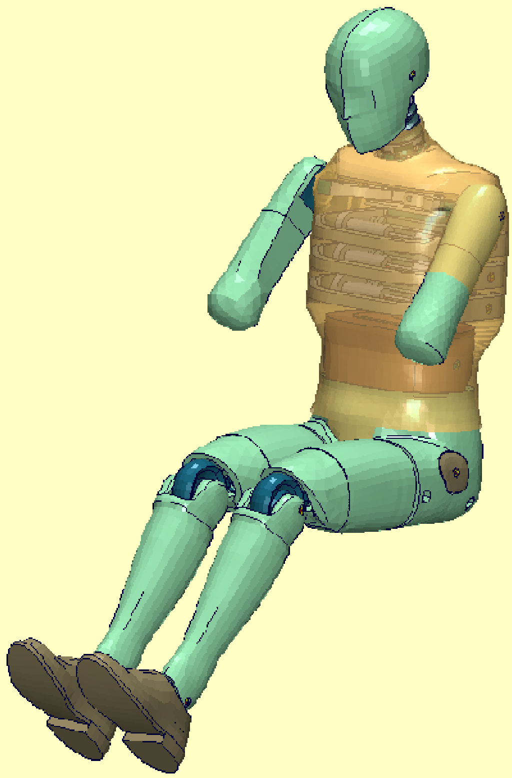
Documentation

LS-DYNA

ES-2 50th - Version 4.5

ES-2re 50th - Version 4.5



User's Manual
Manual Release 1.2 for Model 4.5
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Content

1. General information

The development and validation has been performed on different platforms. The following LS-DYNA versions have been used:

LS-DYNA Version	Date	Revision Nr.
971 R3.2.1 SMP	09/18/2008	47756
971 R4.2.1 SMP	06/08/2009	53450
971 R3.2.1 MPP	09/18/2008	47756
971 R4.2.1 MPP	06/08/2009	53450

Table 1: LS-DYNA versions.

With the version 4.5 of the Euro-SID 2 50th model the following keyword files are delivered:

File name	Content
es2_v4.5_mm_ms_kg.key	Dummy model, the file name might vary depending on the system of units
es2_v4.5_nullshells.key	Optional contact shells
es2_v4.5_mm_ms_kg_load_curves_work.key	Dummy curves for working on the model with a pre-processor
es2_vendor_a.date_license_comp_e.date.asc	License file including the table and curves of the model
Positioning_es2_v4.5_mm_ms_kg_torso.key	File for positioning the dummy by a pre-simulation

Table 2: Files delivered.

The numbering scheme of the original model is shown in Table 3. On demand we deliver renumbered input decks, according to user specifications.

Component	Min ID	Max ID	Total number
Nodes	10001	153624	113888
Solids	12000	186162	174163
Beams	10000	11240	335
Shells	190000	307689	87850
Discrete elements	10500	10514	15
Mass elements	10502	15011	10
Accelerometer	1	8	8
Set nodes	1001	1004	4
Set parts	1	1501	23
Parts	1	341	281
Materials	1001	1140	114
Sections	1003	1157	135
Hourglass	1001	1009	9
Joints	1001	1019	19
Joint stiffness	1	321	13
Contacts	1	10	10
Local coordinate systems	1001	1040	39

Load curves / tables	1001	1110	145
Time history nodes	10001	10117	15
Time history elements	10000	10016	17

Table 3: Model numbering scheme.

1.1 Keywords Used

The following control and database keywords are used:

*CONTROL_ACCURACY *CONTROL_BULK_VISCOSITY *CONTROL_CONTACT *CONTROL_CPU *CONTROL_ENERGY	*CONTROL_OUTPUT *CONTROL_SHELL *CONTROL_TERMINATION *CONTROL_TIMESTEP

Table 4: Used Control cards.

The following database cards are defined:

*DATABASE_ABSTAT *DATABASE_BINARY_D3PLOT *DATABASE_BINARY_RUNRSF *DATABASE_DEFORC *DATABASE_ELOUT *DATABASE_EXTENT_BINARY *DATABASE_GLSTAT *DATABASE_HISTORY_BEAM_ID	*DATABASE_HISTORY_NODE_ID *DATABASE_JNTFORC *DATABASE_MATSUM *DATABASE_NODOUT *DATABASE_RCFORC *DATABASE_SLEOUT

Table 5: Used Database cards.

