WorldSID Dummy Model Development in Cooperation with German Automotive Industry

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Abstract

The paper describes methodology used to develop the PDB WorldSID model. The test database generated to build and validate the models is described, as well as the design process of a new barrier shape to validate the model in respect to the new FMVSS 214 oblique pole test. Finally, the performance of the current development release is presented.

Introduction

In November 1997 the WorldSID Task Group was formed under the led management of the ISO (International Organization for Standardization). The Task Group's aim was to develop a unique, technologically advanced side impact dummy with greater biofidelity to replace the variety of side impact dummies used in regulation and in other testing. The development of the WorldSID under direction of ISO/TC22/SC12/WG5, the dummy design was completed in March 2004 [1].

The Partnership for Dummy Technology and Biomechanics (PDB) decided to develop WorldSID finite element models for the crash codes LS-DYNA, PAMCRASH and ABAQUS. The PDB is a group established by a subset of the FAT members to work dummy technology and modeling. Within the project DYNAmore is responsible for the development of the LS-DYNA model and contributes to the test definitions for the experimental database. The project was launched in 2006 and the participants of this project are:

- Audi	- BMW	- Daimler
- Porsche	- Volkswagen	

The project is defined similarly to the known FAT projects for development of the US-SID, Euro SID 1, ES-2/ES-2re and BioRID II dummy models [2]. These models are frequently used world wide and proved their suitability in enhancing vehicle safety since many years. Since the success of the previously developed models the methodology to develop the PDB WorldSID model is based on the previous ones.

This paper describes the PDB project and the different steps which will be used to build an accurate model of the WorldSID. A short overview presents the huge test database. An emphasis is on the design of a new barrier shape that targets to loads the dummy model similarly to a load in a vehicle with an oblique pole impact, like in the new FMVSS 214. Finally the first internal model is described and its performance is outlined.

Database of Tests

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 provide the majority of experimental data close to the type of loading experienced in real crash scenarios. In order to estimate the scatter of the WorldSID each test was performed with 2 or 3 different dummies. The dummies were supplied by the participating automobile companies.

Material Tests:

The following types of tests were performed: Static tension tests, dynamic tension tests, static compression tests, and dynamic compression tests. These 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 for foam and rubber parts, respectively. The following materials were tested: pelvis rubber foam, upper arm rubber foam, upper leg rubber, lower leg rubber, shoe rubber, pubic rubber buffer, lumbar spine rubber, all neck rubber materials (three different), vinyl (head skin), lower arm foam, thorax pad foam (Ensolite), rib material (Nitinol), blue rib damping material and all plastics like the iliac wings, arm bone and head bone. 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.

Figure 1: Material test samples of the WorldSID.

Following strain rates were used: 0.001 1/s, 20 1/s, 100 1/s, 400 1/s. For the rubber-like materials cyclic compression and tension tests were performed with different maximum compressions and tensions.

Component Tests:
The approved combination of the previous FAT dummy projects to validate the model by component and sled tests was the base for the WorldSID project as well.

The following component tests were performed. The majority of test setups were specified after simulations with the first internal release of the dummy model.

- *Head and Neck*
  Sled test: three different loads under two different angles, head impact on a rigid plate.

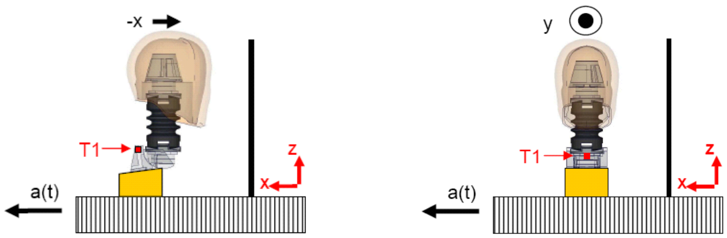

Figure 2: Head and Neck component test setup.

- *Arm*
  Impact tests: two different masses and two different velocities, hits on shoulder, elbow and between these points on a single arm.

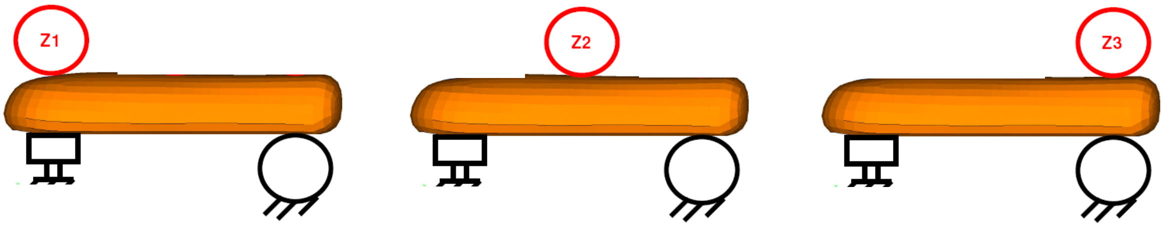

Figure 3: Arm component test setup for different impact points.

- *Spine box*
  Pendulum test: two different masses and three different velocities under different angles, hits on separate rib parts and assembly, for shoulder, thorax and abdomen.

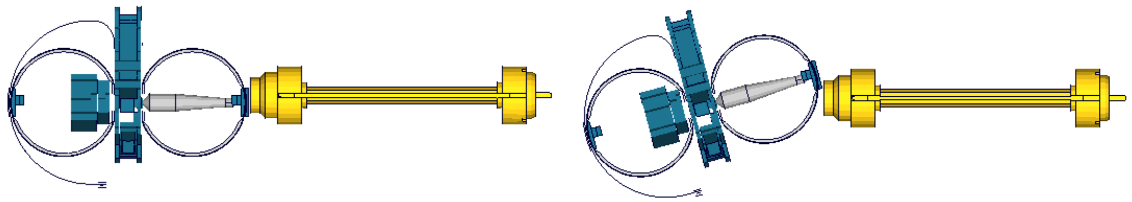

Figure 4: Spine box component test setup on inner band of rib for two different angles.

- *Lumbar spine*
  Sled test: three different loads in use of three different angles, torso mass replacement is used as weight on top of lumbar spine.

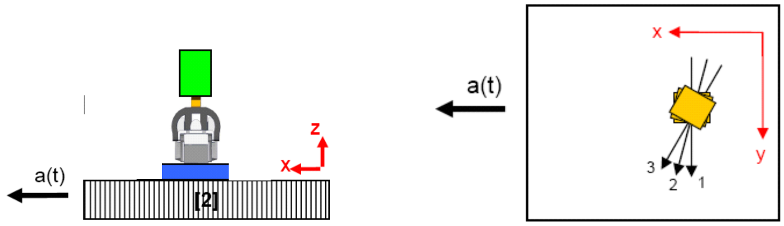

Figure 5: Lumbar spine component test side and top view.

