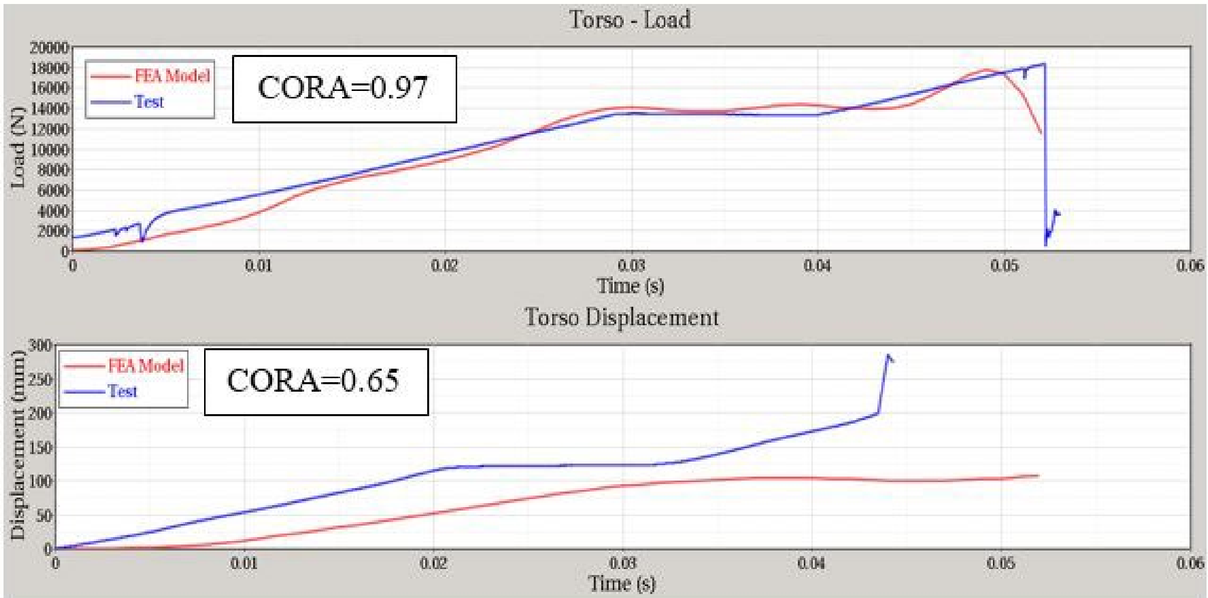

Figure 24. Force and Displacement Curves – Torso Block

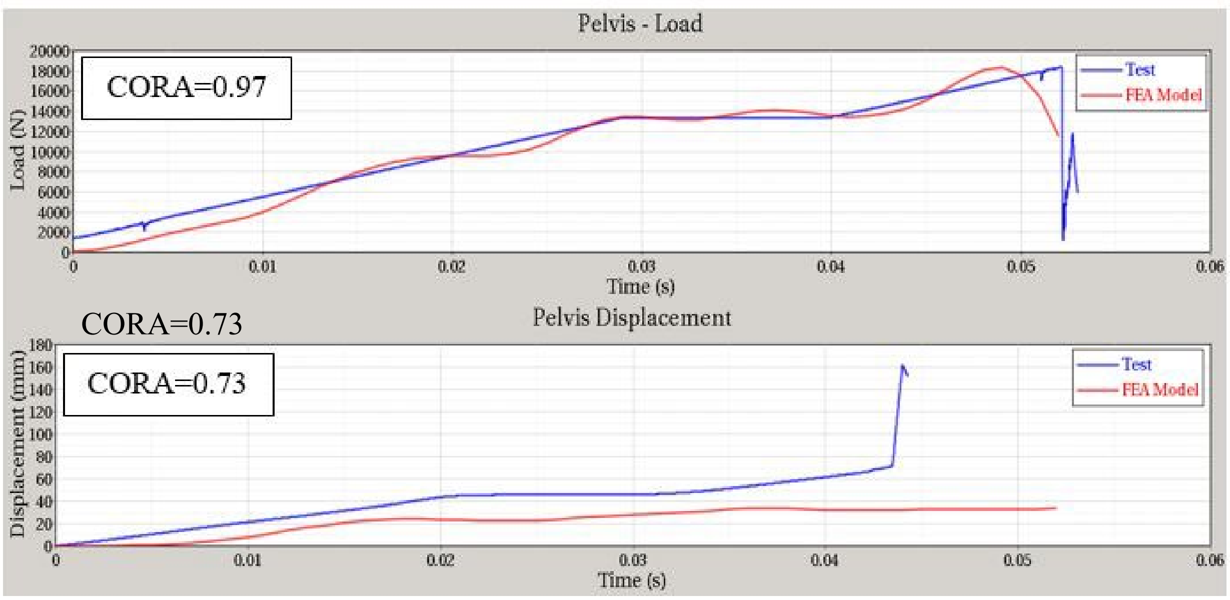

Figure 25. Force and Displacement Curves – Lap Block

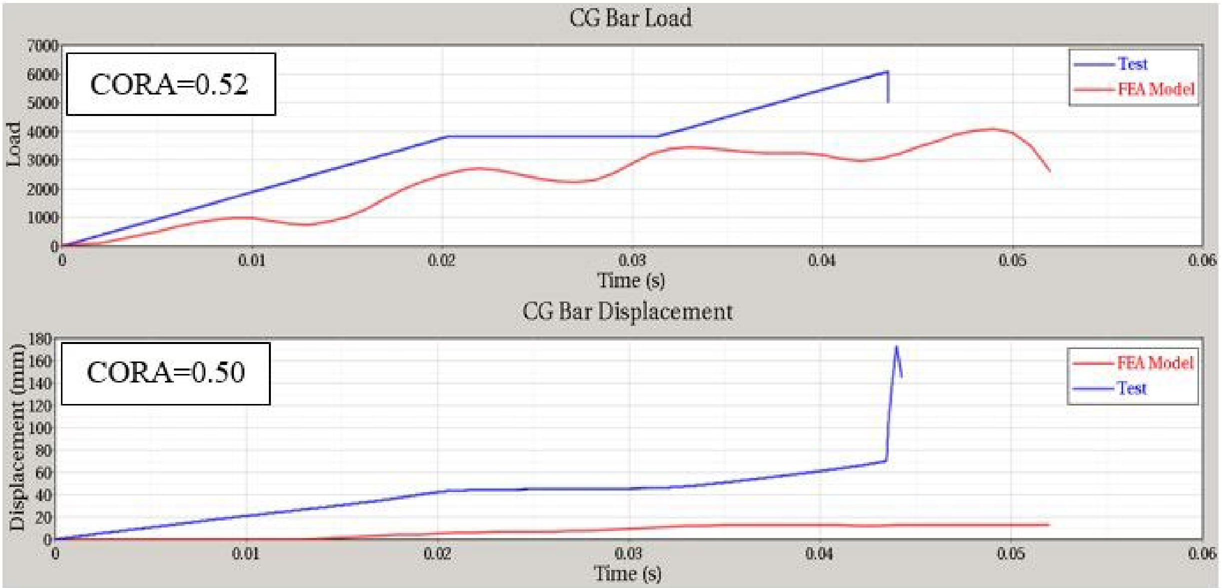

Figure 26. Force and Displacement Curves – CG Bar

The CORA[4] tool was used to compare the CAE and test curves. The force and displacement curves for torso and lap blocks, CG bar shows an average correlation rating of about 72 percent, which is a generally acceptable rating for such curves as good correlation.

From the above comparisons of frame deformation and stiffness, it can be concluded that the seat correlates well with the physical test. Thus, the FE seat was modeled with acceptable detail and accuracy.

[4] Partnership for Dummy Technology and Biomechanics. (n.d.).

4 FMVSS No. 301 High-Speed Rear-Impact Sled Test

The objective of this test is to study the occupant kinematics and injury in high-speed FMVSS No. 301 rear-impact scenario. The FMVSS No. 301 rear-impact test subjects the vehicle to rear impact by a moving deformable barrier (MDB) at 55 mph with 70 percent offset. This test generates similar acceleration pulse of the vehicle. The FE model of the correlated ISS seat was used for this simulation. To evaluate the occupant kinematics and injury, the FMVSS No. 301 test was conducted with a physical sled and BioRID-II positioned on the seat.

The contractor sub-contracted the testing to conduct the rear-impact sled test for the ISS seat. The necessary vehicle pulse was computed by running the FMVSS No. 301 Rear-Impact simulation using a MY2014 Honda Accord Structural Model. The rear-impact vehicle pulse is shown in Figure 27.

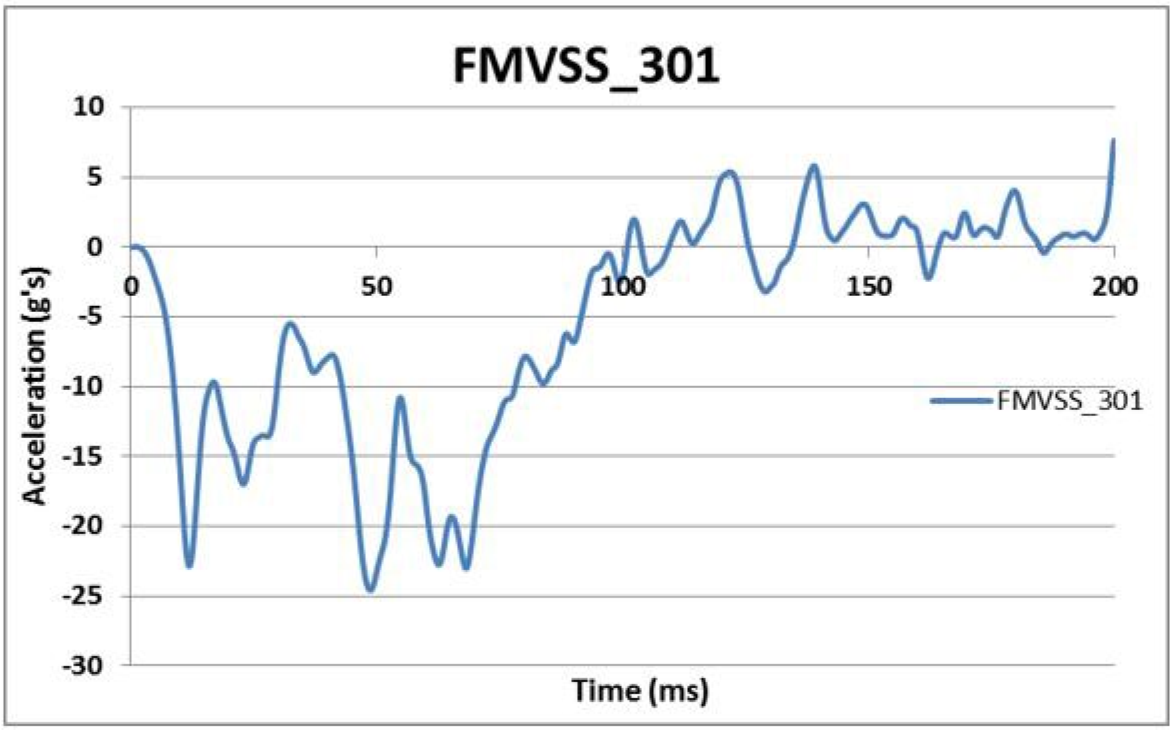

Figure 27. FMVSS No. 301 Rear-Impact Vehicle Pulse (CAE Simulation)

The BioRID-II rear-impact dummy was used in the sled test provided by NHTSA. The rear-impact dummy was calibrated with necessary channels. Considering the BioRID-II dummy loading capacity is limited to a rear-impact speed of 17 mph, the vehicle pulse was tuned to approximately 20 G. The vehicle pulse was calculated based on the FMVSS No. 301 rear-impact test obtained from the CAE simulation (shown in Figure 27). The generic vehicle pulse used in the sled test is shown in Figure 28.

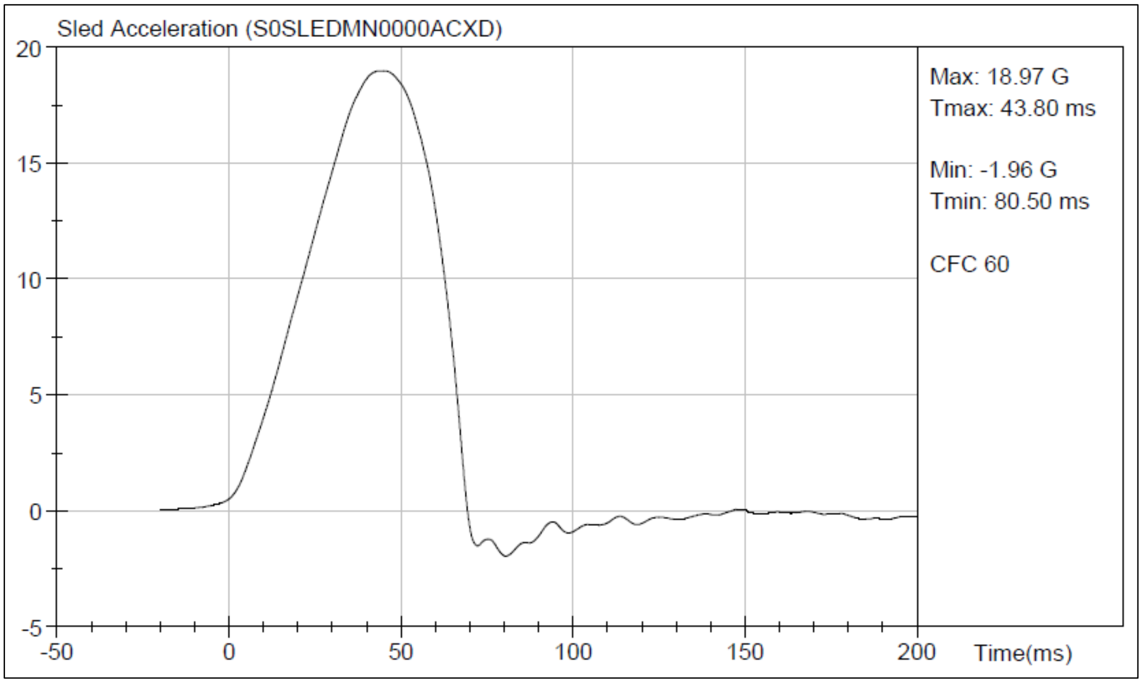

Figure 28. FMVSS No. 301 Sled Pulse (Generic, 20 G Pulse)

The seat track was welded to the fixture to prevent the seat off from the fixture. The FMVSS No. 301 rear-impact sled test setup for the fully trimmed integrated seat belt system seat is shown in Figure 29.

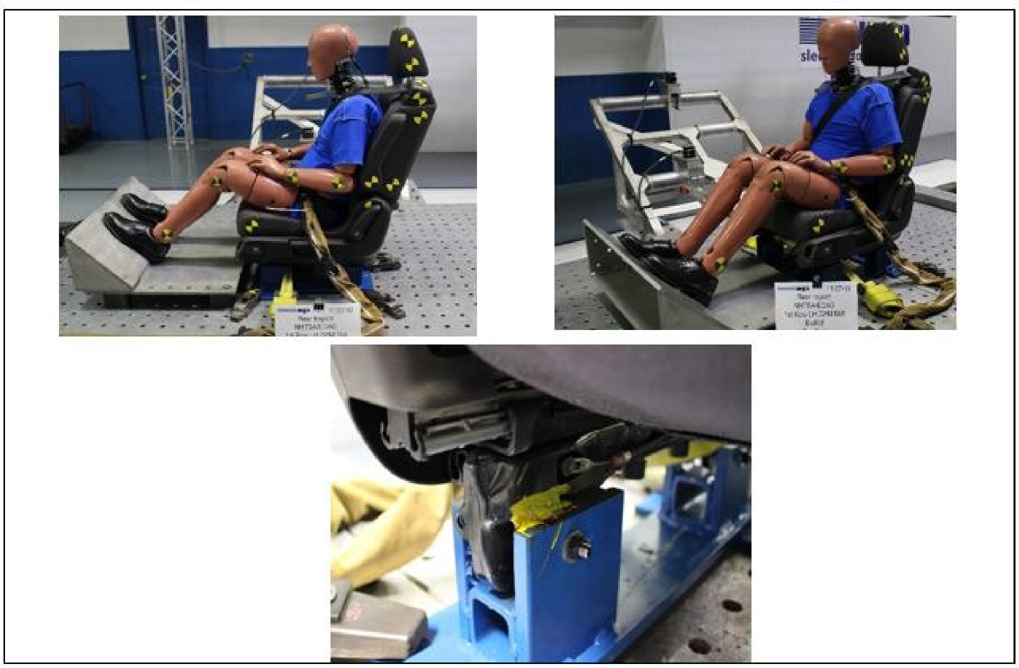

Figure 29. FMVSS No. 301 Sled Test Setup

The ISS seat was tested in the mid track position. Occupant characteristics including head acceleration and neck injury parameters were recorded. The seat back angle for the ISS seat is set to 18.1 degrees by using an inclinometer on the back of the seat on the frame bar. There was no significant deformation observed after the test. The seat back was twisted about vertical axis during the test due to ISS seat frame structure. Pre- and post-test images are shown in Figure 30.

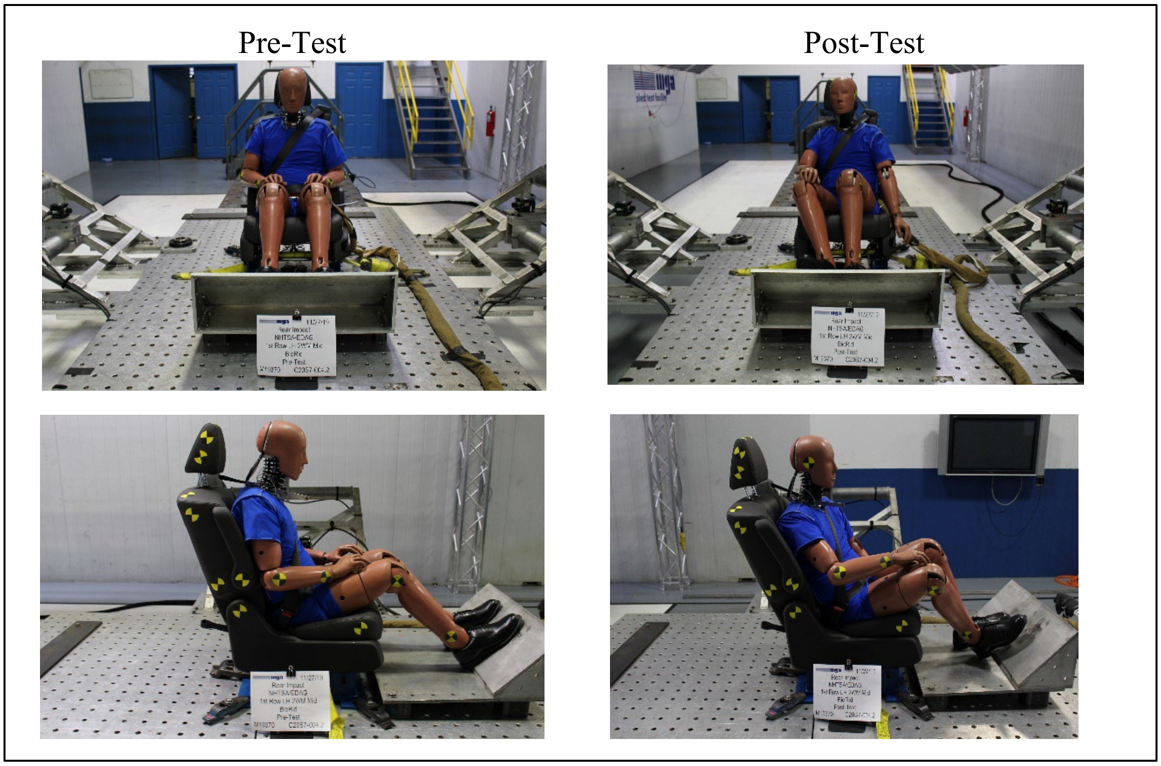

Figure 30. FMVSS301 Sled Test

5 FMVSS No. 301 Model Development

After developing and validating the FE seat model with respect to the quasi-static physical rearward and forward pull tests, the FE seat model was used in the FMVSS No. 301 FE modeling.