The following material models are used:

*MAT_DAMPER_NONLINEAR_VISCOUS *MAT_ELASTIC *MAT_FU_CHANG_FOAM *MAT_LINEAR_ELASTIC_DISCRETE_BEAM *MAT_NULL *MAT_PLASTIC_KINEMATIC *MAT_RIGID *MAT_SIMPLIFIED_RUBBER *MAT_SPRING_NONLINEAR_ELASTIC *MAT_SIMPLIFIED_RUBBER_WITH_DAMAGE	*MAT_SPRING_ELASTIC *MAT_VISCOELASTIC *MAT_VISCOUS_FOAM *MAT_KELVIN_MAXWELL *MAT_PIECEWISE_LINEAR_PLASTICITY

Table 6: Used Material models.

The following other keywords are used:

*CONSTRAINED_JOINT_CYLINDRICAL_ID *CONSTRAINED_JOINT_REVOLUTE_ID *CONSTRAINED_JOINT_SPHERICAL_ID *CONSTRAINED_JOINT_STIFFNESS_ GENERALIZED *CONSTRAINED_JOINT_TRANSLATIONAL *CONSTRAINED_RIGID_BODIES	*ELEMENT_SEATBELT_ ACCELEROMETER *ELEMENT_SHELL *ELEMENT_SOLID *HOURGLASS *NODE *SECTION_BEAM

*CONTACT_AUTOMATIC_SINGLE_SURFACE *CONTACT_FORCE_TRANSDUCER_PENALTY *CONTACT_TIED_SHELL_EDGE_TO_ SURFACE_ID_OFFSET *DAMPING_PART_STIFFNESS *DEFINE_COORDINATE_NODES *DEFINE_CURVE *DEFINE_TABLE *ELEMENT_BEAM *ELEMENT_DISCRETE	*SECTION_DISCRETE *SECTION_SHELL *SECTION_SOLID *SET_PART_LIST *SET_SHELL_LIST

Table 7: Other keywords used in the model.

After the *END keyword the following Primer keywords are defined:

*ASSEMBLY *DUMMY_START *UNITS	*DUMMY_END *H_POINT

Table 8: Used Primer keywords.

2. Extraction of occupant injury criteria

To extract occupant injury criteria from the model, the following preparations have been made.

2.1 Rib accelerations

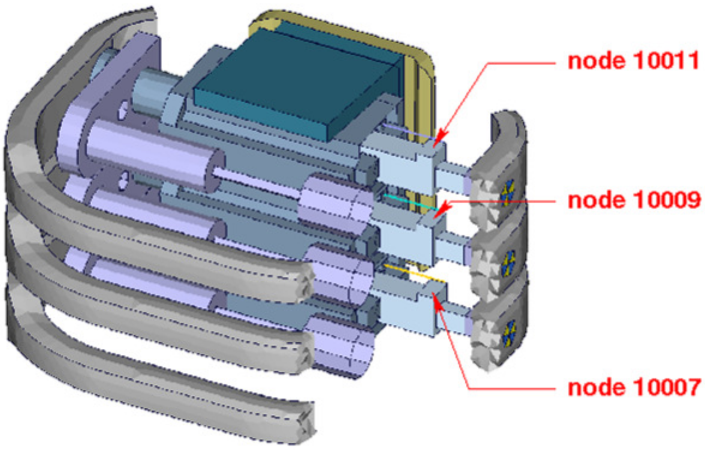


Figure 1: Nodes for extracting rib accelerations

The marked nodes, which are shown in Figure 1, are accelerometer nodes. The description of the accelerometer definitions for the local output is shown in next table.

