BioRID II Dummy Model Development
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Influence of Parameters in Validation and Consumer Tests

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Abstract

Whiplash injuries frequently occur in low speed rear crashes. Many consumer and insurance organizations use the BioRID II dummy, to assess the risk of whiplash injuries in car accidents. An LS-DYNA model of the BioRID II dummy has been developed by DYNAmore GmbH in cooperation with the German Automotive Industry. In the consortium a huge effort has been made to build a test database for the development of the FE-dummy. This paper describes the effort performed to generate the experimental data for material, component and full dummy validation. The dummy contains a considerable number of pre-stressed parts which can not be neglected since it stiffens the neck significantly. In order to capture the occurring pre-stresses appropriately the modeling techniques require the application of new features in LS-DYNA and specific handling during pre-processing. The paper describes the model and shows its performance in validation tests. Finally, different whiplash simulations are used to emphasize influences of selected parameters on injury criteria of the BioRID II model.

Introduction

Often simulations regarding passive safety for passenger cars focus on structural behavior in accident scenarios with large deformations in the vehicle. Surprisingly, there is also a low speed impact scenario which causes painful and long lasting injuries. The so-called whiplash injury is often observed after rear crashes, even with considerably small damages to the vehicle. The impact results in an acceleration-deceleration mechanism in the neck and leads to soft-tissue injuries; this may turn to a variety of clinical manifestations. Symptoms such as neck pain may be present directly after the accident or may be delayed for several days. In addition to neck pain other symptoms may include increased neck stiffness, injuries to the muscles and ligaments, headache, dizziness, abnormal sensations such as burning or prickling, or shoulder or back pain.

The pain often lasts for a long time period and economic costs are very high. Whiplash claims cost UK insurers 1.6 billion BP, US insurers pay 10 billion USD per annum, as published in [1].

In the late 1990's Johan Davidson from Chalmers University in Gothenburg established with various studies the basis to develop a new test dummy to predict accurately spinal injury risks. As result of Davidson's work a BioRID (Biofidelic Rear Impact Dummy) prototype evolved in 1999 [2]. Modifications of the initial BioRID led finally to the so called BioRID II in 2002. The dummy consists of a detailed spine and neck and is equipped with a specially designed torso. The dummy and the spine of a human model are depicted in Figure 1. The limbs are identical with the Hybrid III 50% dummy. Head and pelvis are similar to the corresponding parts of the Hybrid III 50% dummy.

Today the BioRID II is used in various tests to access injury risks of vehicles in a rear crash. All tests focus on the interaction of the dummy with the seat. The influence of the car is estimated by a pulse applied to the bottom track of the seat. Since the tests lead to a considerably low plastic deformation in the seat it is difficult to determine by testing the different load paths between the dummy and the seat. A finite element model of the dummy allows an effective investigation of the interaction between the dummy and the seat.

Due to the need of a finite element model of the BioRID II a working group at the German Association for Automotive Research (FAT) has been established. In the FAT nearly all German automotive companies join parts of their research activities. In the past years a couple of projects were launched to develop impact dummy models of the Eurosid-1, USSID, ES-2 and ES-2re [3]. The models are intensively used world wide. The new working group focused on the development of the BioRID II. Participants of the FAT group are from Audi, BMW, Mercedes, Porsche, Keiper Recaro, Hammerstein, Johnson Controls, Volkswagen and Karmann. Within the project DYNAmore is responsible for the development of the LS-DYNA model. The model is commercially available from DYNAmore and local distributors.

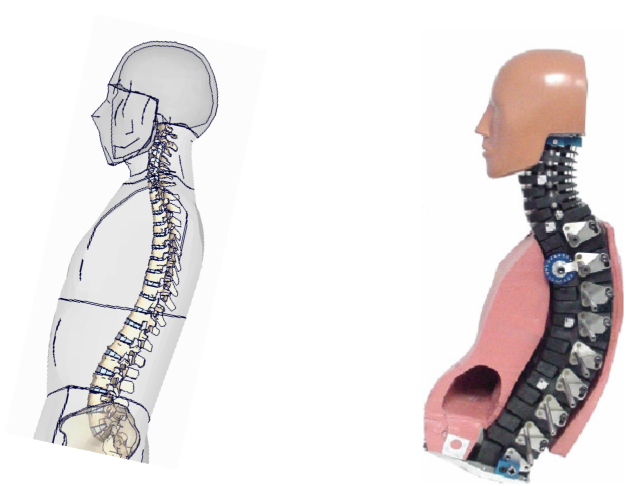

Figure 1: Spine, thorax, and head of human model THUMS [4] and BioRID II [5].

Test Database

A significant effort was made to generate a database on the static and dynamic material behavior, and the dummy behavior in component and fully assembled tests. An essential goal was to have the majority of experimental data close to the type of loading experienced in real crash scenarios. In order to estimate the scatter of the BioRID II each test was performed with 3 or 4 dummies. The dummies were supplied by different automobile companies.

Material tests

The specimens were taken from blocks delivered by Denton CAE. The blocks were specifically manufactured with the same material and manufacturing process as the dummy parts. Figure 2 depicts the blocks used to cut the specimen. The following types of tests were performed: Static tension tests, dynamic tension tests, static compression tests, and dynamic compression tests. The tests were chosen to obtain material data that could be used with very small adaptations for material *Mat_Fu_Chang_Foam and *Mat_Simplified_Rubber. The following materials were tested: pelvis foam, upper arm foam, upper leg foam, lower leg foam, yellow urethane bumper, black urethane bumper, vinyl (skin), and silicone (thorax flesh). For the rubber like materials the compression tests with constrained lateral expansion and with free expansion were performed. For all other tests the lateral strains were not constrained. The following strain rates were used: 0.001 1/s, 0.1 1/s, 10 1/s, 100 1/s, 500 1/s. For the rubber like materials cyclic compression and tension tests were performed with different maximum compressions and tensions.

Figure 2: Material block for specimen extraction.

Component tests

The main focus for the component tests was on the behavior of the spine and neck. Therefore, the spine was fixed on the bottom. In the tests the spine could be coupled piecewise with the ground plate to investigate the behavior of specific sections of the spine and the neck. The test frame with the support brackets is depicted in Figure 3 on the left hand side. Figure 3 on the right hand side shows the model in a test similar to the calibration test. The tests were performed with and without the damper and with and without the pre-stress in the cables. Some tests were performed with and some without the thorax flesh. In total 13 different tests were performed. Each test was repeated with 3 different dummies.

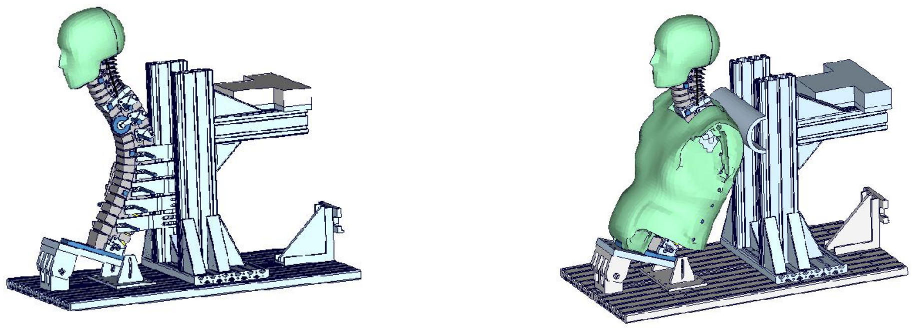

Figure 3: Left: BioRID II component test with supported spine. Right: Component test of assembled thorax.

Fully assembled dummy test

Since the current seat systems are very complex a simplified seat system was used to validate the dummy model. The seat used for the tests, is a modified version of a seat that originally was built at Chalmers University to develop the BioRID dummy [2]. This simplified seat is depicted in Figure 4. At the back of the dummy the simplified seat provides four pads, which can move separately with a specific resistance. The resistance of each panel was adapted to behave similarly the local stiffness of the back rest. Additionally, the frame (grey color in Figure 4) of the four pads can rotate about a pivot center (red circle in Figure 4) at the bottom. The rotation of the frame was resisted by a break system which represents the stiffness of the back frame against rotation. The seat and the head rest were equipped with foam pads to provide contact conditions for the head and the arms comparable to a seat. In total 22 different tests were performed. Each test was repeated 3 or 6 times. In total 3 different pulses were used. The tests were performed with 2 different dummies supplied by different car manufacturers.

