# Abaqus BioRID-II Crash Dummy Model

Summary

The Biofidelic Rear Impact Dummy (BioRID-II) hardware model has been developed to measure automotive seat and head restraint system performance in low-speed rear end crashes. It has also been used to further the understanding of whiplash injuries. This technology brief focuses on the Abaqus BioRID-II finite element model, which has been developed in cooperation with the German Association for Research in Automobile Technology FAT. The capabilities of the model will be described, and a comparison with experimental data is shown.

Background

Soft tissue neck injuries, also termed whiplash associated disorders (WAD), are among the most frequently reported injuries of car occupants. Approximately 10% of whiplash injuries are long-term and 1% are permanent [1]. Long term and permanent WAD in motor vehicle accidents are an important public concern since they lead to disabilities and high insurance/health costs [2].

To address this problem the members of International Insurance Whiplash Prevention Group (IIWPG) developed geometric head restraint and dynamic seat evaluations for whiplash injury prevention [3]. While the geometric head restraint requirement (height and horizontal distance to the back of the head) is a necessary condition for good protection, it is not sufficient; protection also depends on the relative stiffness of the seatback. To assess seatback stiffness and other characteristics of whiplash injury prevention, crash testing and other dynamic assessments are required. To perform dynamic evaluations, a test dummy with a realistic spine and neck configuration is needed. In recent years, a new crash dummy, BioRID-II, with a construction intended to mimic the response of the human spine in the sagittal plane, was developed for testing in rear crashes at low to moderate speeds.

Finite element crash dummy models allow for an experimental test cost reduction and can provide insight on the response occurring during a crash event. In order to facilitate the development of a finite element BioRID-II crash dummy model, the FAT formed a BioRID-II Working Group that includes the following German OEMs and their suppliers: BMW, Daimler, Audi, Volkswagen, Porsche, Opel, Johnson Controls, Hammerstein, Keiper, and Karmann. The Abaqus BioRID-II model has been developed by SIMULIA in cooperation with FAT, which defines the tests and requirements and approves the models.
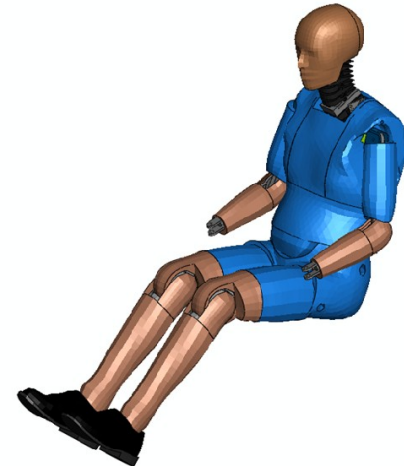
Key Abaqus Features and Benefits

- General contact capability in Abaqus/Explicit allows for easy definition of complex contact conditions within the dummy and between the dummy and its environment

- Integration of Abaqus/Explicit and Abaqus/ Standard allows for the development of numerous analyses and increased robustness by evaluating the dummy response under various types of loads

- Connector elements in Abaqus allows for modeling complex connections and instrumentation

- Extensive material library allows for modeling of rate sensitive foams, hyperelastic, and viscoelastic materials

- Scripting interface allows for reading of data from the output database file for further post processing