Item	Node-ID	Label	Component
Upper Rib	10011	acceleration upper rib	Local y-acceleration
Middle Rib	10009	acceleration middle rib	Local y-acceleration
Lower Rib	10007	Acceleration lower rib	Local y-acceleration

Table 9: Rib acceleration nodes

2.2 Rib intrusion

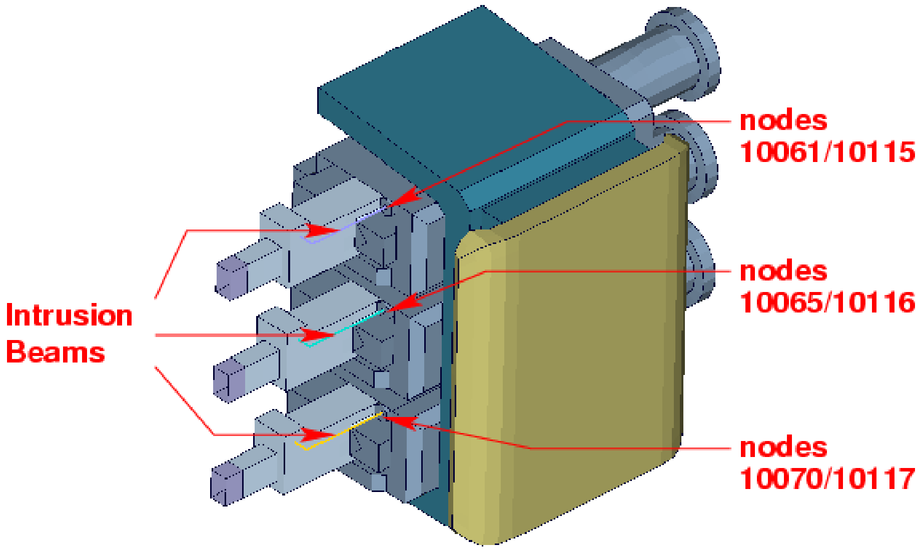


Figure 2: Nodes for extracting rib intrusions

The rib intrusions can be measured by determining distances of nodes. The nodes, shown in Figure 2 are coincident at the beginning of the simulation. An appearing distance of the nodes gives the rib intrusion of the model.

Item	Node-ID	Label	Component
Upper Rib	10061	Intrusion upper rib 1	Relative displacement
intrusion	10115	Intrusion upper rib 2	Relative displacement
Middle Rib	10065	Intrusion middle rib 1	Relative displacement
intrusion	10116	Intrusion middle rib 2	Relative displacement
Lower Rib	10070	Intrusion lower rib 1	Relative displacement
Intrusion	10117	Intrusion lower rib 2	Relative displacement

Table 10: Rib intrusion nodes

Alternatively, the elongation of a spring can be used to determine the rib intrusion. The spring elements are listed in the following table. The springs are located in the piston bearing system.
We do recommend to use spring elements to determine the elongation.

Item	Element-ID	Component
Upper Rib intrusion	10500	Change in length
Middle Rib intrusion	10501	Change in length
Lower Rib Intrusion	10502	Change in length

Table 11: Rib intrusion elements

2.3 Spine accelerations

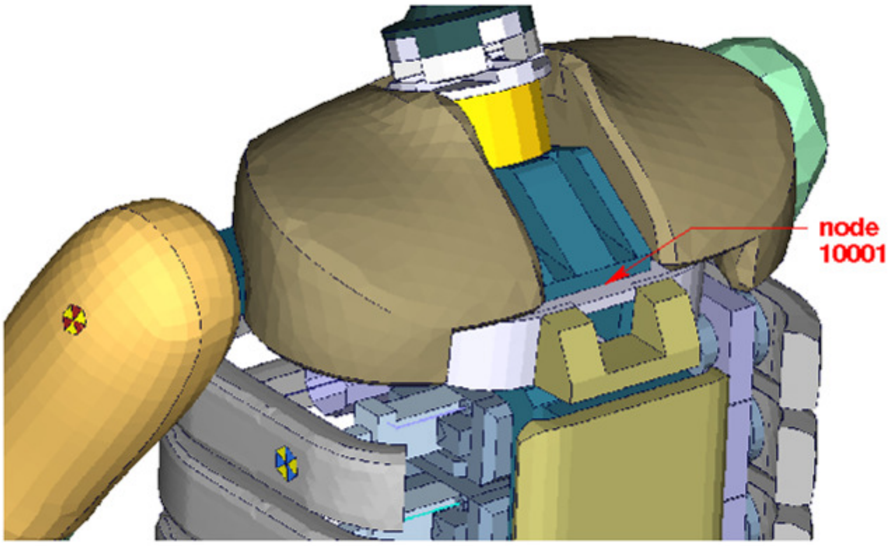


Figure 3: Node for extracting upper spine acceleration

Node 10001, which is marked in Figure 3 is part of the lower plate of neck bracket. An accelerometer is defined.

