

Development of the PDB WorldSID 50th Model with the German Automotive Industry

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Summary:

In times where simulation methods are well-established in Vehicle Passive Safety Development, it is indispensable to provide a virtual equivalent of current hardware dummies. Thus, German car manufacturers decided to build up a WSID50th finite element model. Due to the experience of former FAT dummy development projects, the processing of the WSID50th model achieves a high efficiency level.

The project started with building up a model using the material data of other dummy projects - release version 0. After an immense number of material and component tests the WSID50th model validation level is increased and qualifies the model for production - release version 1.

This paper describes the evolution and features of version 1 in detail. There is a detailed description of the individual component test validation and its results.



Keywords:

WorldSID, Dummy, PDB, Validation

1 Introduction

After the finalization of the WorldSID 50th dummy and the approach of its possible introduction in legislation the need of a finite element counterpart of the dummy is on the rise. Hence, five German car manufacturers which are represented by the PDB decided to develop a WorldSID 50th finite element model for the crash codes being used. The PDB is the Partnership for Dummy Technologies and Biomechanics, which consists of the German car manufacturers – Audi, BMW, Daimler, Porsche and Volkswagen. Together with the software vendors a task group was founded in 2006. DYNAmore is consigned to build up the LS-DYNA version of the dummy model. The methodology and proceeding of the task group is similar to former FAT projects like the EuroSID1/2 and BioRID II. After the kick off meeting in autumn 2006 the first production release – version 1 – is now ready to be delivered.

2 Methodology

For the development of the WorldSID FE-model the task group decided to introduce four major steps. The first one of them which is called version 0 is the built-up of a stable running FE model. This model should provide all sensor data of the hardware equivalent as well as every part should feature its correct mass and inertia. Due to the lack of WorldSID material data at this point in time the model should consist of adequate material data of the BioRID or ES-2 model. Version 0 was released in November 2008. The second major release of the dummy – called version 1 – has been released in May 2009. This version includes all the material data which has been gathered from the hardware tests as well as the validation of all available component tests. The level of validation of version 1 qualifies the model for the first time for production use.

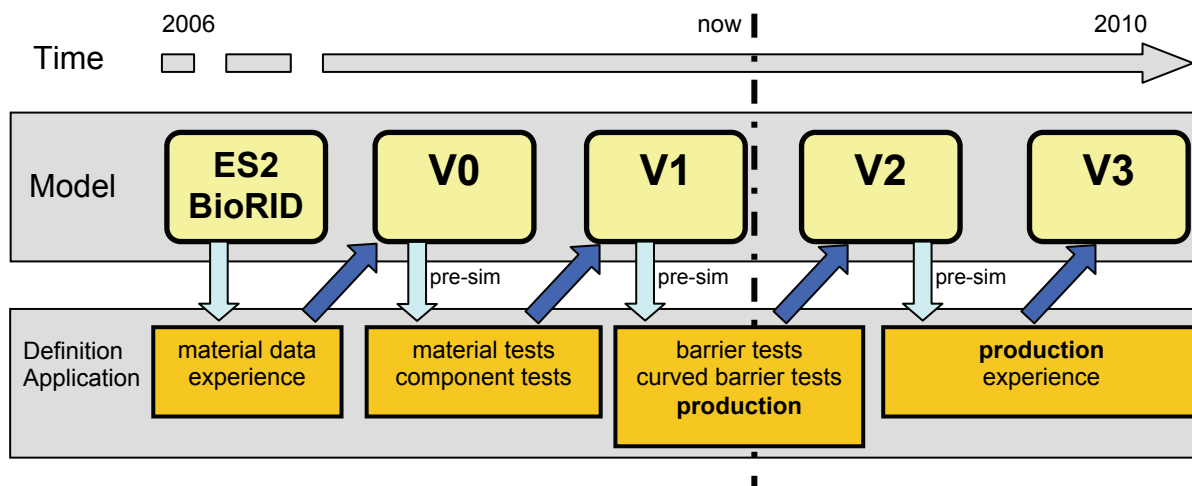


Figure 1: WorldSID FE-model development flow

In parallel to the release of version 1, barrier sled tests are defined and conducted. These tests are used to validate the whole dummy model. Once this is done, the model shall reach the status of version 2, which is expected to be released by the end of 2009. The final step – version 3 – will be released after the users' feedback of production applications of version 2 is included.

Figure 1 shows the flow of the WorldSID FE-model development. As depicted, every current model is used to define adequate test requirements for its follower. Hence, it is possible to gain a great amount of experience in model use even in the early state of development despite of the lack of production feedback.

3 Model

In the following section, the PDB LS-DYNA-WorldSID 50th model and its features are described. All facts and figures correspond to the version 1 of the model.

3.1 Geometry and Mesh

The complete geometry of the WorldSID 50th model is based on the CAD data of the ISO 15830 of 2005. The only exception is shape of the dummy suit. This was provided by a hardware scan.

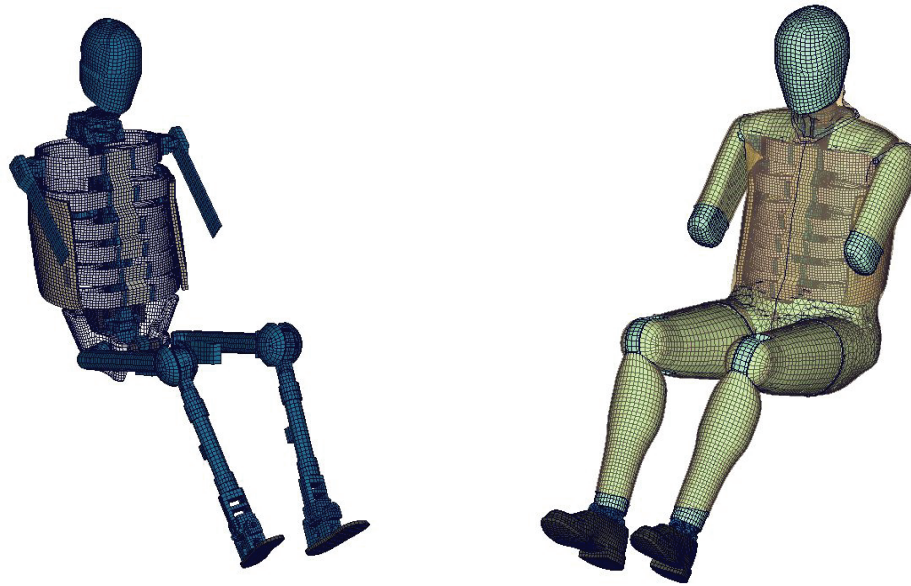


Figure 2: Mesh of the PDB WSID50th bone structure (left) and complete model with suit (right)

The goal of modeling the geometry was to capture the shape of all dummy parts in a high detail level and to keep the number of elements moderate. Thus, an average element length of 4 to 7 mm was chosen. As a modification of the mesh of version 0, the pelvis flesh of the dummy is now meshed with hexahedron elements. Finally, there are no tetrahedron elements in the dummy, which reduces the number of solid elements dramatically. Nearly every hardware part is modeled separately so the number of properties in the dummy model is very large.

Component	Total number
Nodes	~ 166000
Shell elements	~ 110000
Solid elements	~ 96000
Beam elements	~ 600
Materials	~ 50
Sections	~ 60
Parts	~ 590
Coordinate systems	~ 50

Figure 3: Overview about the PDB WordSID50th model size

The following pictures should give one an imagination and impression of the PDB WorldSID 50th dummy model.

The first picture shows the head and neck assembly of the dummy. As one can see, the model captures all details of the hardware. Every sensor of the head as well as the fore, aft and lateral buffers of the neck are modeled. Hence it is possible to gain the exact mass and inertia as well as the mechanical response of the assembly.

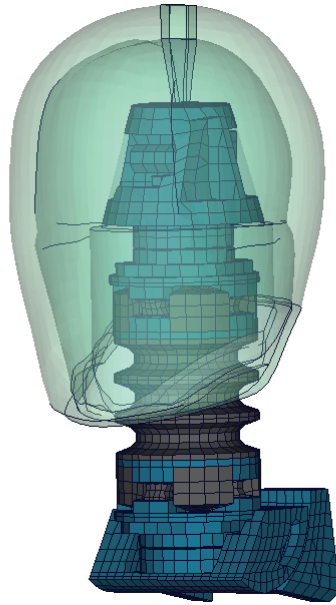


Figure 4: PDB WorldSID 50th head and neck assembly with load cells and neck bracket

The component depicted in the next picture, is the arm assembly with the shoulder load cell. Due to the large influence of the arm on the dummy behavior under crash load, it is necessary to model this area in a very accurate way. Thus, the arm joint is modeled including joint friction and rubber buffers as stopper.

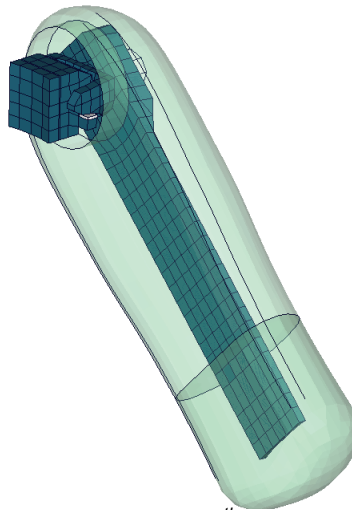


Figure 5: PDB WorldSID 50th arm with load cell

Another main component of the dummy is the rib-cage. Every single rib assembly with its two bands – the inner and outer rib band – is modeled by fully integrated shell elements. The rib damping material of the inner rib band is represented by solid elements. To measure the rib deflection an IR-TRACC device is modeled.