Finite Element Model

The BioRID-II crash dummy represents a 50th percentile male, and is used for dynamic evaluations of seat designs by a number of original equipment manufacturers that are part of the FAT consortium. It contains a fully articulated spine in the sagittal plane (Figure 1) composed of 24 vertebrae (L5-L1 lumbar, T12-T1 thoracic and C7-C1 cervical) connected by joints. Rubber bumpers are glued at the top of each vertebra in the anterior and the posterior sides. Muscle substitute and damper cables are added to
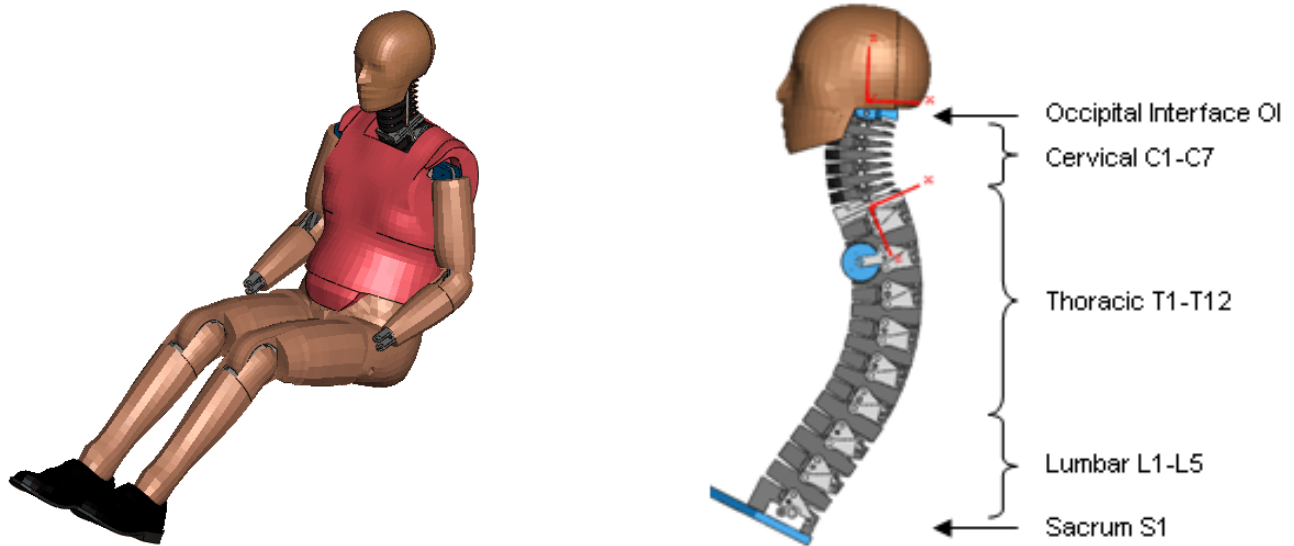
Figure 1: Abaqus BioRID-II model (left); spine-head subsystem showing vertebrae (bottom)

the neck region to model muscle strength. The torso flesh, modeled with silicone material, connects to the spine by means of interface pins. The abdomen is filled with water for proper mass distribution. Head, pelvis and limbs are modified parts of the Hybrid III dummy [4].

The Abaqus BioRID-II model (Figure 1) consists of approximately 66,000 elements and 250,000 degrees of freedom (DOF) with a total mass of 79.48 kg. It has been developed using Abaqus/Standard and Abaqus/Explicit.

Strategic use of connector elements helps to reduce the size of the model. Connector elements in Abaqus provide a convenient way to model complex joints and mechanisms. Figure 2 highlights (in red) the cables and torsional pins in the spine; these, along with the damper in the
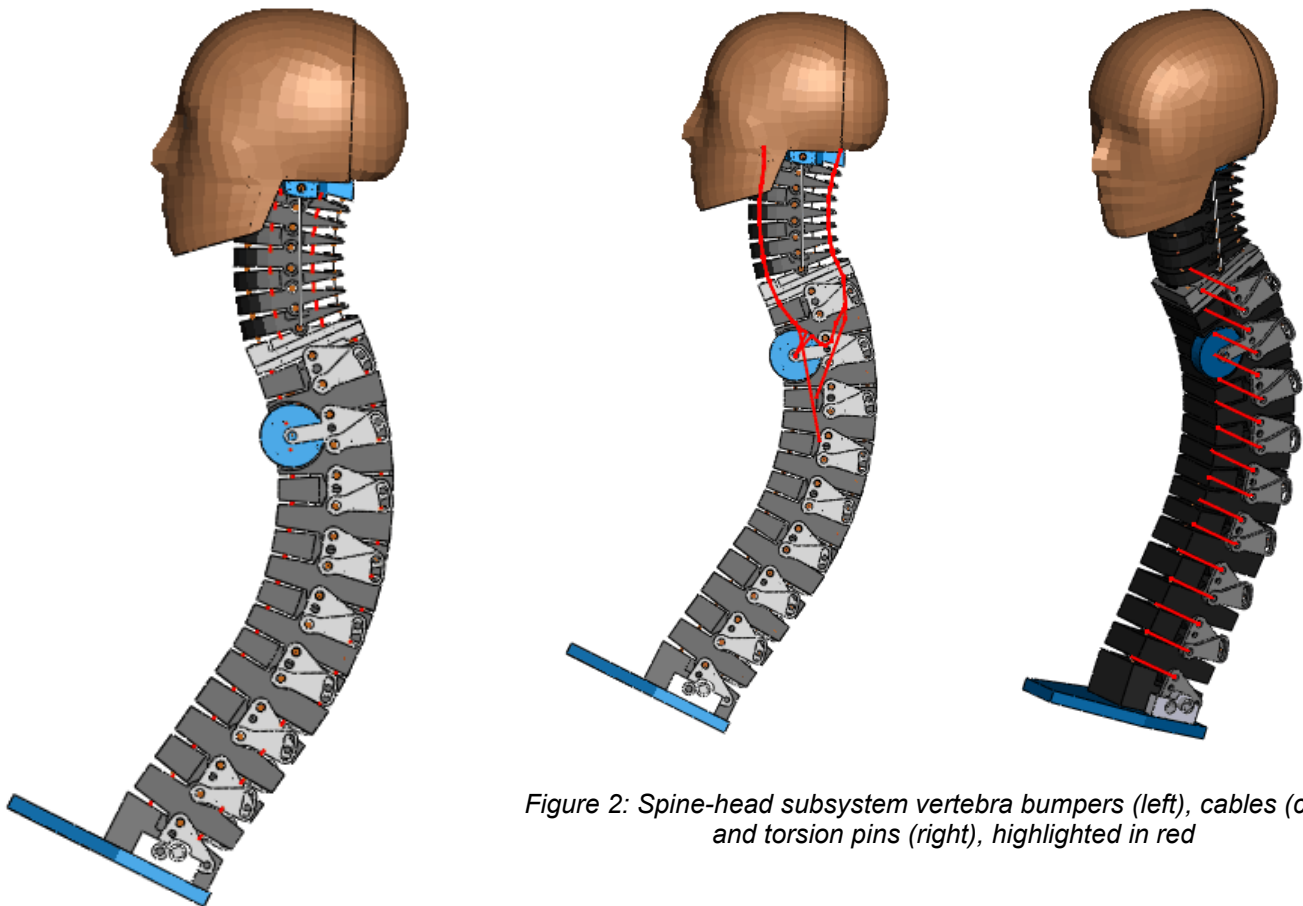