- *Iliac wings*
  Pendulum test: two different masses and two velocities, hits on iliac middle and pubic area.

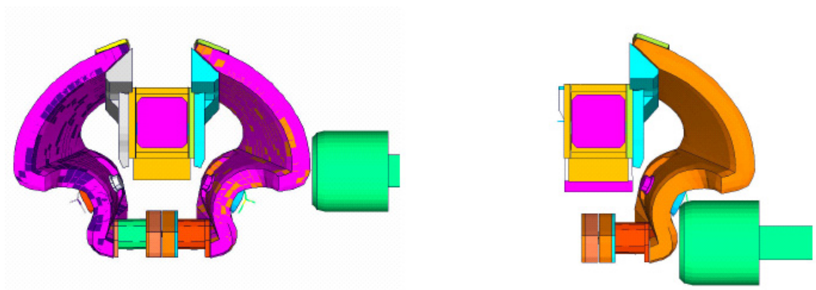

Figure 6: Iliac wing component test. Two different impact points are depicted.

Sled Tests:
The interaction of the parts has a significant influence of the load level in the parts and overall behavior. Hence, sled tests are crucial to finally assess the model quality of an assembly, even if each part itself had a good correlation in component tests.

Selective barrier configurations of the ES-2 were rebuilt according to the WorldSID bench and are the base of sled tests [4]. The selection was made in pre-simulations with the first model of the PDB WorldSID.

The current FMVSS214 oblique pole configuration is a new load case in the development on side impact safety restrained systems. As result a new barrier design was considered to be used in addition to the flat ones from previous projects. How the specifications and geometry were found is described in the following.

In a first step an intrusion profile from different cars were collected. All members of the PDB simplified the interior impact geometry via polygons. These lines were placed horizontal on the major load paths in different heights at 40 and 52 ms (Figure 7).

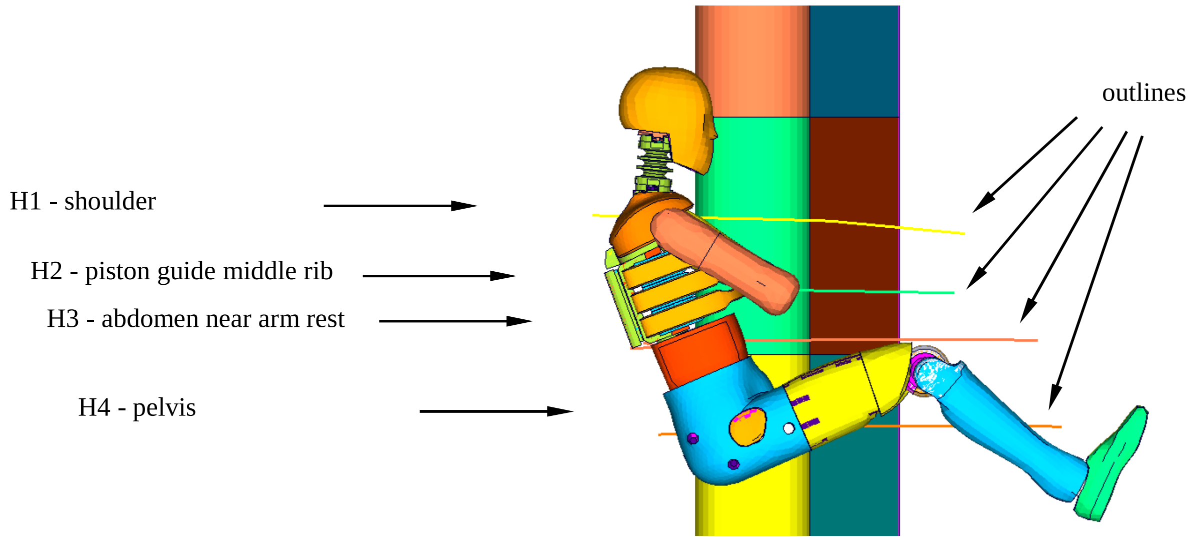

Figure 7: ES-2 in front of the pole, definition of the heights to get the interior outlines.

The collected outlines show the following findings (Figure 8):

- different y-contours are insignificant
  - ⇨ the shape of the barrier should have a perpendicular direction
- frame and side wall of the seat back are quite similar in different cars
  - ⇨ wedge as additional top part of the barrier with same direction of the seat back
- outline angle in front of the pole is very similar by cars with or without b-pillar
  - ⇨ leg support and pelvis rotation about height axis
- outline angle behind the pole is stronger by cars with b-pillar
  - ⇨ due to the influence of the side wall the difference is insignificant
- because of the b-pillar the package between pole and interior is bigger
  - ⇨ the stopping distance of the dummy is getting shorter, the efficiency of the re-strained system decreases

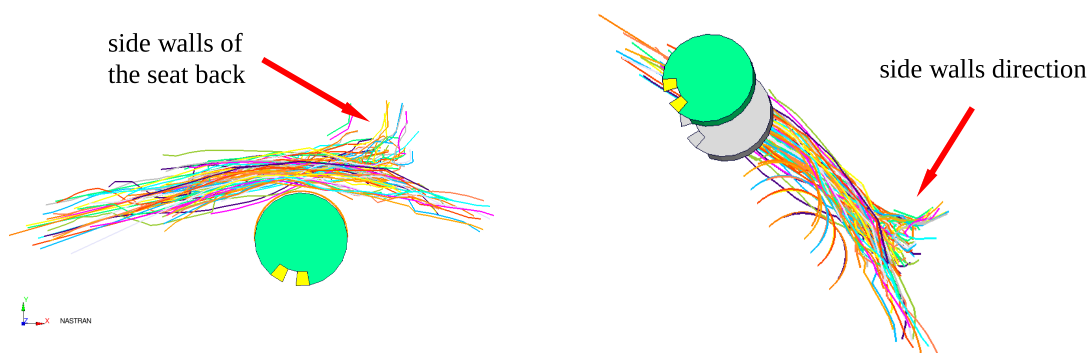

Figure 8: collected outlines: left - top view; right - view along the back frame of the seat.