5.1 FMVSS No. 301 FE Model Development

The FMVSS No. 301 Rear-Impact simulation included the BioRID-II dummy FE model, positioned on the fully trimmed ISS seat. The ISS seat with the BioRID-II dummy is anchored to the rigid floor. The above validated seat models were integrated by including the standard seat bottom and seat back cushion (or foam) modeling for realistic dummy to seat interaction. The seat frame and the fully trimmed ISS seat with cushions are shown in Figure 31.

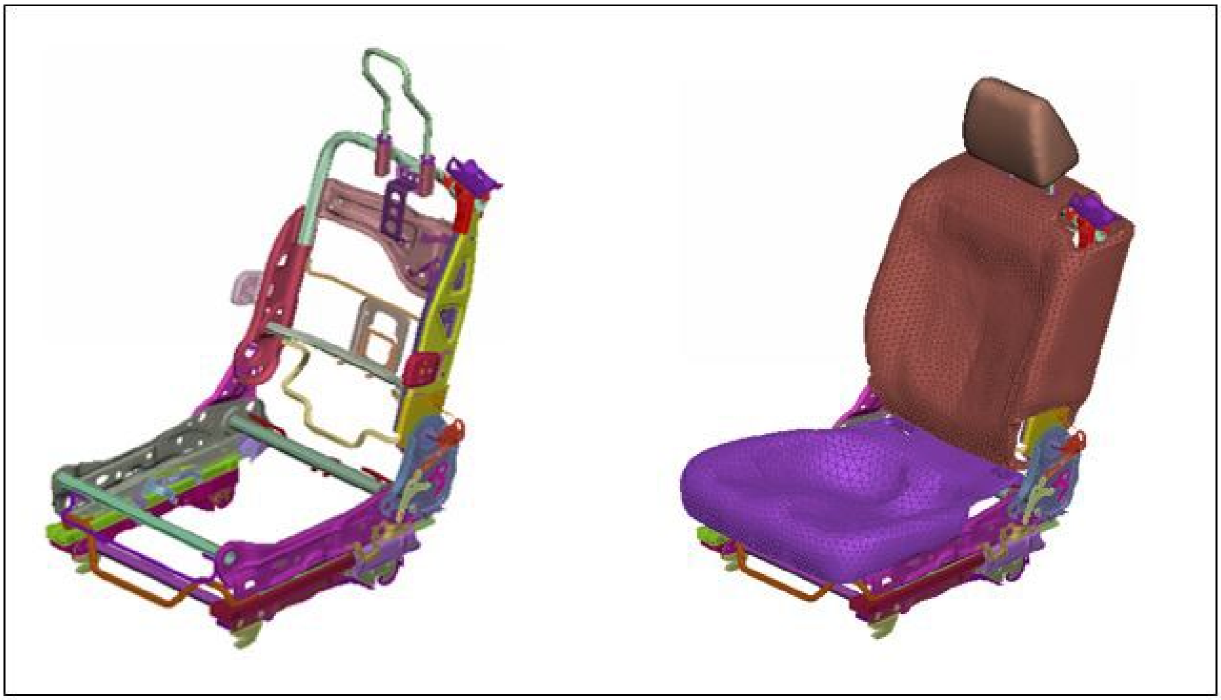

Figure 31. Seat Frame and Fully Trimmed Seat

The seat cushions were modeled as solid elements and were assigned foam material properties. Another important requirement to have more realistic occupant kinematics is to have the seat cushions pre-deformed due to weight of the dummy to match the lower torso profile impression on the seat bottom cushion and upper torso impression over the seat back cushion. The model was gravity settled prior to simulation. The seat cushions were deformed to the BioRID-II dummy shapes by using LS-DYNA pre-simulations.

5.2 FMVSS No. 301 Test Versus CAE Comparison

The ISS seat was integrated with the seat position and seat back angle as per the test. The BioRID-II occupant dummy was positioned as per the required H-point and seat back angle. The ISS with the shoulder belt and lap belt were modeled and wrapped over the BioRID-II dummy, and gravity load was applied to the overall sled. LS-DYNA simulation was run for 200 milliseconds, and the characteristics of the BioRID-II dummy and seat structure were computed. In particular, occupant head acceleration and neck forces were plotted and compared with that of physical test. The kinematics of the seat back rotation and occupant position are shown in Figure 32 for 0 ms and 90 ms of the simulation and test.

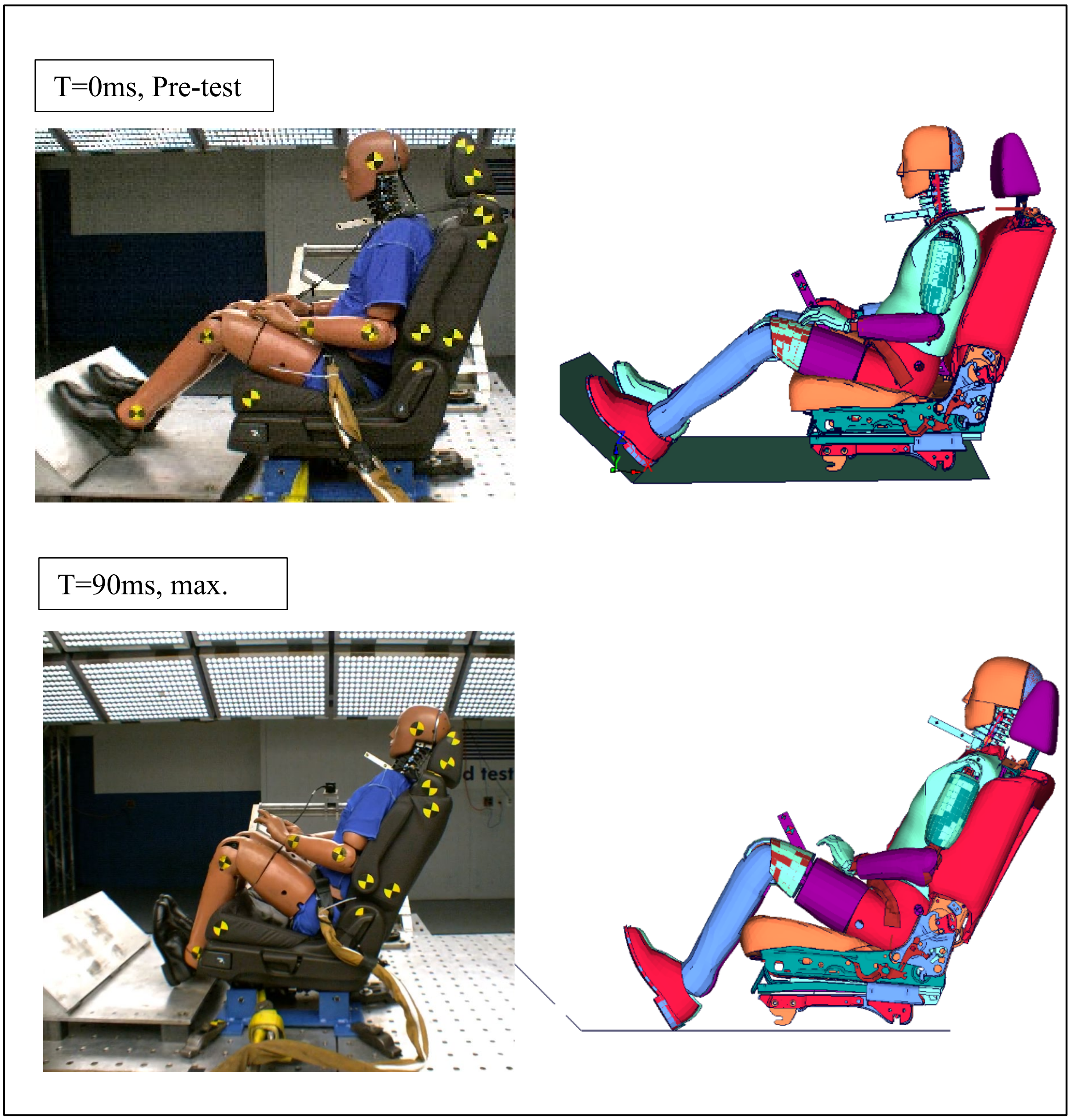

Figure 32. FMVSS No.301 Sled Test FEA and Test

The ISS seat FE simulation and the sled test results comparison, including head acceleration plot, Head Injury Criteria (HIC) value, and neck forces for Neck Injury Criteria (NIC), are shown in Figures 33, 34, and 35.

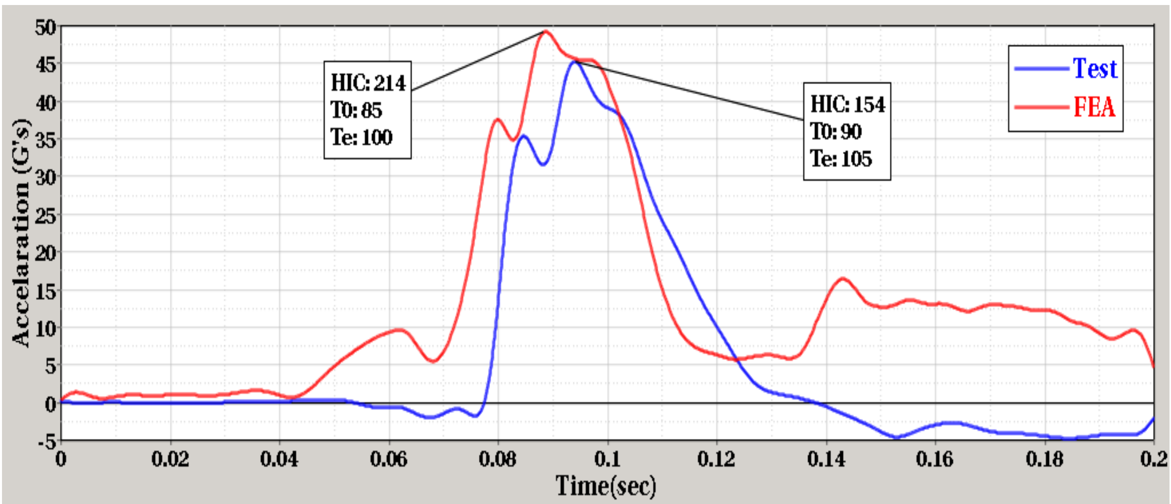

Figure 33. HIC – ISS Seat

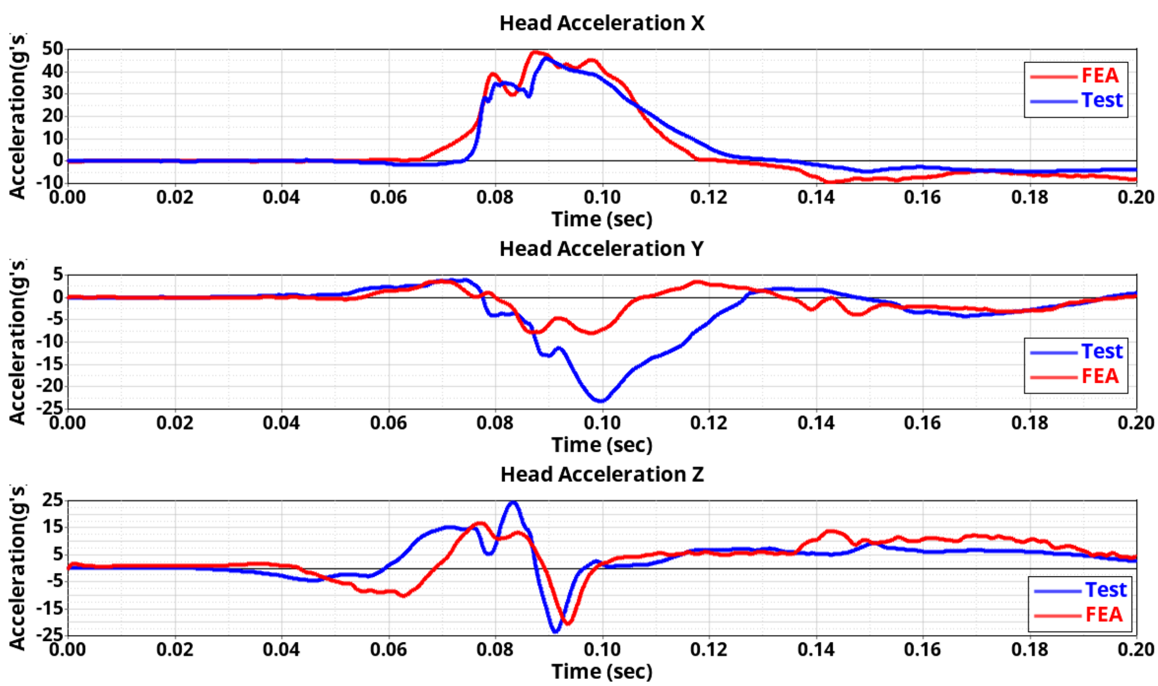

Figure 34. Head Acceleration in X, Y, and Z

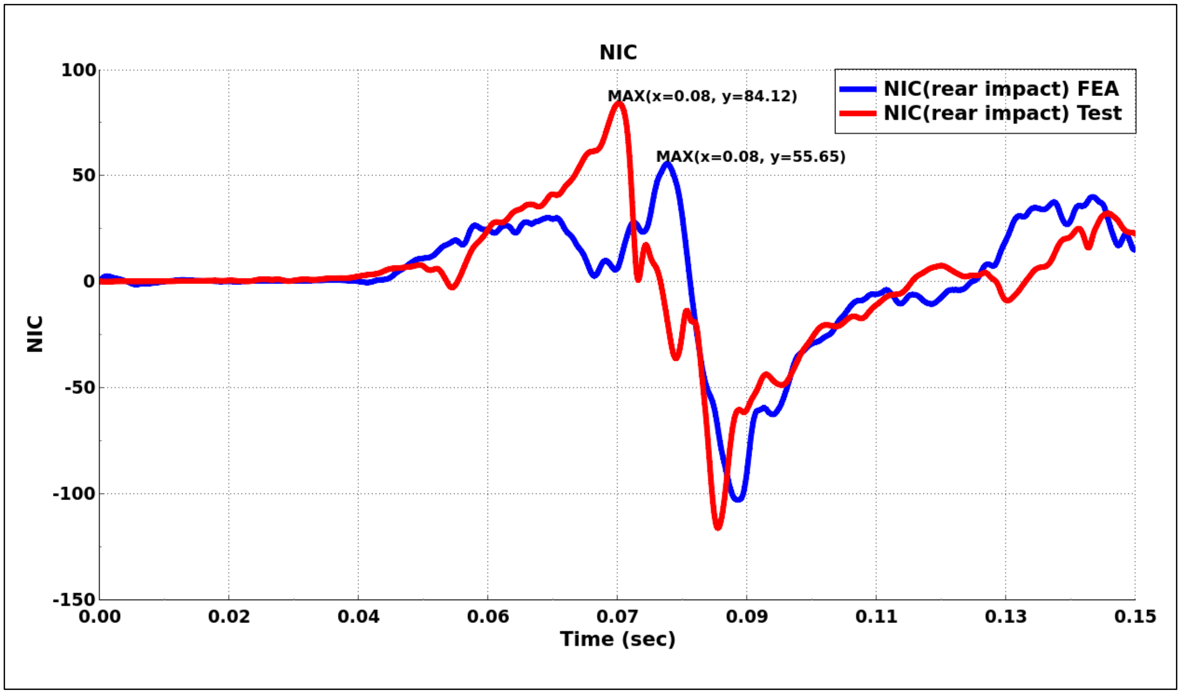

Figure 35. Neck Injury Criteria

The HIC curve and head acceleration curve were following similar trends. The NIC curves had a slight offset to the peak, because in the physical test headrest is deflecting more rearward compared to the FE model. The FE animation and physical test video showed similar kinematics. The HIC in FE model is high compared to the test because the head restraint is slightly stiffer in FE model. The HIC and NIC values for the test and FEA are listed in Table 5.

Table 5: FMVSS No. 301 HIC and NIC Value Comparison

		Injury Measures	
		Test	FEA Model
Head	HIC 15	154	214
	Peak Acceleration X(g)	46	49
	Peak Acceleration Y(g)	-23	-8
	Peak Acceleration Z(g)	-24	-21
Neck	NIC	84	56

6 PHASE 2 – Seat Additional Sled Testing and Validation

Upon completion of Phase 1, it was determined that additional testing and validation were required for the ISS seat model. The contractor therefore conducted additional sled tests and simulations to represent each of the additional sled tests. As in Phase 1, simulation results were objectively compared with sled test data.

After discussion with NHTSA, the contractor performed five sled tests to evaluate the ISS seat model in frontal and rear impacts at two different reclined seating angles.

Rear Impact

- 18° Seat back angle/THOR-50M @ 27 kph
- 45° Seat back angle/THOR-50M @ 27 kph

Frontal Impact

- 18° Seat back angle/THOR-50M @ 40 kph
- 45° Seat back angle/THOR-50M @ 40 kph
- 18° Seat back angle/THOR-50M @ 56 kph

7 Rear-Impact Sled Tests

Two rear-impact sled tests were conducted with two different seat back angles (18° and 45°). The THOR-50M occupant dummy was used in the sled test. The FE model of the ISS seat was configured for both recliner angle scenarios. The vehicle pulse was generic and calculated based on the FMVSS No. 301 Rear-Impact pulse obtained from the CAE simulation.

7.1 Rear-Impact Sled Test (18° Seat Back Angle/27 kph)

THOR-50M was supplied by NHTSA and positioned in the ISS seat with 18° seat back angle. The ISS seat was subjected to 27 kph rear-impact pulse, which was applied on the sled. This test pulse generates peak acceleration of 19 G. The generic vehicle pulse used in the sled test is shown in Figure 36.