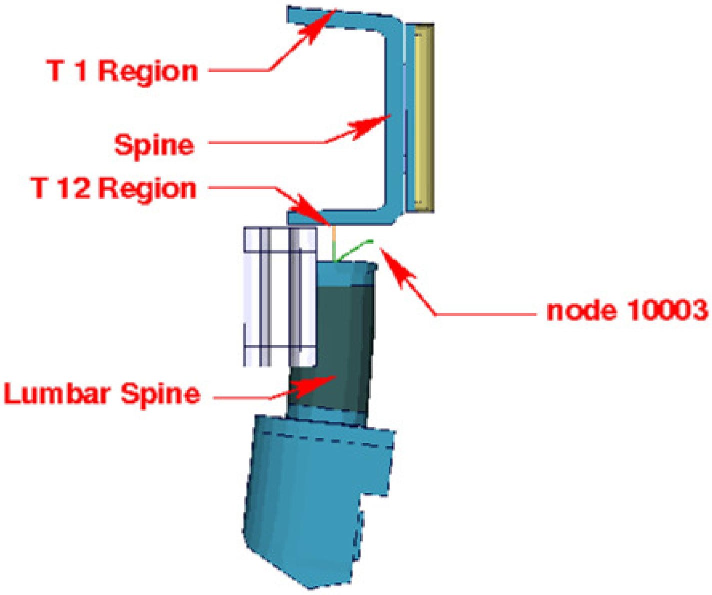


Figure 4: Node for extracting lower spine acceleration

Figure 4 shows parts of the dummy model from y direction. Node 10003 is located between upper spine and lumbar spine. An accelerometer is defined.

Item	Node-ID	Label	Component
Upper spine	10061	Acceleration upper spine	y-acceleration
Lower Spine	10003	Acceleration lower spine	y-acceleration

Table 12: Spine acceleration nodes

2.4 Pelvis acceleration

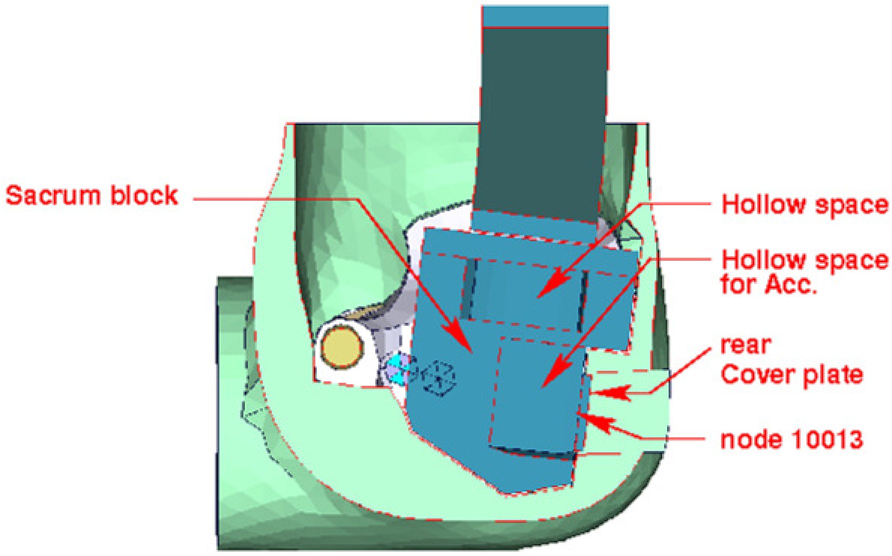


Figure 5: Node for extracting pelvis acceleration

Figure 5 shows a plane cut along the z-x-plane. The accelerometer is mounted in the marked hollow space. Node 10013 is located on the rear cover plate of sacrum block. An accelerometer is defined.

Item	Node-ID	Label	Available components
Pelvis	10013	accelerometer pelvis	Local y-acceleration

Table 13: Pelvis accelerometer node.