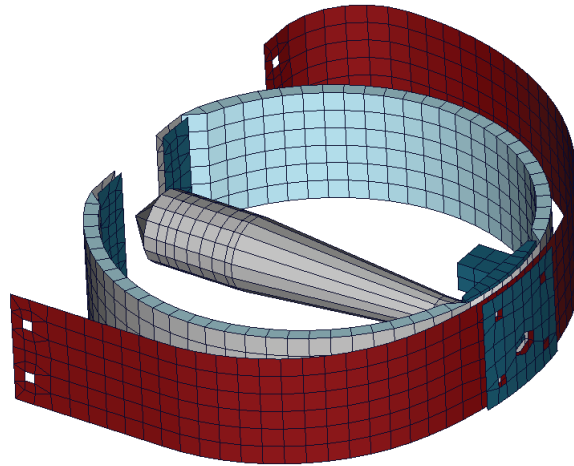


Figure 6: PDB WorldSID 50th first thorax rib assembly with IR-TRACC

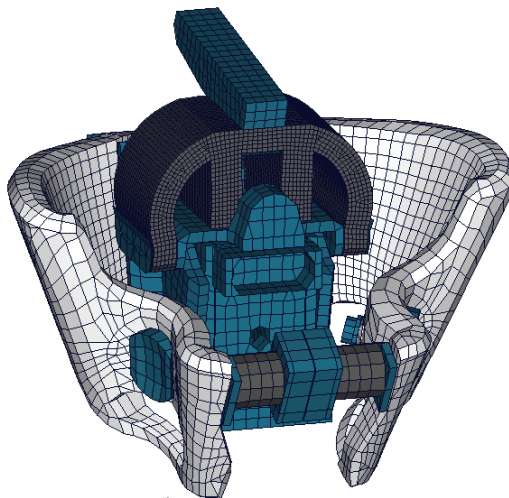


Figure 7: PDB WorldSID 50th inner pelvis assembly with lumbar spine

The lumbar spine rubber is meshed with elements having an average edge length of 4 mm. In terms of the validation process the mesh refinement of the lumbar spine rubber could improve the performance of the component.

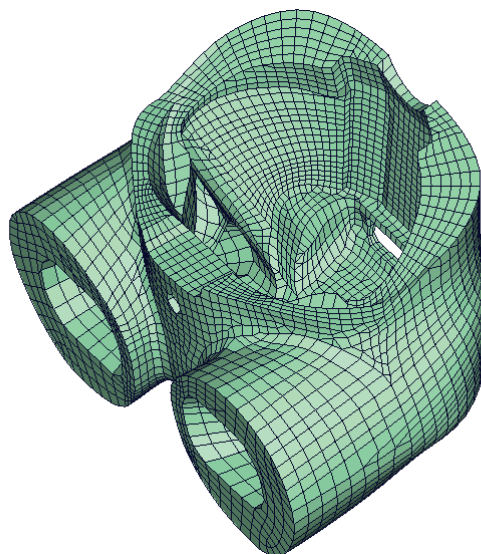


Figure 8: PDB WorldSID 50th pelvis flesh mesh

The picture before shows the hexahedron element mesh of the dummy pelvis. This was done to reduce the element number and the CPU time of the dummy. The corresponding tetrahedron mesh consists of about 40000 elements; the hexahedron counterpart has only about 13000 elements.

3.2 Materials

There are a variety of different materials in the WorldSID. The skeleton of the dummy mainly consists of aluminum and steel parts. These parts are generally modeled as rigid. The majority of the dummy flesh is rubber or rubber-like. For all these parts the *MAT_SIMPLIFIED_RUBBER-material model is chosen. Only a few parts like the thorax foam pad or shoulder pads are made out of foam. The LS-DYNA-WorldSID model uses *MAT_FU_CHANG_FOAM for these parts. The plastics like iliac wings or arm bone are modeled with the *MAT_SIMPLIFIED_RUBBER_WITH_DAMAGE. The ribs of the dummy consist of Nitinol which is a shape memory alloy. This material can be characterized as a nonlinear elastic one, so the *MAT_SIMPLIFIED_RUBBER-material model is used for it too. The *MAT_ANISOTROPIC_VISCOPLASTIC-model is most appropriate for representing the rib damping material.

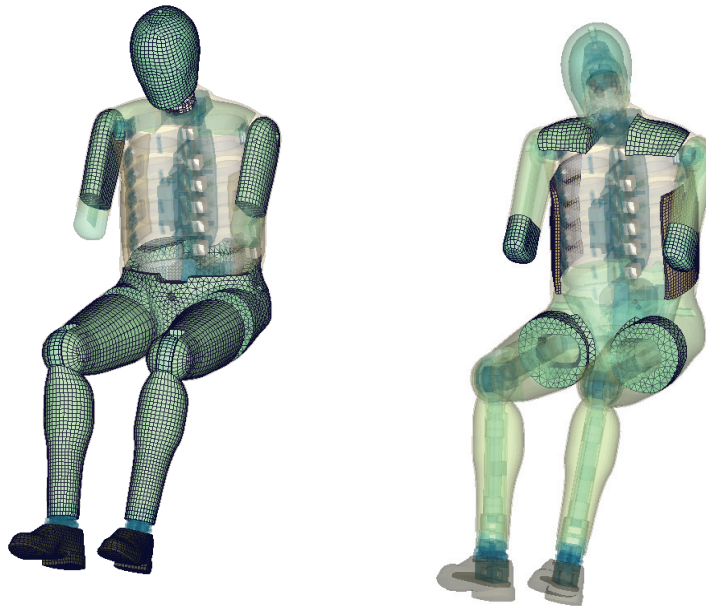


Figure 9: Rubber parts (left) and foam parts (right) of the WorldSID

3.3 Requirements

The complete dummy development and validation until now – has been carried out in LS-DYNA 971-R3.2.1. Thus, it is recommended to use this version for production. To avoid mass scaling a time step of 0.9 microseconds or smaller should be used.

4 Material Tests

On the way to a high validation level of the dummy model it is essential to capture the material behavior under load in a realistic way. For this reason every flesh and foam part material of the dummy was tested. When possible, the specimens were cut out of dummy parts. All in all 26 material tests were performed. Every material was tested under static and dynamic tension and compression.



Figure 10: Material test samples of the WorldSID

The strain rates of the dynamic tests range from 1/s to 400/s. In addition there were some tests with constrained lateral expansion for the rubber-like materials. For the Nitinol, some extra tests with cyclic tension and expansion were conducted. Most of the resultant data of these tests can be directly included in the chosen material models.

5 Component Tests

For the validation of the dummy model, the WorldSID project group under the direction of the PDB designed a large number of component tests. Every single test design was created with respect to typical load cases in the current car side impacts tests. The tests of the most important dummy components will be introduced in the following sections. Generally, the test data is depicted in black and the simulation results are represented by the red lines.

5.1 Head and Neck

Due to the fact that the neck calibration load has only one pulse and load direction there is a necessity to define some different loads to cover most of the car crash energy entries. The idea was to get different loads with different angles. Therefore, a sled test for the head neck assembly was designed. In this test the head and neck including the lower neck load cell and bracket are fixed on the sled. The sled is accelerated with different pulses. Hence, the neck tilts because of the head's inertia. To limit the tilting of the neck a blocking plate is installed on the sled.

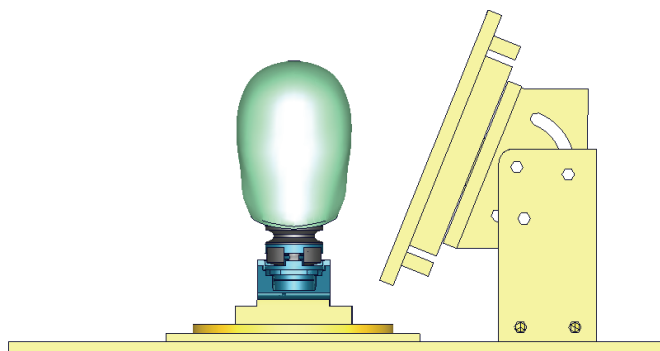


Figure 11: WorldSID head and neck test setup

For the variation of the loading direction the assembly can be rotated. The validation of the model is performed by the output of the load cells and the head accelerometer. In the picture below the performance of the PDB WorldSID 50th head and neck assembly can be seen.