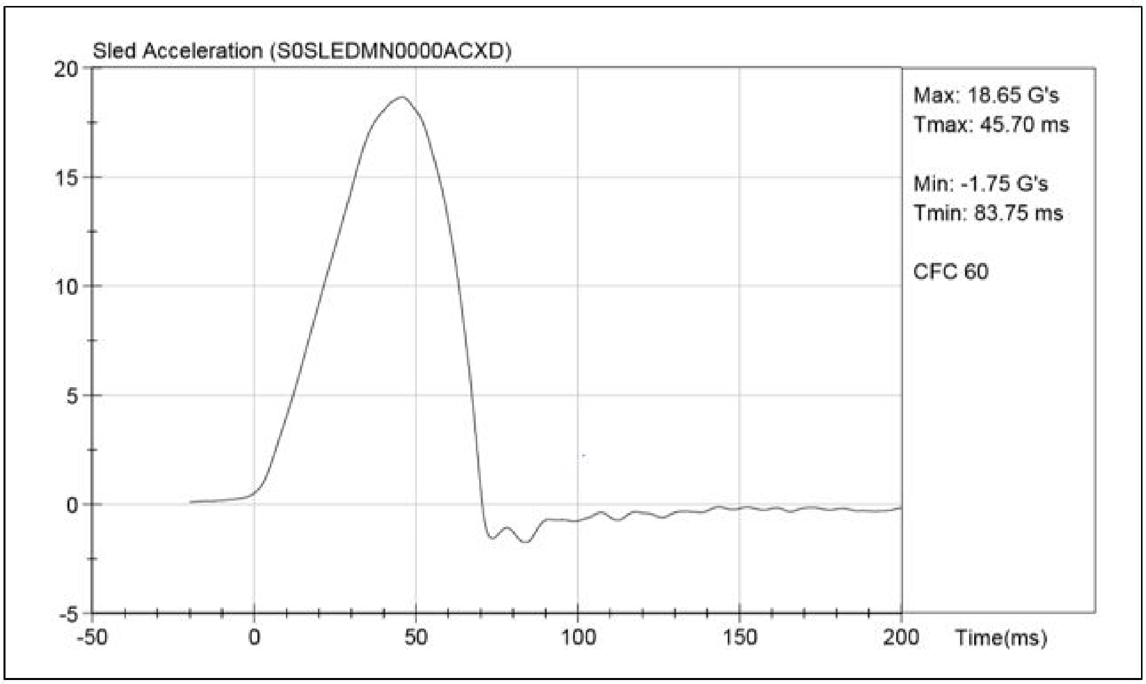

Figure 36. Rear Sled Pulse (Generic, 19 G Pulse)

The seat track was welded to the fixture to secure the seat coming off from the fixture. The rear-impact sled test setup for fully trimmed seat with 18° seat back angle and THOR-50M are shown in Figure 37.

Figure 37. Rear-Impact Sled Test Setup (18° Seat Back Angle)

The seat was tested in the mid track position. Occupant characteristics including head acceleration and neck injury parameters were recorded. LHS of the seat supports the seat belt; hence, it is slightly stiffer than the RHS. Therefore, more deformation was observed on the RHS due to seatback after the rear-impact sled test. Pre- and post-test images are shown in Figure 38.

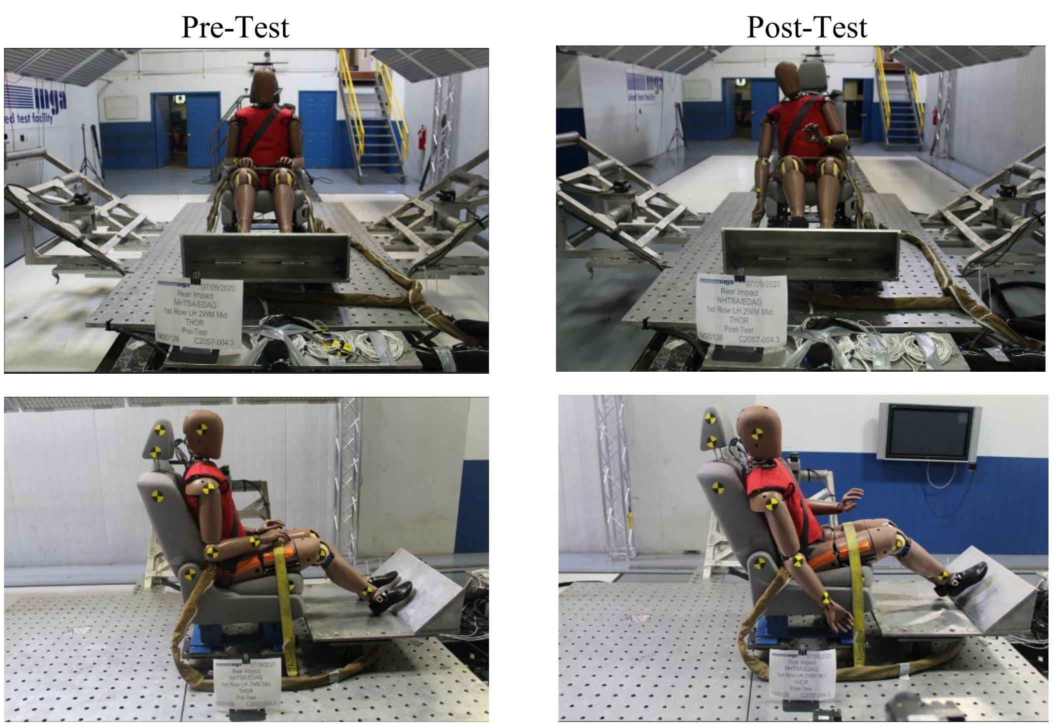

Figure 38. Rear-Impact Sled Test (18° Seat Back Angle)

7.1.1 Rear-Impact Sled Test Versus CAE Comparison (18° Seat Back Angle)

The seat model was set up with the mid track position and seat back angle as per the test. THOR-50M was positioned as per the sled test setup and seat back angle. The ISS with the shoulder belt and lap belt were modeled and wrapped over the THOR-50M, and gravity load was applied to the overall sled. LS-DYNA simulation was run for 200 milliseconds, and the characteristics of the THOR dummy and seat structure were computed. In particular, occupant head acceleration and neck forces were plotted and compared with that of physical test. The kinematics of the seat back rotation and occupant position are shown in Figure 39 for 0 ms and 90 ms of the simulation and test.

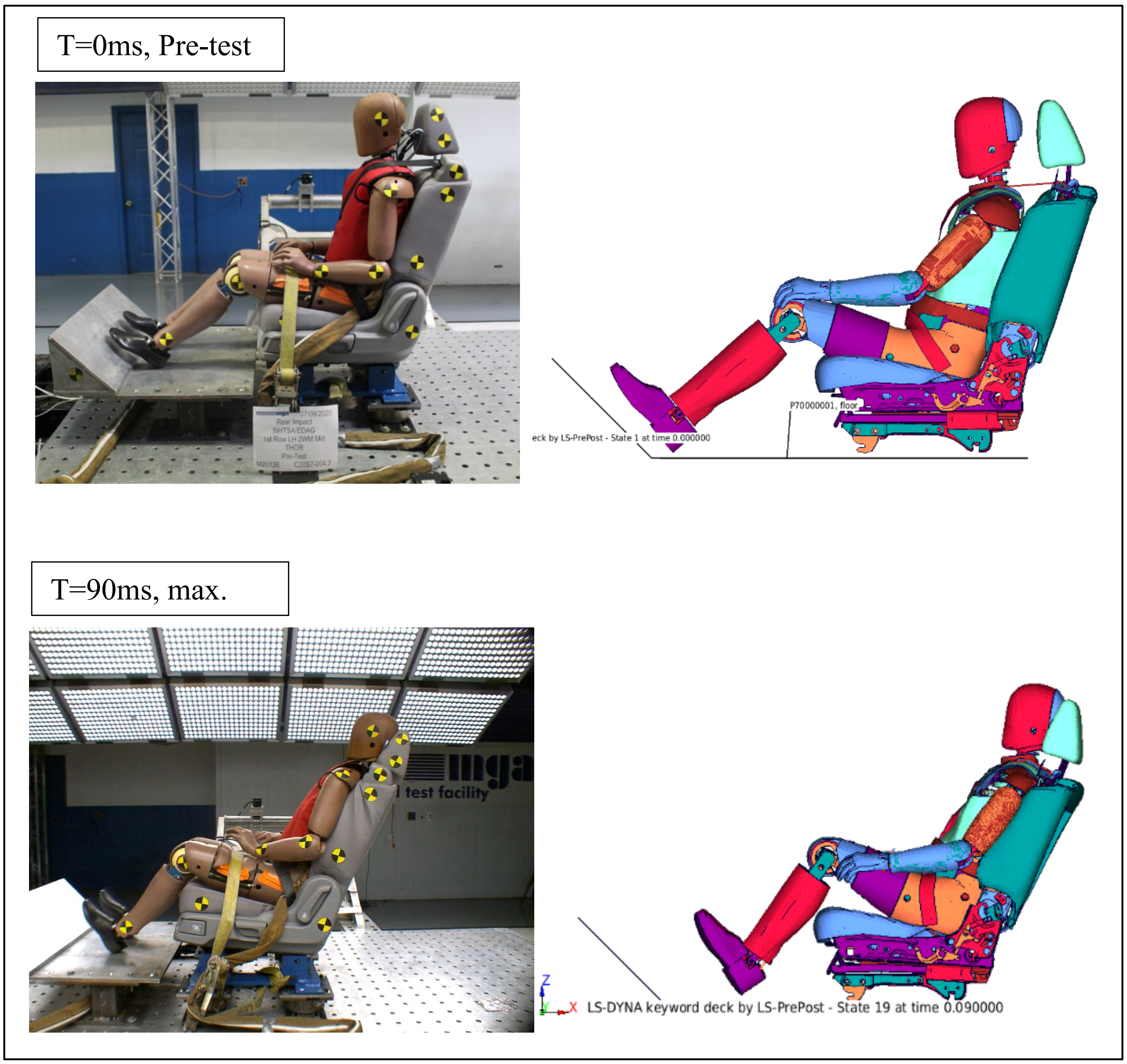

Figure 39. Rear-Impact Sled Test and FEA Simulation

The rear-impact FE simulation and the sled test results comparison, including occupant head acceleration plot, resultant head acceleration, and NIC, are shown in Figures 40, 41, and 42.

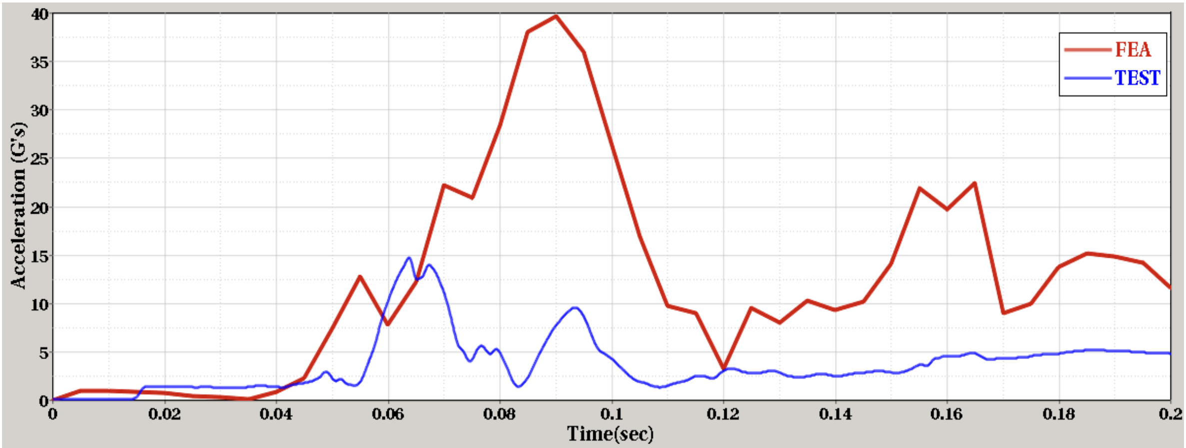

Figure 40. Head Resultant Acceleration

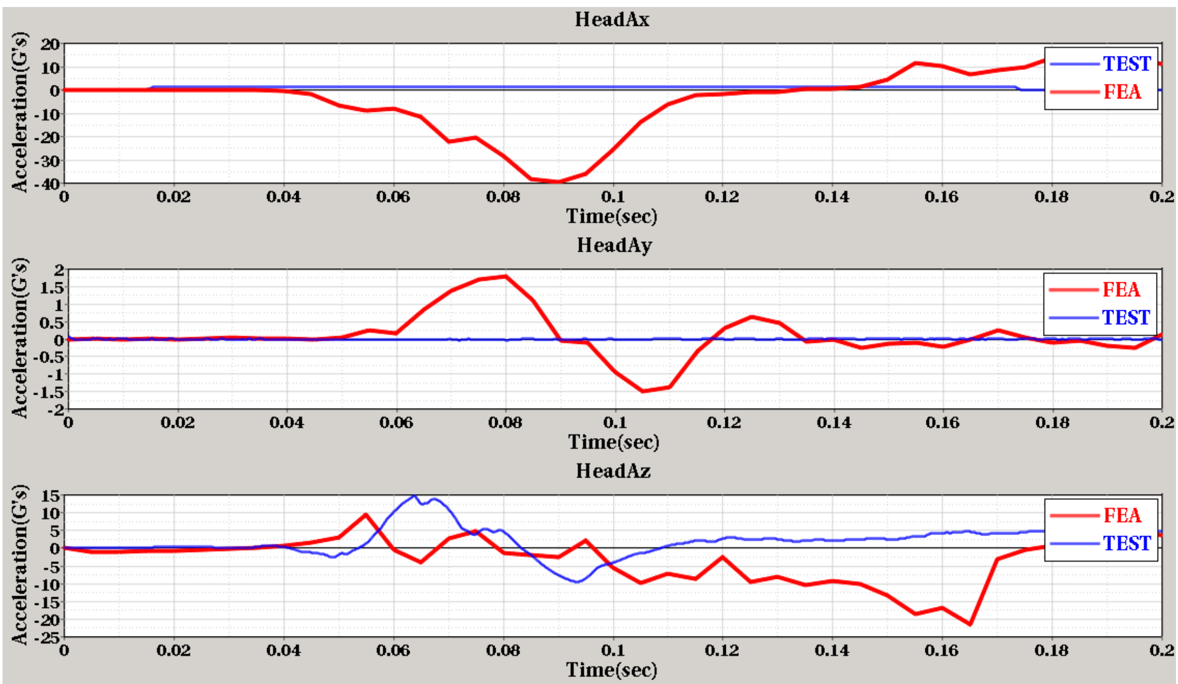

Figure 41. Head Acceleration in X, Y, and Z

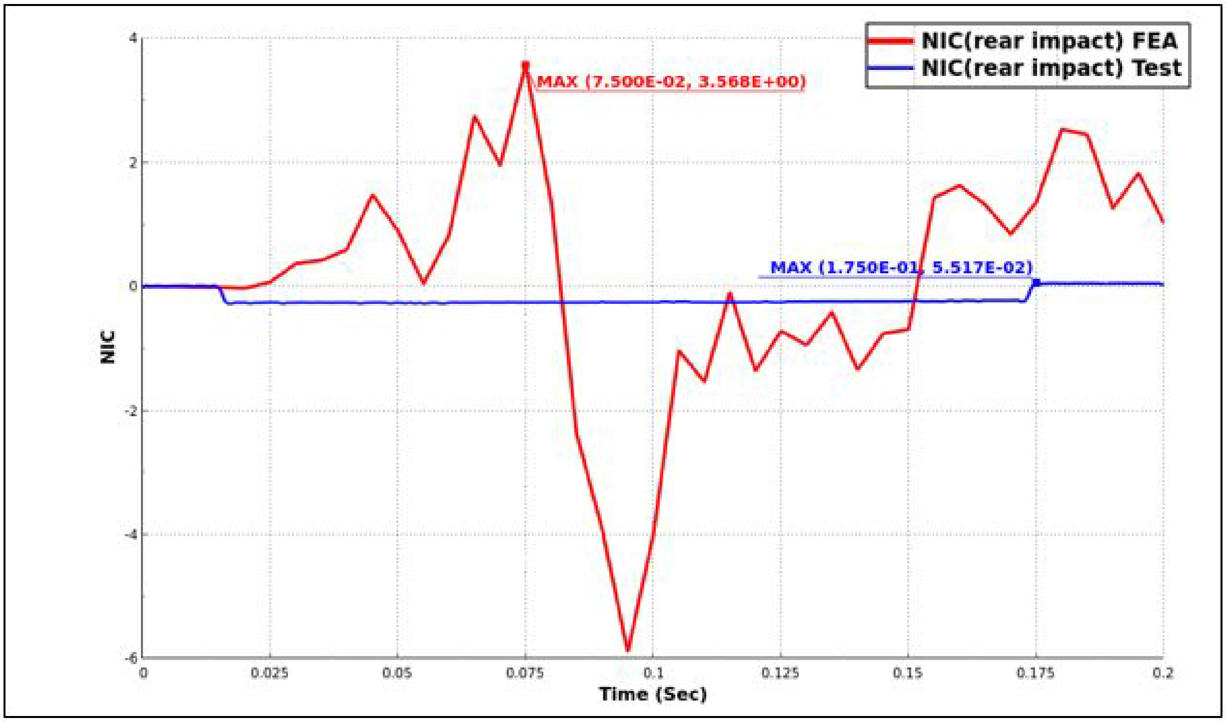

Figure 42. Neck Injury Criterion

We see that the resultant head acceleration, head acceleration in X and Y direction, and NIC curves are not comparable, because head acceleration channels in X and Y direction were not recorded appropriately in the test. As per sub-contractor research, there was an issue with the lemo connector between the sensor and DTS system.

The anchor forces were recorded from both test and FE simulation. Anchor forces from the test were recorded from the load cell attached to the anchor points, whereas in FEA cross-sectional planes were created on the anchors to extract the forces. The anchor forces from FEA and test comparison are shown in Figure 43 and Figure 44.

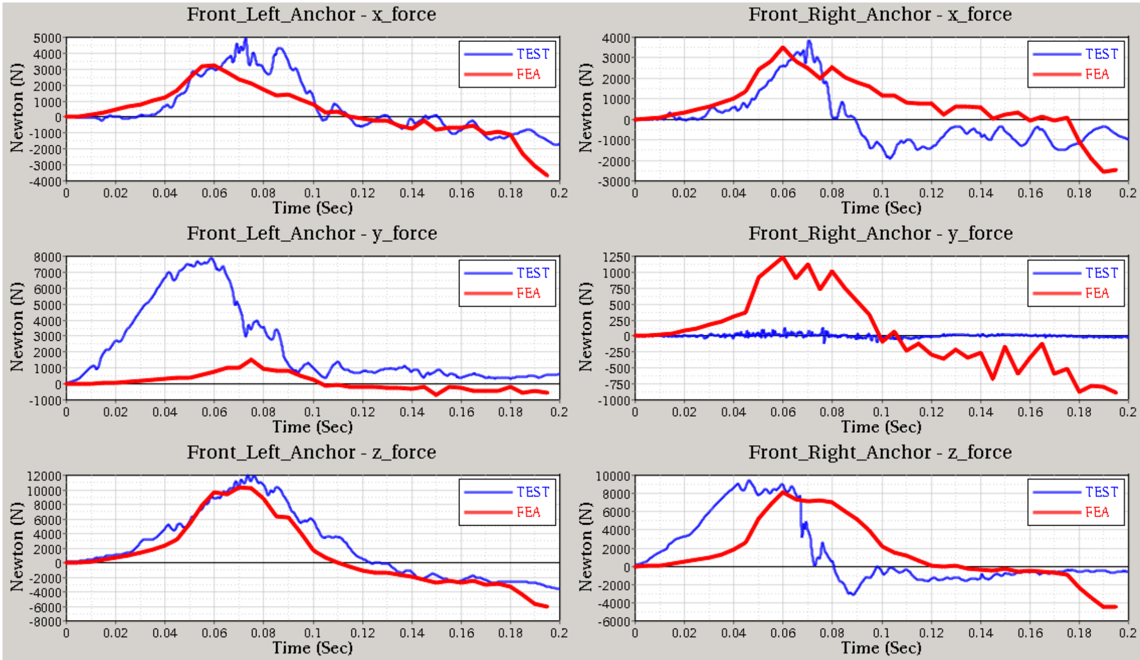

Figure 43. Front Anchor Forces

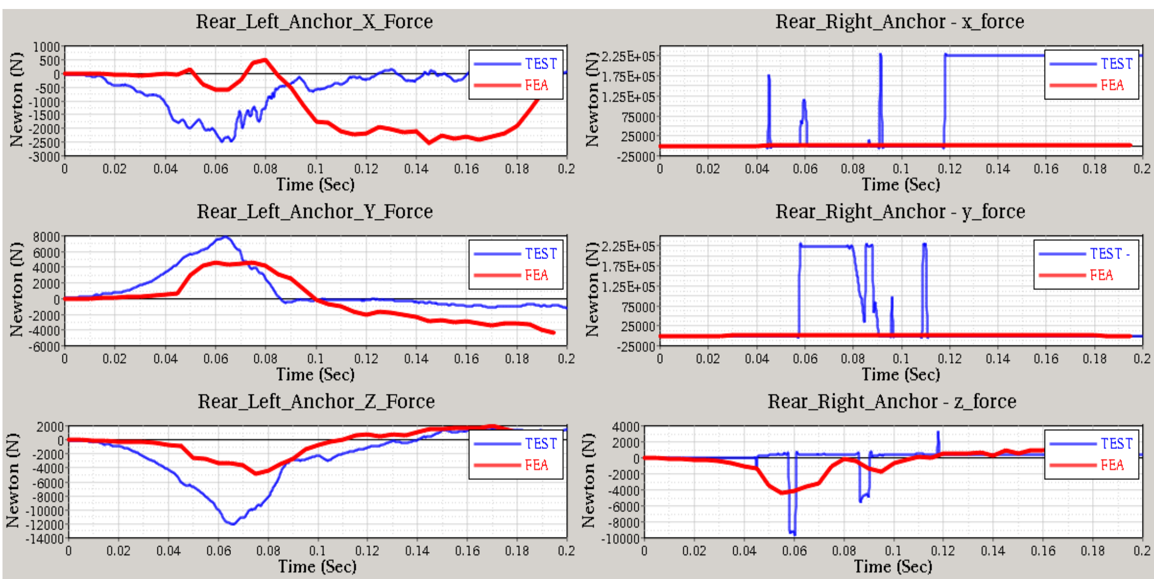

Figure 44. Rear Anchor Forces

Seat anchor forces will be depending on the 3-point belt system and twisting of the dummy in the actual test.