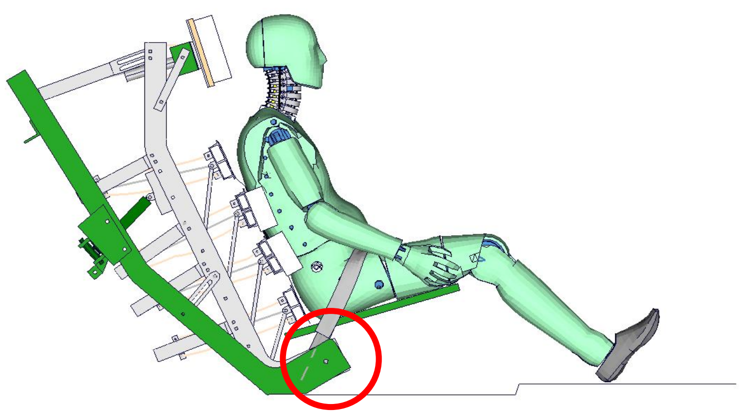

Figure 4: Simplified seat model to perform the assembled dummy tests.

Model Outline

The first commercially available release of the BioRID II model was available in June 2005. The current model is based on CAD data from the dummy manufacturer Denton CAE for the BioRID II specific parts and scanned data for parts also used in Hybrid III dummies. The masses are adapted according to a detailed measurement of each part.

Release 1.0 consists of approximately 140,000 nodes, 88,000 hexahedron elements, 22,000 tetrahedron elements, 71,000 shell elements , 4,000 beam elements and a couple of discrete elements. The model uses 45 material definitions in 380 parts. Figures 5 and 6 depict the model and selected details. The foam materials are modeled with material type 83 (*Mat_Fu_Chang_Foam). The vinyl coverings are defined with material type 181 (*Mat_Simplified_Rubber) and the urethane bumpers are defined in the current release by material type 27 (*Mat_Mooney-Rivlin_Rubber). The parts made of steel and aluminum are modeled with material type 20 (*Mat_Rigid). One major single surface contact (Type 13, *Automatic_Single_Surface) with the soft constraint option is used to preserve the contacts in the dummy. All other contact parameters use the default settings. The cable in the neck is modeled with slip-rings and seatbelt elements. The recent model uses the stiffness based joint definition in combination with the generalized joint option (*Contrained_Joint_Stiffness_-Generalized). Global damping is not applied. The models run with LS-DYNA version 970 upwards on computers with SMP and MPP architecture.

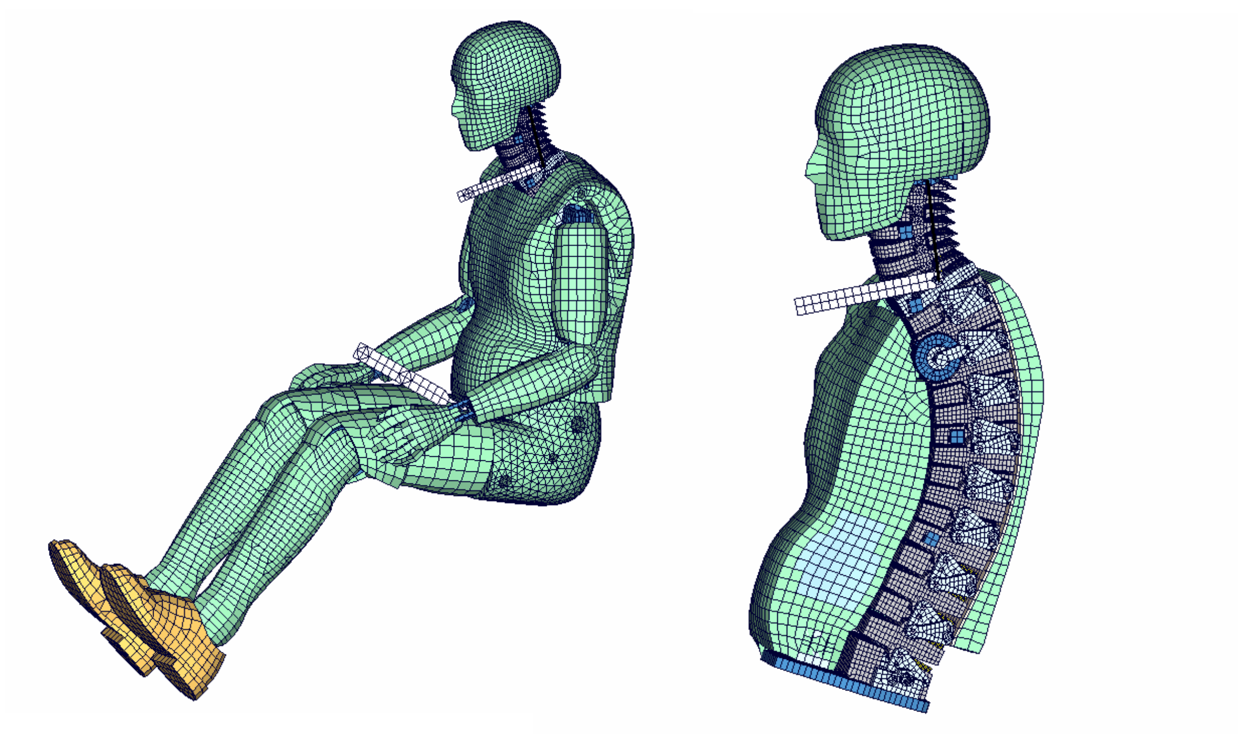

Figure 5: FAT LS-DYNA BioRID II dummy model. Left: completely assembled model. Right: Thorax and head model cutted along the spine.

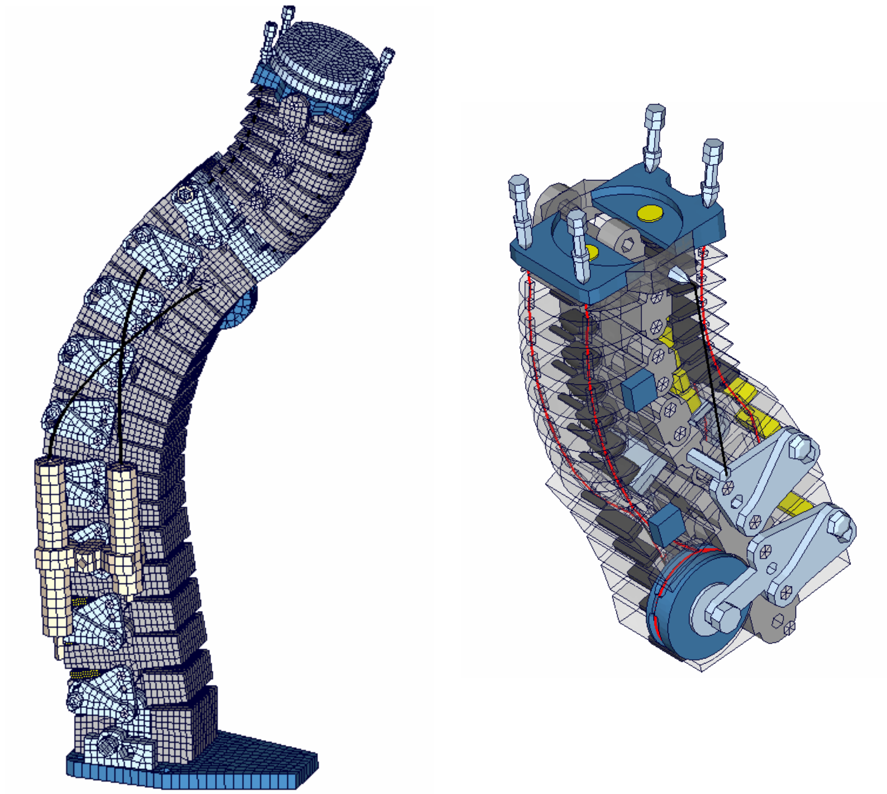

Figure 6: Selected parts of dummy model. Left: Spine and neck model. Right: Neck model, with steel cable in red.

The model is delivered with a pre-stressed neck. Therefore, the bumpers in the neck use the feature *Initial_Foam_Reference_Geometry. The pre-tensioned cable uses options available for discrete materials. The geometry in release 1.0 of the spine is such that the torsional beams and the bumpers in the spine are not pre-stressed. The torsional beams are modeled by *Constrained_Joint_Stiff-ness_Generalized with local coordinate systems attached to the washers. These features allow that a once positioned dummy can be used as an ASCII input file without loosing any pre-stress in the model in the neck and the spine. Consequently, the common procedure to use the *Include command to generate a final input is still applicable. The determination of pre-stress is presented in [6].

Validation

In the following the performance of the model in 2 tests is showcased. Much more correlation information is available in the manual of the dummy model [7].