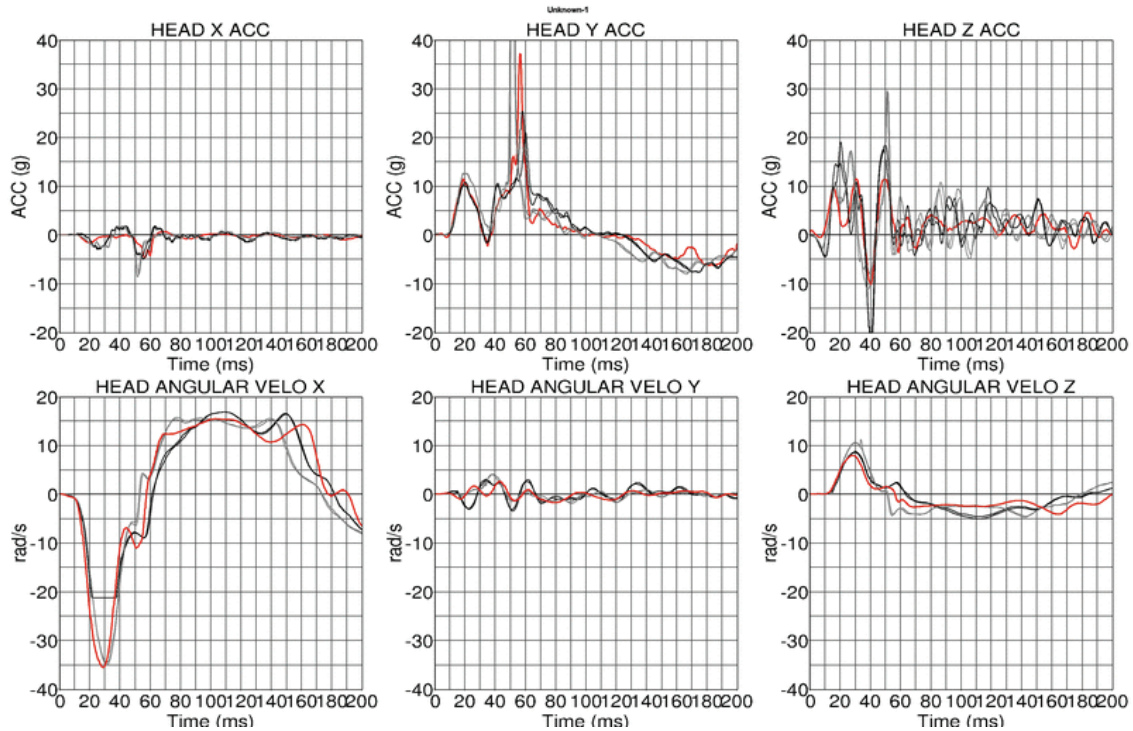


Figure 12: Results of head-neck test, high pulse, 90 degrees

5.2 Arm

For the investigation of the behavior of the WSID arm, the project group decided to conduct pendulum tests with different configurations. After fixing the WorldSID arm including the shoulder joint and load cell, a pendulum hits the arm in three locations - in the shoulder area, the mid arm area and the lower arm area. To cover a larger range of energy entries the impact velocity is varied.

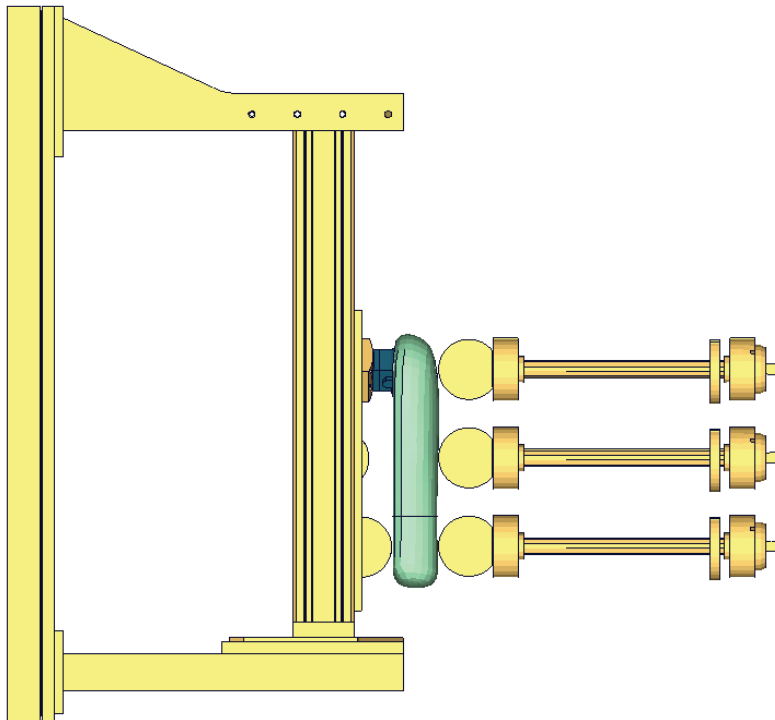


Figure 13: WorldSID arm test setup

The input for the dummy model calibration is obtained by the evaluation of the shoulder load cell data and the pendulum acceleration. As an example of the performance of the model arm, the results of an arm test (impact point: lower arm, high velocity) are shown in the picture below.

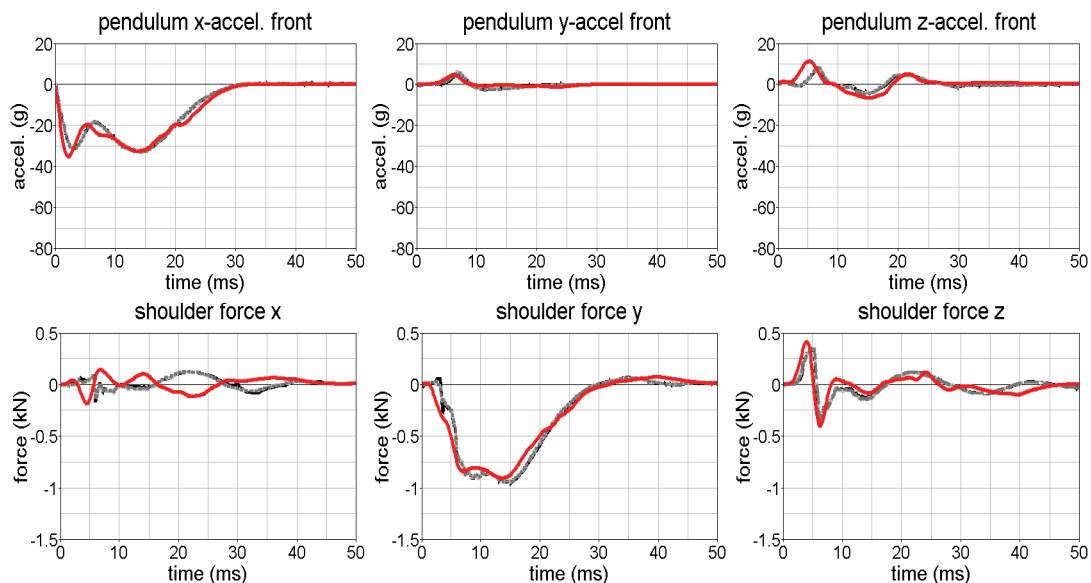


Figure 14: Results of the arm test, middle arm impact, high velocity

5.3 Ribs

The component which has the highest interest of the task group is the rib-cage. The challenges involved in testing the different ribs are first the complete new design of the rib assemblies and second the Nitinol alloy which has never been used in a dummy before. The requirement of the component tests is to give an idea of the rib behavior under every possible load appearing in a real car crash test. In order to meet this requirement a huge number of pendulum tests were defined.

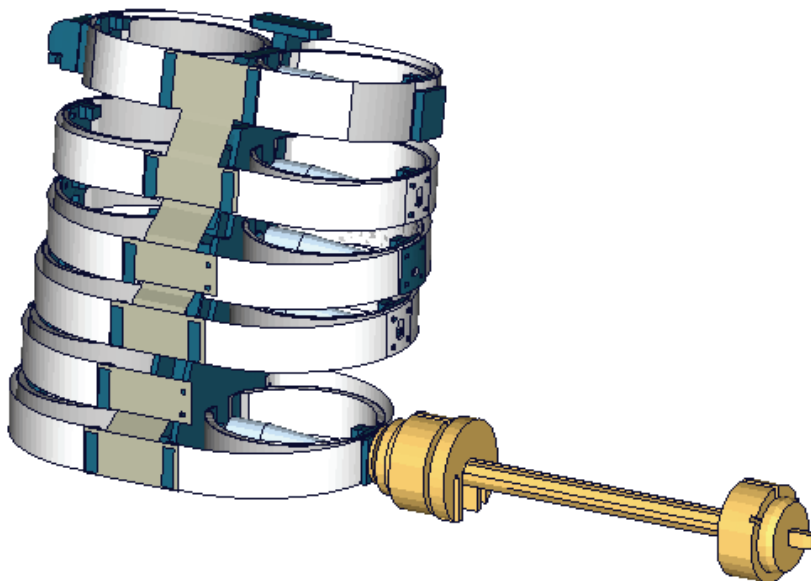


Figure 15: Second abdomen rib test with outer rib band

The rib-cage of the WorldSID consists of six ribs on each side. Four of them are unique: shoulder rib, 1st thorax rib, thorax rib and abdomen ribs. This means every test configuration has to be done for these four ribs. Due to the low experience with the Nitinol alloy there were some extra tests concerning only the inner rib band without the damping material. Hence, the validation of the material was eased. The behavior of the complete rib assembly was very complex, therefore the group decided to conduct extra tests including only the inner rib bands of the different ribs. For every rib test, configurations are varied by pendulum mass and velocity and impact angle. Finally there were about 160 different load cases defined. Including the reruns a test database of more than 400 rib tests was created.

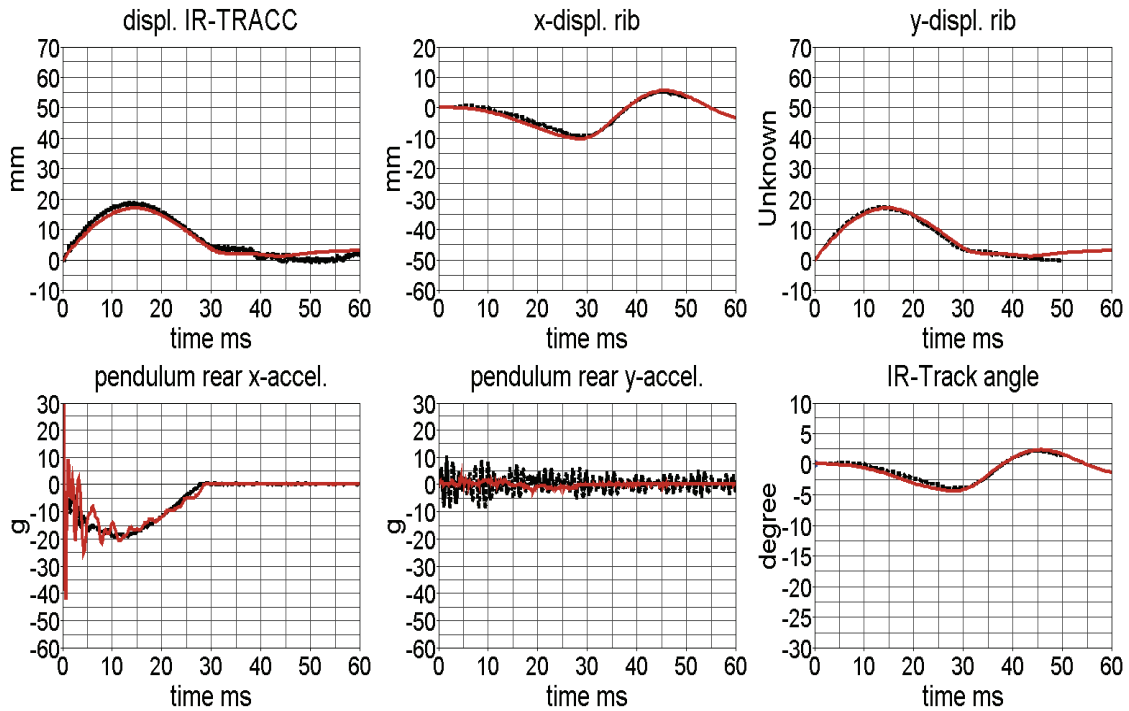


Figure 16: Abdomen rib test on outer band, low velocity and high mass, 90°

To calibrate the finite element models the pendulum and the rib accelerations are evaluated. In addition to this, the rib deflections and displacements were adjusted. The picture above shows the comparison between the hardware test and the FE-model's abdomen rib.