To build a wooden barrier the outlines have to be simplified. In Figure 9 the resulting proposal for a new barrier shape is described. By using pre-simulation the angle, edge characteristic and heights were adjusted to reach results close to real crash scenarios. Specified outline situations and shoulder loads could be described by additional top parts on the shape of the barrier.

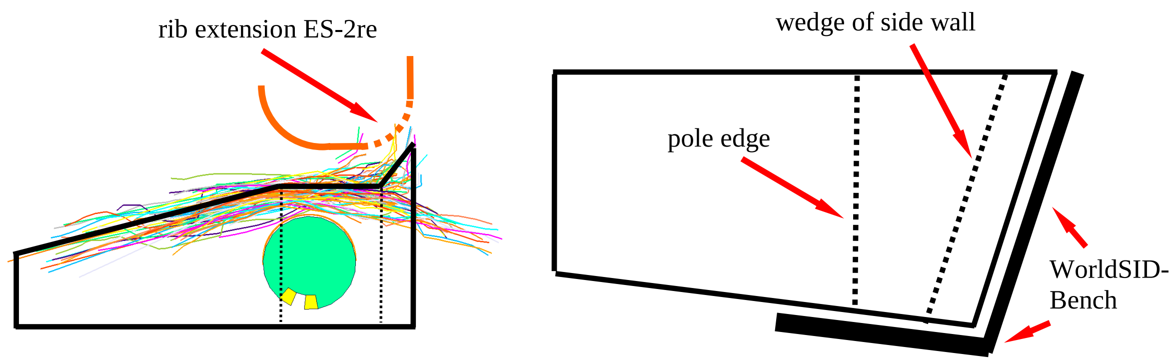

Figure 9: simplified shape of the barrier, LEFT: top view; RIGHT: side view with WorldSID-bench.

To observe the influence of an oblique velocity component several simulations using the ES-2re dummy on the WorldSID bench were performed. The base line simulation is done with a straight sitting dummy and a 90-degree barrier like it is shown in
Figure 10 on the left. For the modified simulation the velocity direction and value is the same. The dummy and the barrier are rotated about 15 degree along the z-axis. Thus the velocity component of the barrier has the same angle relative to the dummy as in a 75 degree pole test (Figure 10). The velocity of the barrier is for both simulations the same.

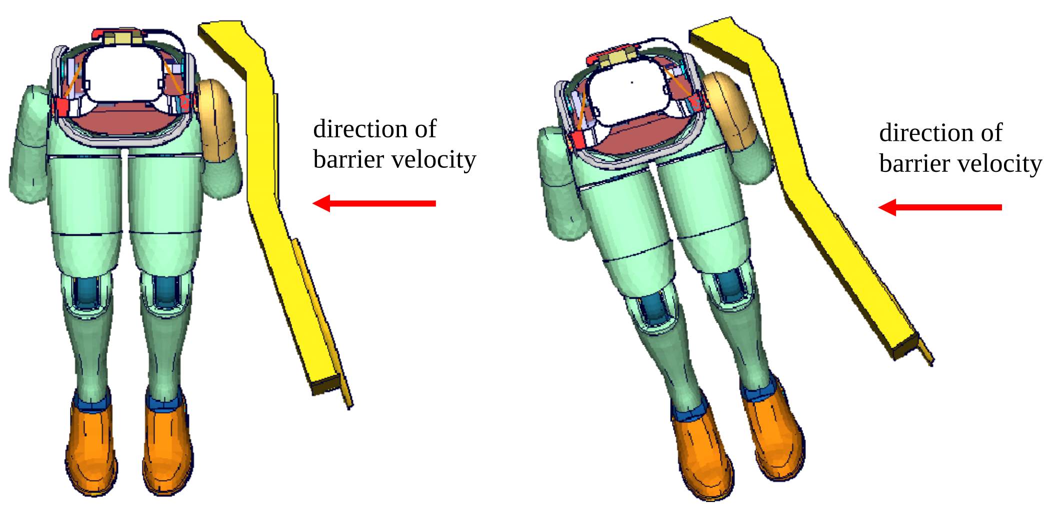

Figure 10: Pre-simulation setup to check influence of oblique velocity component for new barrier shape. Left: baseline position, RIGHT: dummy and barrier rotated 15 degree.

Below, the comparison of the results with and without oblique velocity component is depicted.

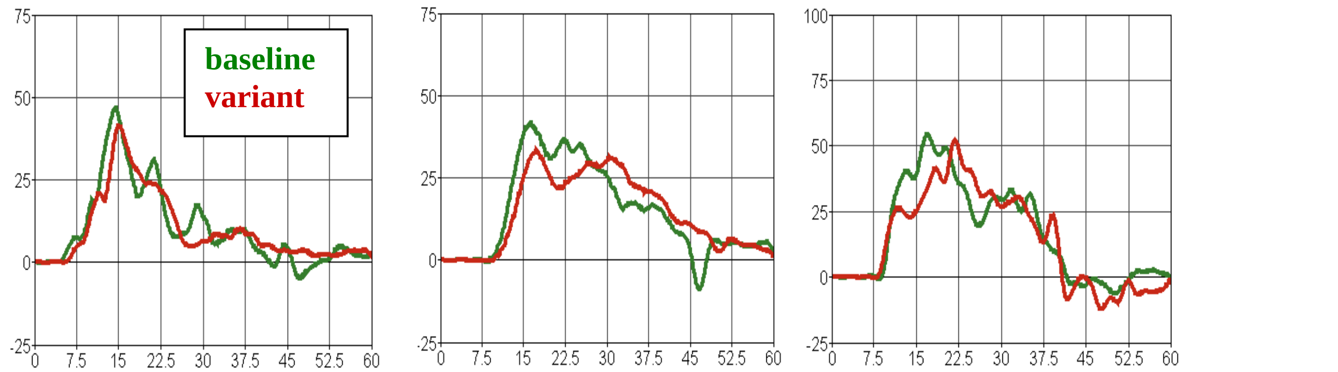

Figure 11: acceleration [g] vs. time [ms], LEFT: upper spine, MIDDLE: lower spine, RIGHT: pelvis acceleration.