Component Test

In the considered test the spine is equipped with the head and only supported at the lower end of the lumbar spine. The neck is equipped with damper and the pre-stressed steal cable. Figure 7 depicts the model at different stages during the test. Figures 8-14 present the correlation of the model with the test results.

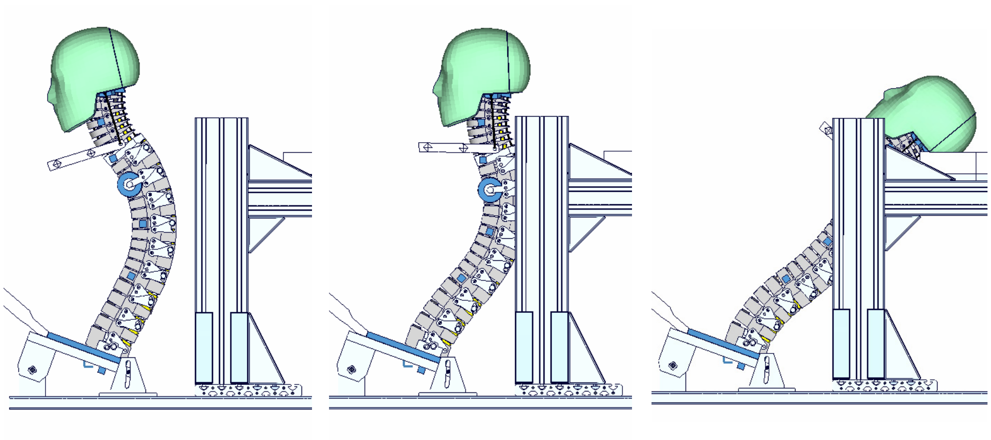

Figure 7: Spine, neck, and head during component test at 0, 90, and 200 ms.

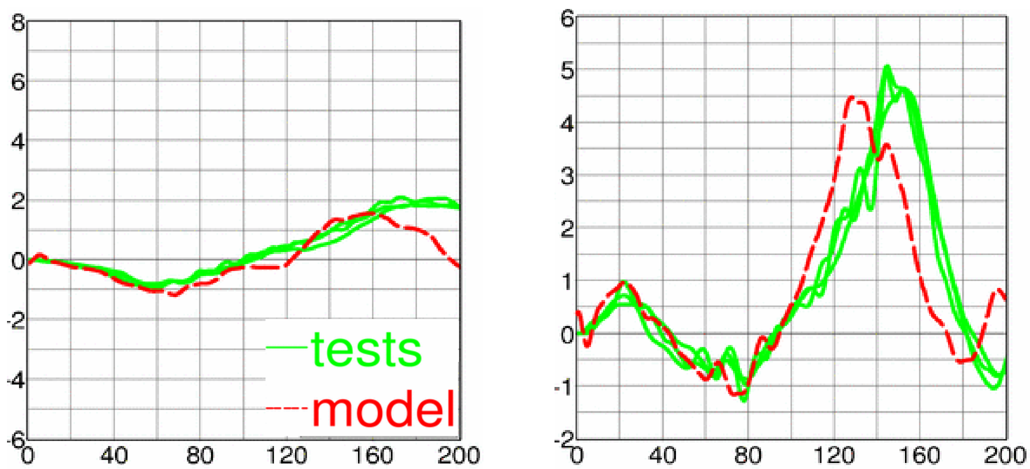

Figure 8: Head acceleration [g] vs. time [ms]. Left: x-acceleration. Right: z-acceleration.

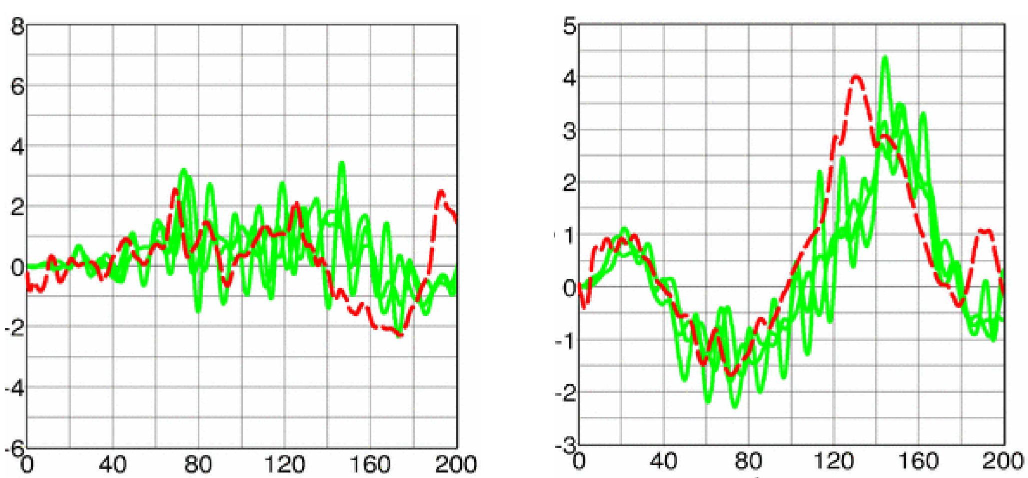

Figure 9: Neck acceleration [g] vs. time [ms] at C4. Left: x-acceleration. Right: z-acceleration.

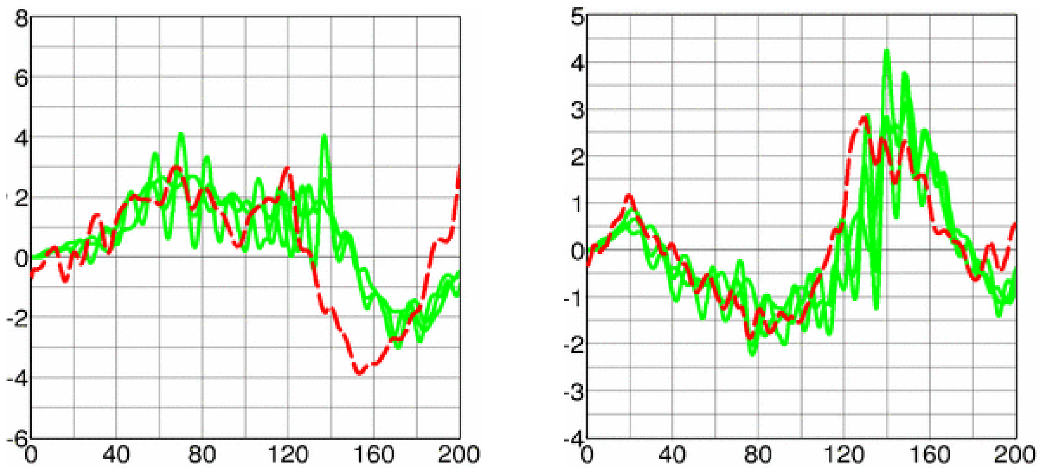

Figure 10: Upper spine acceleration [g] vs. time [ms] at T1. Left: x-acceleration. Right: z-acceleration.

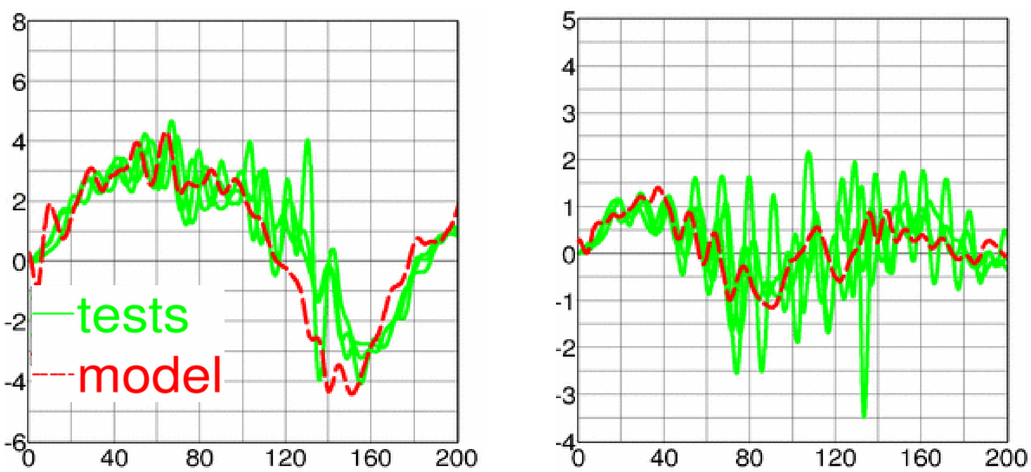

Figure 11: Spine acceleration [g] vs. time [ms] at T8. Left: x-acceleration. Right: z-acceleration.