2.5 Head acceleration

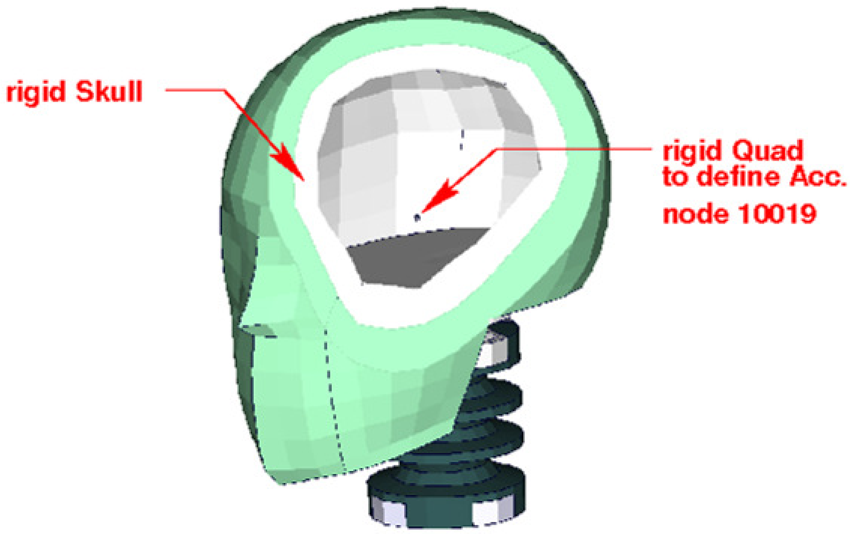


Figure 6: Node for extracting head acceleration

Figure 6 shows the head model; the aluminum skull is merged with the marked rigid quad. Node 10019 is located on the quad. An accelerometer is defined.

Item	Node-ID	Label	Available components
Head	10019	accelerometer head	local x-,y-,z- acceleration

Table 14: Head accelerometer node

2.6 Pubic Symphysis force

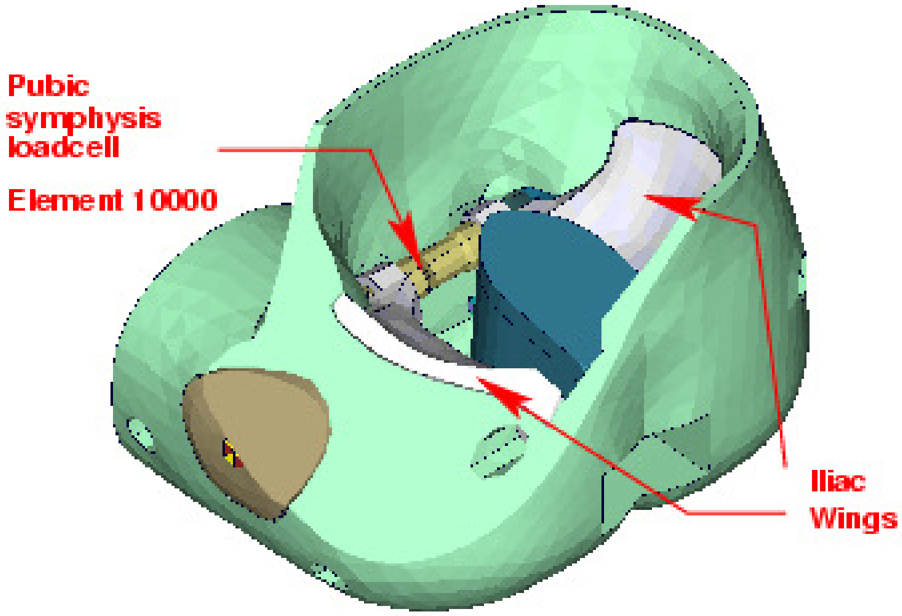


Figure 7: location for extracting signals of pubic symphysis load cell

Figure 7 shows the pubic symphysis load cell. The left iliac wing is connected to the first part of the load cell. The right iliac wing is connected to the second part. Both load cell parts generate under load the force in the connecting element 10000. The pubic symphysis force is the shear-S force of beam element 10000.