Figure 2: Spine-head subsystem vertebra bumpers (left), cables (center), and torsion pins (right), highlighted in red

spine and all joints throughout the dummy are modeled with connector elements. Further, connectors are also used to capture the instrumentation output.

Rate sensitive models are used for all rubber, silicone, and foam materials. Solid element subcomponent models were used to capture the rate dependent response of rubber bumpers for various dynamic loads. The information obtained from these models was used to build a simplified and more robust representation for each vertebra bumper (Figure 2) using truss elements and rate sensitive foam material.

Instrumentation that can be used to obtain output is also included in the model. Connectors are used to measure the acceleration of the head, pelvis, and spine. Connector elements were also used to model lower and upper neck load cells, as well as a neck link device that measures relative rotations between the T1 vertebra and the occipital interface (OI). A real-time, antialiasing filter available in Abaqus/Explicit was used to optimally create history output. During postprocessing, the output was then read from the output database file using the Abaqus Scripting Interface and filtered according to SAE specifications.

Finite Element Analysis Approach

The full dummy model is experimentally validated on the universal Chalmers seat [5]. Developed at Chalmers University of Technology in Sweden, the seat (Figure 3) has a number of separate and adjustable elements that allow for a thorough investigation of isolated seat parameters and the interaction between dummy and seat.

The Abaqus BioRID-II model contains appropriate initial deformations and stresses from the assembly procedure. The most important effects of this procedure are introduced during the spine shape calibration, in which the spine curvature is adjusted by applying tension in the muscle substitute cables.

Dummy positioning in Abaqus is accomplished by performing a separate quasi-static analysis prior to the dynamic loading step. The dummy is first positioned at the H-point using a preprocessor. In the subsequent quasi-static analysis, the dummy is locked at the H-point, gravity loading is applied and contact is resolved.

The frictional contact behavior between the dummy and the seating platform, back seat panels and foam arm supports was modeled using data obtained from experiments.

In order to validate the numerical model of the entire assembly (dummy and seat), Abaqus results were compared to test results provided by the FAT consortium. Three test pulses were used from the EuroNCAP proposal for whiplash tests [6]: (a) Low severity pulse: trapezoidal 16km/h delta-v, 5g max; (b) Middle severity pulse (IIWPG): triangular 16km/h delta-v, 10g max; and (c) High severity pulse: trapezoidal 24km/h delta-v, 7g max.

The following test data were recorded: (a) head, C4, T1, T8, L1, pelvis accelerations in local x and z directions; (b) upper and lower neck force in local x and z direction and moment in local y direction; (c) Neck link rotation about OC and about T1; and (d) Head and T1 rotation and rotational velocity.