7.2 Rear-Impact Sled Test (45° Seat Back Angle/27 kph)

The THOR-50M was positioned in the ISS seat with a 45° seat back angle. The ISS seat was subjected to the same 27 kph rear-impact pulse that was used in the 18° recline test. This test pulse generates peak acceleration of 19 G. The generic vehicle pulse used in the sled test is shown in Figure 45.

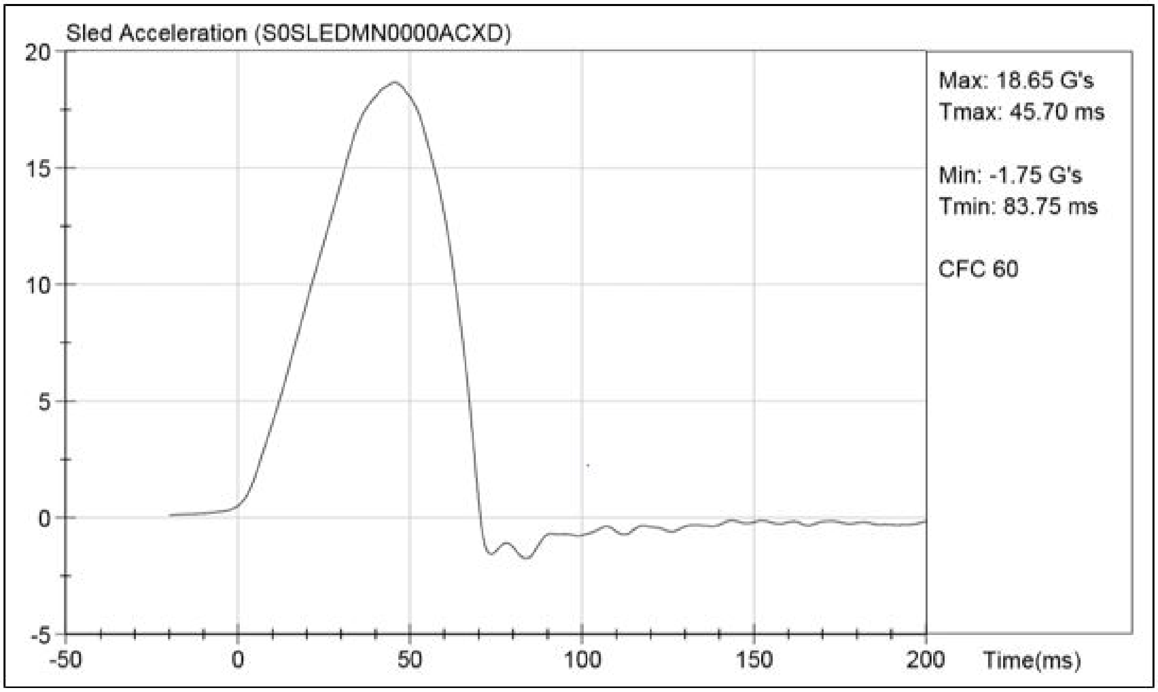

Figure 45. Rear Sled Pulse (Generic, 19G Pulse)

The seat track was welded to the fixture to prevent the seat coming from the fixture. The rear-impact sled test setups for the fully trimmed seat with a 45° seat back angle and the THOR dummy are shown in Figure 46.

Figure 46. Rear-Impact Sled Test Setup (45° Seat Back Angle)

The seat was tested in the mid track position. Occupant characteristics including head acceleration and neck injury parameters were recorded appropriately. LHS of the seat supports the seat belt; hence, it is slightly stiffer than the right-hand side. Apart from this seatback twist, there is no other significant deformation observed after the rear-impact test.

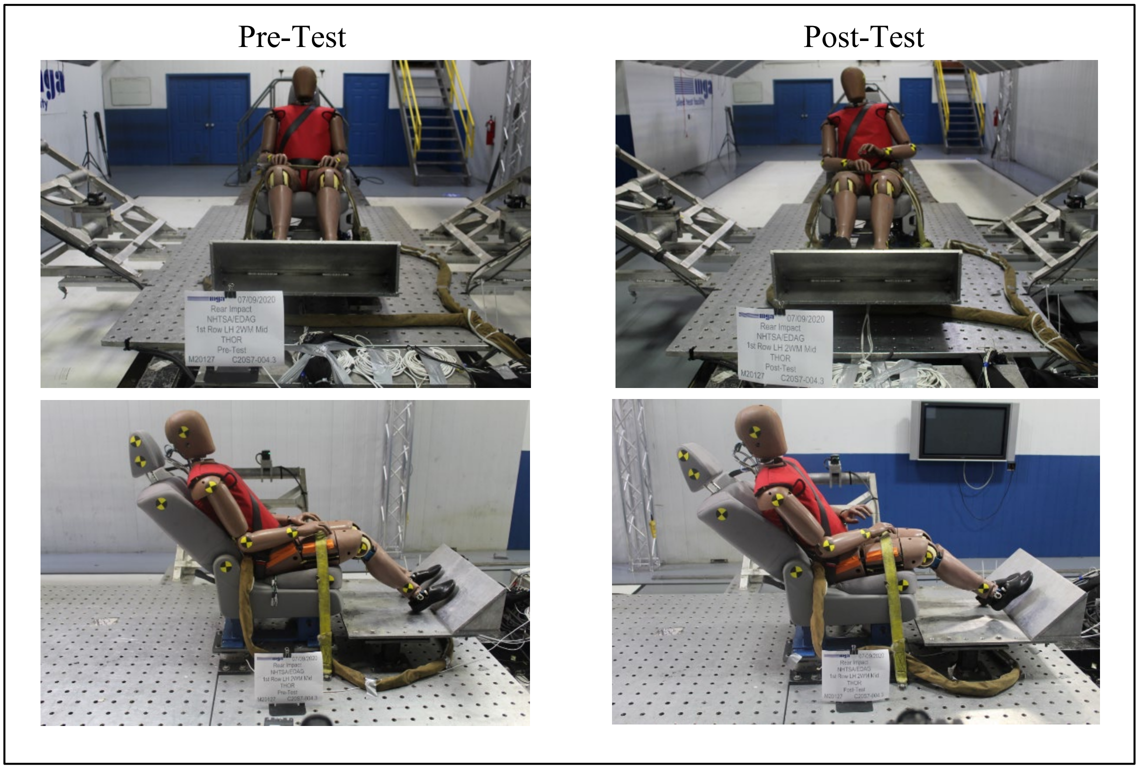

Figure 47. Rear-Impact Sled Test (45° Seat Back Angle)

7.2.1 Rear-Impact Sled Test Versus CAE Comparison (45° Seat Back Angle)

The seat model was set up with the mid track position and seat back angle (45°) as per the test. THOR occupant dummy was positioned as per the sled test setup and seat back angle. The ISS with the shoulder belt and lap belt were modeled and wrapped over the THOR dummy, and the gravity load was applied to the overall sled. LS-DYNA simulation was run for 200 milliseconds, and the characteristics of the THOR dummy and seat structure were computed. In particular, occupant head acceleration and neck forces were plotted and compared with that of physical test. The kinematics of the seat back rotation and occupant position are shown in Figure 48 for 0 ms and 90 ms of the simulation and test.

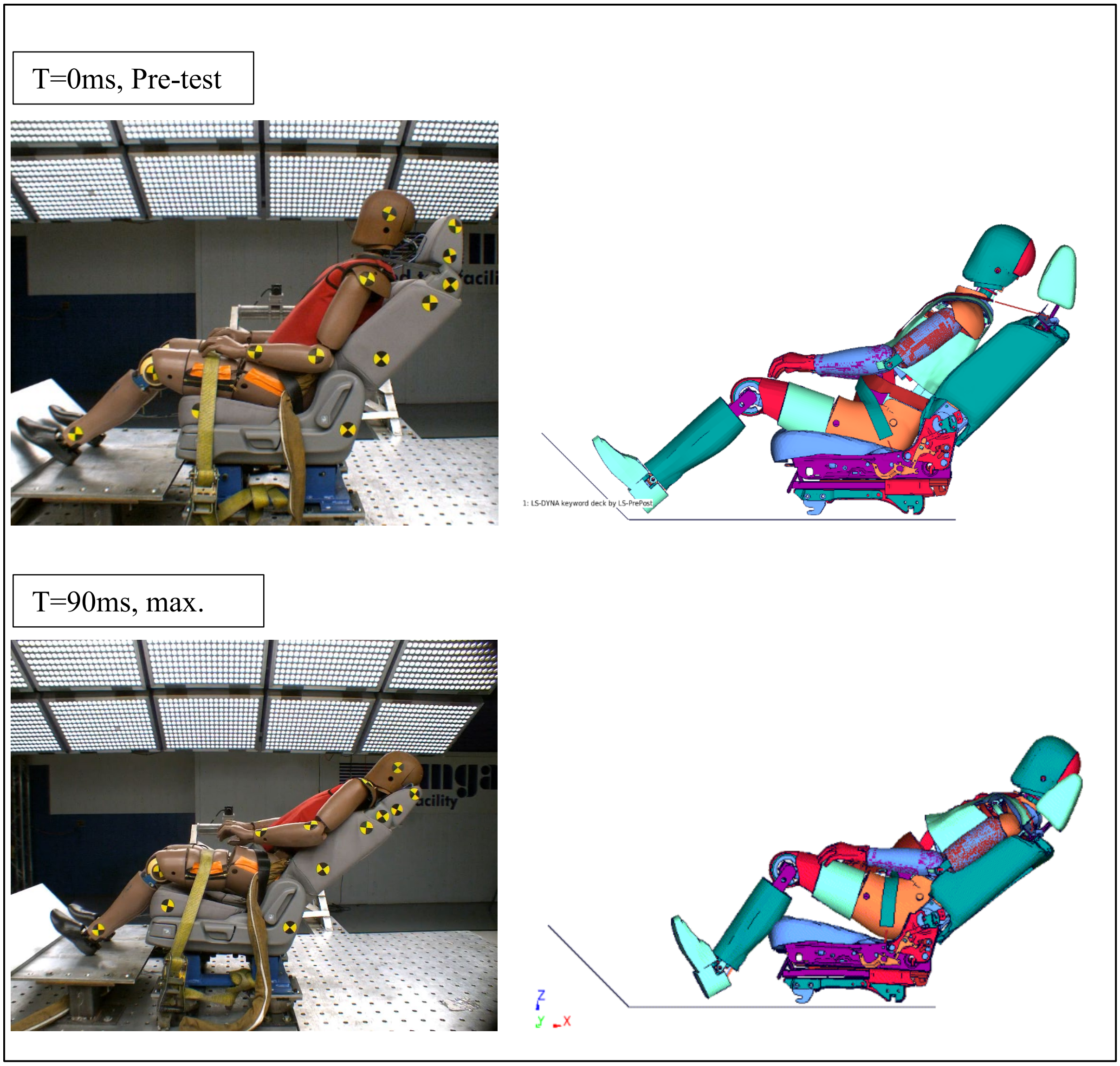

Figure 48. Rear-Impact Sled Test and FEA Simulation (45° Seat Back Angle)

The rear-impact FE simulation and the sled test results comparison, including occupant head acceleration plot, HIC value, and neck forces for NIC, are given in Figures 49, 50, and 51.

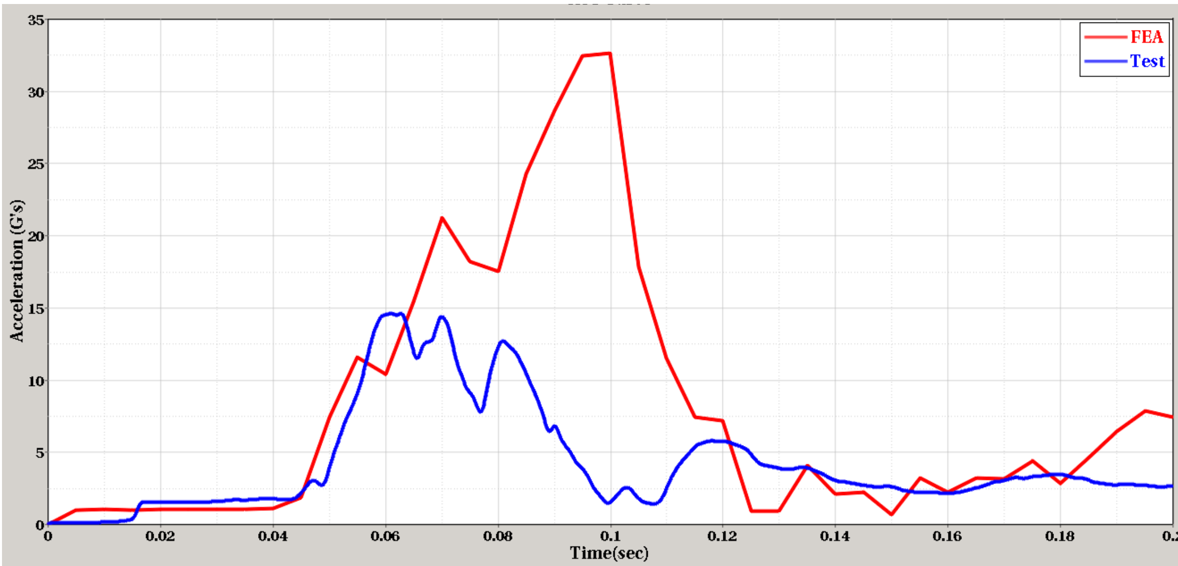

Figure 49. Head Resultant Acceleration

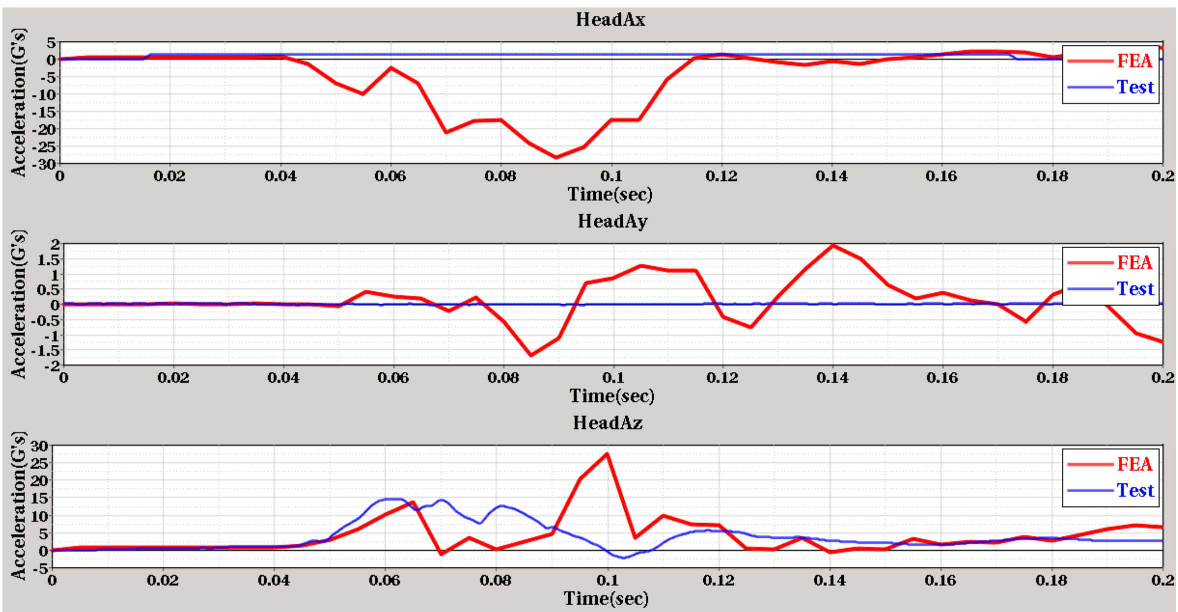

Figure 50. Head Acceleration in X, Y, and Z

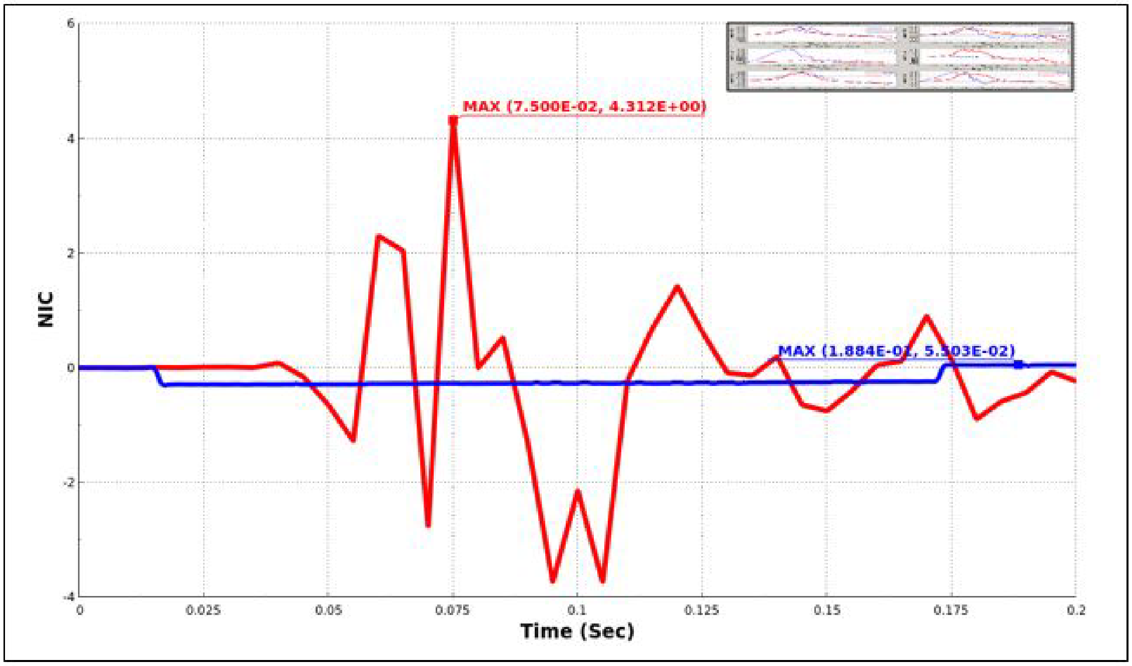

Figure 51. Neck Injury Criterion

We see that the resultant head acceleration, head acceleration in X and Y direction, and NIC curves are not comparable, because head acceleration channels in X and Y direction were not recorded appropriately in the test. As per sub-contractor research, there was an issue with the lemo connector between the sensor and the DTS system.