Item	Beam-ID	Label	Component
Pubic symphysis force	10000	Pubic symphysis load cell	Shear-S force

Table 15: Pubic force beam

2.7 Shoulder force

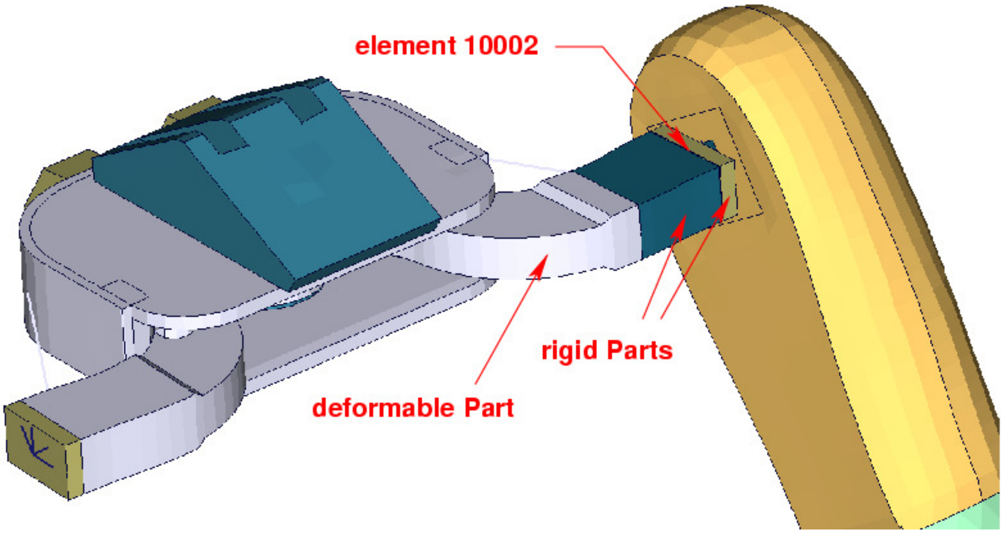


Figure 8: clavicle box with adapted clavicle to measure shoulder forces

Element 10002 which is marked in Figure 8 is a discrete beam with coincident nodes. The clavicle is equipped with load cell. The load cell is represented by a rigid box. The discrete beam is located between the rigid box and the arm adaptor plate. For local determination a local coordinate system is provided. The components are shown in table below.

Item	Beam-ID	Label	Component
Shoulder force x-direction y-direction	10002	Clavicle load cell	force axial shear-S

Table 16: Shoulder force beam

2.8 Back plate load cell

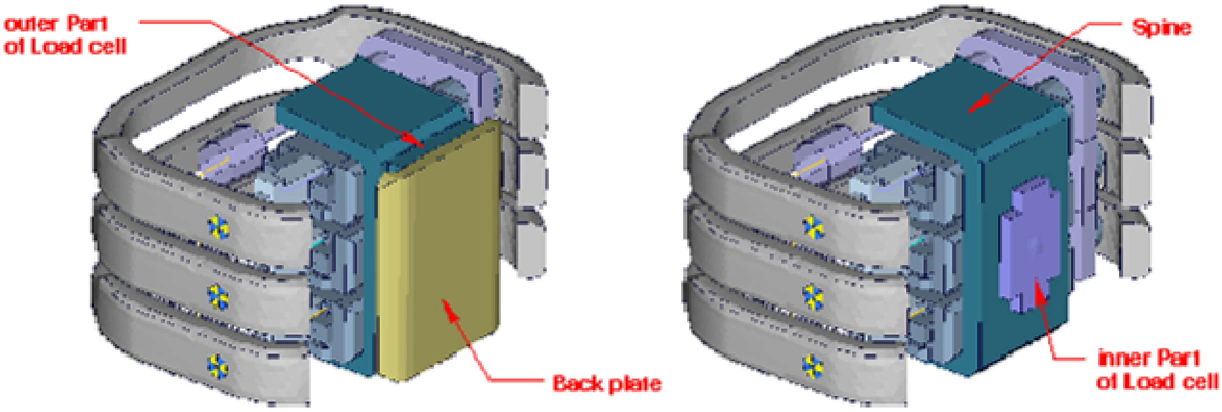


Figure 9: spine box with back plate

Figure 9 shows the spine box from back. The inner part of back plate load cell is connected to spine. The outer part is the adapter to the back plate. A discrete beam between both parts measures the forces and moments.