Results and Discussion

Figures A1-A6 in Appendix A show the instrumentation output for a low severity pulse test. The graph-based comparisons between simulation results and experimental data were used to compute "accuracy indicators", to assess the dummy model quality.

Overall, the full dummy model shows acceptable correlation with the experimental results and demonstrates the utility of computational analysis in the assessment of restraint system effectiveness.
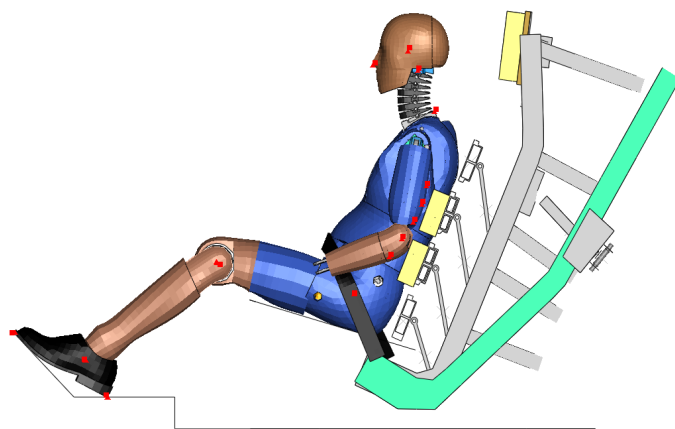

Figure 3: Test setup of BioRID-II in Chalmers seat (top); Abaqus BioRID-II in Chalmers seat (bottom)

Conclusions

The Abaqus BioRID-II model was developed using a systematic approach, utilizing extensive material, component and full dummy tests to calibrate and validate the model response. Techniques used in building the model include numerous connector elements and advanced material models. Both implicit and explicit solution methods were used to generate results. The results presented in this technology brief confirm that the Abaqus BioRID-II model can be very useful in investigating whiplash injury prevention and assessing the realistic performance of a complete seat system.

Acknowledgements

The Abaqus BioRID-II development has been partially sponsored by the German Association for Research in Automobile Technology FAT.

References

1. Avery M., Weekes A.M., "Dynamic testing of vehicle seats to reduce whiplash injury risk: an international protocol", The Motor Insurance Repair Research Centre (Thatcham) UK, ICrash International Crashworthiness Conference, 2006.
2. Ad-Hoc Group on Whiplash Injuries at European Enhanced Vehicle-Safety Committee, "Working Group 12 Report. Document No. 157", 2002.
3. International Insurance Whiplash Prevention Group, "Rationale for IIWP Ratings of Seats and Head Restraints for Neck Injury Prevention", 2004.
4. Robert A. Denton, Inc., "BioRID-II User's Manual", 2005
5. Deter T., Malczyk A., Kuehn M., "Validation Of A Seat-Dummy Simulation Model For Rear-Impact", German Insurance Association – Accident Research, NHTSA, Paper Number 07-0151
6. Bortenschlager K. et all, "Review of existing injury criteria and their tolerance limits for whiplash injuries with respect to testing experience and rating systems", NHTSA, Paper Number 07-0486

Abaqus References

For additional information on the Abaqus capabilities referred to in this brief please see the following Abaqus 6.11 documentation references:

- Analysis User's Manual

  - "Hyperelastic behavior of rubberlike materials," Section 21.5.1

  - "Defining contact interactions," Section 34

  - "Connector elements," Section 30.1

- Abaqus Scripting User's Manual

  - "Reading from an output database," Section 9.5

Appendix A: Low Severity Pulse Results

Figure A1: Comparison of Abaqus BioRID-II model results with experimental test data for head, C4, T1, T8, L1, and pelvis accelerations in x direction.