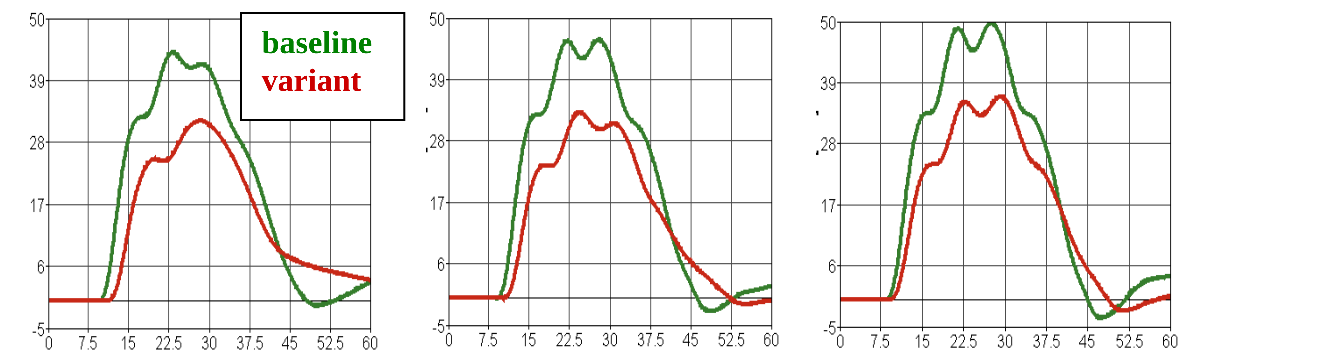

Figure 12: Rib intrusion [mm] vs. time [ms], LEFT: upper rib, MIDDLE: middle rib, RIGHT: lower rib of ES-2re.

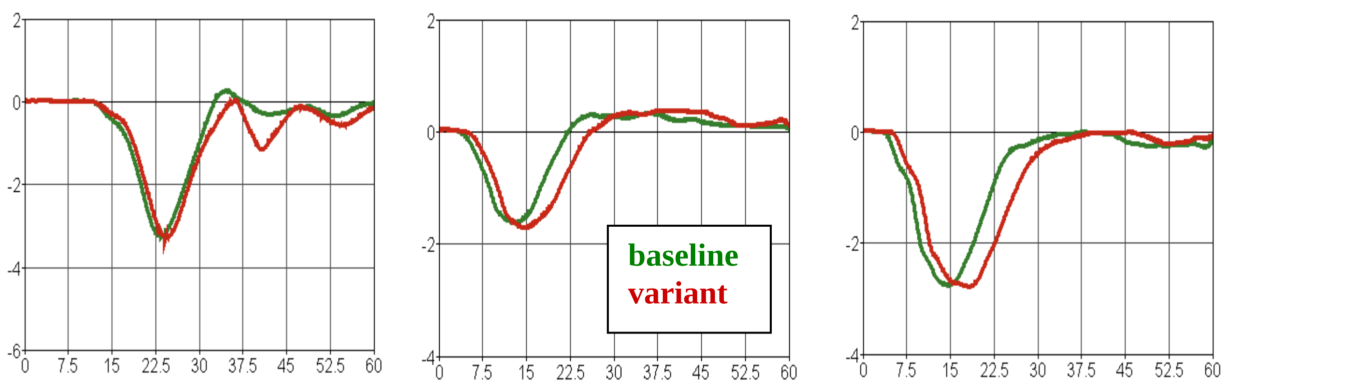

Figure 13: Forces [kN] vs. time [ms], LEFT: pubic symphysis force, MIDDLE: shoulder x-force, RIGHT: shoulder y-force.

The results in use of the oblique velocity component are mainly the same as without oblique component. Only the rib defections differ. As result the working group decided that the oblique velocity component will be neglected in the first test sequence. Furthermore it was decided that the barrier should also be used to validate the ES-2/ES-2re model for the new loading case.

First Model

In a first step the mesh is generated based on CAD data which is constructed out of the drawings of the ISO 15830 of 2005 for the WorldSID [3] and 3 D scanned data of the jacket. The rubber parts are mainly meshed by use of hexahedron elements except the pelvis rubber foam. Due to a very complex geometry the pelvis rubber foam is meshed in use of tetrahedron elements. The WorldSID model is depicted in the Figure 14.

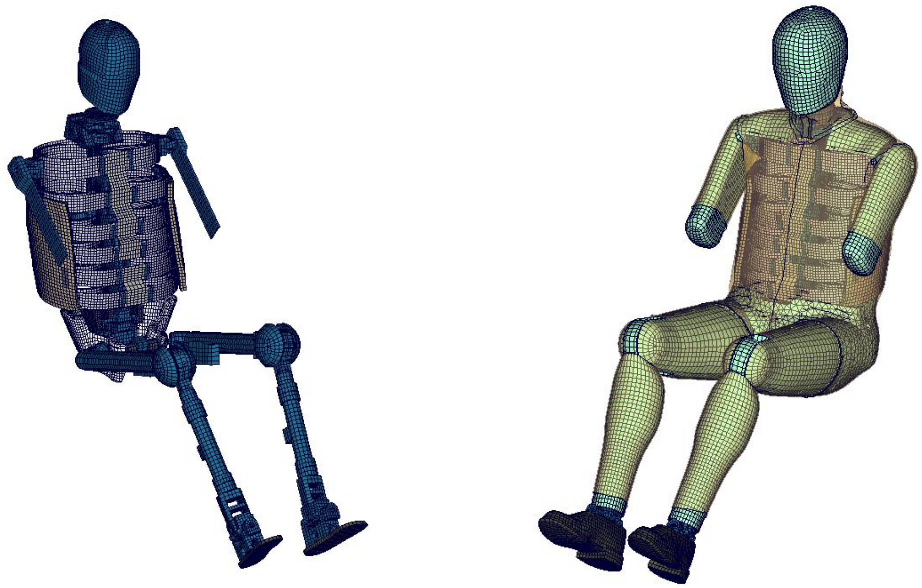

Figure 14: Mesh of PDB WorldSID model v0.0, LEFT: bone structure, RIGHT: complete model with jacket

The mesh density is chosen for a time step of one microsecond and the total number of elements should not exceed 200 thousand. The current model size is described in Table 1.

Component	Total number
Nodes	~ 135000
Shell elements	~ 97500
Solid elements	~ 102100
Beam elements	~ 600
Materials	~ 50
Sections	~ 60
Parts	~ 560
Coordinate systems	~ 50

Table 1: Overview about the PDB WorldSID model size.

The current production release of the WorldSID model uses material data from other FAT dummy models which have a similar behavior. The material tests are still in progress and will be finished soon. Based on these material tests the version 1.0 will then be created.