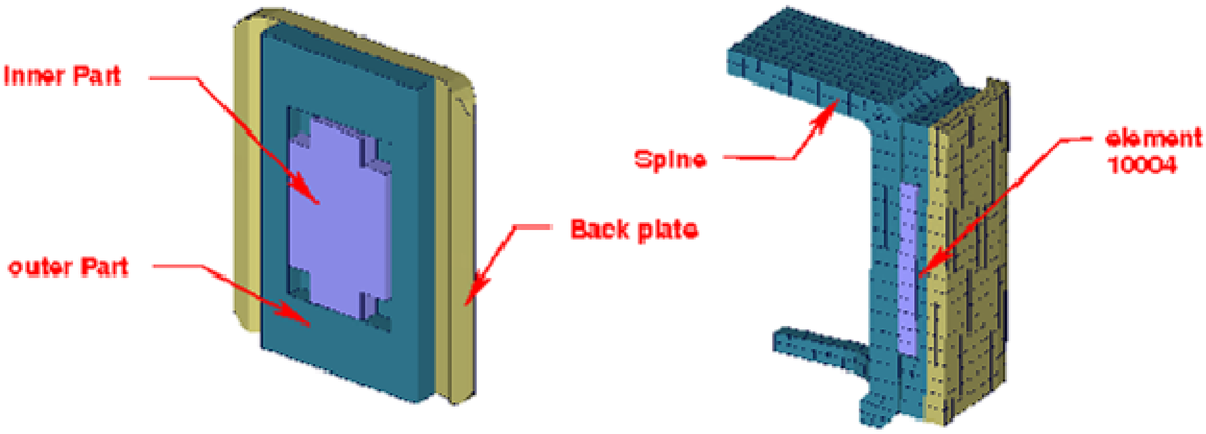


Figure 10: model of back plate load cell

Figure 10 shows the back plate assembly and a plane cut in y-direction. The discrete beam is located between the inner and outer parts of load cell. The local components to determine the forces and moments are shown in table below.

Item	Beam-ID	Label	Component
Back plate forces	10004	Back plate load cell	force
x-direction			axial
y-direction			shear-S
Back plate moment	10004	Back plate load cell	moment
About z-direction			moment-T

Table 17: Back plate forces and moment beam

2.9 Neck load cells

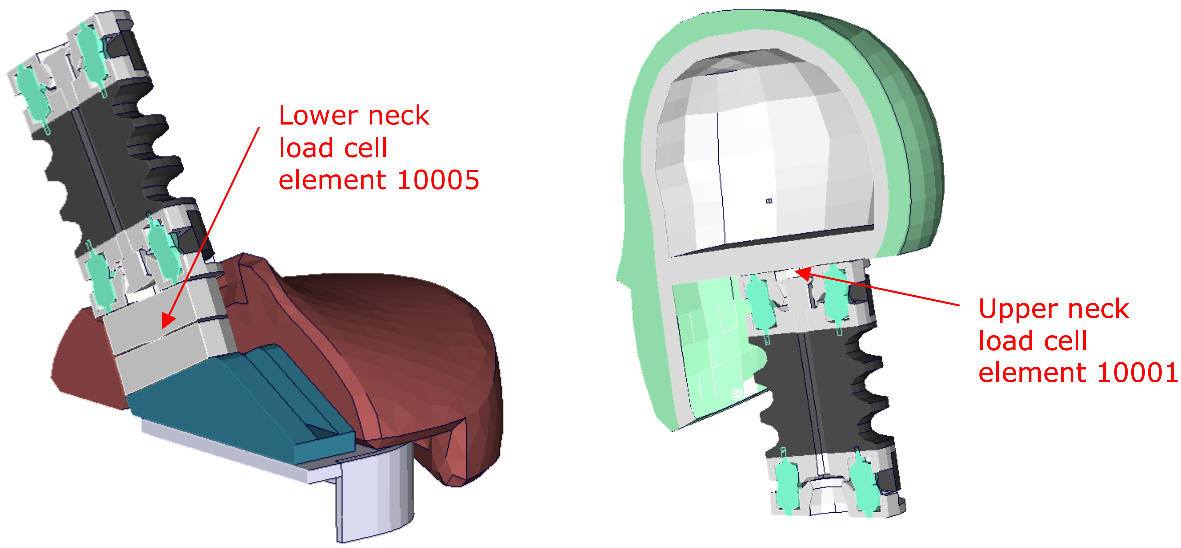


Figure 11: models of lower and upper neck load cell

Figure 11 shows the location of upper and lower neck load cell. Both are discretized as discrete beams. The table below gives details on the extraction of the loads.