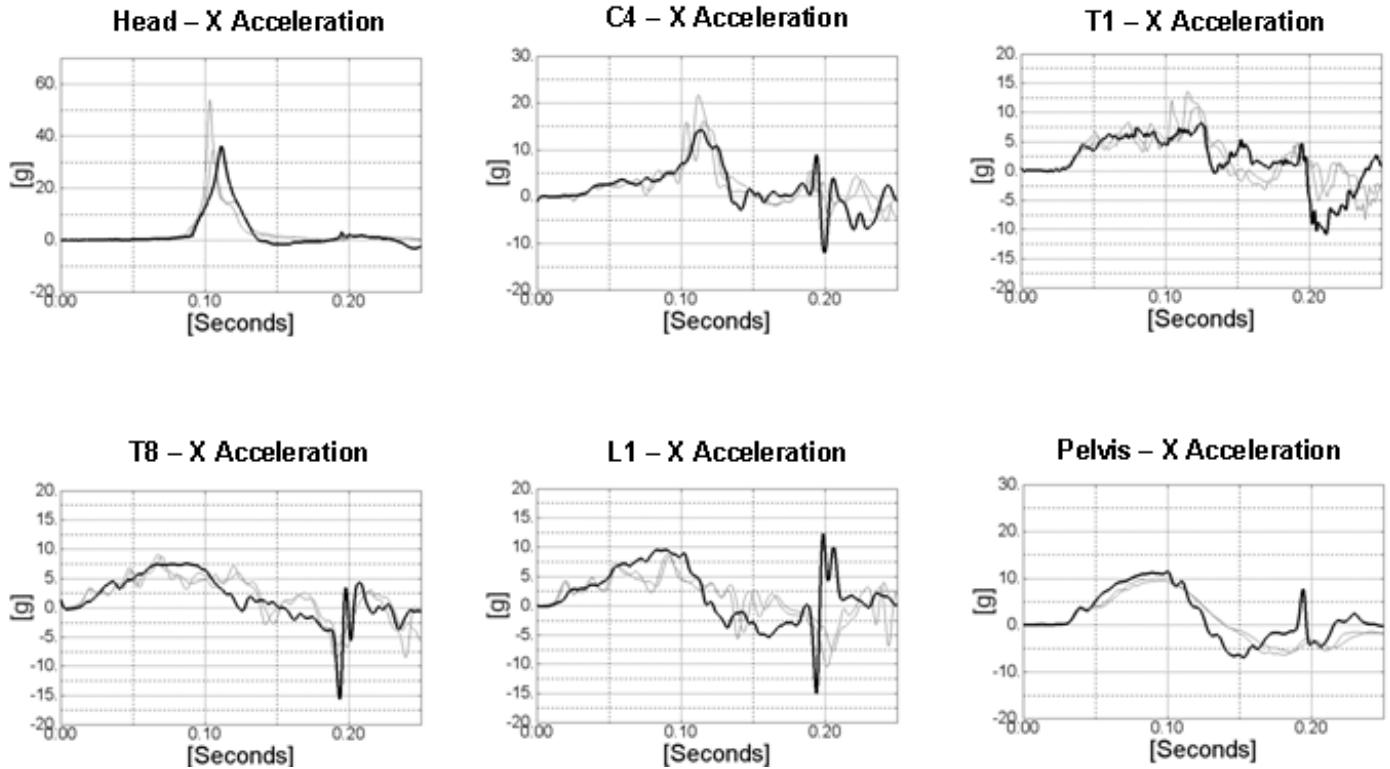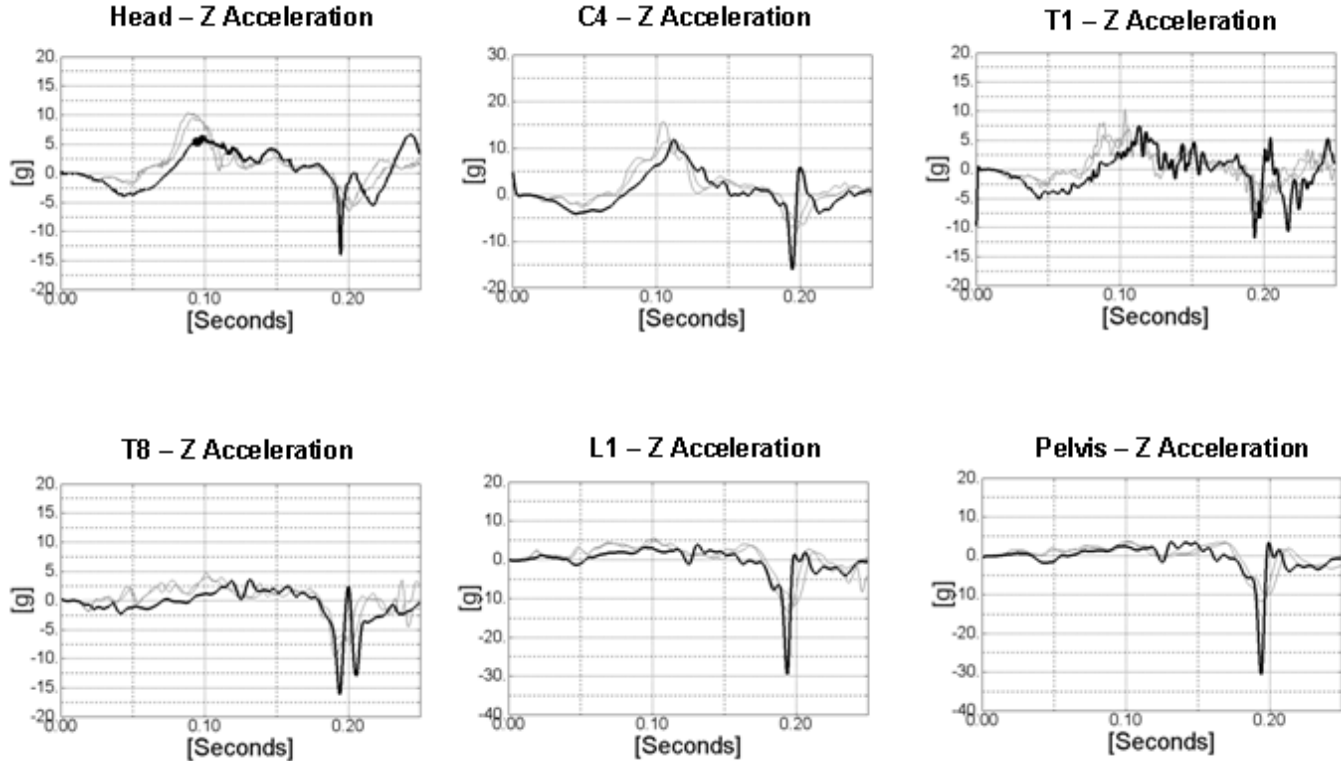
Figure A2: Comparison of Abaqus BioRID-II model results with experimental test data for head, C4, T1, T8, L1, and pelvis accelerations in z direction.
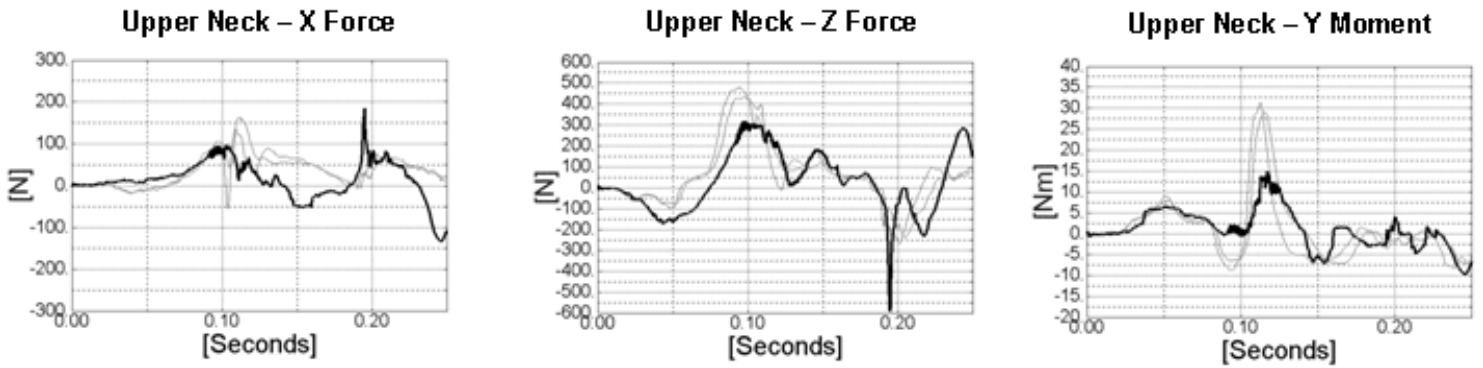
Figure A3: *Comparison of Abaqus BioRID-II model results with experimental