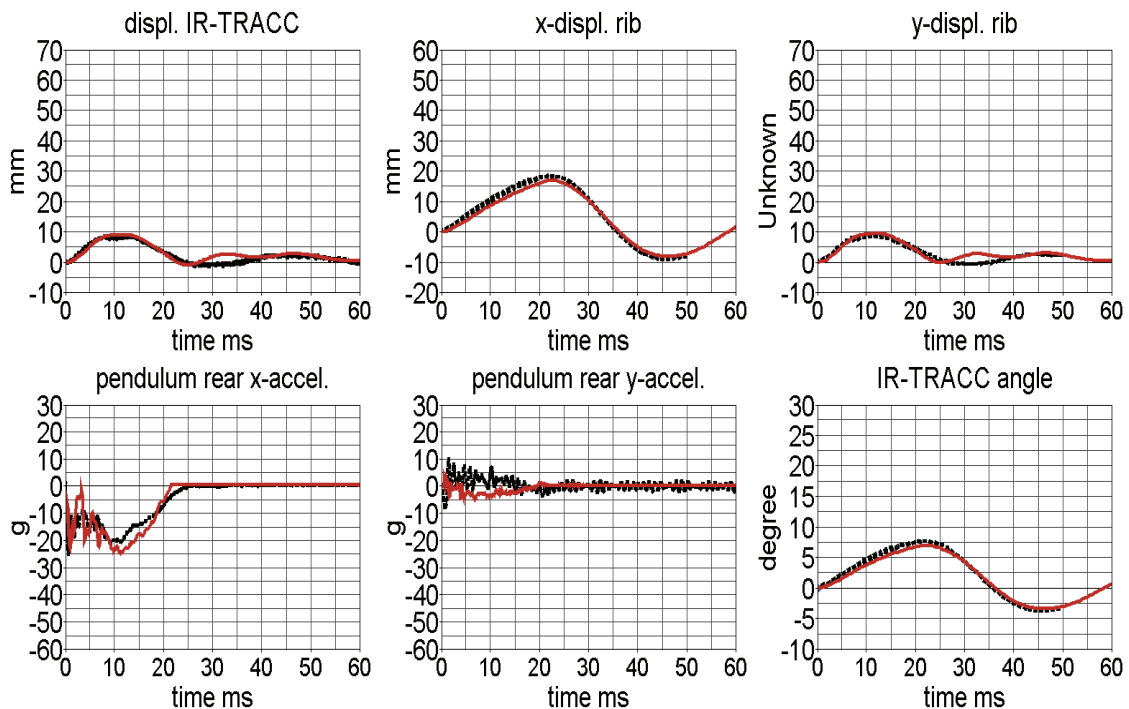


Figure 17: Shoulder rib test on outer band, low velocity and high mass, 60°

In the figure above the results of the 60 degree shoulder rib test is depicted. As one can see, even in extreme impact directions of the pendulum a very good correlation of the model is achieved.

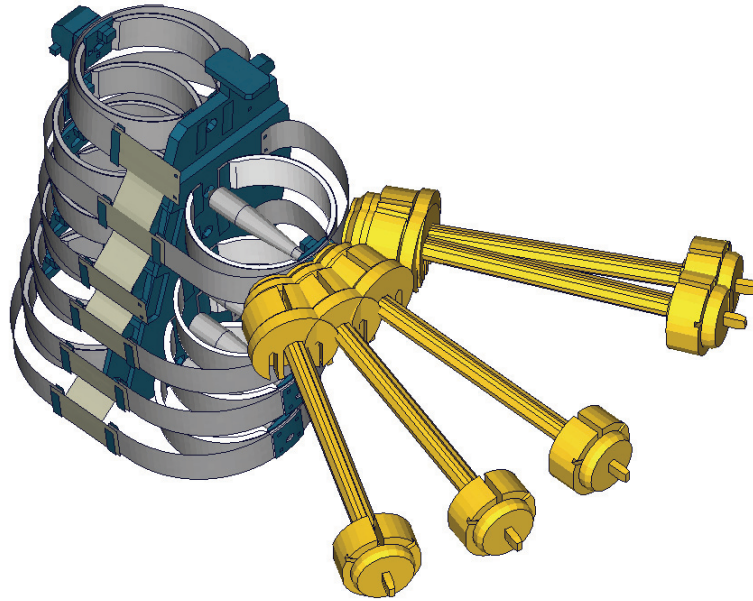


Figure 18: Angular variation for one individual rib assembly test

5.4 Lumbar Spine

The lumbar spine test is very similar to the head neck test. The sacrum block including the sacro-iliac load cell is fixed on a sled. The lumbar spine is connected above the sacrum block. On top of the lumbar spine a mass replacement body is mounted.

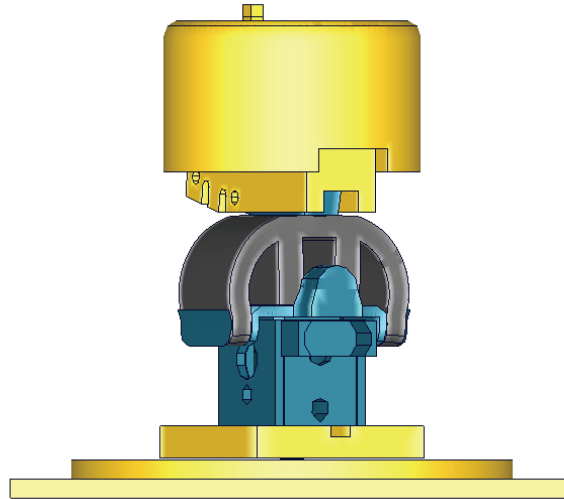


Figure 19: Lumbar spine test setup

This body should represent the upper torso of the WorldSID. The load is imparted by the sled using a defined pulse. The target of this component test is to produce shear and bending behavior of the lumbar spine. Different load scenarios are realized by the variation of the sled pulse and the rotation of the lumbar spine assembly. The data for the evaluation is provided by acceleration and angular rate sensors in the mass replacement and the load cell within the sacrum block.

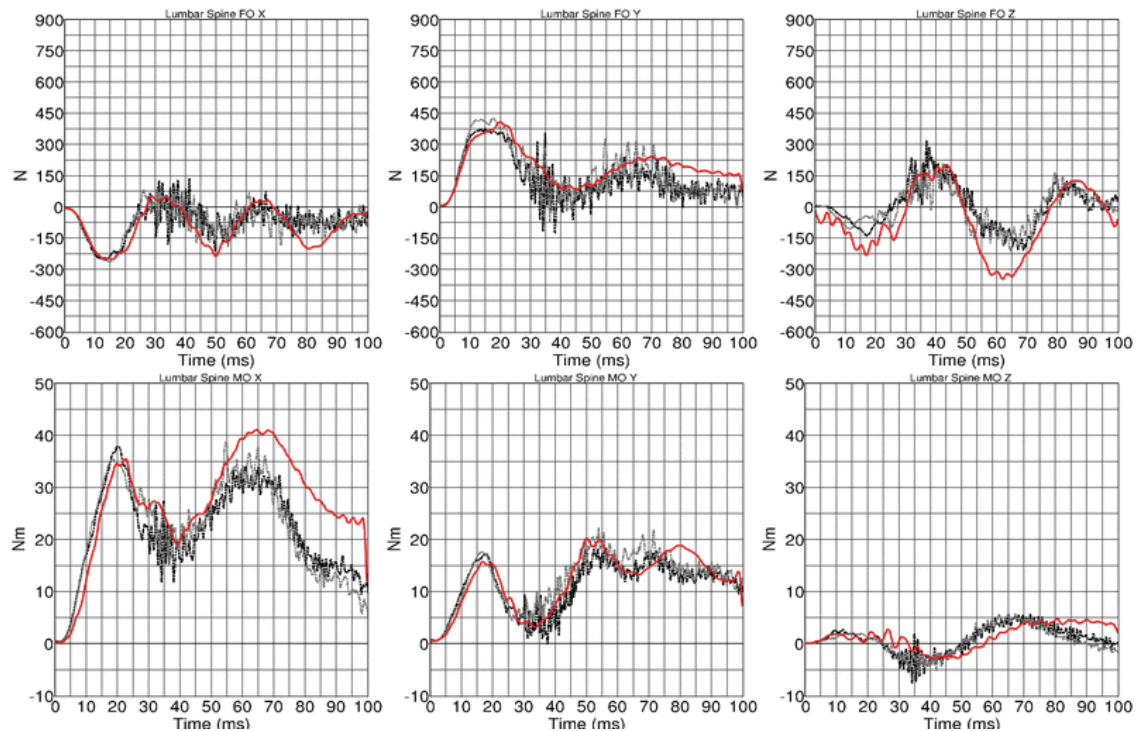


Figure 20: Result of lumbar spine test, lower pulse, 60 degrees lumbar load cell forces and moments

In the picture a comparison between the test and the simulation is given. As depicted, the model shows an excellent correlation in the initial slope. This was the main focus of the validation process. Generally, the calibration of the lumbar spine model was very ambitious due to the friction dominated behavior of the two rubber legs in the middle of the spine at the initialization of the load.