For evaluating injury criteria the model is equipped with the same measurement devices which are available for the physical dummy. Therefore, accelerometers, load cells, rotational accelerometers, deflection measurements, and rotation measurements are defined. In total, 54 different kinds of signals could be extracted.

First Validation

Rib module test:
The first component tests which are used to validate the model are the rib tests. These component tests are still in progress and in the following a test on an inner band of a thorax rib is described. Over-all the WorldSID has one shoulder rib, three thorax ribs and two abdomen ribs which are constructed in a similar way. The ribs consist of an inner and outer band of Nitinol. This material is a memory shape alloy which passes through a crystal transformation during deformation; this has a high influence on the material stiffness. On the inner band of Nitinol there is put on a damping material which behaves similar to the damping material of the SID-IIs.
Figure 15 depicts the construction of the ribs of the WorldSID.

To validate this complex construction there are component tests on the inner band of the rib and also on the full assembled rib. Therefore, the influence of the single parts of the ribs and also the interaction can be observed and it is possible to understand the behavior of the construction.

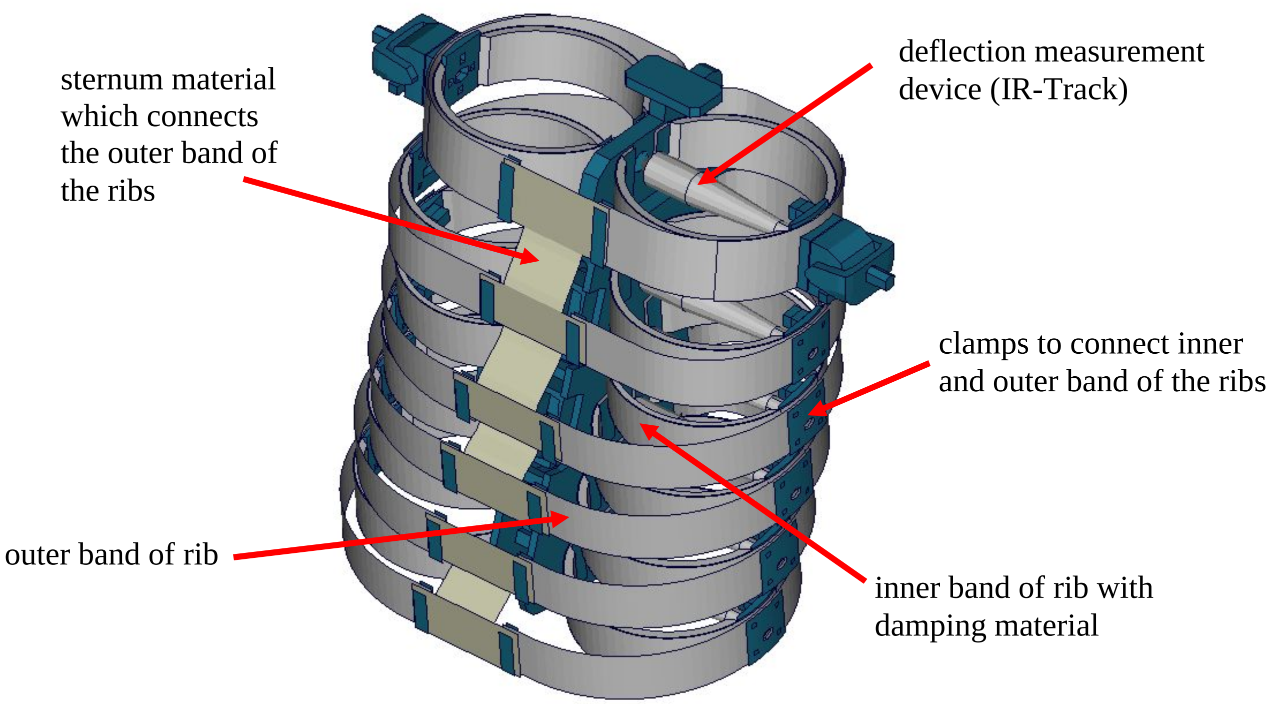

Figure 15: Thorax model.

To test the inner band of the thorax rib, it is impacted by a pendulum with three different impact velocities. The loading direction is normal to the spine box and the pendulum is covered with an Ensolite foam on the front side. The test is depicted in Figure 16.

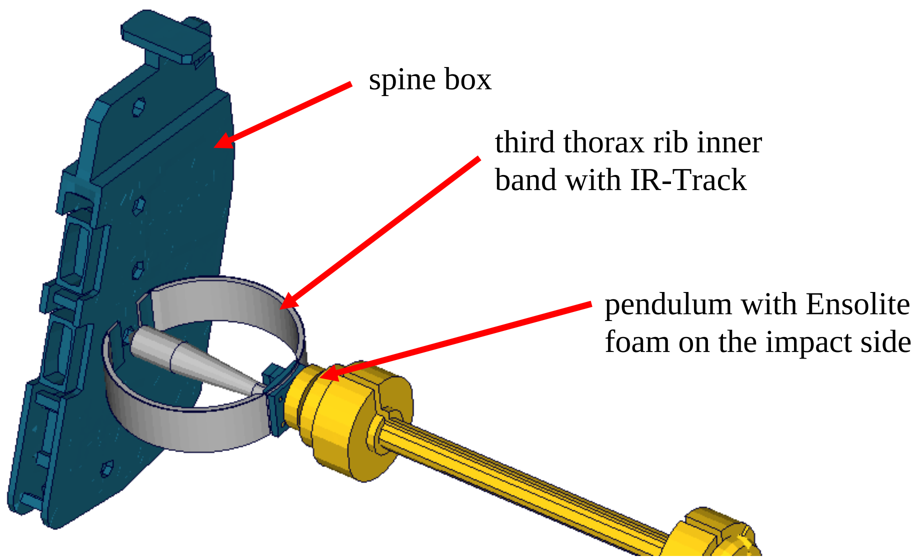

Figure 16: Component test of inner band on third thorax rib.

In the following the results of the rib component test for three different velocities are shown. The blue lines represent the test data and the red lines are extracted from simulation results.