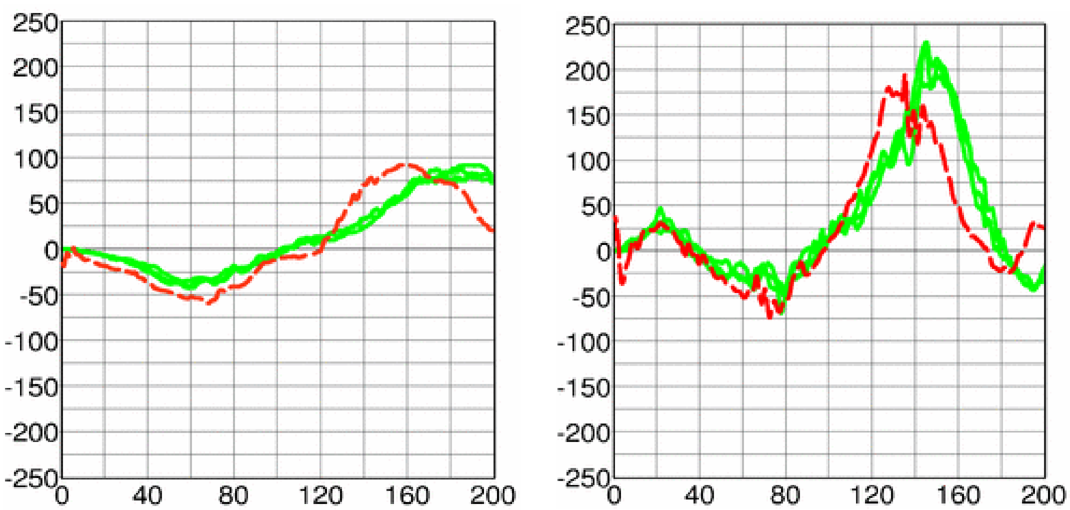

Figure 12: Upper neck force [N] vs. time [ms]. Left: Force in x. Right: Force in z.

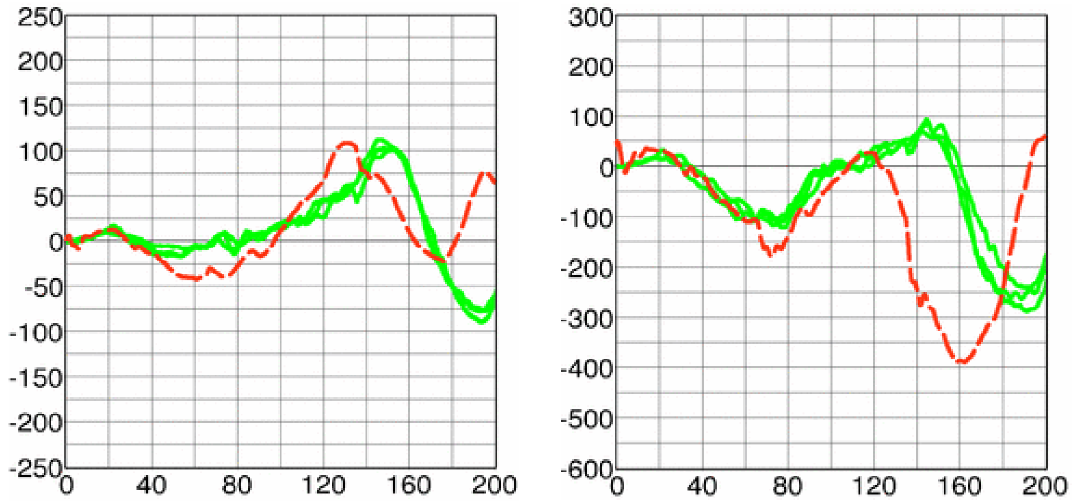

Figure 13: Lower neck force [N] vs. time [ms]. Left: Force in x. Right: Force in z.

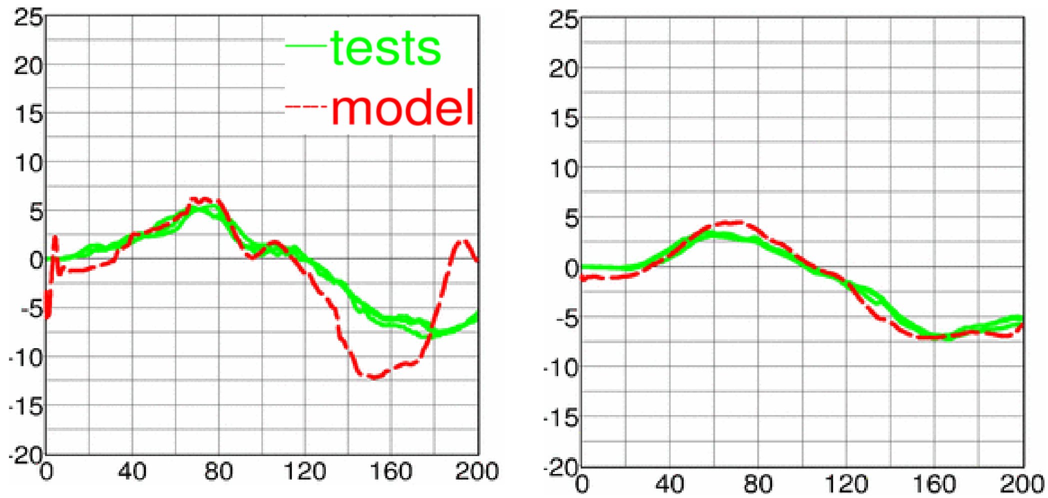

Figure 14: Left: Upper neck moment [Nm] along y vs. time [ms]. Right: Lower neck moment [Nm] along y vs. time [ms].

Fully assembled dummy tested in a simplified seat

The behavior of the dummy model in the simplified seat is shown in Figure 15. The seat is accelerated according to the Euro-NCAP 5g trapezoid pulse.

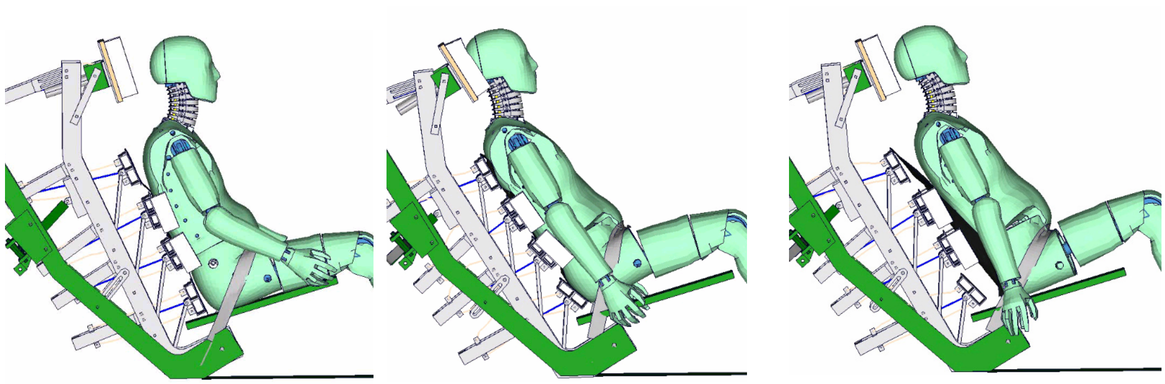

Figure 15: Behavior of dummy model in simplified seat test.

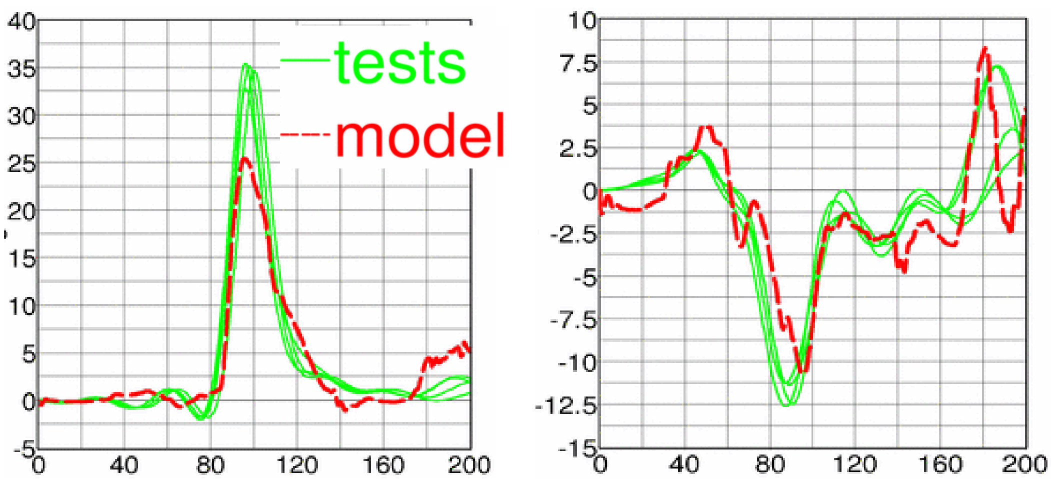

Figure 16: Head acceleration [g] vs. time [ms]. Left: x-acceleration. Right: z-acceleration.