5.5 Iliac Wings

To get an idea of the inner pelvis behavior of WorldSID a further component test was defined. There are two different test arrangements. The first one consists of only one iliac wing, the fixed sacrum block and one pubic buffer as well as the pubic load cell. The intention of this test is the identification of the pubic buffer and the pelvis bone behavior. As the second test setup, the complete inner pelvis assembly - fixed at the sacrum block - was chosen to investigate interaction between the iliac wings and the characteristics of the several connections in the assembly. The load was imparted by a pendulum in two different impact areas. As in the other component tests, the impact energy was varied changing the pendulum velocity. In every test the pendulum acceleration, the pubic force and the forces and momentums of the sacro-iliac load cells are recorded.

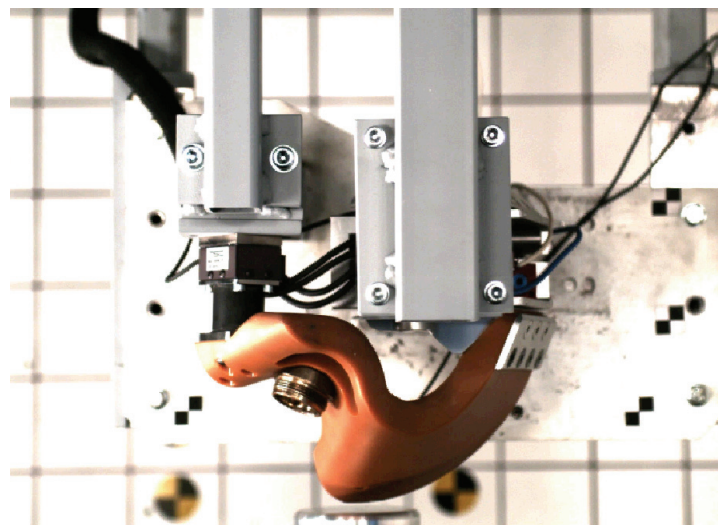


Figure 21: Iliac wing test setup

The model correlation of the depicted iliac wing test is shown in the following. The picture illustrates the correlation between the hardware test and version 1 of the finite element model of the 6 sacro-iliac load cell channels.

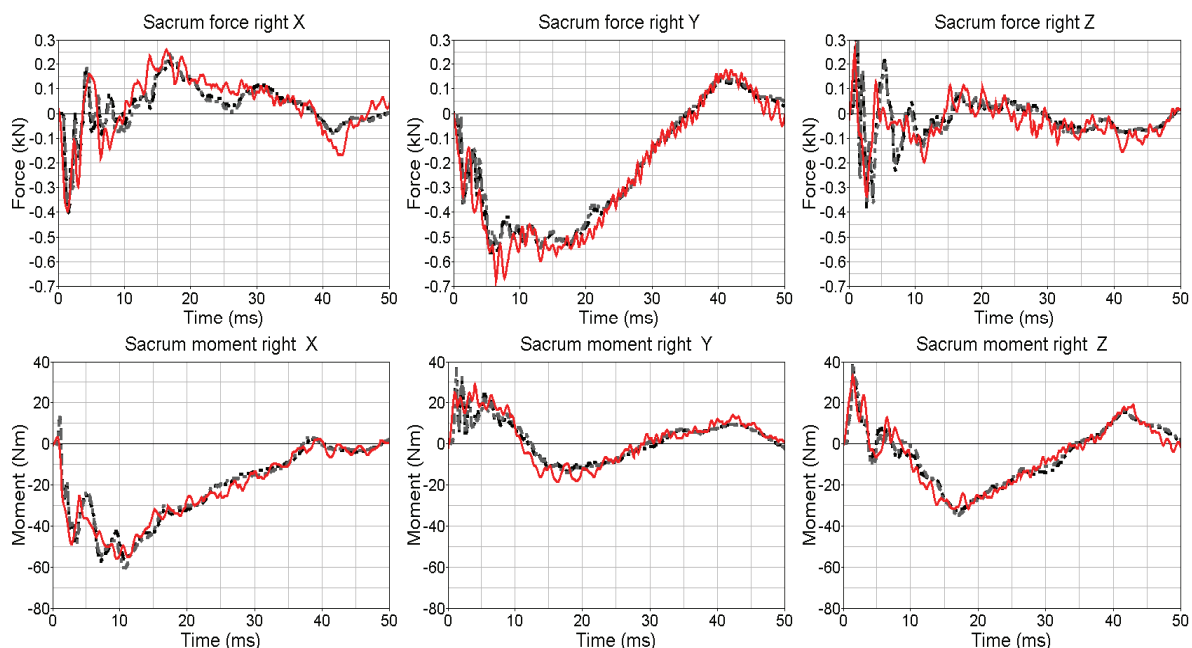


Figure 22: Result of iliac wing test with high velocity, complete pelvis, sacro-iliac load cell

6 Sled Test

All the component tests introduced in the paper are designed with respect to realistic load levels of typical car crash tests. Hence, the validation of the single components was possible and finally, the finite element model's components correlate very well to their hardware counterparts. However, for a high level of validation of the complete dummy model this is only a first step. For understanding the dummy behavior in a car crash it is necessary to conduct barrier sled tests. Here it is possible to impose realistic load characteristics and load levels not only to components but on the whole dummy. So the interaction between the individual dummy components can be investigated and validated.

6.1 Flat Barriers

The flat barrier tests are intended to reproduced severe and mid severe loading conditions. Hence, the tests were performed with two impact velocities of the barriers. These velocities were determined by the maximum rib deflection and the pubic force.

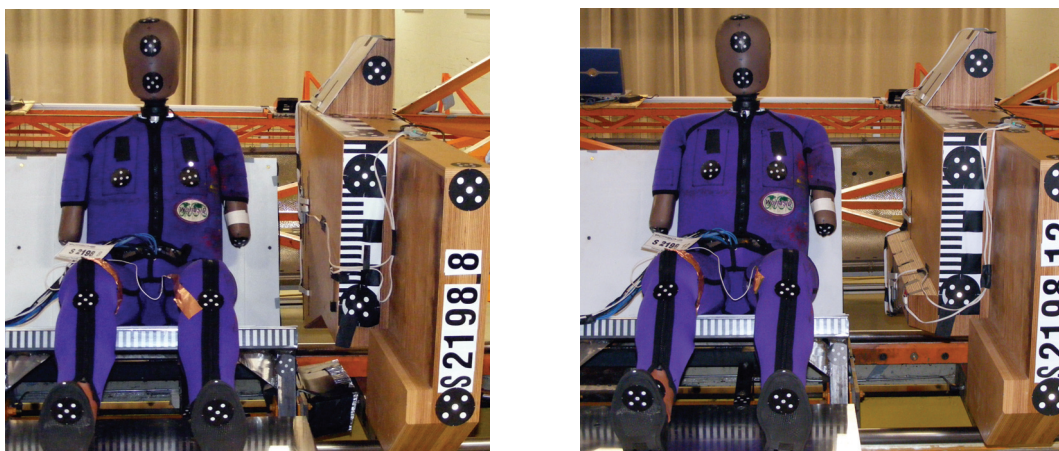


Figure 23: Flat barrier sled test set up with WS50th (left) and barrier with pelvis pusher (right)

In the flat barrier sled tests, most of the load is applied to the dummy through the shoulder. To get a variation of the load path a modified barrier geometry with a pelvis pusher is used.

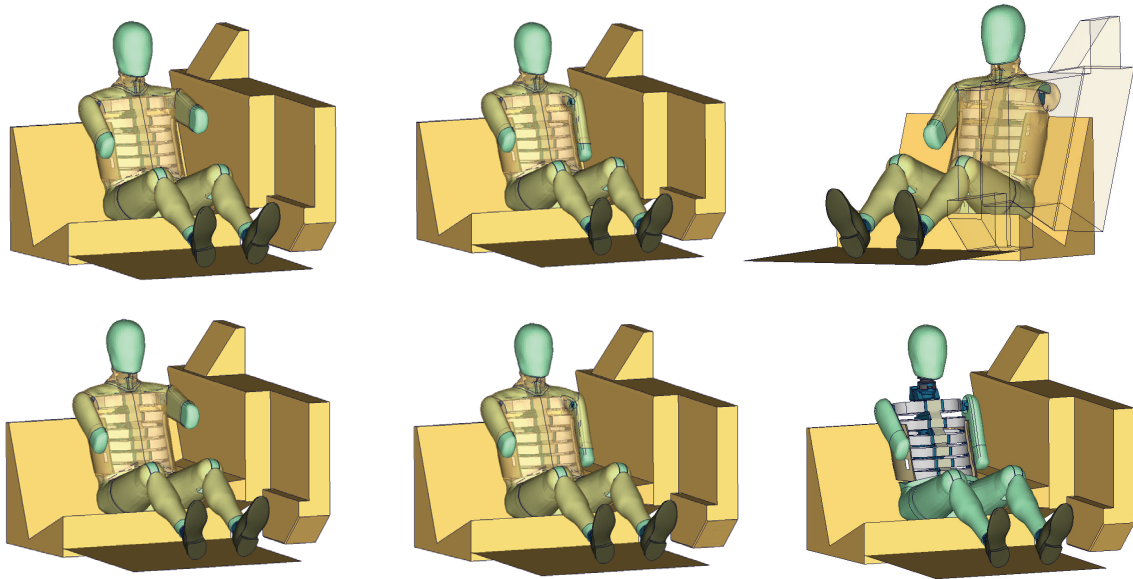


Figure 24: complete PDB flat barrier test program for the present

The picture above shows the complete PDB barrier test program for the present with the two flat barrier shapes. There are six different test configurations. Four of them differ in the arm positions. Additional test without arm respectively without suit were conducted.