test data for upper neck force (x and z direction) and moment (y direction) measured at the load cell location.*
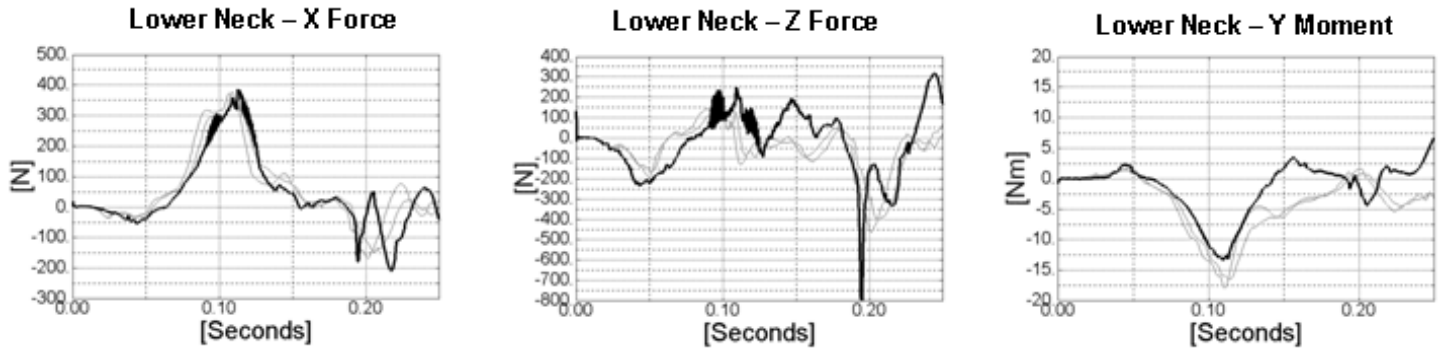
Figure A4: *Comparison of Abaqus BioRID-II model results with experimental test data for lower neck force (x and z direction) and moment (y direction) measured at the load cell location.*