The anchor forces were recorded from both test and FE simulation. Anchor forces from the test were recorded from the load cell attached to the anchor points, whereas in FEA cross-sectional planes are created on the anchors to extract the forces. The anchor forces from FEA and test comparison are shown in Figure 52 and Figure 53.

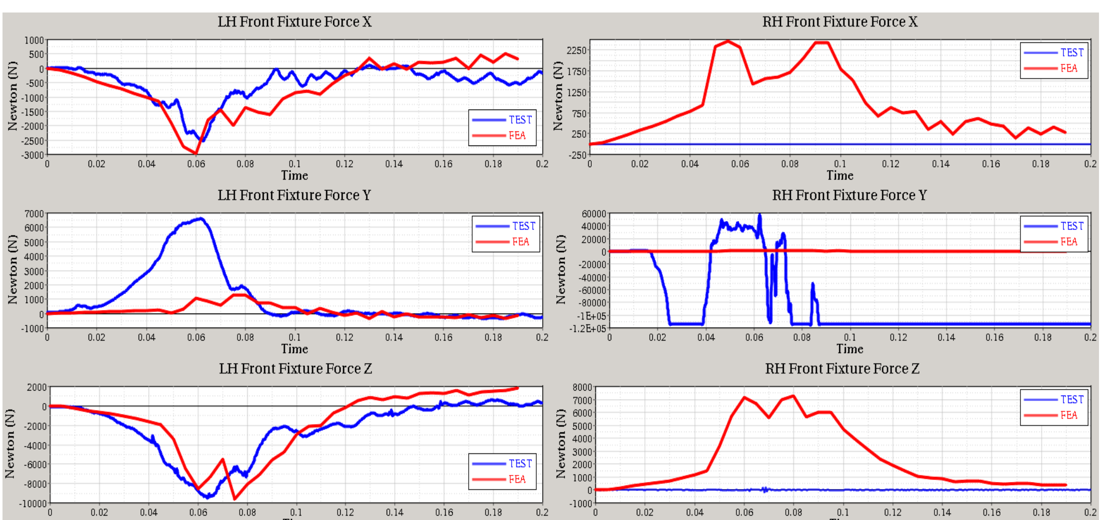

Figure 52. Front Anchor Forces

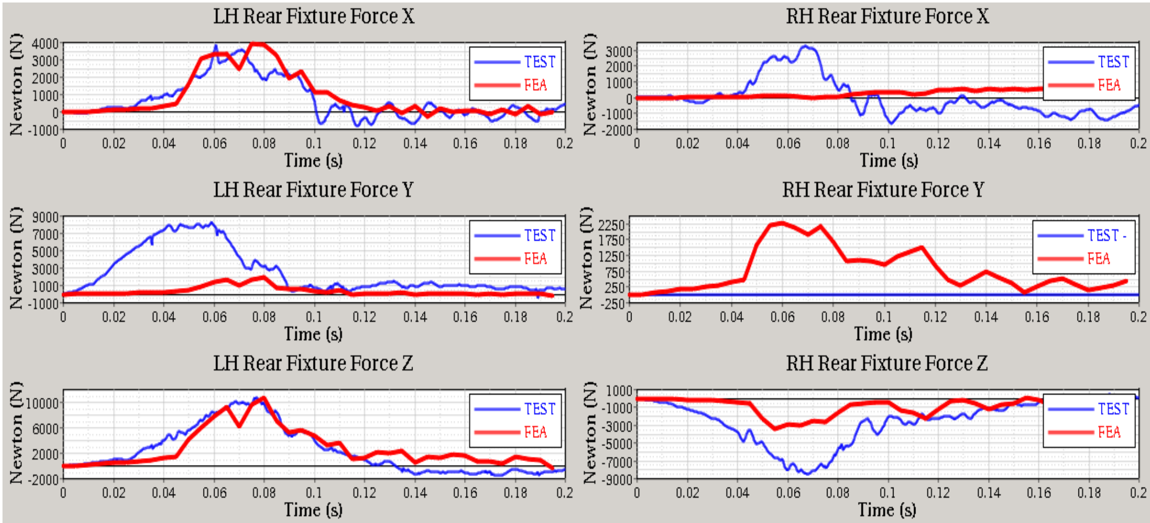

Figure 53. Rear Anchor Forces

Seat anchor forces will be depending on the 3-point belt system and twisting of the dummy in the actual test.

8 Frontal Impact Sled Tests

Three frontal impact sled tests were conducted, among which first two frontal impacts were conducted at same speed of 40 kph with 18° and 45° recliner angles and the last frontal impact was conducted at high speed with 56 kph and 18° recliner angle. The THOR 50th percentile male occupant dummy was used in the sled test. The FE model of the ISS seat was developed for all three scenarios, and the correlated quasi-static seat was used to study the head injury and neck injury measures of the THOR dummy. The THOR dummy was supplied by NHTSA, and the dummy was calibrated with necessary channels. The vehicle pulse was generic and calculated based on the FMVSS No. 208 frontal impact pulse obtained from the CAE simulation.

8.1 Frontal Impact Sled Test (18° Seat Back Angle/40 kph)

THOR-50M was positioned in the ISS seat with 18° seat back angle. The seat was subjected to 40 kph frontal crash pulse, which was applied on the sled. This test pulse generates peak acceleration of 28 G. The generic vehicle pulse used in the sled test is shown in Figure 54.

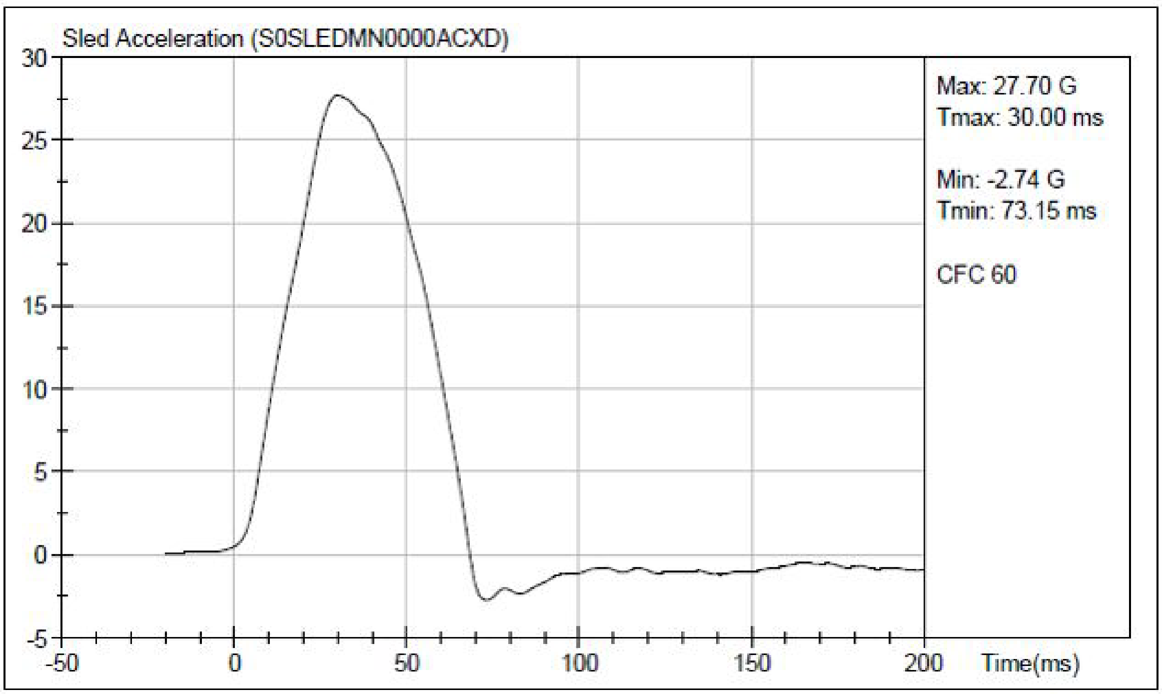

Figure 54. Front Sled Pulse

The seat track was welded to the fixture to secure the seat coming off from the fixture. The frontal impact sled test setups for the fully trimmed seat with 18° seat back angle using the THOR dummy are shown in Figure 55.

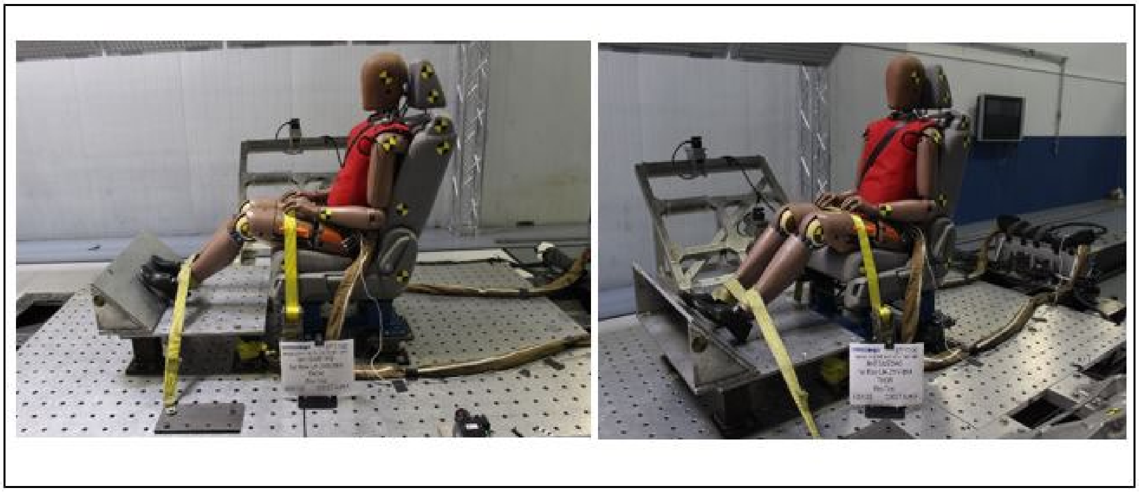

Figure 55. Frontal Impact Sled Test Setup (18° Seat Back Angle)

The seat was tested in the mid track position, and occupant characteristics including head acceleration and neck forces were recorded. In the physical test, there was no significant permanent deformation observed after the frontal impact.

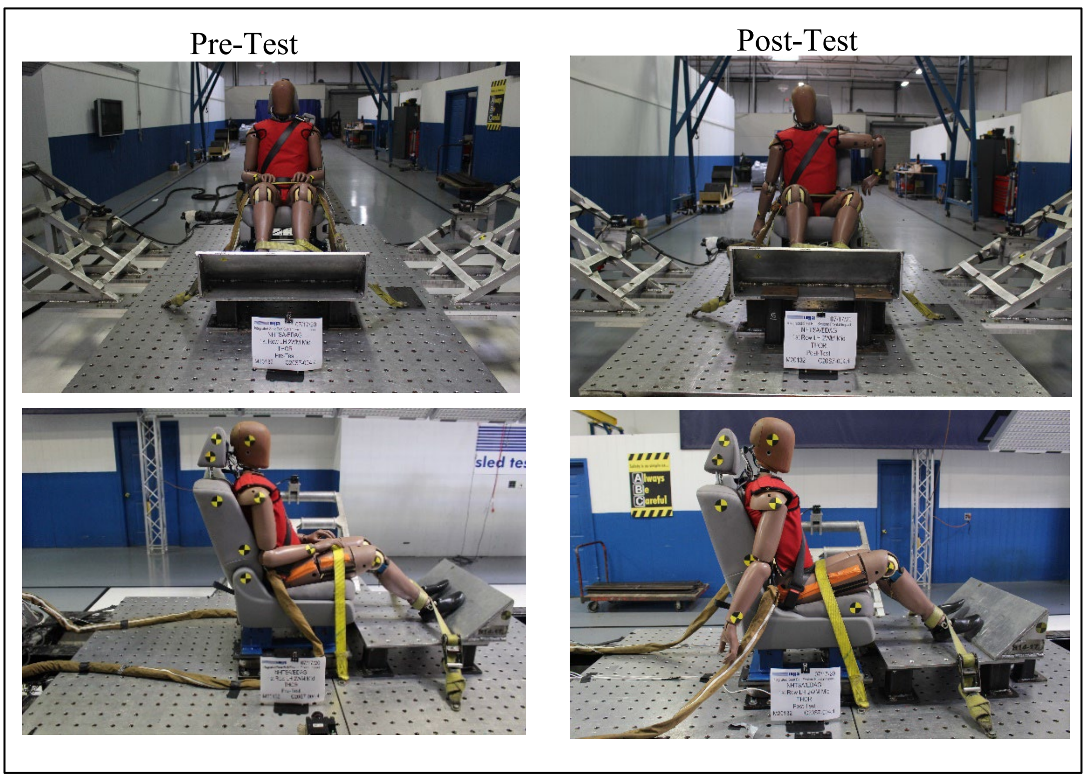

Figure 56. Frontal Impact Sled Test (18° Seat Back Angle)

8.1.1 FMVSS No. 208 Test Versus CAE Comparison

The correlated finite element ISS seat was positioned with seat back angle (18°) as per the test. The THOR dummy was positioned as per the sled test setup. The ISS seat with the shoulder belt and lap belt were modeled and wrapped over the THOR dummy, and gravity load was applied to the overall sled. LS-DYNA simulation was run for 200 milliseconds, and the characteristics of the THOR dummy and seat structure were computed. In particular, occupant head acceleration and neck forces were plotted and compared with that of physical test. The kinematics of the seat back rotation and occupant position are shown in Figure 57 for 0 ms and 90 ms of the simulation and test.

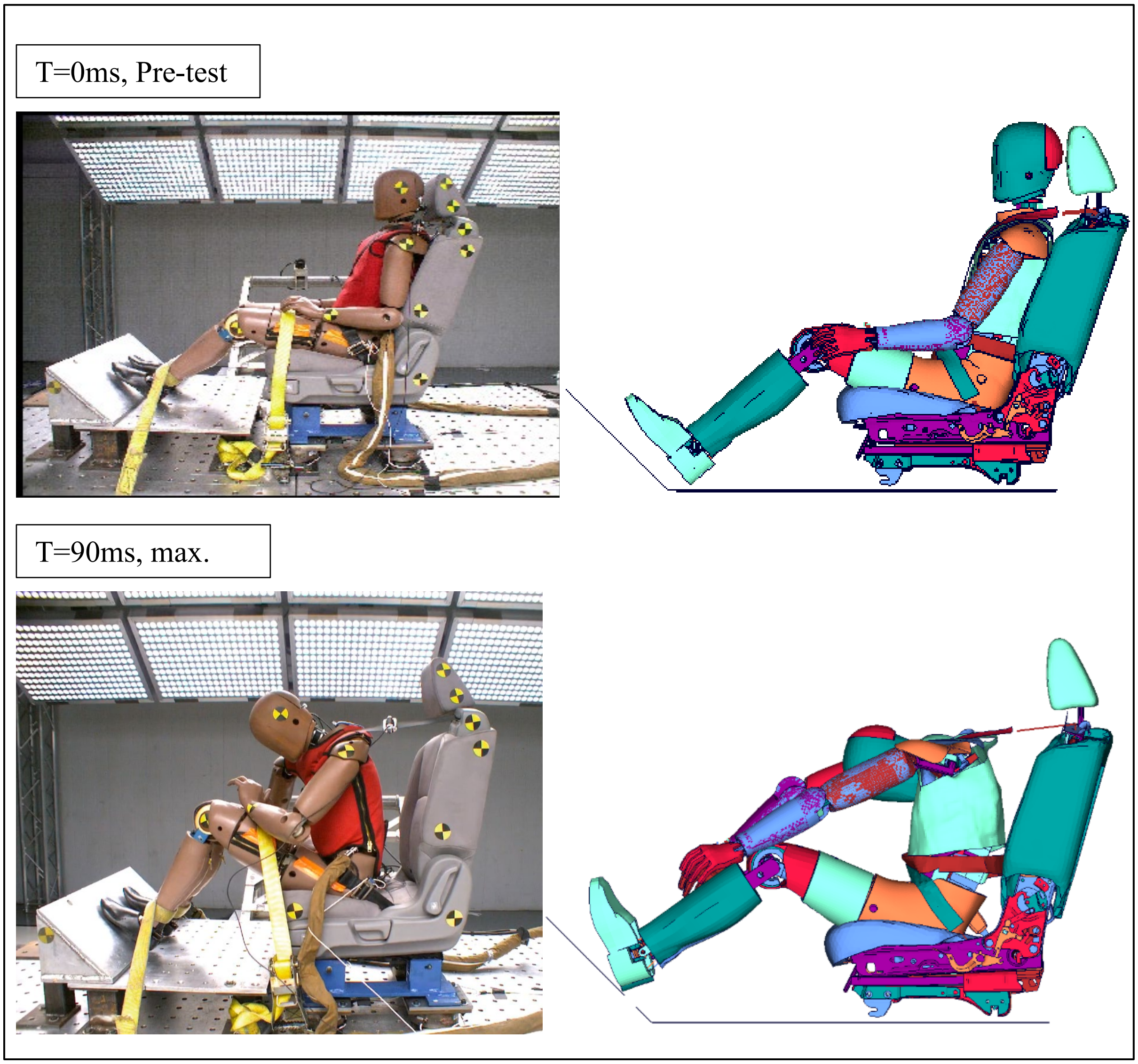

Figure 57. Frontal Impact Sled Test and FEA Simulation (18° Seat Back Angle)

The frontal impact FE simulation and the sled test results comparison, including occupant head acceleration plot, HIC value, and neck forces Nij, are shown in Figures 58, 59, and 60.

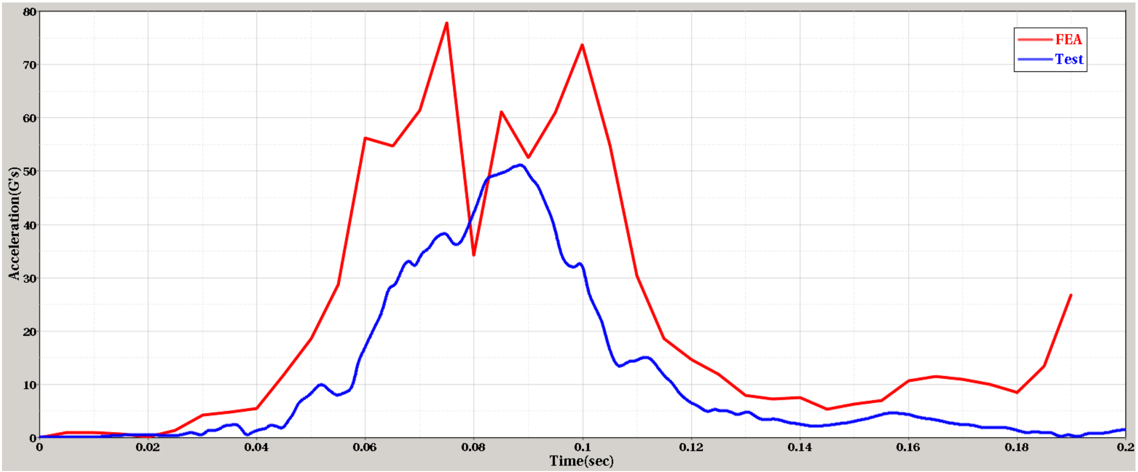

Figure 58. Resultant Head Acceleration

The fluctuation in the resultant head acceleration of FEA curve is because of the dummy's head impact on the chest during the simulation.