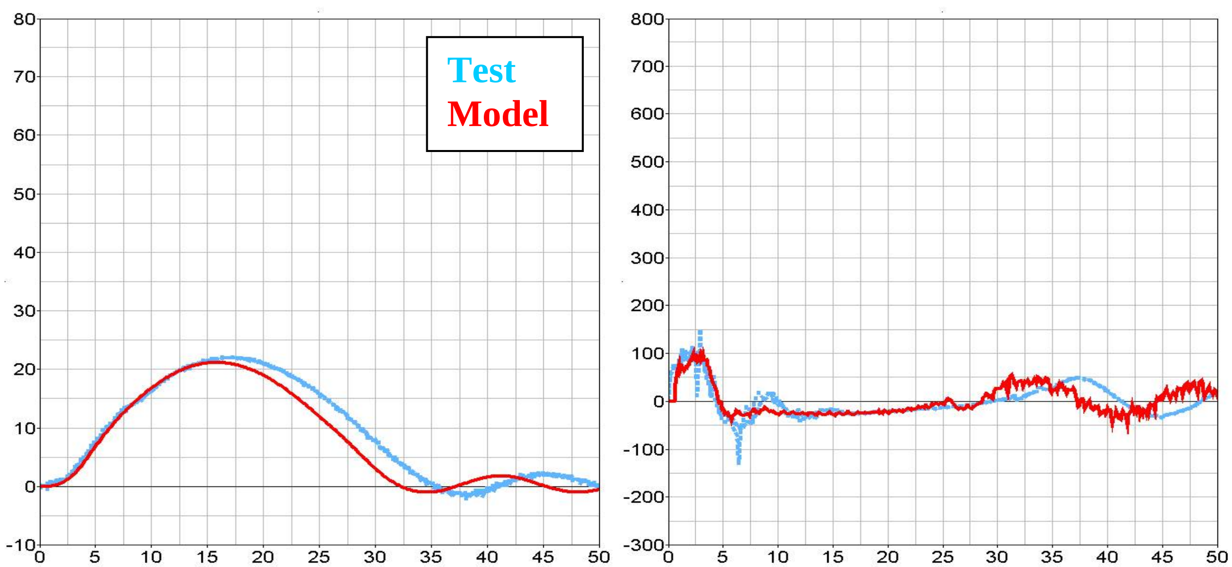

Figure 17: Rib component test 3.5 m/s pendulum speed vs. time [ms],
LEFT: deflection [mm], RIGHT: acceleration [g]

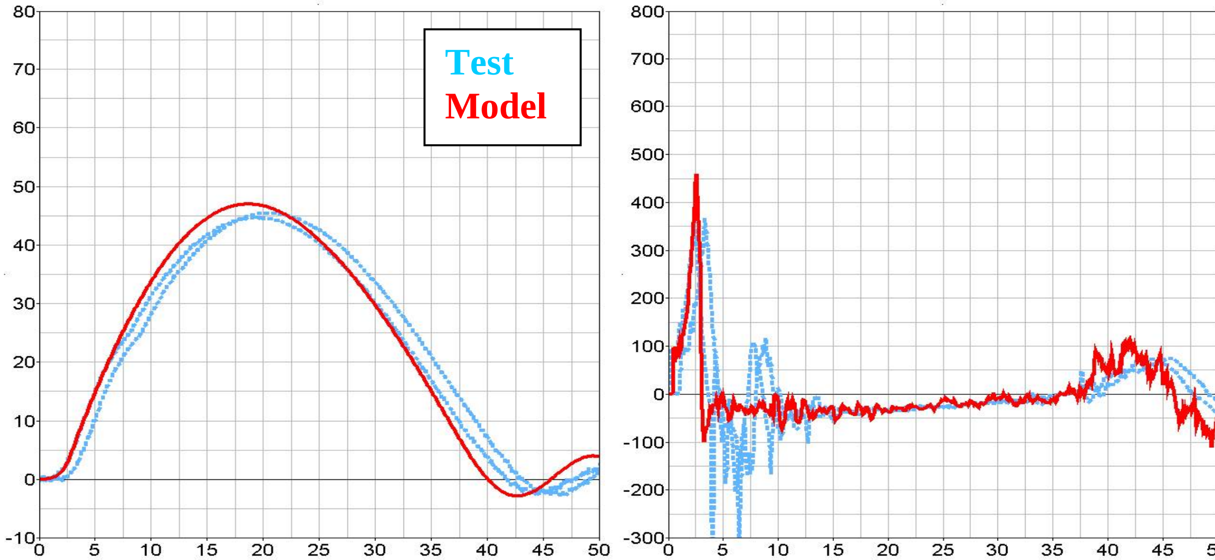

Figure 18: Rib component test 6.0 m/s pendulum speed vs. time [ms],
LEFT: deflection [mm], RIGHT: acceleration [g]

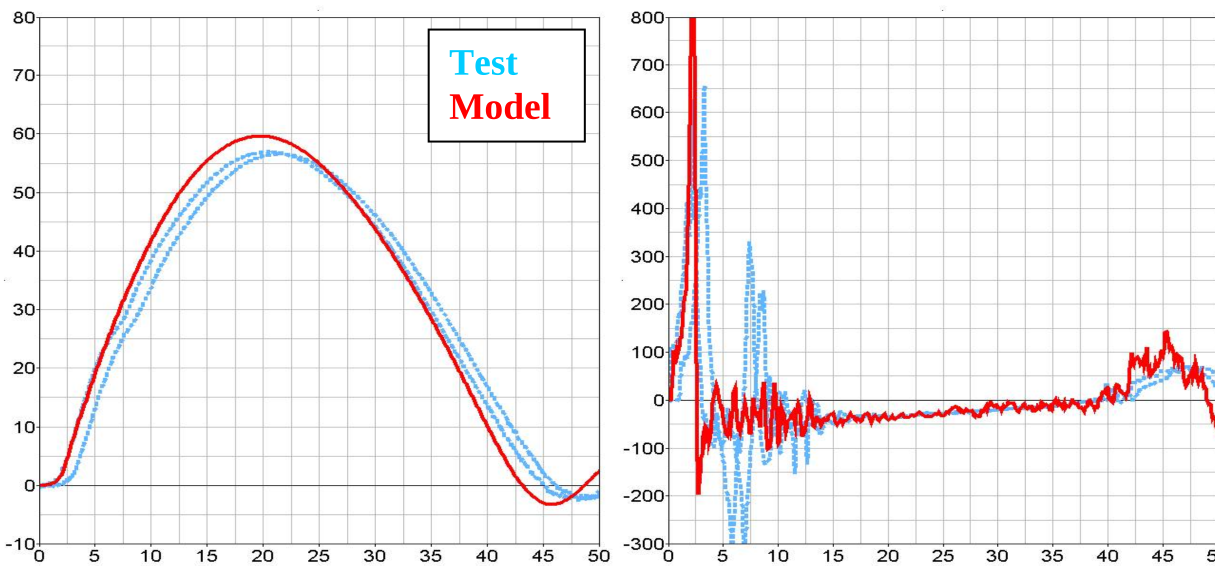

Figure 19: Rib component test 7.0 m/s pendulum speed vs. time [ms],
LEFT: deflection [mm], RIGHT: acceleration [g]

For the initial simulations the results are surprisingly good if you take into account that this is the starting point for the validation work. The deflection maximum is captured well, but there is a capability visible to enhance the model in the maximum deflection values and also in the un-loading path of the deflection. It seems that the strain rate behavior of the damping material is not captured accurately enough. Thus the deflection of the lower speed is under-predicted and the higher speeds are over-predicted. The detailed material tests of the damping material of the WorldSID are in progress. The strain rate behavior will be much more increased if the exact material test data of the damping material is used.