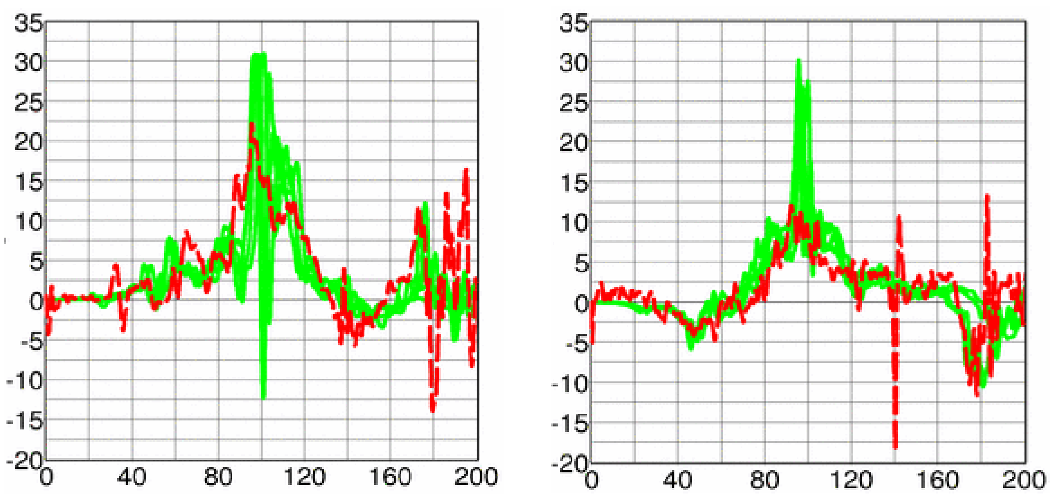

Figure 17: Neck acceleration [g] vs. time [ms] at C4. Left: x-acceleration. Right: z-acceleration.

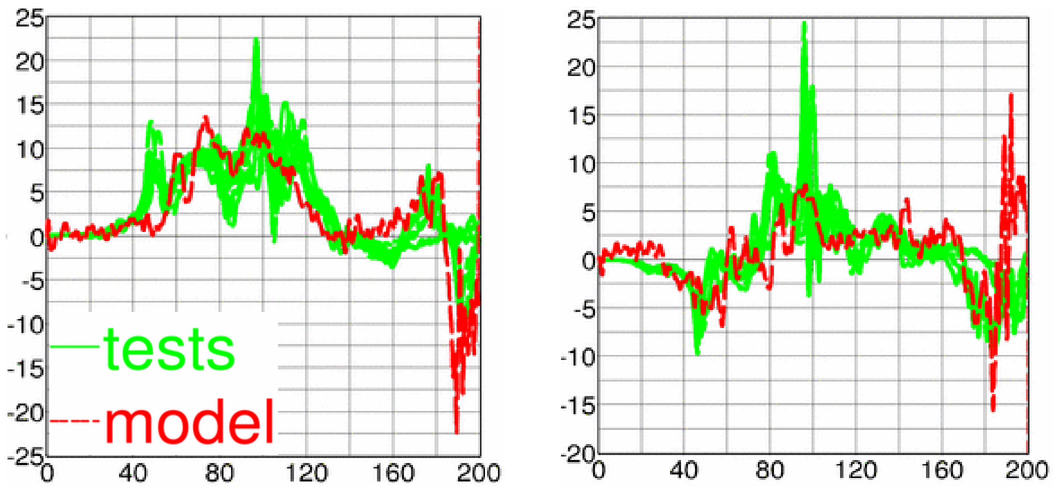

Figure 18: Upper spine acceleration [g] vs. time [ms] at T1. Left: x-acceleration. Right: z-acceleration.

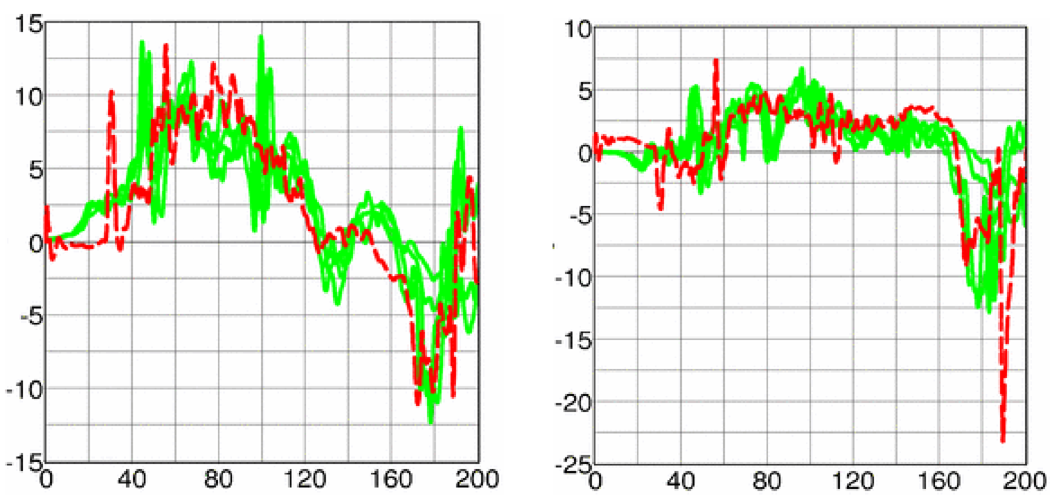

Figure 19: Spine acceleration [g] vs. time [ms] at T8. Left: x-acceleration. Right: z-acceleration.

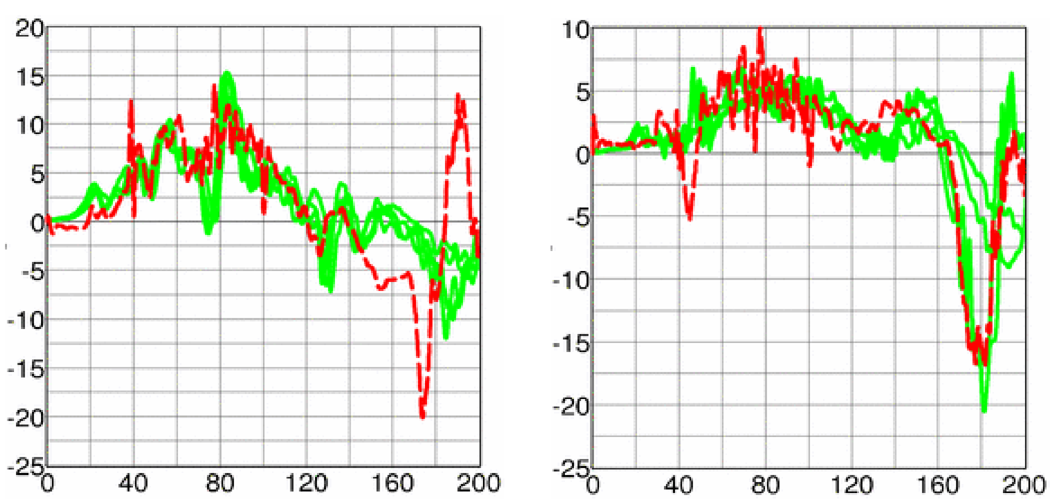

Figure 20: Spine acceleration [g] vs. time [ms] at L1. Left: x-acceleration. Right: z-acceleration