6.2 Curved Barriers

The current FMVSS214 oblique pole configuration is a new load case in the development on Side Impact Safety Restrained Systems. Due to the fact that flat barriers only induce lateral loads but not oblique ones, a new barrier design was created.

In a first step intrusion profiles from different cars were collected. All members of the PDB simplified the impact intrusion of the door trim and created feature lines.

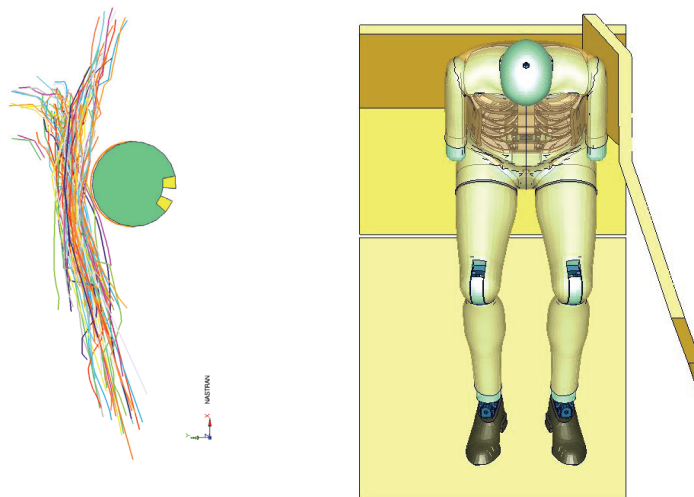


Figure 25: Collected intrusion profiles (left) and draft of the curved barrier with WS on bench (right)

These feature lines are the fundamentals of the new barrier design. The figure above shows the draft of the curved barrier. A wooden arm rest replacement can be added to the final version of the barrier. After the first validation loops for the flat barriers, pre-simulations will be used to determine the impact velocities of the barrier.

7 Performance Version 1

In the following sections the performance of the PDB WorldSID50th model in the four whole dummy pendulum calibration tests are depicted.

The calibration corridors are drawn in blue, the test data is represented by the black lines and the model is shown in red.

7.1 Shoulder

The WorldSID shoulder calibration test procedure prescribes the calibration pendulum (mass 23.4kg) which hits the dummy sitting on the bench in the shoulder joint axis. The pendulum velocity amounts to 4.3 m/s.

For the evaluation of the test the pendulum acceleration and the deflection of the shoulder rib is needed. In Figure 27 below one can see version 1 passes the calibration procedure.

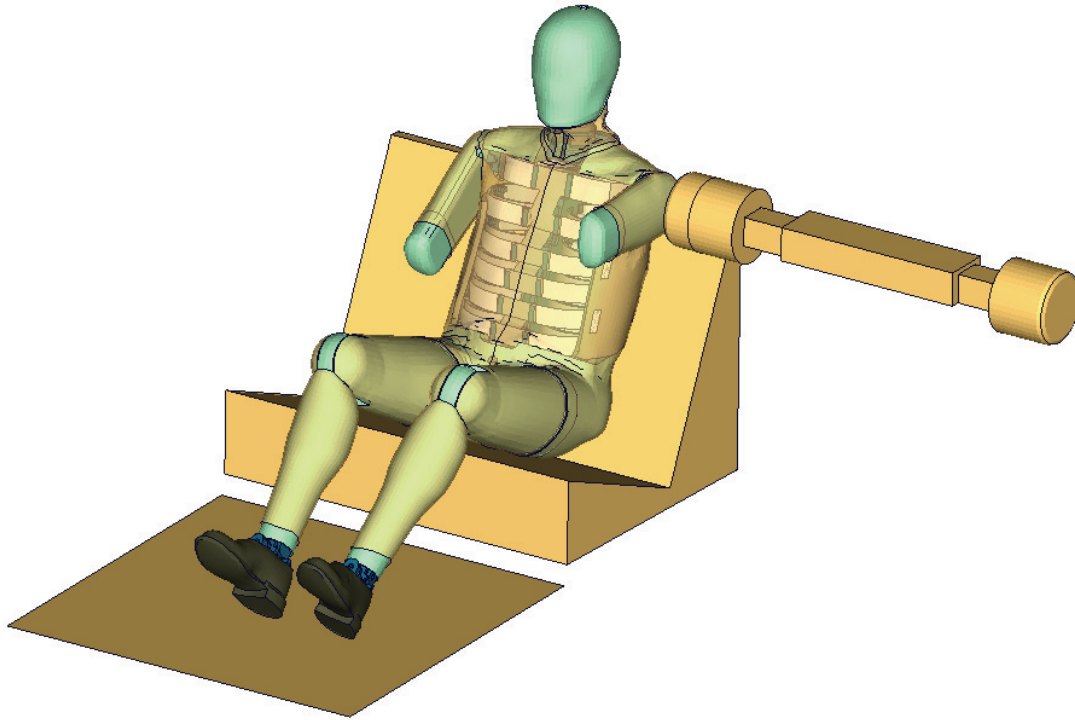


Figure 26: WSID 50th shoulder calibration test

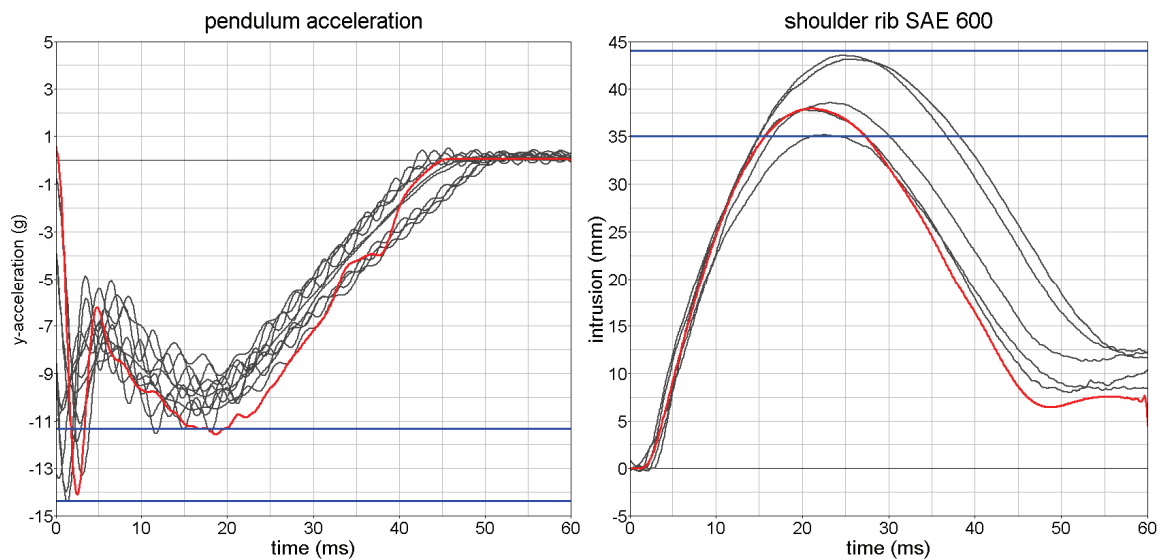


Figure 27: Result of the shoulder calibration test of WSID 50th model version 1

7.2 Thorax without arm

The calibration of the WorldSID's thorax consists of two different tests. The first one is the thorax test without arm; e. g. the calibration pendulum hits the dummy directly on the middle thorax rib. To reach this the arm is raised vertically.

The rib deflections of the three thorax ribs should lie in a range of 34 to 43 mm in the maximum.