Figure A5: *Comparison of Abaqus BioRID-II model results with experimental test data for neck link about OC rotation, head rotation and head rotational velocity.*
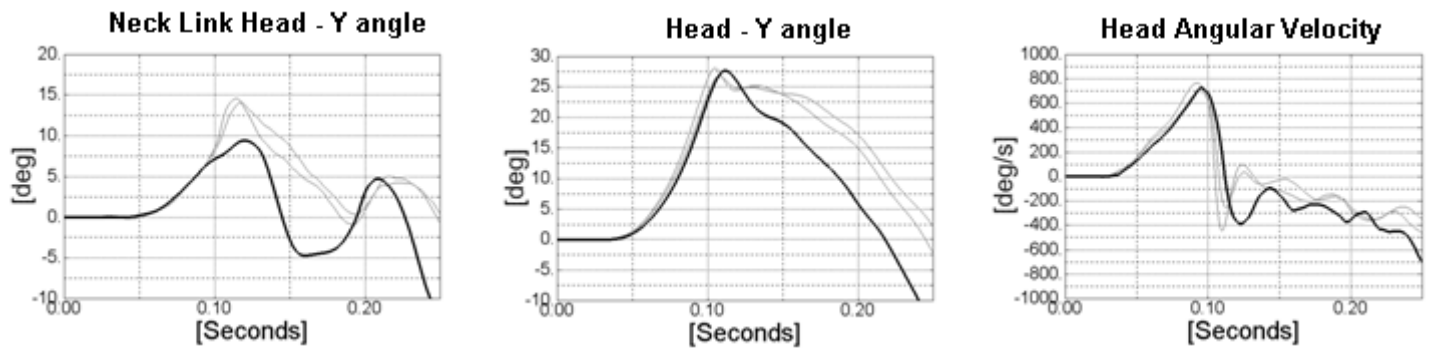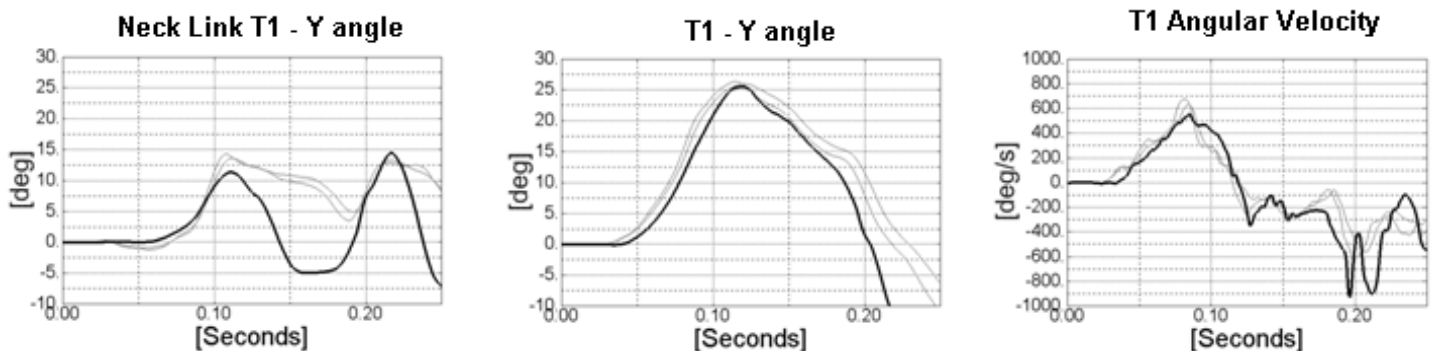
Figure A6: *Comparison of Abaqus BioRID-II model results with experimental test data for neck link about T1 rotation, T1 rotation and T1 rotational velocity.*