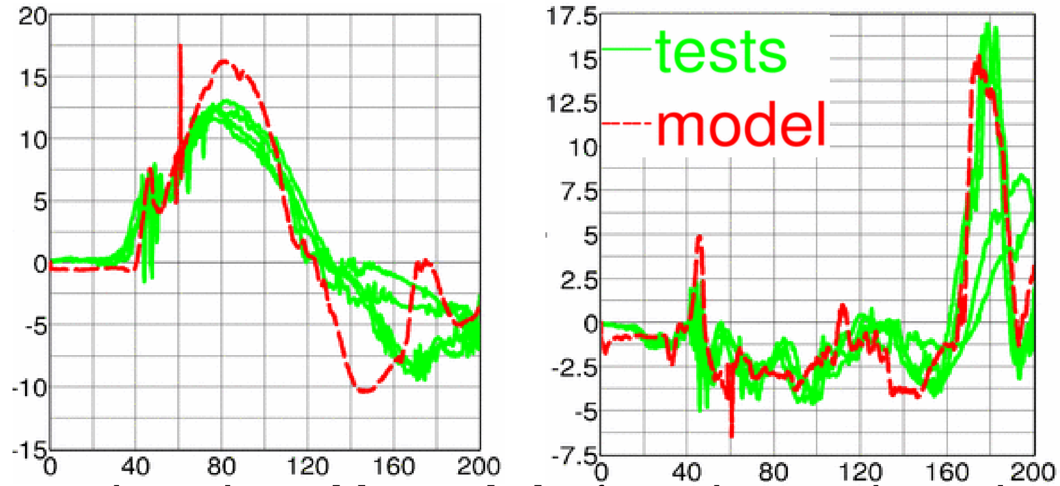

Figure 21: Pelvis acceleration [g] vs. time [ms]. Left: x-acceleration. Right: z-acceleration

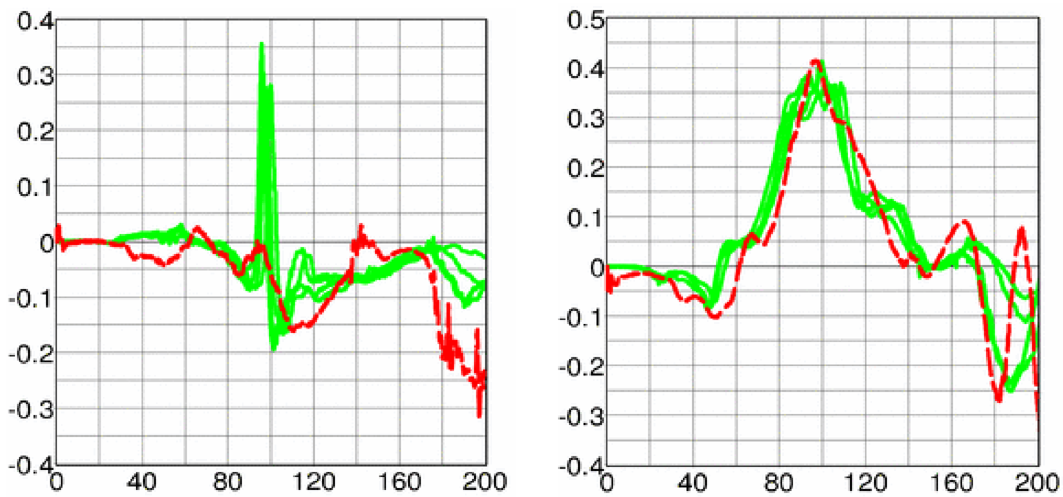

Figure 22: Upper neck force [kN] vs. time [ms]. Left: Force in x. Right: Force in z.

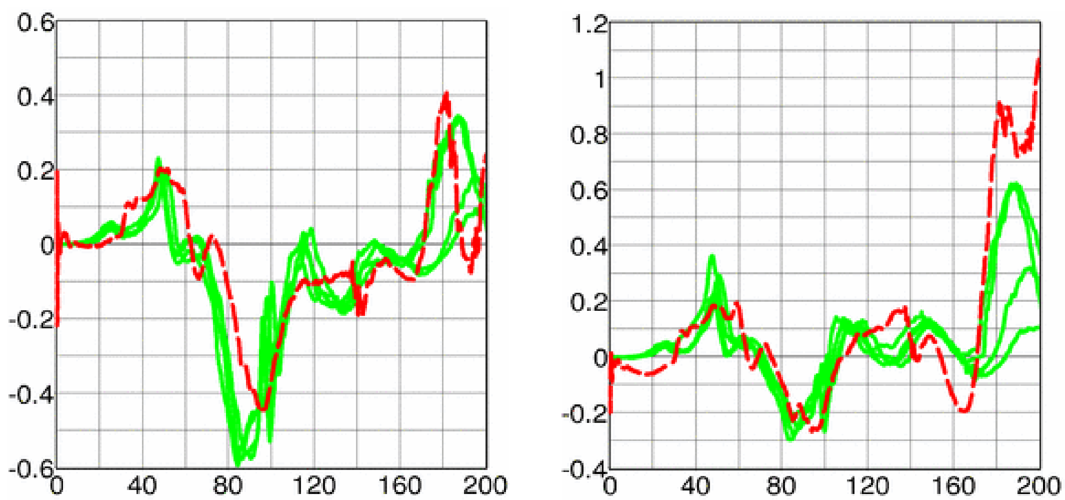

Figure 23: Lower neck force [kN] vs. time [ms]. Left: Force in x. Right: Force in z.

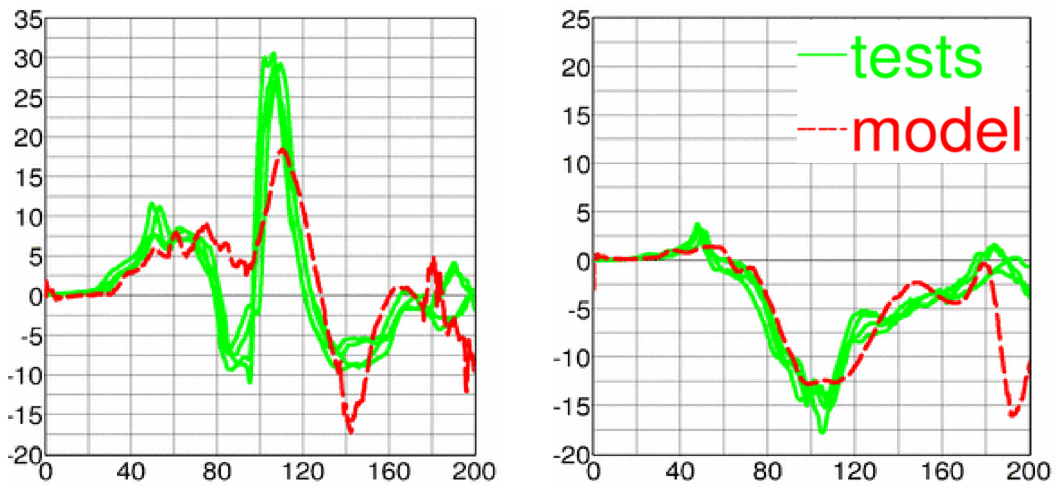

Figure 24: Left: Upper neck moment [Nm] along y axis vs. time [ms]. Right: Lower neck moment [Nm] along y axis vs. time [ms].

Discussion

The model shows a good correlation with the tests. Since not all tests have been used for validation further enhancement are expected with the future releases. The model is easy to handle, even with the pre-stress. Another future work is to “correlate” the oscillations. The signals of the dummies have a remarkable amount of noise. The dummy model shows also oscillations, but the amplitudes are higher. Since the dummy is modelled in detail the target is to capture the physically sources of the oscillations and the damping correctly.

Observations in Seat Simulations

For validation it is very important to assess the ability of a test in providing relevant information to the final goal to run a predictive whiplash analysis. Of course, it would be ideal if the model behaves like the dummy in every situation, even if the situation is not comparable to a whiplash analysis. Unfortunately, such model would be extremely complex and costly in terms of development and computation. Thus, many simulations were performed to understand the dummy model behavior in a seat model. The following simulations were selected for the paper because they provide helpful information for usage of the dummy model. The used seat model can not be depicted due to confidentiality, but is similar to the seat model depicted in Figure 25. It has approximately 75,000 shell and 100,000 solid elements. The pivot joint of the back rest, the anchorage points of the head rest, and the seat foams are modeled with high accuracy.

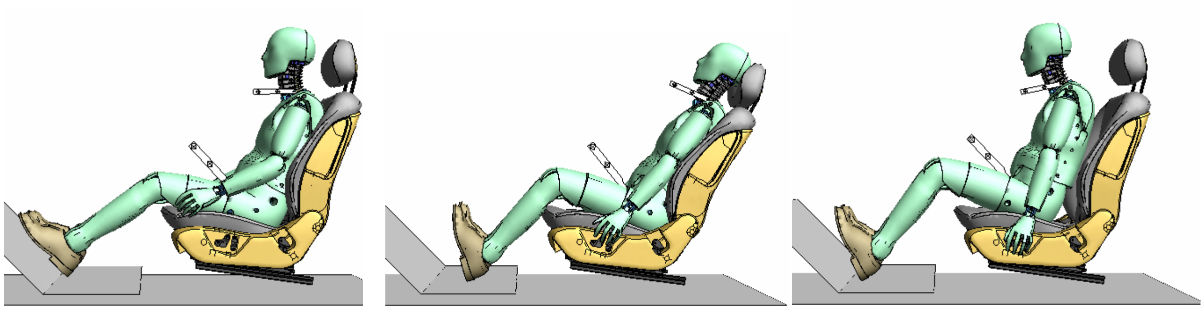

Figure 25: Dummy in seat model at time: 0, 105, and 200 ms.