Neck module test:
A second test which is used at that time for validation is the neck calibration test of the WorldSID. The test is performed with the neck and the upper neck load cell. The WorldSID parts are connected to a large pendulum which uses a honeycomb braking system. At the other side of the neck there is a head form connected. For a detailed description of this test please see [3]. By decelerating the pendulum the neck bends in direction of motion like it is depicted in Figure 20.

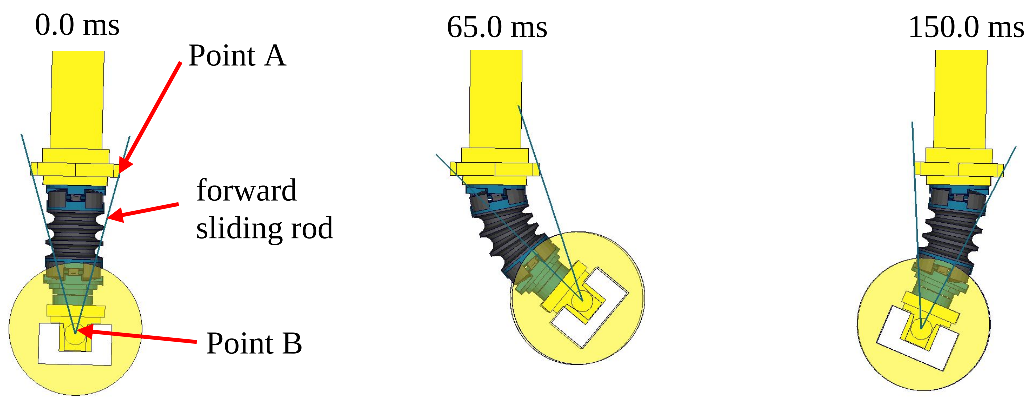

Figure 20: Neck component test at time 0ms, 65 ms and 150ms

On one side of the test setup rotational potentiometers are installed, to measure the rotations of the neck at two points. Point A of Figure 20 gives the angular displacement between the forward sliding rod and the pendulum. At Point B the angular displacement of the head form about the forward sliding rod is measured. These two angles describe the rotation of the neck very accurately. In the following the results of the pendulum test are shown.

Figure 21: angular displacement [degree] vs. time [ms], LEFT: about point A of Figure 20, RIGHT: about point B of Figure 20.

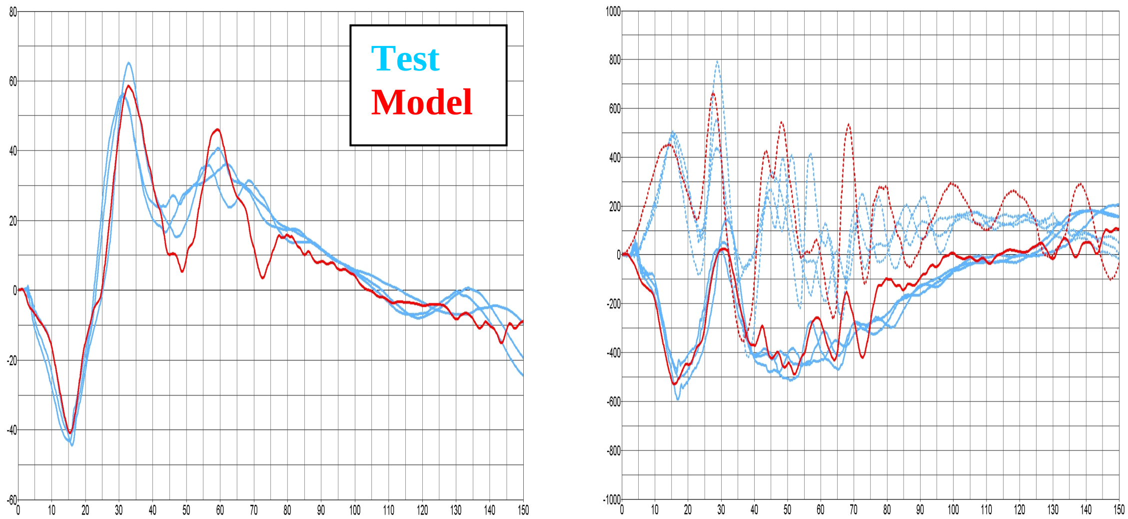

Figure 22: Upper neck load cell, LEFT: y-moment [Nm], RIGHT: solid line y-force [N], dotted line z-force [N].

All signals are captured very well. The forces as well as the moment or the rotations are quite near to the test data. The neck validation is in this case finished in a first step. A second step for neck validation will then be the additional component test for the neck described above in the chapter 'Test Database'.

Calibration Test

To get a better understanding about the behavior of the full assembled model in the current state, the calibration tests of the World-SID are considered. The calibration tests consist of simple pendulum tests on the shoulder, the thorax without arm, the thorax with arm and the pelvis. During these tests the dummy is sitting on the WorldSID bench and is fully assembled with the jacket. As example Figure 23 depicts the calibration test setup for the abdomen test. For hitting only the abdomen rib an additional wooden block in front of the pendulum is used.