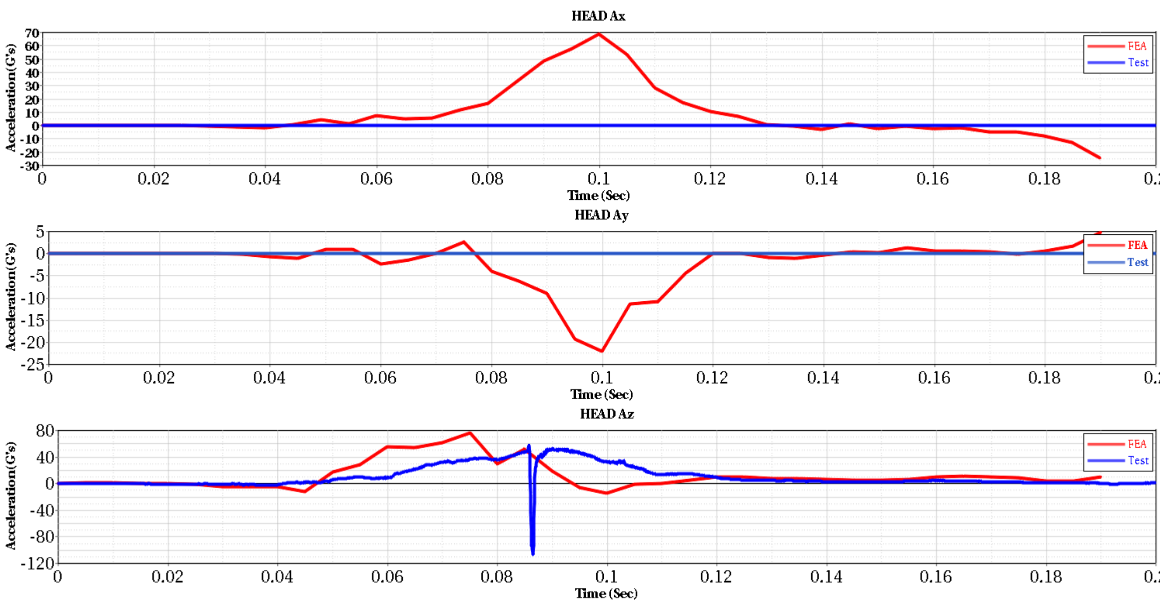

Figure 59. Head Acceleration in X, Y, and Z

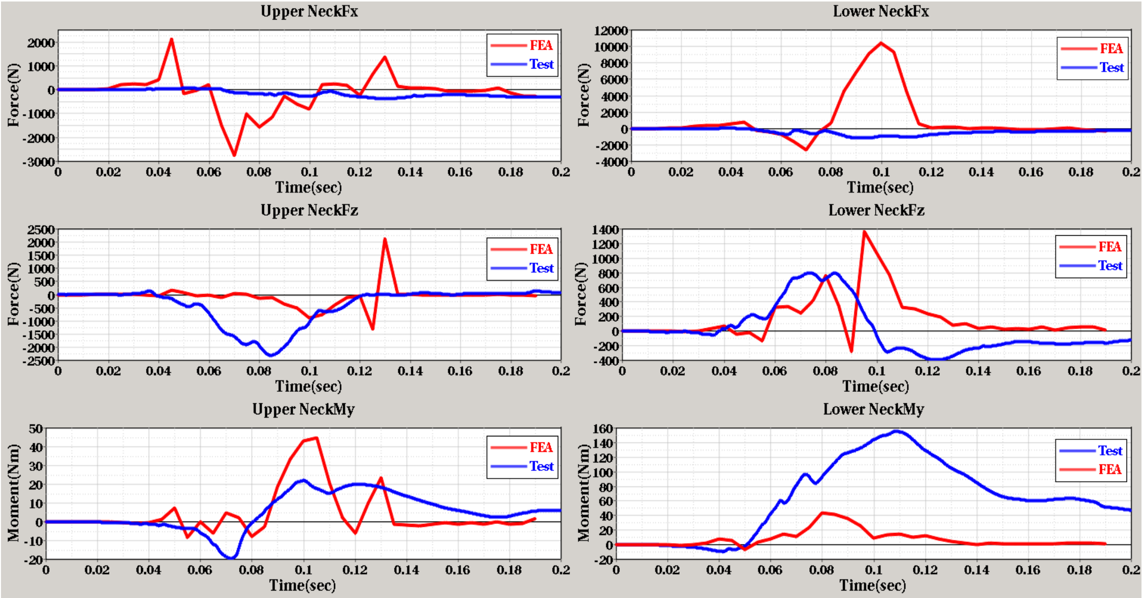

Figure 60. Neck Injury Forces

We see that the resultant head acceleration, along with head acceleration in X and Y direction curves, is not comparable, because head acceleration channels in X and Y direction were not recorded appropriately in the test. As per sub-contractor Research, there was an issue with the lemo connector between the sensor and the DTS system.

The anchor forces were recorded from both test and FE simulation. Anchor forces from the test were recorded from the load cell attached to the anchor points, whereas in FEA cross-sectional planes were created on the anchors to extract the forces. The anchor forces from FEA and test comparison are shown in Figure 61 and Figure 62.

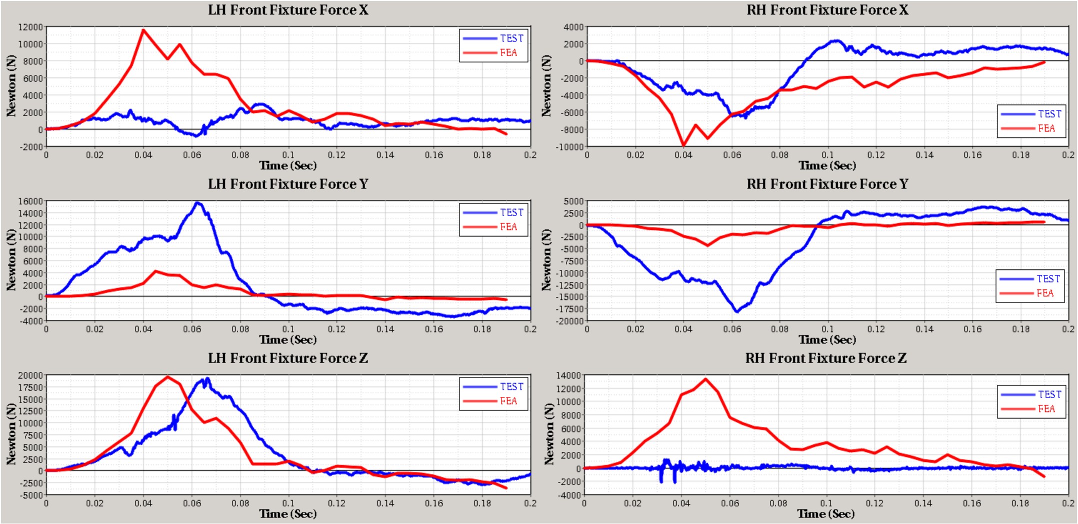

Figure 61. Front Anchor Forces

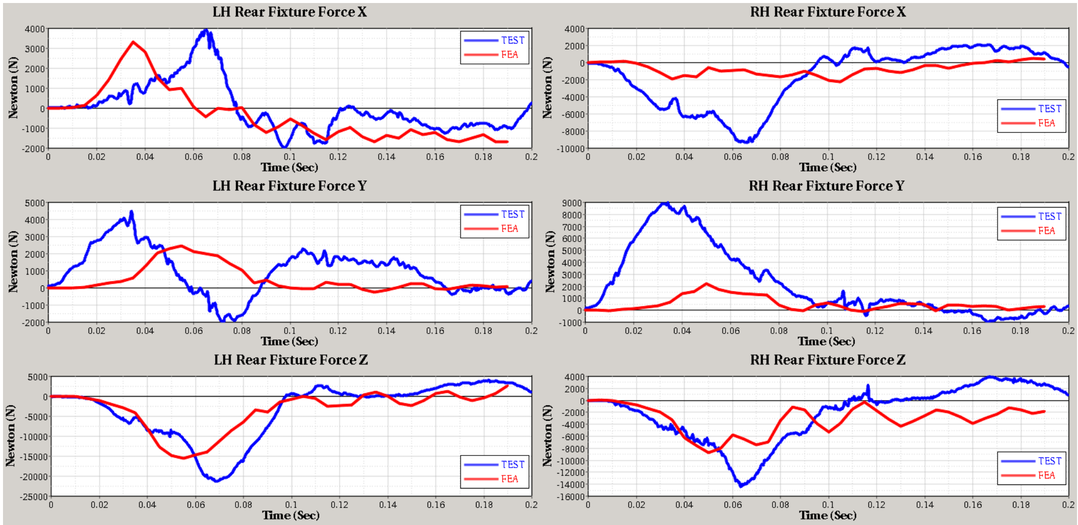

Figure 62. Rear Anchor Forces

Seat anchor forces will be depending on the 3-point belt system and twisting of the dummy in the actual test.

8.2 Frontal Impact Sled Test (45° Seat Back Angle/40 kph)

THOR-50M was positioned in the ISS seat with 45° seat back angle. The seat was subjected to 40 kph frontal crash pulse, which was applied on the sled. This test pulse generates peak acceleration of 28 G. The generic vehicle pulse used in the sled test is shown in Figure 63.

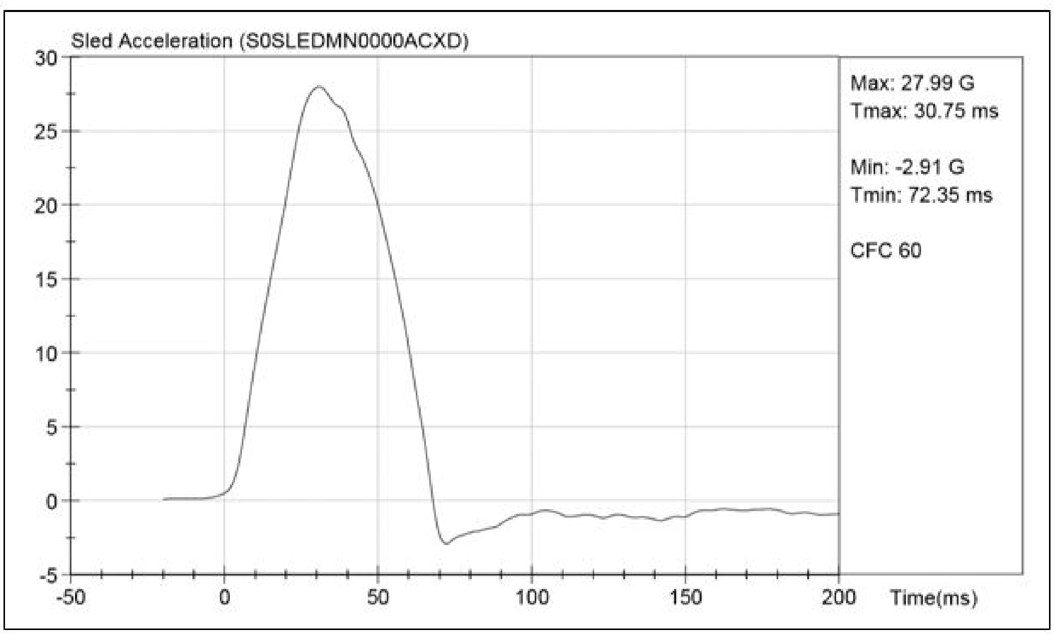

Figure 63. Rear Sled Pulse (Generic, 28 G Pulse)

The seat track was welded to the fixture to secure the seat coming off from the fixture. The frontal impact sled test setups for the fully trimmed seat with 45° seat back angle and the THOR dummy are shown in Figure 64.

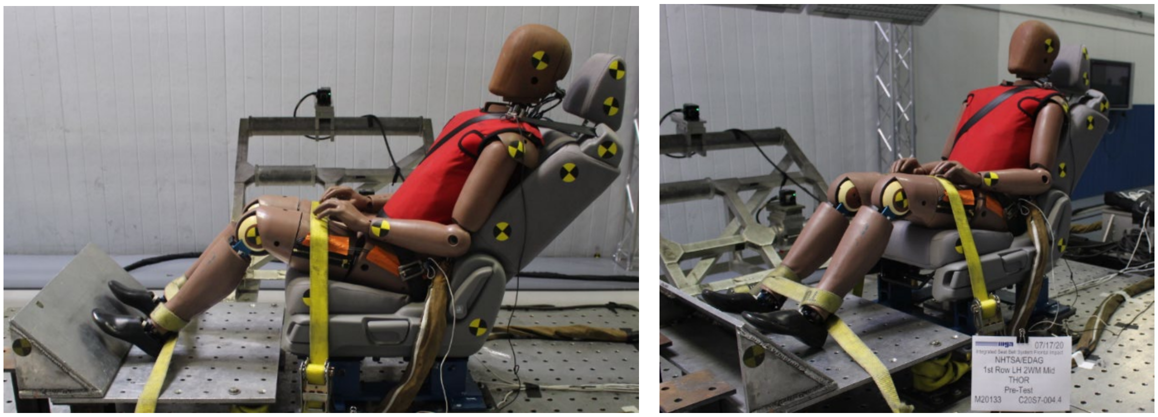

Figure 64. Frontal Impact Sled Test Setup (45° Seat Back Angle)

The seat was tested in the mid track position. Occupant characteristics including head acceleration and neck forces parameters were recorded. There was no significant permanent deformation observed after the frontal impact test.

Pre-Test Post-Test

Figure 65. Frontal Impact Sled Test (45° Seat Back Angle)

8.2.1 Frontal Impact Sled Test Versus CAE Comparison (45° Seat Back Angle)

The finite element ISS seat was positioned with seat back angle (45°) as per the test. The THOR occupant dummy was positioned as per the sled test setup and seat back angle. The ISS with the shoulder belt and lap belt were modeled and wrapped over the THOR dummy and gravity load was applied to the overall sled. LS-DYNA simulation was run for 200 milliseconds, and the characteristics of the THOR dummy and seat structure were computed. In particular, occupant head acceleration and neck forces were plotted, and compared with that of physical test. The kinematics of the seat back rotation and occupant position are shown in Figure 66 for 0 ms and 90 ms of the simulation and test.

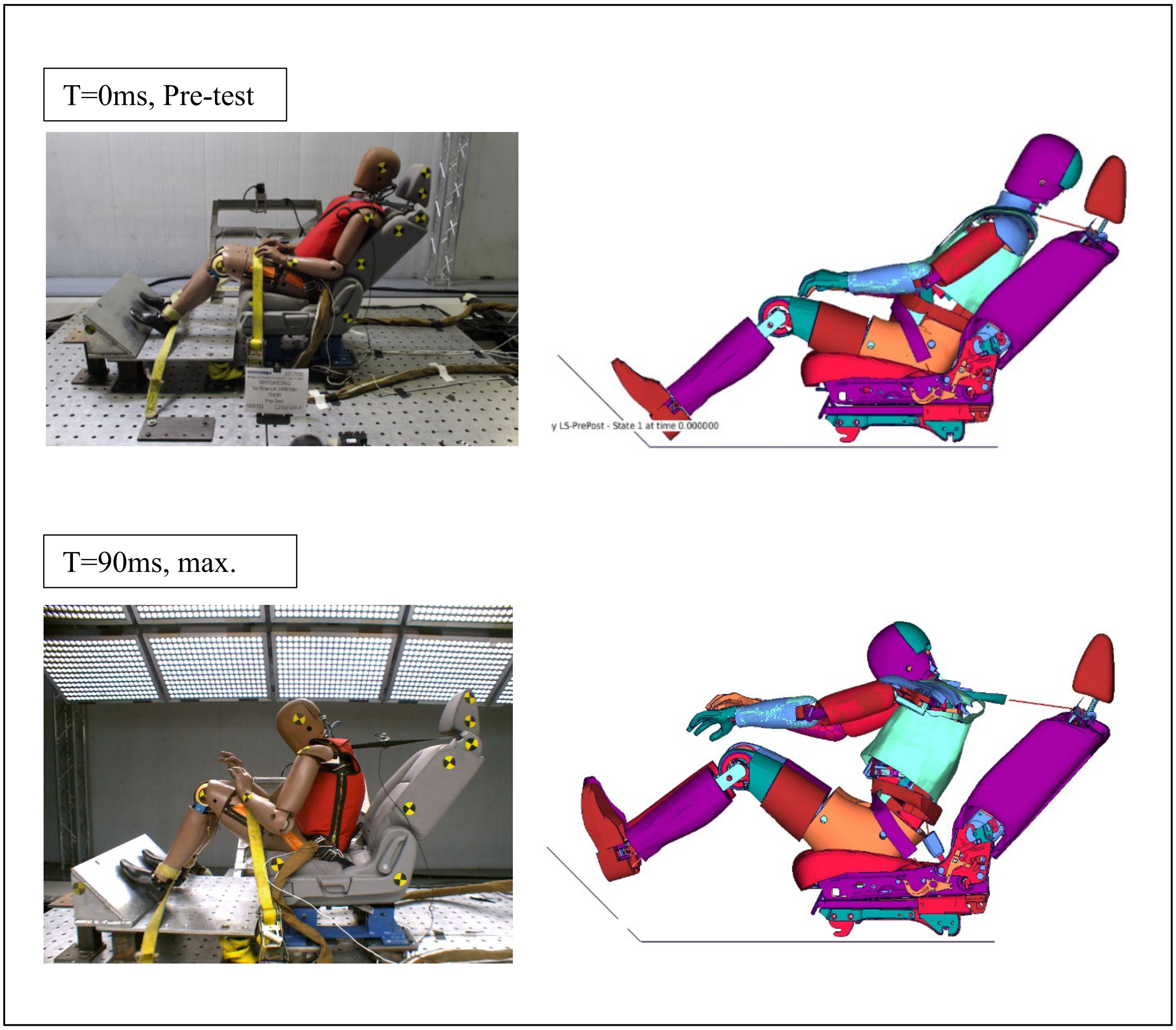

Figure 66. Frontal Impact Sled Test and FEA Simulation (45° Seat Back Angle)

The frontal impact FE simulation and the sled test results comparison, including occupant head acceleration plot, resultant head acceleration, and neck forces, are shown in Figures 67, 68, and 69.

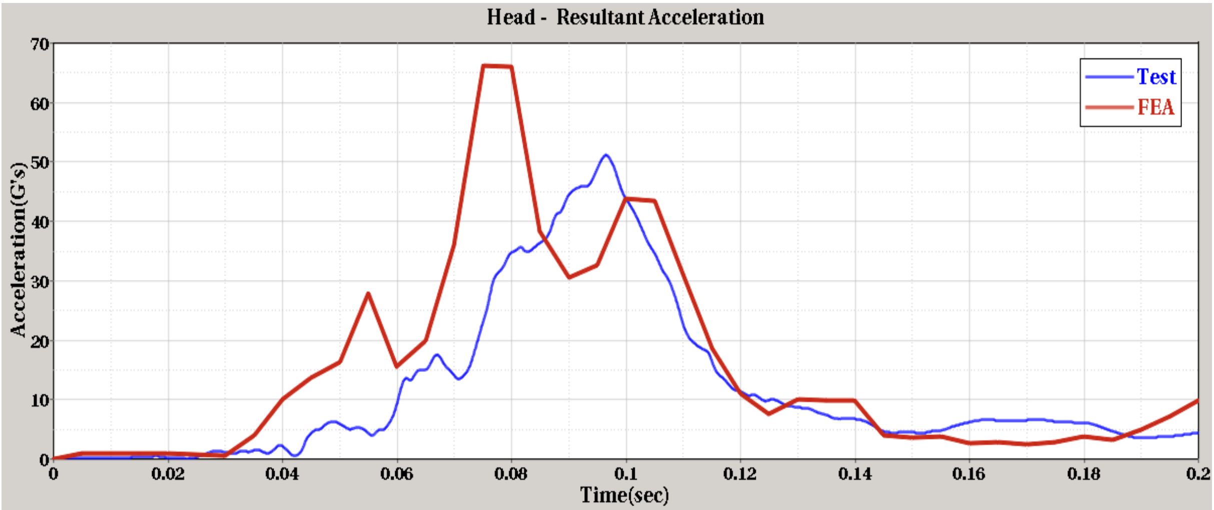

Figure 67. Head Resultant Acceleration

The fluctuation in the resultant head acceleration of FEA curve is because of the dummy's head impact on the chest during the simulation.