3DS SIMULIA

Result		Abaqus BioRID-II		Physical BioRID-II		Individual and average error [%]			
		Impact phase	Rebound phase	Impact phase	Rebound phase	Impact phase		Rebound phase	
Head	Ax	36.1	3.2	53.5	2.1	32.6		51.4	
	Az	6.5	-13.9	9.4	-6.5	30.8		115.3	
C4	Ax	14.0	-12.1	15.9	-4.4	11.8		177.5	
	Az	11.8	-16.0	12.0	-7.3	1.2		118.0	
T1	Ax	8.1	-10.8	10.9	-5.1	26.2		113.9	
	Az	7.4	-11.7	7.1	-7.3	4.9		60.6	
T8	Ax	7.4	-15.5	8.7	-8.4	15.1		83.7	
	Az	3.4	-16.1	4.7	-9.6	28.3		67.7	
L1	Ax	9.5	-14.7	8.8	-10.3	8.8		43.1	
	Az	3.1	-29.6	4.9	-13.5	36.6		118.9	
Pelvis	Ax	10.9	7.6	10.0	-2.9	9.4		359.9	
	Az	2.4	-30.6	3.3	-11.6	27.0	19.4	162.8	122.7
Upper neck	Fx	91.1	184.9	85.6	74.9	6.3		146.8	
	Fz	301.2	-588.7	427.4	-265.3	29.5		121.9	
	My	14.2	-3.0	28.2	-3.2	49.6		5.4	
Lower neck	Fx	381.7	-208.4	377.5	-168.4	1.1		23.7	
	Fz	240.0	-879.1	124.3	-447.3	93.1		96.5	
	My	-13.3	-4.4	-16.4	-5.4	19.0	33.1	19.9	69.0
Head	Ang. Vel	725.3	-368.6	697.4	-361.0	4.0		2.1	
T1	Ang. Vel	554.0	-898.2	631.6	-619.2	12.3	8.1	45.1	23.6
Head	Y angle	27.6	N/A	28.1	N/A	1.5		N/A	
T1	Y angle	25.5	N/A	26.0	N/A	1.8		N/A	
Neck link Head	Y angle	9.4	4.7	14.1	5.0	33.1		5.8	
Neck link T1	Y angle	11.4	14.3	13.6	13.3	16.2	13.2	7.3	6.6

Table A1: Accuracy indicators generated from Figures A1 – A6

Most of the response variables typically show multiple peak magnitudes during the test. Up to three most critical peak magnitudes for each response variable were compared against their experimental counterparts from one physical dummy (i.e. no averaging was performed for the responses of different physical dummies). A percentile error was computed using the formula:

$$\left| \frac{Experimental - Numerical}{Experimental} \right| * 100 \quad [\%]$$

These errors were then averaged separately for likewise variables (i.e. accelerations and forces) to generate the above mentioned model accuracy indicators. Also, a distinction was made between the two main phases of the experiment: the impact phase (of main interest, up to roughly 100ms) and the rebound phase (of secondary interest, afterwards). For the main impact phase the dummy model shows correlation with the experimental data that is, on average, 15% different at peak response. Some variables (head and T1 accelerations along the spine profile, Az, and the upper neck load cell results) show smaller peaks for numerical results when compared with experimental ones. For the rebound phase, differences are significant between numerical and experimental results for most of the output variables monitored. These large differences arise mostly from the lack of experimental data for an accurate modeling of the seatbelt and its connection to the seat, both of which being very important factors in the dummy behavior during this portion of the dynamic test.

The level of correlation between the Abaqus BioRID-II model and experimental test data for the IIWPG pulse and the high severity pulse are similar to the low severity case presented in this technology brief.

3DS SIMULIA