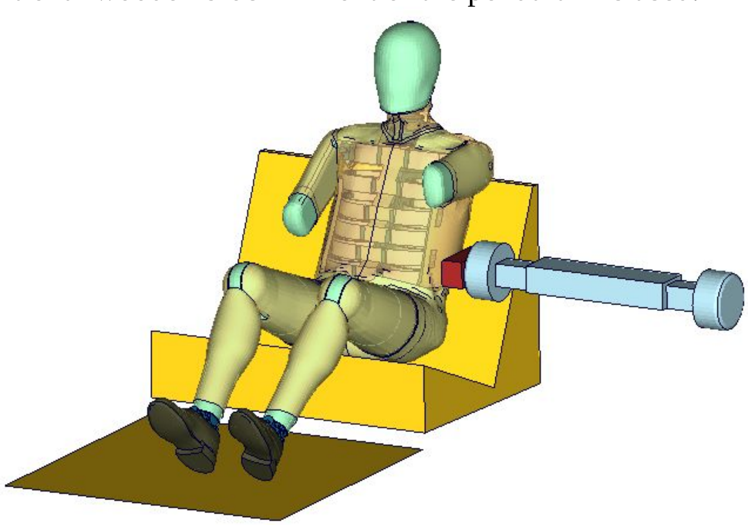

Figure 23: World-SID shoulder calibration test setup.

The pendulum for the abdomen test weighs 24.4 kg. The velocity of the pendulum is 4.3 m/s and it is aligned to the center point between the two abdomen ribs. For calibration the deflection of the abdominal ribs, the T12 and pendulum accelerations are measured. The following pictures show the first results of the abdomen calibration test in use of the current production release.

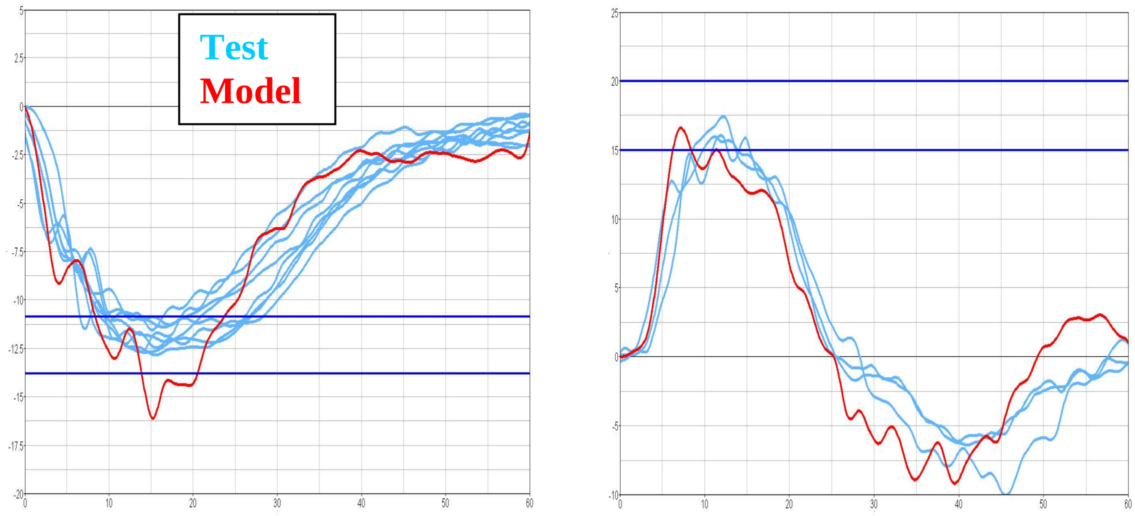

Figure 24: Abdomen calibration results vs. time [ms], LEFT: Pendulum acceleration [g], RIGHT: T12 acceleration [g]

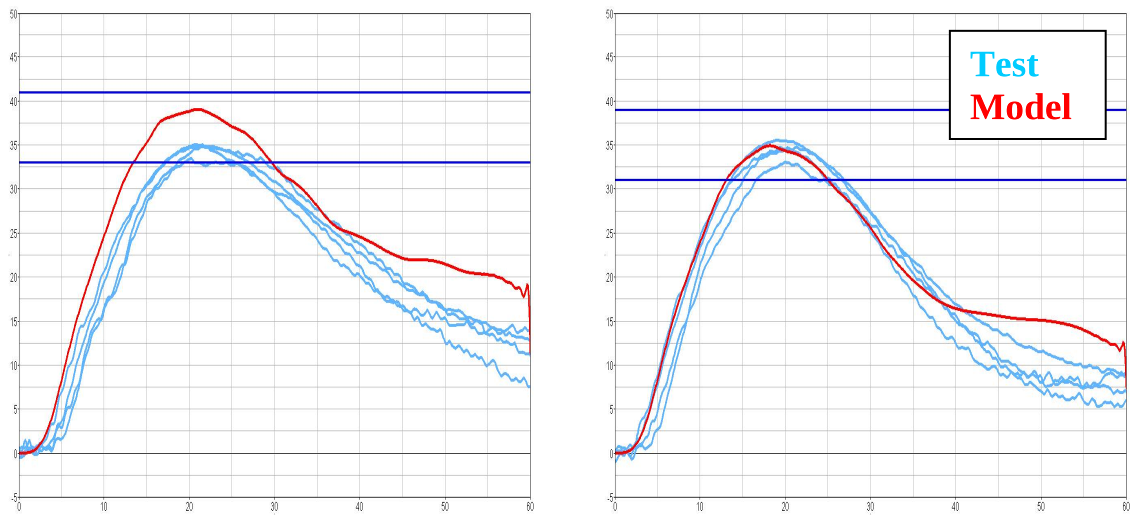

Figure 25: Abdomen calibration results vs. time [ms], LEFT: upper abdomen rib deflection [mm], RIGHT: lower abdomen rib defection [mm].

The first model gives good results in the calibration test in particular if you take into account that this is the starting point for the validation work. The correlation in the other calibration tests is similar to the abdomen test result of Figure 24 and Figure 25. But the validation of the inter-action of all the dummy components is still missing. Currently, only load cases are considered which conduct a very concentrated load on single part of the dummy. Furthermore, there is still a lack of exact material data of some parts. Using this data the performance will be increased.

Conclusion

The LS-DYNA version of PDB model of WorldSID is meshed very accurately and the element number is in a moderate range. An extended material database was used to generate an initial model. This model shows an already surprisingly good correlation in a first set of tests. The initial model was then used to investigate the dummy loads during an impact and to define adequate tests for validation. Currently, these tests are in progress. The next development steps are to validate the model with the component and sled test database. The methodology follows the guidelines from the previous FAT projects, with an emphasis on using more pre-simulations to define appropriate tests.

A first commercial release of the LS-DYNA PDB WorldSID model will be available in summer of 2008. It will include detailed material tests, and a first sequence extended of component tests. The model will be supported from DYNAmore and the local distributors of the previous FAT models.

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