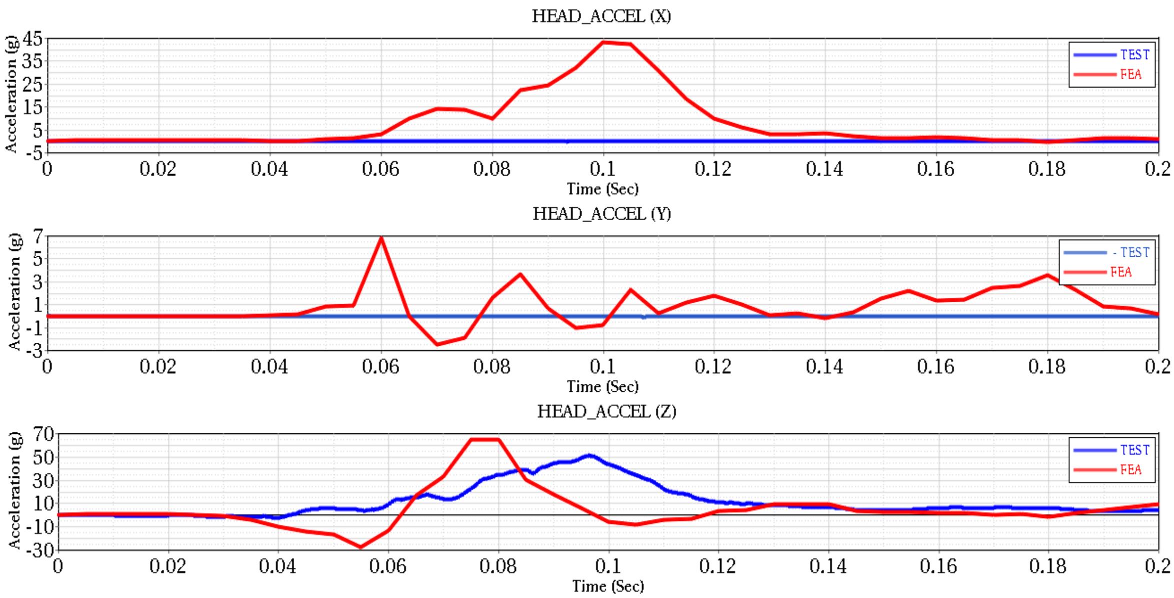

Figure 68. Head Acceleration in X, Y, and Z

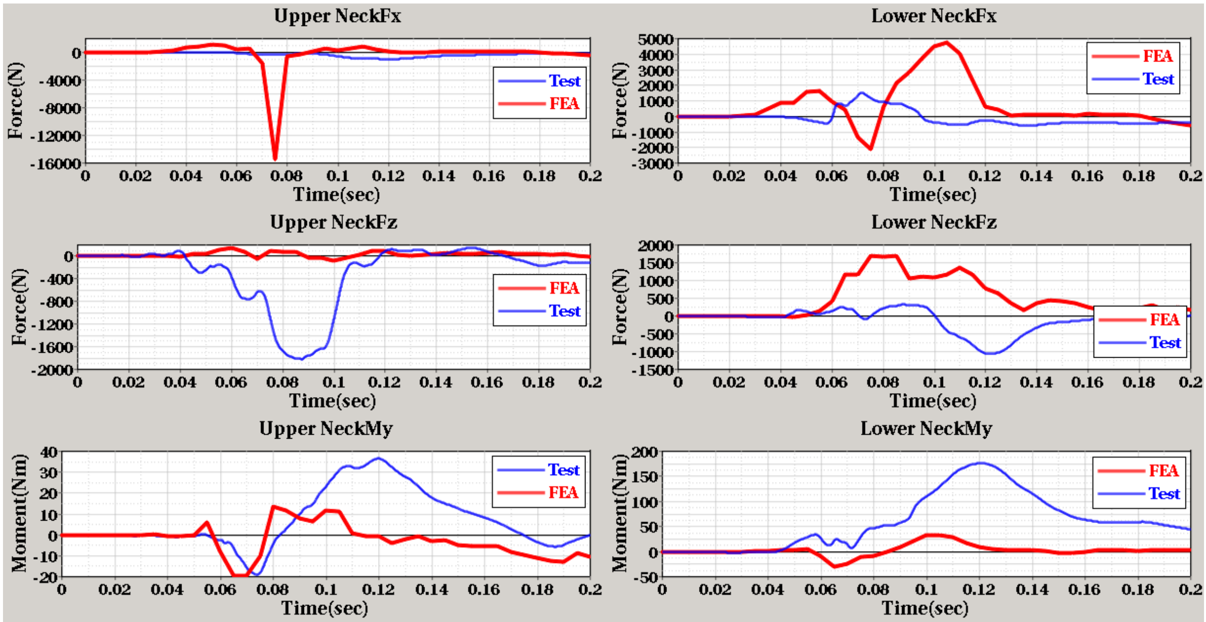

Figure 69. Neck Injury Forces

We see that the resultant head acceleration, along with head acceleration in X and Y direction curves, is not comparable, because head acceleration channels in X and Y direction were not recorded appropriately in the test. As per sub-contractor research, there was an issue with the lemo connector between the sensor and the DTS system.

The anchor forces were recorded from both test and FE simulation. Anchor forces from the test were recorded from the load cell attached to the anchor points, whereas in FEA cross-sectional planes were created on the anchors to extract the forces. The anchor forces from FEA and test comparison are shown in Figure 70 and Figure 71.

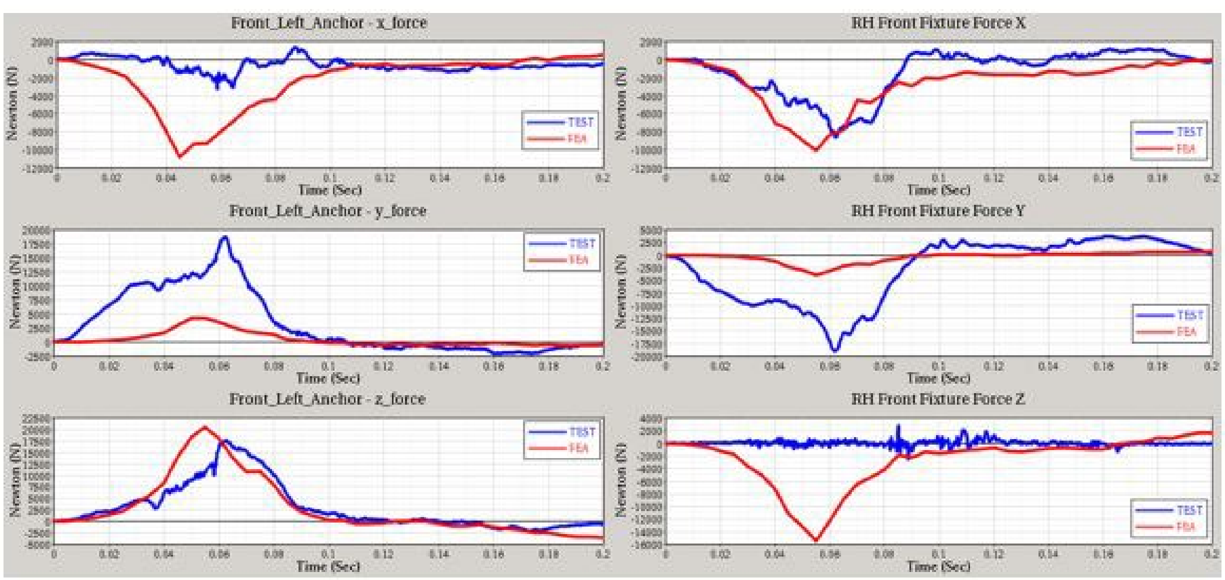

Figure 70. Front Anchor Forces

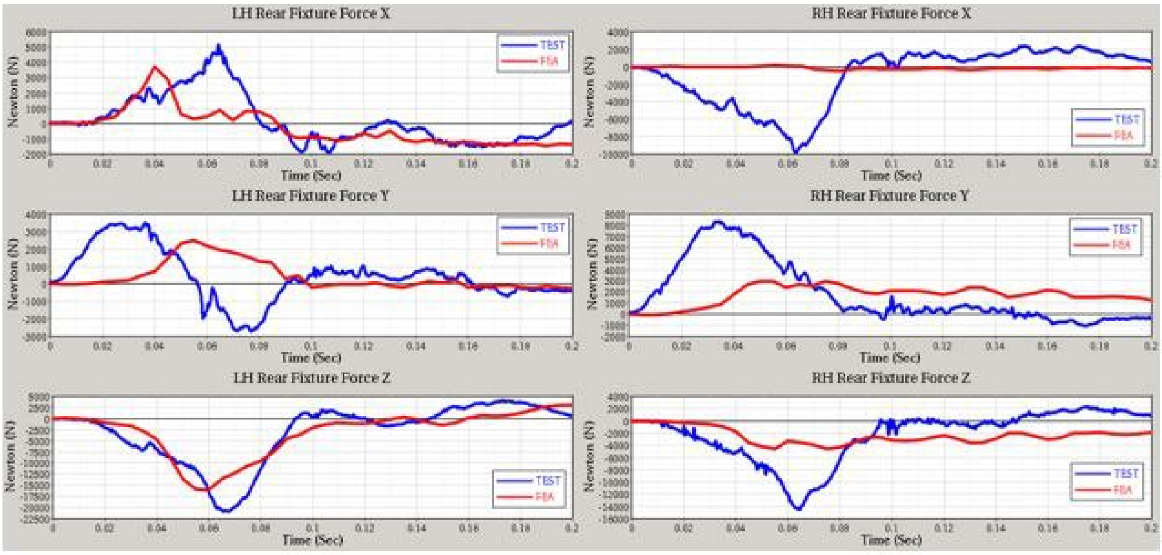

Figure 71. Rear Anchor Forces

Seat anchor forces will depend on the 3-point belt system and twisting of the dummy in the actual test.

8.3 Frontal Impact Sled Test (18° Seat Back Angle/56 kph)

THOR-50M was positioned in the ISS seat with 18° seat back angle. The ISS seat was subjected to 56 kph frontal crash pulse, which was applied on the sled. This test pulse generates peak acceleration of 36 G. This was the high generic vehicle pulse used in the sled test, and the pulse is shown in Figure 72.

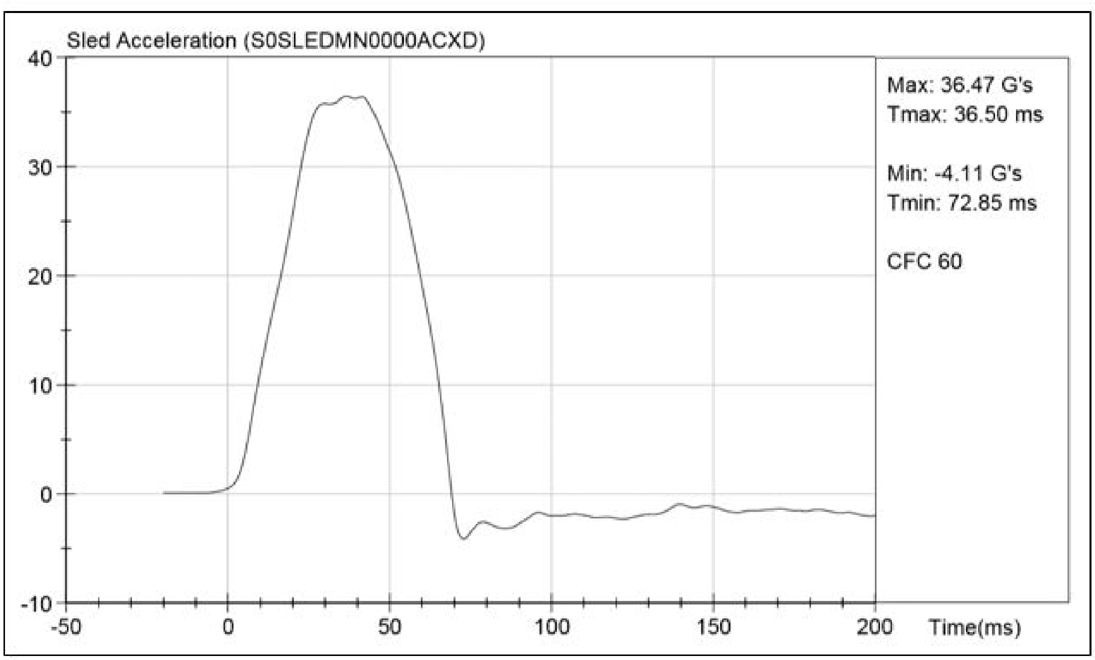

Figure 72. Front Sled Pulse (Generic, 38 G Pulse)

The seat track was welded to the fixture to secure the seat coming off from the fixture. The frontal impact sled test setup for the fully trimmed seat with 18° seat back angle with THOR-50M is shown in Figure 73.

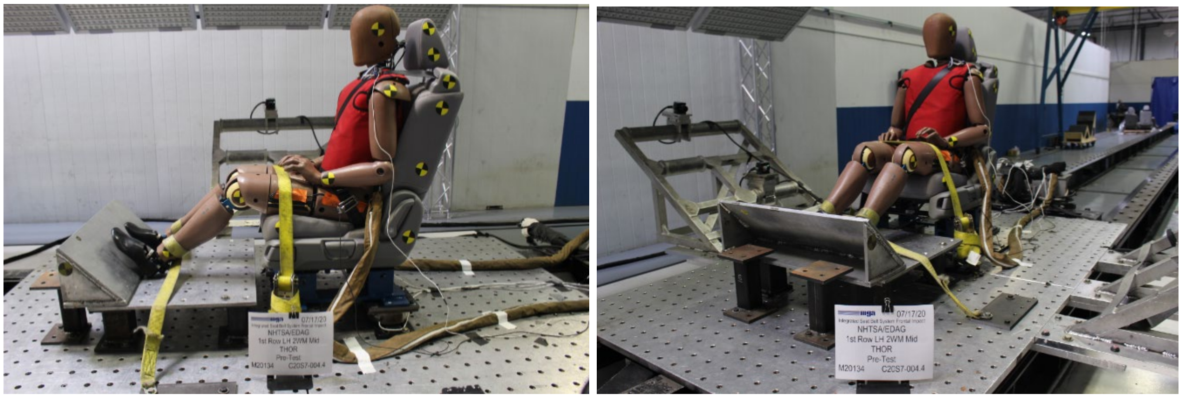

Figure 73. Frontal Impact Sled Test Setup (18° Seat Back Angle)

The seat was tested in the mid track position. Occupant characteristics including head acceleration and neck forces parameters were recorded. There was no significant deformation observed after the frontal impact test.

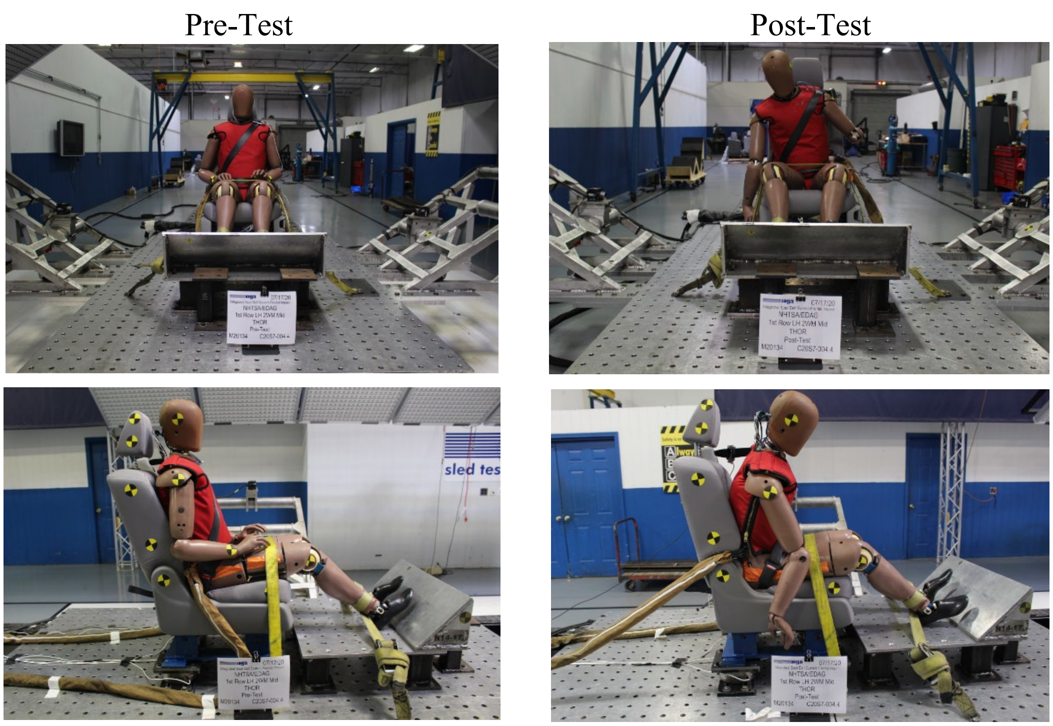

Figure 74. Frontal Impact Sled Test (18° Seat Back Angle)

8.3.1 FMVSS No. 208 Test Versus CAE Comparison (18° Seat Back Angle, 56 kph)

The FE (ISS) seat is positioned with seat back angle (18°) as per the test. THOR-50M was positioned as per the sled test setup. The ISS seat with the shoulder belt and lap belt were modeled and wrapped over the THOR dummy. Gravity load was applied to the overall sled, and 36 G pulse was given to sled in negative X direction. LS-DYNA simulation was run for 200 milliseconds, and the characteristics of the THOR dummy and seat structure were computed. In particular, occupant head acceleration and neck forces were plotted and compared with that of physical test. The kinematics of the seat back rotation and occupant position are shown in Figure 75 for 0 ms and 90 ms of the simulation and test.