In all examples the results are compared with a base line simulation. In the base line simulation the dummy is positioned by a pre-simulation with the model considered as rigid and the seat as deformable. Before the pre-simulation the limbs and the thorax angle were adapted by simple pre-processing operations. During the pre-simulation the dummy model is pushed in the seat such that the h-point fits to test measurements. The simulation for positioning lasts 100 ms, plus 10 ms to smooth out oscillations. The geometry determined by the pre-simulation was used in the whiplash analysis. The stresses in the seat are neglected in the base line simulation. Hence, initial stresses due to calibration in the dummy are considered and initial stresses due to positioning and gravity are neglected in the base line simulation. The applied crash pulse is a slightly modified triangular 10g pulse according to IIWPG2.

Importance of initial position

In the dynamic calibration test the model shows a high sensitivity to the initial position. The test is depicted in Figure 3 on the right hand side. During the test the thorax of the dummy is accelerated by the bottom mounting plate and the tube in the back. The results are very sensitive regarding a gap between the tube and the back of the dummy. In the test the gap is always closed similarly by gravity. In simulation the results with a pre-simulation to apply gravity show much better correlation than simulations with initial positions generated roughly by pre-processing operations. Obviously, it is important to see if the dummy model in the seat shows the same sensitivities. To address this question a pre-simulation with a fully deformable seat and dummy model was conducted. The simulation was terminated after 500 ms since at this time the h-point approached to the h-point measured in test. A double precision version of LS-DYNA was used. The differences of the 2 initial positions are depicted in Figure 26.

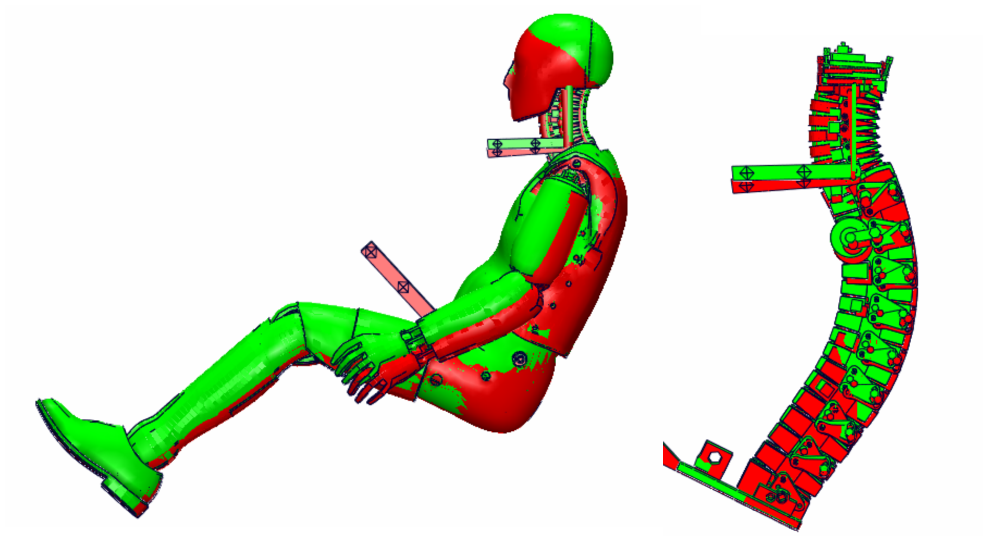

Figure 26: Varying initial position due to different types of pre-simulations (Green: Base line. Red: Complete deformable positioning). Left: Complete model. Right: Spine and neck model.

Even with the significant differences particularly in the spine the measured injury quantities are very similar between both simulations. Hence, the simulation with a simplified pre-processing in the base line run seems to be sufficient for the considered load case. Of course, this statement is limited to seat structures that already have a cushion shape similar to the back and the pelvis of the BioRID II model. Differences in the results may also appear if the different initial positions lead to modified load paths from the seat to the dummy.

Modeling of pivot point of back rest

In the following the stiffness of the pivot joint at the bottom of the back rest is varied. Usually, the joint is built by complex mechanisms, far too small to be modeled entirely. Hence, the stiffness in the model is determined by some modeled parts and a torsional spring that captures the elasticity in the not modeled parts. The stiffness in the base line run is adapted to correlate with the movement of the back rest in tests. In the modified model the back rest is stiffened due to a stiffer torsional beam such that the back rest shows only one third of the rotation. The results are surprisingly similar if we consider the head and pelvis accelerations. The time shift for the head acceleration is obviously due to the earlier contact of the head with the head rest. If we compare neck forces and moments the signals differ significantly. This may result in different head positions and subsequently in different moment arms at the time the head contacts the head rest. The observation that occupant criteria measured by accelerations are easier to predict than forces and moments was also made for side impact dummies [8].

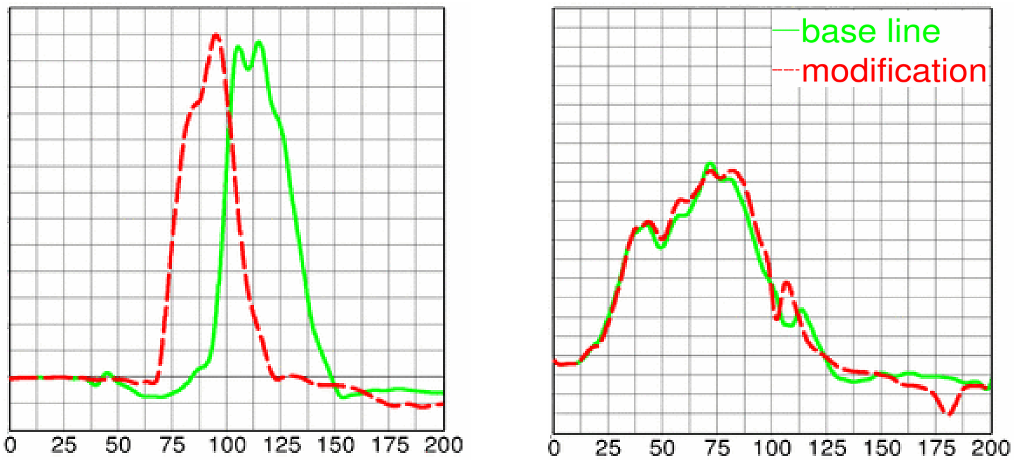

Figure 27: Head and pelvis x-acceleration vs. time [ms]. Influence of back rest stiffness.

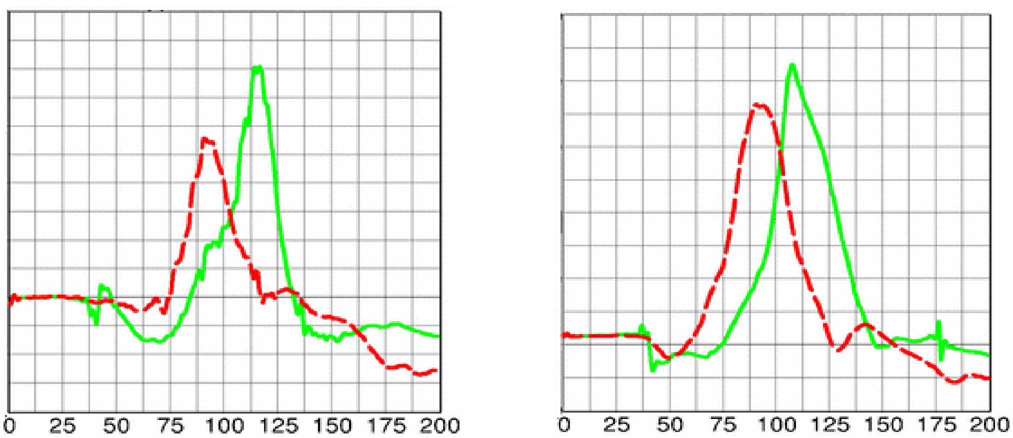

Figure 28: Upper and lower neck x-force vs. time [ms]. Influence of back rest stiffness.