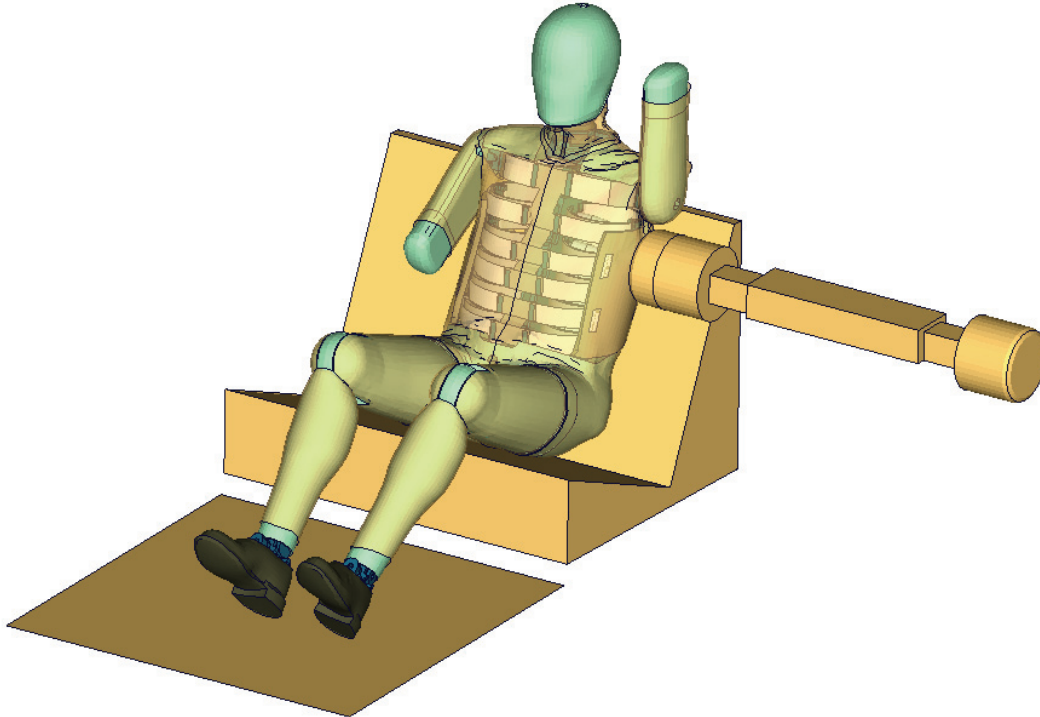


Figure 28: WSID 50th thorax calibration test without arm

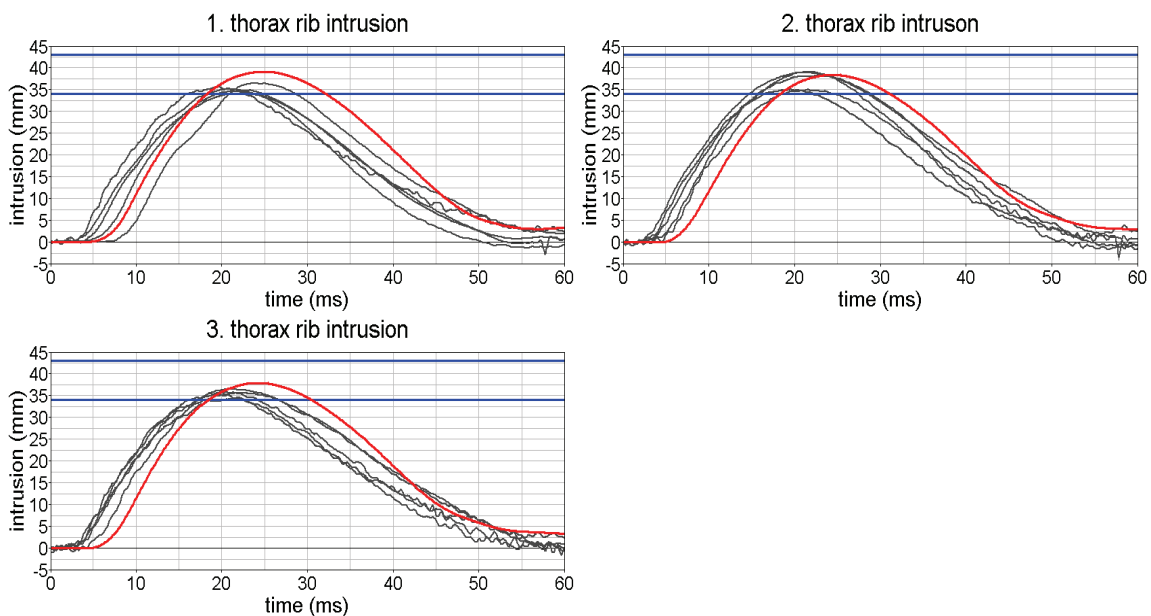


Figure 29: Result of the thorax without arm calibration test of WSID 50th model version 1

The diagrams above show the calibration results of some hardware test and version 1. As one can see version 1 passes calibration again.

7.3 Thorax with half arm

The second thorax test is the calibration test with the half arm. This test is performed involving a lateral impact to the thorax with the half arm assembly. The calibration pendulum velocity amounts to 6.7m/s and is aligned to the middle thorax rib.

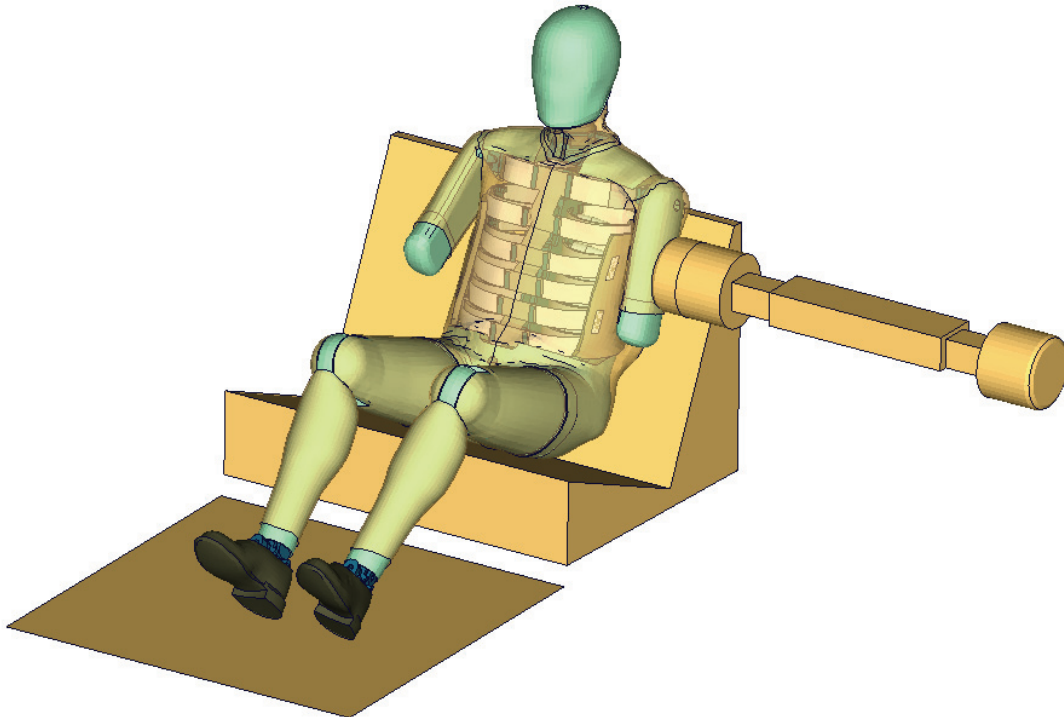


Figure 30: WSID 50th thorax calibration test without arm

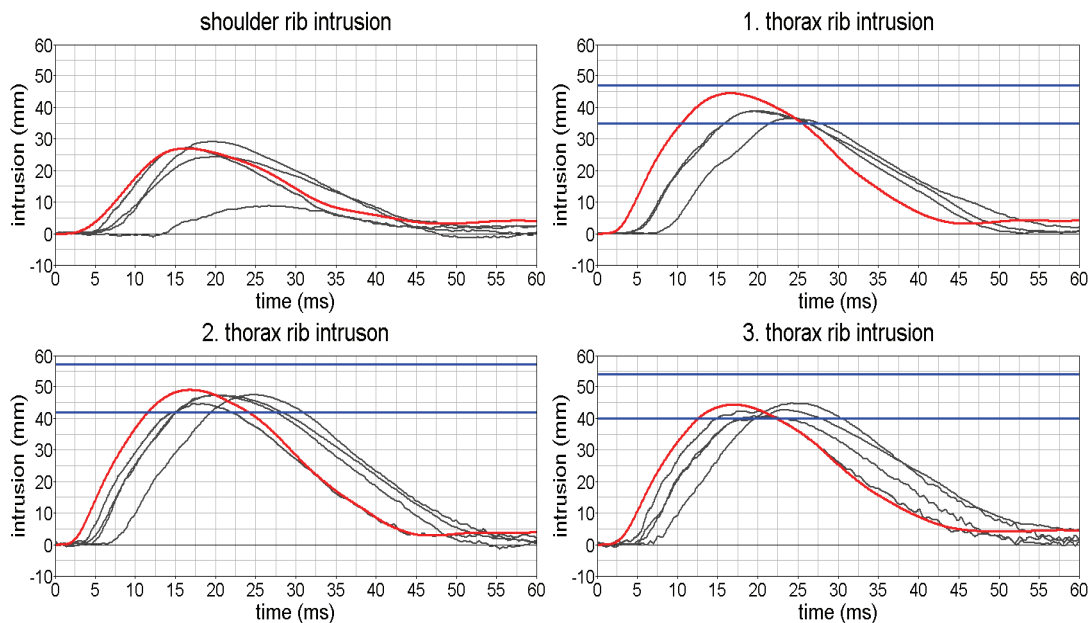


Figure 31: Result of the thorax with half arm calibration test of WSID 50th model version 1

Again, the dummy model passes the calibration test as shown above.

7.4 Abdomen

For the abdomen calibration, a hardwood block is mounted on the pendulum front. After that it is aligned between the abdomen ribs.