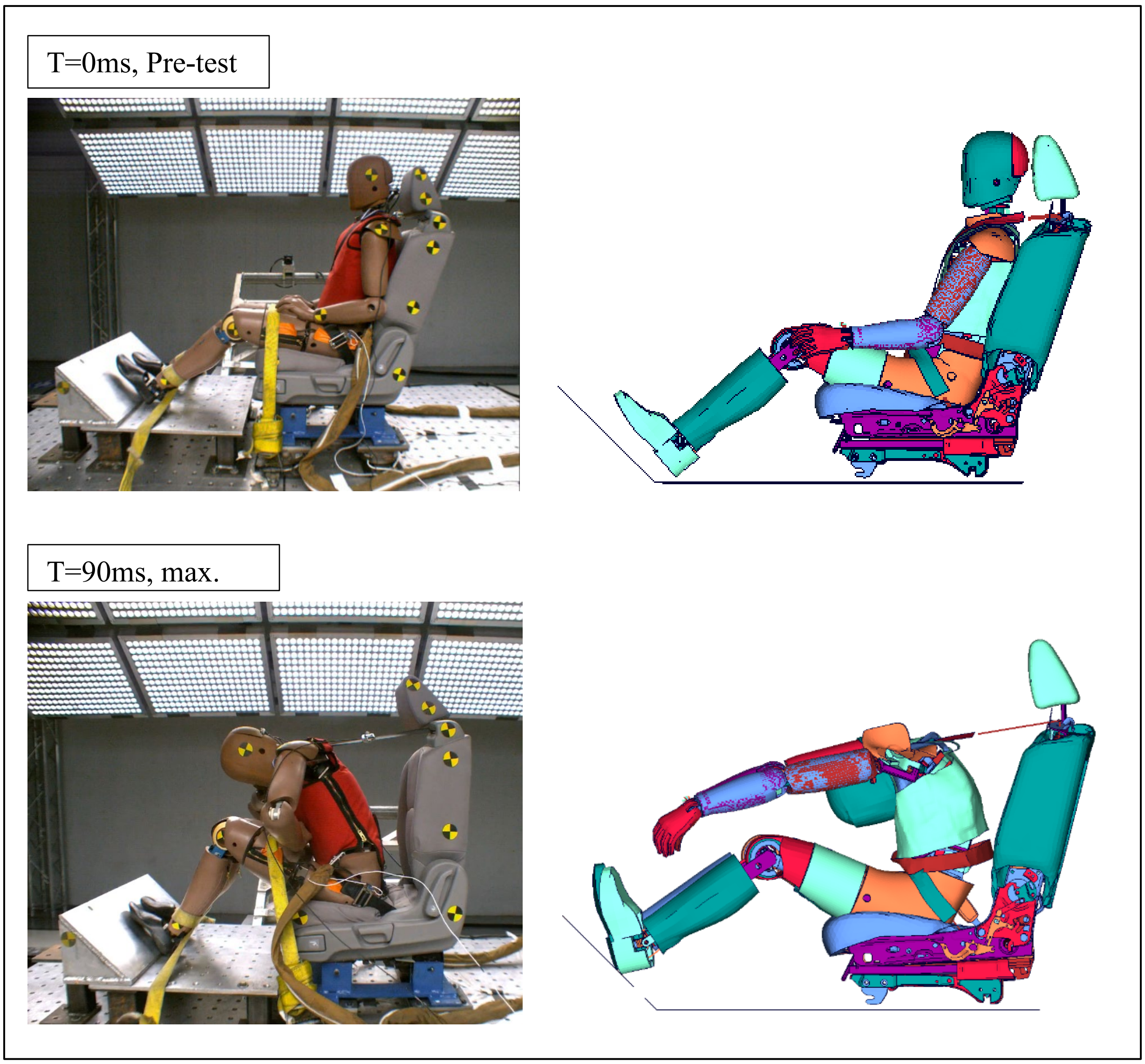

Figure 75. Frontal Impact Sled Test and FEA Simulation (18° Seat Back Angle)

The frontal impact FE simulation and the sled test results comparison, including occupant head acceleration plot, resultant head acceleration, and neck forces, are shown in Figures 76, 77, and 78.

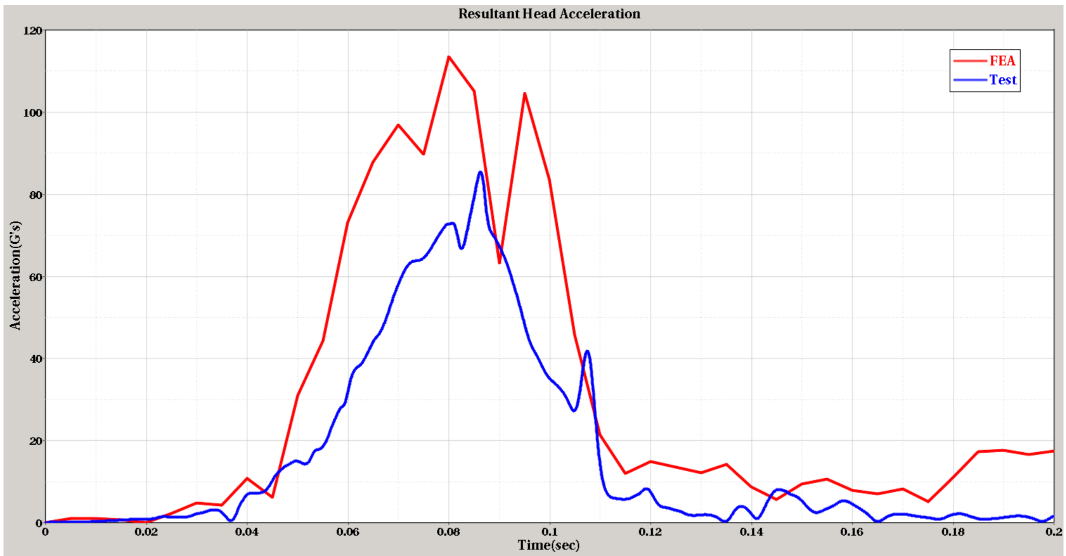

Figure 76. Resultant Head Acceleration

The fluctuation in the resultant head acceleration of FEA curve is because of the dummy's head impact on the chest during the simulation.

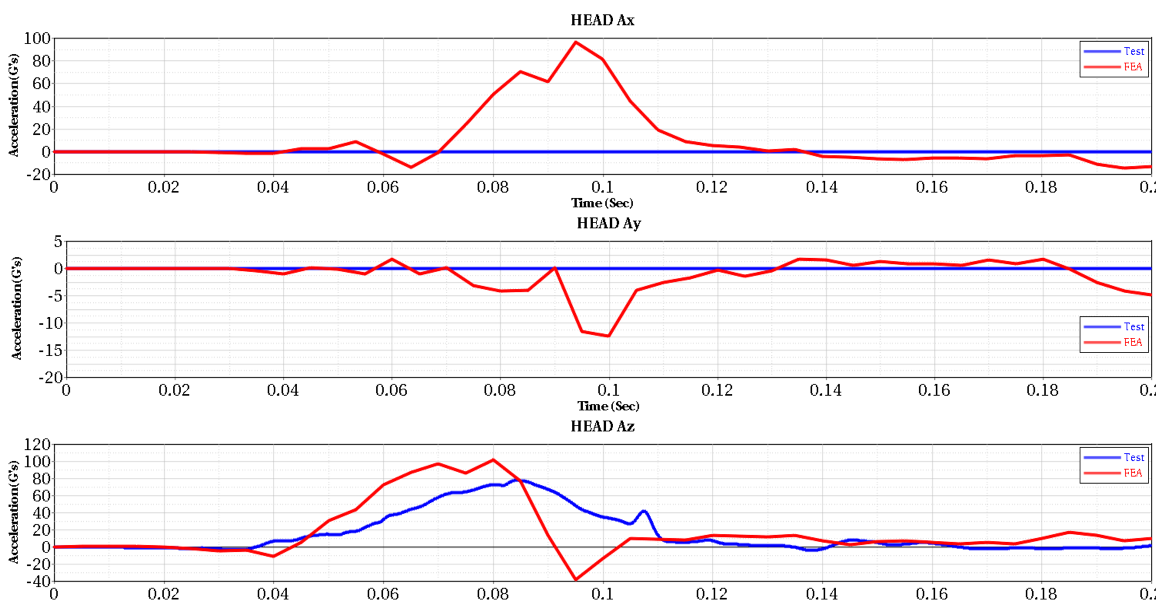

Figure 77. Head Acceleration in X, Y, and Z

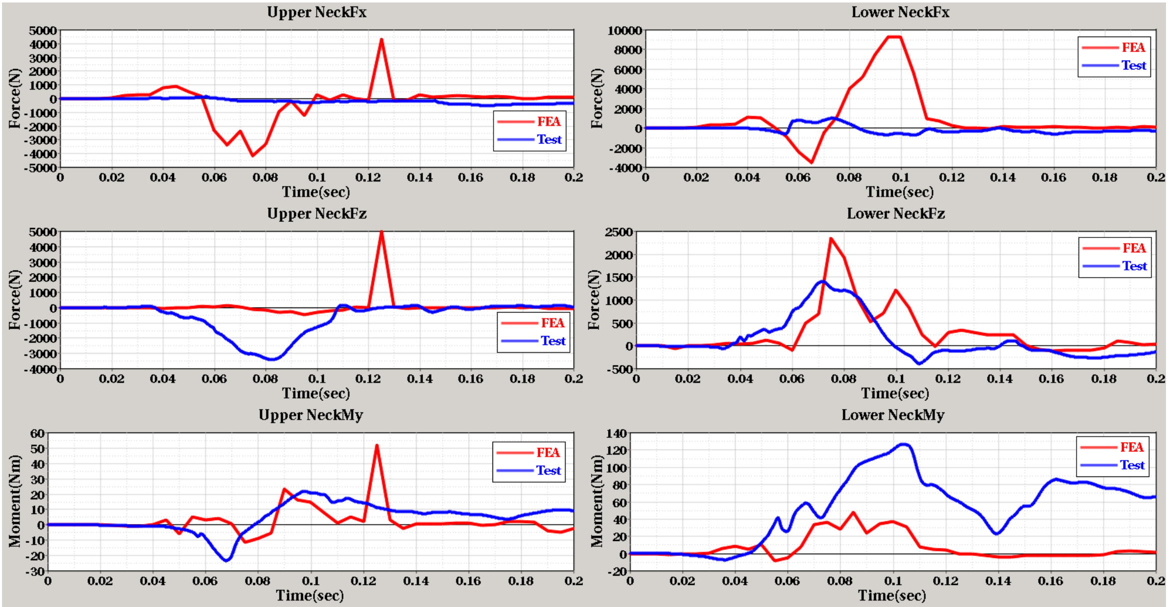

Figure 78. Neck Injury Forces

We see that the resultant head acceleration, along with head acceleration in X and Y direction curves, is not comparable, because head acceleration channels in X and Y direction were not recorded appropriately in the test. As per the sub-contractor, there was an issue with the lemo connector between the sensor and the DTS system.

The anchor forces were recorded from both test and FE simulation. Anchor forces from the test were recorded from the load cell attached to the anchor points, whereas in FEA cross-sectional planes are created on the anchors to extract the forces. The anchor forces from FEA and test comparison are shown in Figure 79 and Figure 80.

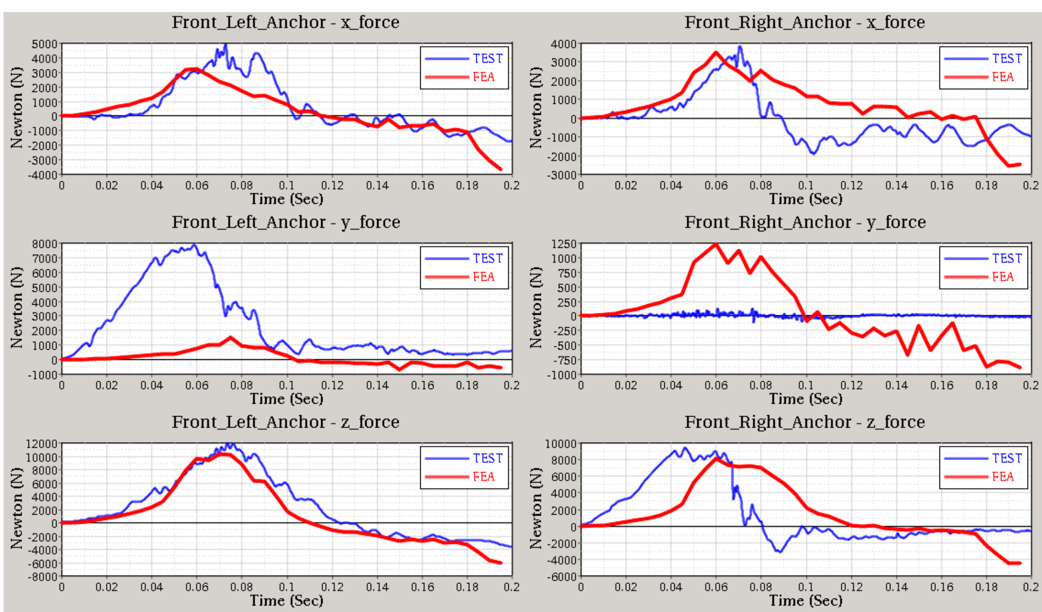

Figure 79. Front Anchor Forces

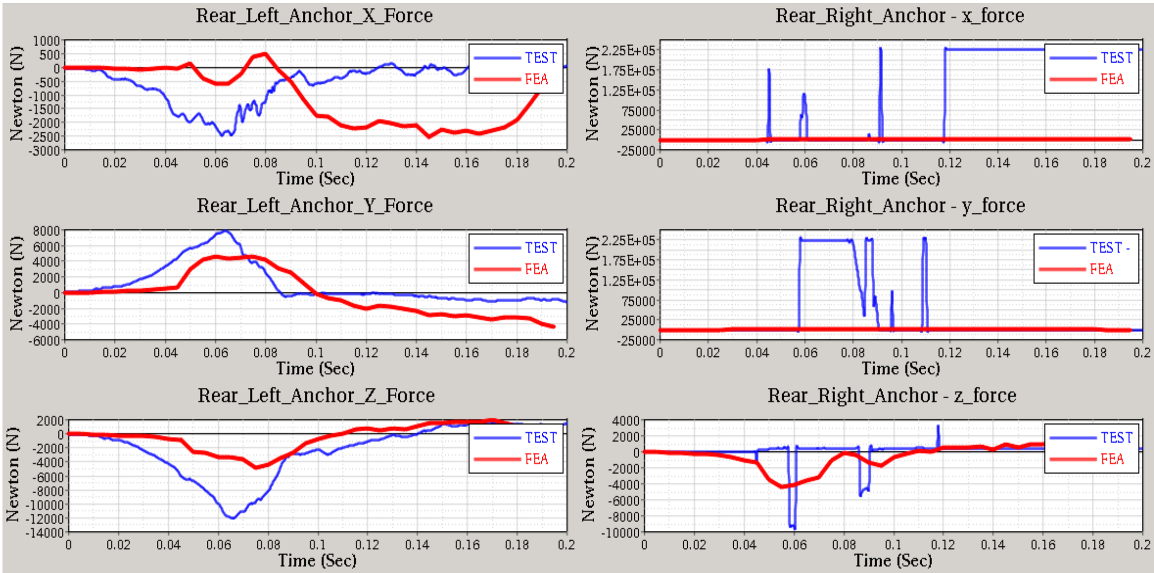

Figure 80. Rear Anchor Forces

Seat anchor forces will be depending on the 3-point belt system and twisting of the dummy in the actual test.

9 Conclusion

The primary objective of the project is to select, acquire, tear down, test, and develop an LS-Dyna FE model of a production automotive seat with an integrated seat belt. Two quasi static pull tests based on FMVSS No. 207 and FMVSS No. 210 were proposed with extended loading until seat collapsed. High-speed rear and frontal impact scenarios were also proposed. The development of an FE model, representing a seat with integrated seat belts from a recent passenger vehicle, was carried out by using CAE techniques in a systematic approach. Starting with identifying the ISS seat of a good performing vehicle, the study was conducted by the steps listed below:

1. Identified a vehicle with ISS seats, which is currently in the market.
2. Procured the necessary ISS seats.
3. Developed the FEA model of the ISS seats.
4. Recliner mechanism was modeled with detailed parts, but the joint is represented by a beam element with assumed torsional stiffness.
5. Conducted quasi-static seat rearward and forward pull tests, validated and compared FEA seat models with respect to tests.
6. Conducted FMVSS No. 301 rear-impact sled test using the BioRID-II dummy, validated and compared FEA seat models with respect to test.
7. Conducted five additional sled tests to evaluate frontal and rear impacts at two different reclined seating angles using the THOR dummy and validated FEA models.

A summary of the study is provided in the next section.

10 Summary of Project Results

In this project, a Honda Odyssey second row seat with an ISS was chosen for CAE model development. The reason for this selection was based on cost and availability of complete assembled seat frame and limited assembly requirement by the OEM parts department. After approval of the selected seat, both a fully trimmed seat and a seat frame were ordered from the selected OEM parts department. The physical tests based on FMVSS No.207 and FMVSS No.210 quasi-static pull tests as well as dynamic rear and frontal impact tests were identified for model development and validation. The FE model was developed using LS-DYNA software. Dynamic crash simulations were done by using appropriate ATD models. The FEA seat models were validated and correlated for quasi-static seat rearward and forward pull simulations with respect to physical test. A third-party testing organization was sub-contracted to conduct the quasi-static and dynamic sled tests. The quasi-static seat model simulation results in terms of seat back rotation kinematics and static deflection were compared, and good correlation was achieved. Seat models were considered to be good for further development.

As per the scope of the project, the study evaluated occupant kinematics and injury in high-severity frontal and rear-impact crashes. FEA models for these two scenarios were developed. To validate the modeling of the ISS seat, the high-speed rear-impact sled test was conducted. Generic vehicle pulse based on FMVSS No. 301 rear-impact pulse (20 G) was used for the sled speed. The BioRID-II 50th percentile male occupant dummy was used, which was calibrated and supplied by NHTSA. The results from the sled tests were used to compare the simulation results. Two parts of the results, seat kinematics and occupant injuries, were included for comparison. The kinematic motion of the seat with the dummy was closely matched to that of the sled test. The HIC and NIC values of the occupant dummy in the physical test and simulation were compared, and a good correlation was achieved. The FEA models were considered good for further development.

The next part of the project was a test plan for five optional sled tests to evaluate rear and frontal impacts at two different seat back angles. The two rear-impact tests were conducted with 18° and 45° seat back angle at 27 kph speed (19 G generic pulse) using the THOR 50th percentile male occupant dummy. The THOR 50th percentile male occupant dummy was used, which was calibrated and supplied by NHTSA. FE simulations replicating these two scenarios were performed. The results from the sled tests were used to compare the simulation results. Three parts of the results (seat kinematics, occupant injuries, and anchor forces) were included for comparison. The HIC and NIC values of the occupant dummy of test and simulation were compared.

Similarly, two frontal impact tests were conducted with 18° and 45° seat back angle at 40 kph speed (28 G generic pulse) using THOR 50th percentile male dummy. The THOR 50th percentile male occupant dummy was used, which was calibrated and supplied by NHTSA. FE simulations replicating these two scenarios were performed. The results from the sled tests were used to compare with the simulation results. Seat kinematics, occupant injuries, and anchor forces were included for comparison. The HIC and Neck force values of occupant dummy of test and simulation were compared. The final frontal impact test was performed with high speed of 56 kph and 40 G generic pulse at 18° seat back angle using the THOR 50th percentile dummy. The FE model was set up to replicate the high-speed scenario, and a simulation was performed.

The results from the sled tests were used to compare the simulation results. Seat kinematics, occupant injuries, and anchor forces were included for comparison. The HIC and NIC force values of occupant dummy of test and simulation were compared.

In the sled tests with respect to the THOR dummy, the head acceleration channels in X and Y direction data were not recorded appropriately. As per sub-contractor, there was an issue with the lemo connector between the sensor and the DTS system. Hence, the head resultant acceleration and NIC plots between test and FEA are not similar.

As per the main scope, an LS-Dyna FE baseline model of a production automotive seat with an integrated seat belt was developed. The recliner mechanism was modeled only for simulation purpose, and beam element was used with assumed stiffness. The recliner mechanism has to be developed independently to get the accurate recliner stiffness for further studies.

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