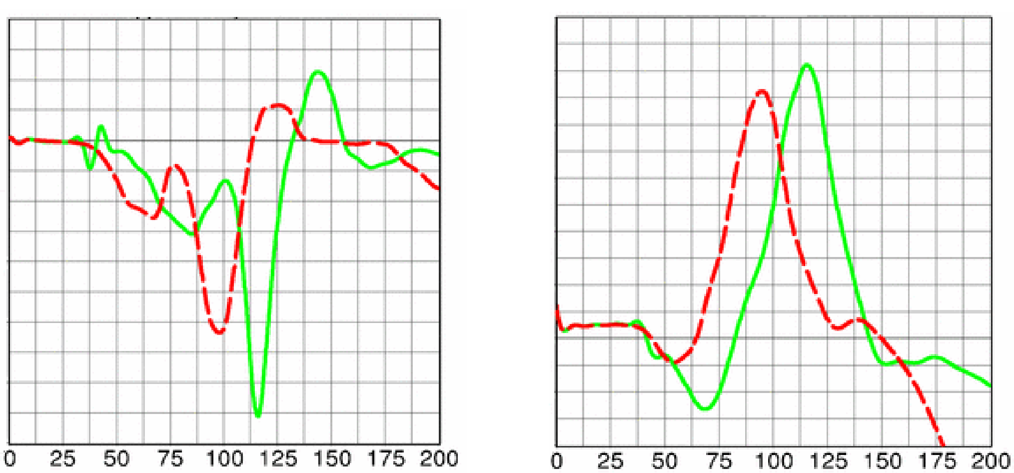

Figure 29: Upper and lower neck y-moment vs. time [ms]. Influence of back rest stiffness.

Friction between dummy and seat

The friction of the dummy with the seat determines the uplift of the dummy in the seat during the crash pulse. The base line simulation has frictional values that may correspond to a seat covered with fabric. The modified simulation uses lower frictional parameters to model a seat covered with leather. The comparisons are depicted in Figure 30-32.

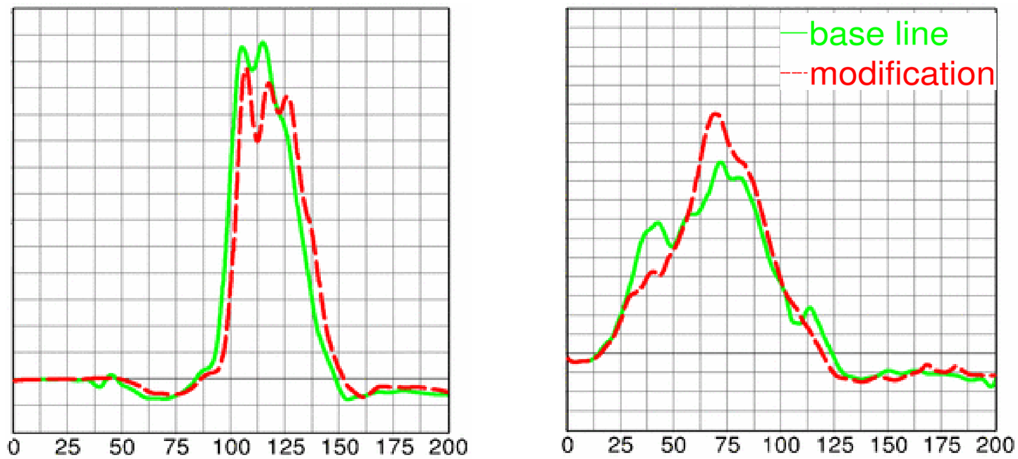

Figure 30: Head and pelvis x-acceleration vs. time [ms]. Influence of friction.

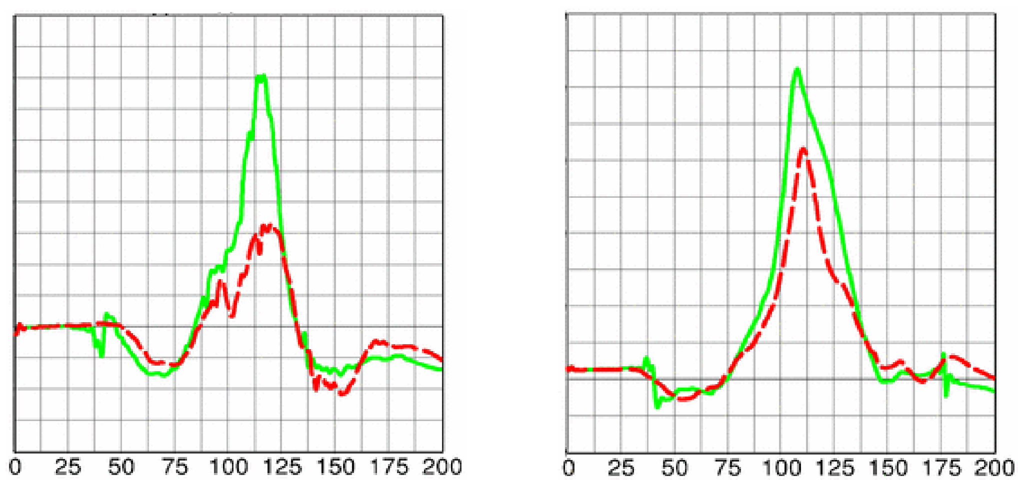

Figure 31: Upper and lower neck x-force. Influence of friction.

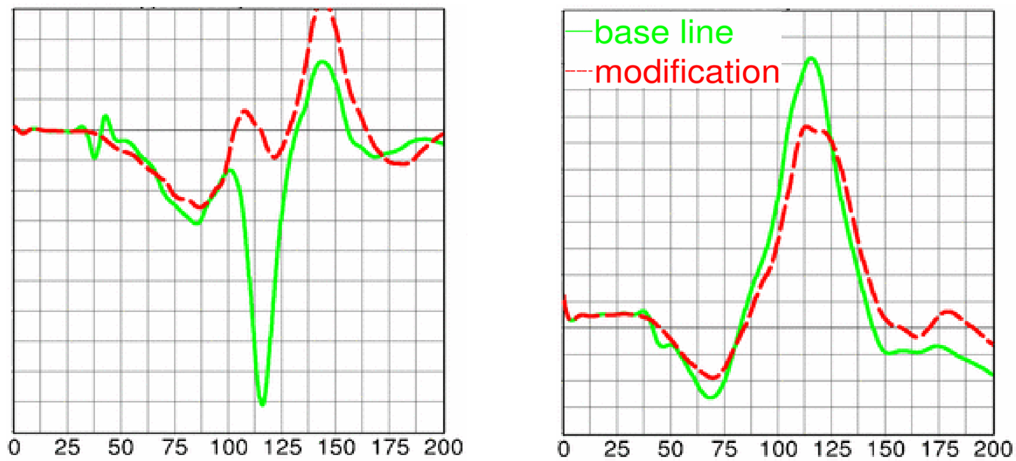

Figure 32: Upper and lower neck y-moment. Influence of friction.

The comparison of the 2 simulations shows that the head acceleration is almost unchanged. The pelvis acceleration decreases. The differences can be explained by the larger z-displacement of the dummy model in the modified simulation which changes the load path from the stiff seat structure at the bottom of the back rest to the pelvis. The differences in forces and moment of the lower and upper neck are again significantly. The explanation is the changed geometric situation, like in the example above.

Conclusion

For the development of the BioRID II model a very significant experimental database has been generated by the FAT. The test database includes detailed material tests, component tests, and tests with a simplified seat. The German OEMs also provide full seat tests for validation purposes. As in former projects dealing with the development of FE dummy models DYNAmore GmbH has been selected to develop the LS-DYNA model for the FAT. The aim of the FAT project is to develop a predictive and detailed finite element model for the BioRID 2. The project to develop the models is still ongoing but commercial releases of the model are already generally available.

The current release of the BioRID II model for LS-DYNA is based on material, component and fully assembled dummy sled tests. The LS-DYNA model of the BioRID II is capable of capturing many details efficiently. Its good performance is shown in this paper. More information on the correlation with tests is presented in the manual of the dummy model. The model relies on new features in LS-DYNA to describe the occurring pre-stresses in an easy to handle manner. The current releases show a good correlation with the experimental tests.

The paper also highlights the importance of the exact modeling of the seat. As a result some of the currently used seat models may need more detailed modeling of the head and back rest and their anchorage points. Furthermore, material properties of cushion foams and coverings should be modeled accurately to achieve predictive results. It is important to note that some of the different occupant injury criteria of the BioRID II are easier to predict than others, e.g. it seems that accelerations are easier to predict than forces and moments.

Upcoming milestones for models include the extension of the validation to further test series with the simplified seat. The development is constantly reviewed and guided by the FAT. Additionally, new releases will be updated according to feedback from users. The new releases will be available regularly. Furthermore, implicit positioning is targeted for the model as well as an even better oscillatory behavior of the spine. The FAT LS-DYNA model is already in use at OEMs and suppliers in Europe, the US and Asia.

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