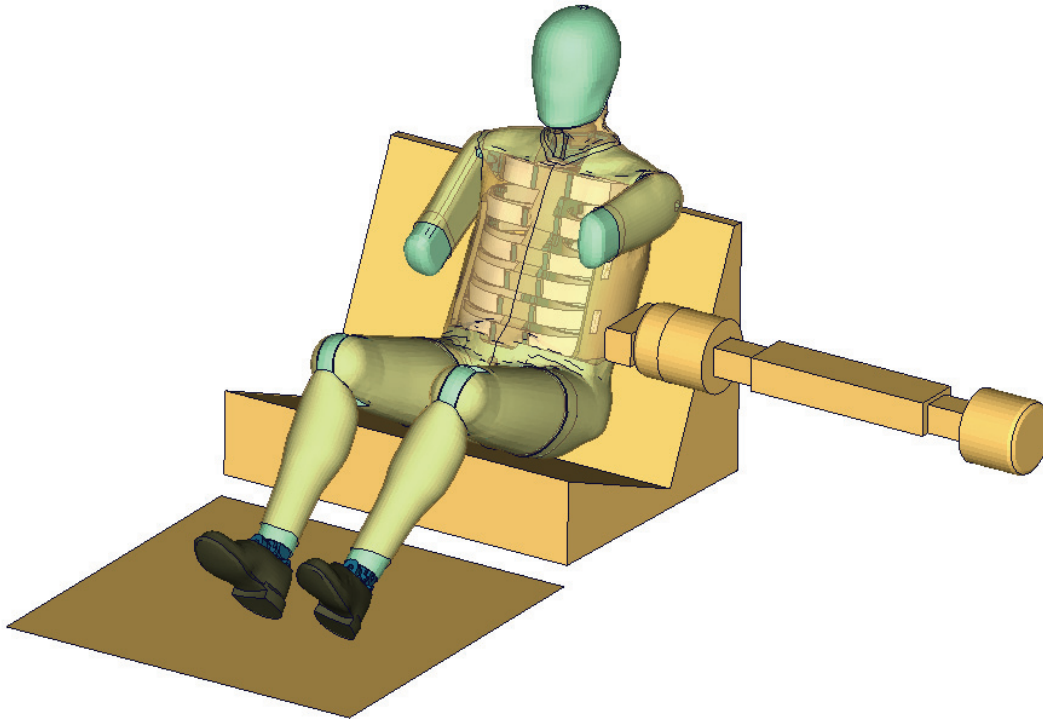


Figure 32: WSID 50th abdomen calibration test

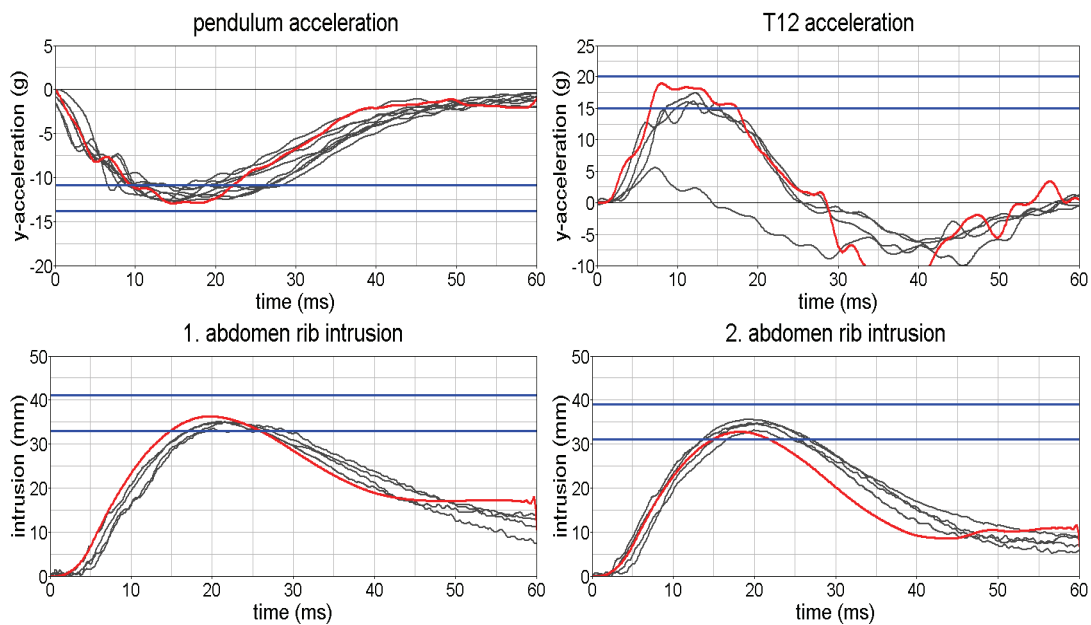


Figure 33: Result of the abdomen calibration test of WSID 50th model version 1

The picture above illustrates that the dummy model's dynamic response lies within all mandatory corridors.

7.5 Pelvis

The last calibration test illustrated in this paper is the pelvis test. Again the full assembled dummy with its suit is sitting on the WorldSID bench. The calibration pendulum is aligned to the H-point and hits the dummy at a velocity of 6.7m/s.

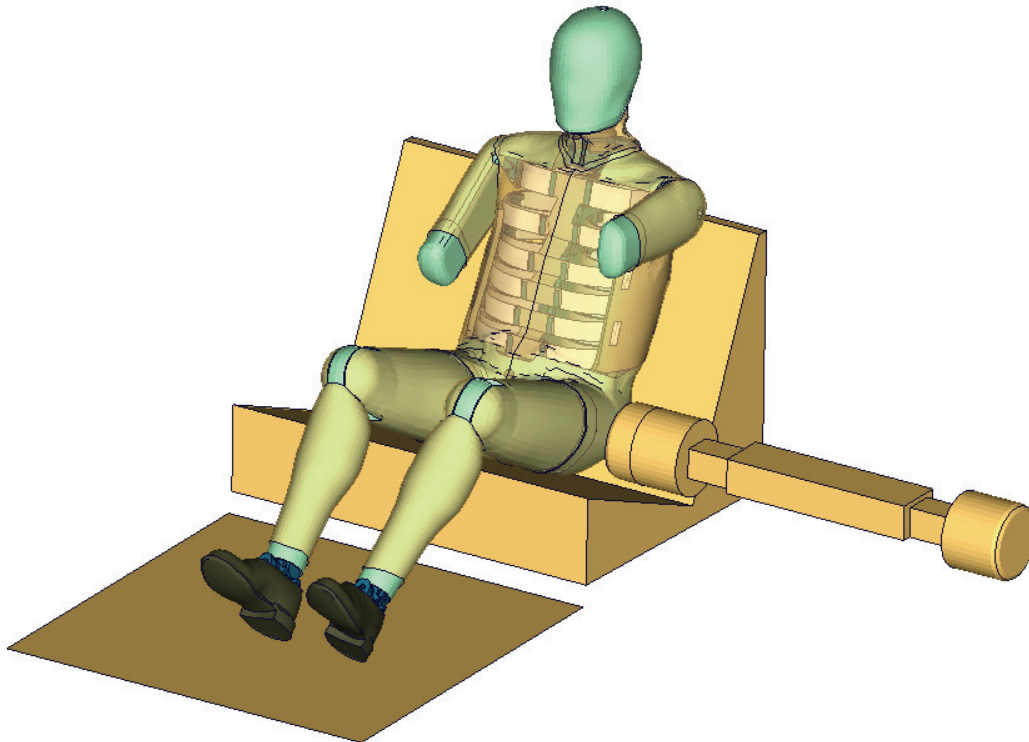


Figure 34: WSID 50th pelvis calibration test

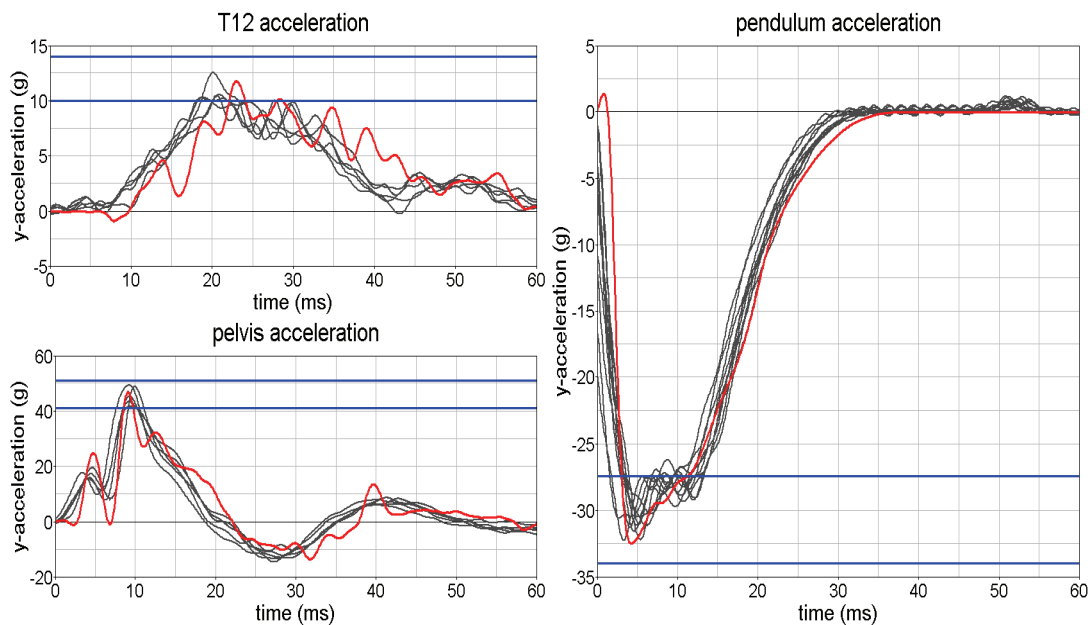


Figure 35: Result of the pelvis calibration test of WSID 50th model version 1

Finally, version of the WorldSID dummy model passes the pelvis calibration test, as depicted in the picture above. Furthermore the model reproduces the quality of the test data very well.

8 Conclusions

The version 1 of the PDB LS-DYNA WorldSID50th dummy model includes a large number of extensive material tests as well as huge test database for component validation. This includes all key components: neck assembly, arm, partial and full rib assemblies, lumbar spine, and inner pelvis assemblies. In total more than 200 different component load cases were used for validation. The tests are performed several times using different dummy models. Section 6 illustrates the very good correlation of the model in some selected tests. More information on the overall good correlation is available in the model manual. In addition the WorldSID model fulfills the complete set of dummy calibration tests. The dummy validation with barrier impacts is the current development focus. In the next months releases with the first set of barrier test database are scheduled. By the end of this year a release that includes all barrier tests is planned.

The model is developed with a working group of the PDB. The companies Audi, BMW, Daimler, Porsche, and Volkswagen contribute to the specifications of the tests and the model development.

9 Literature

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