Item	Beam-ID	Label	Component
Upper neck force y-direction	10001	upper neck load cell	force shear-S
Upper neck moment About x-direction	10001	upper neck load cell	moment torsion
Lower neck force y-direction	10005	lower neck load cell	force shear-S
lower neck moment About x-direction	10005	lower neck load cell	moment torsion

Table 18: Neck force and moment beams

2.10 T12 load cell (lumbar spine)

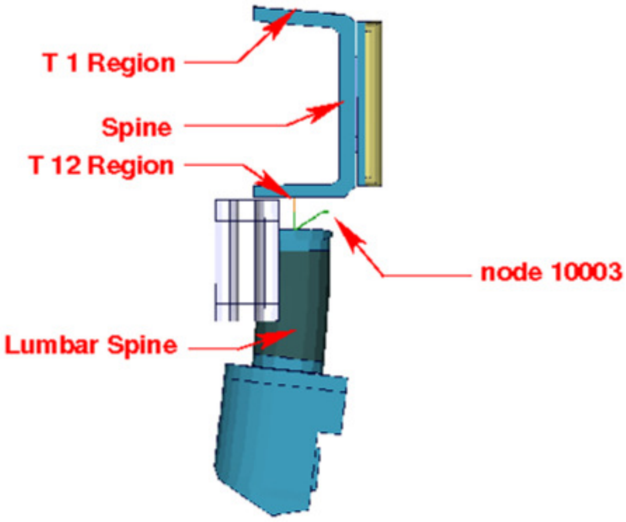


Figure 12: overview spine to sacrum with T12 load cell

Figure 12 shows the T12 area. The upper rigid beam is merged to spine and the lower rigid beam is merged to the upper lumbar spine adapter plate. Between the rigid beams a discrete beam is located to determine the T12- forces and moments. The local directions are shown in table below.

Item	Beam-ID	Label	Component
T12 force y-direction	10006	t12 load cell	force shear-S
T12 moment About z-direction	10006	t12load cell	moment torsion

Table 19: T12 force and moment beam

2.11 Lower lumbar load cell

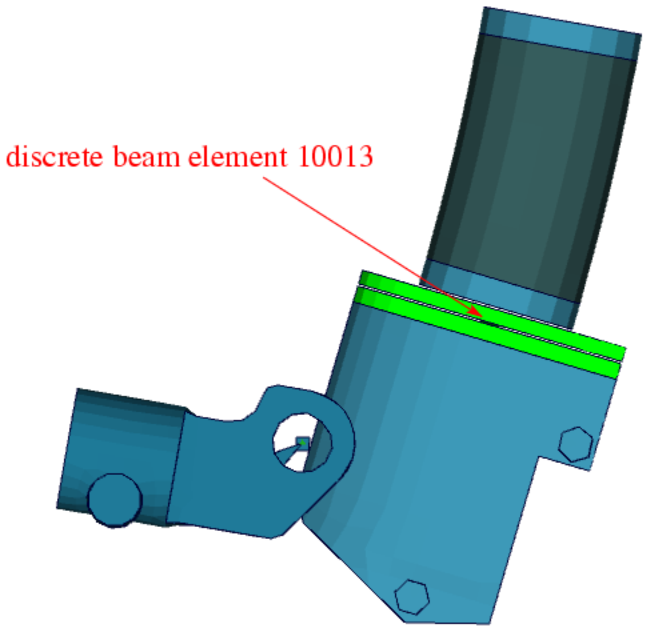


Figure 13: lower lumbar load cell

Figure 13 shows the lower lumbar area. Discrete beam element 10013 located in the lower lumbar spine area can be used to measure forces and moments. The local directions are shown in table below.

Item	Beam-ID	Label	Component
Lower lumbar force y-direction	10013	lower lumbar load cell	force shear-S
Lower lumbar moment About z-direction	10013	lower lumbar load cell	moment torsion

Table 20: Lower lumbar force and moment beam

2.12 Abdominal forces

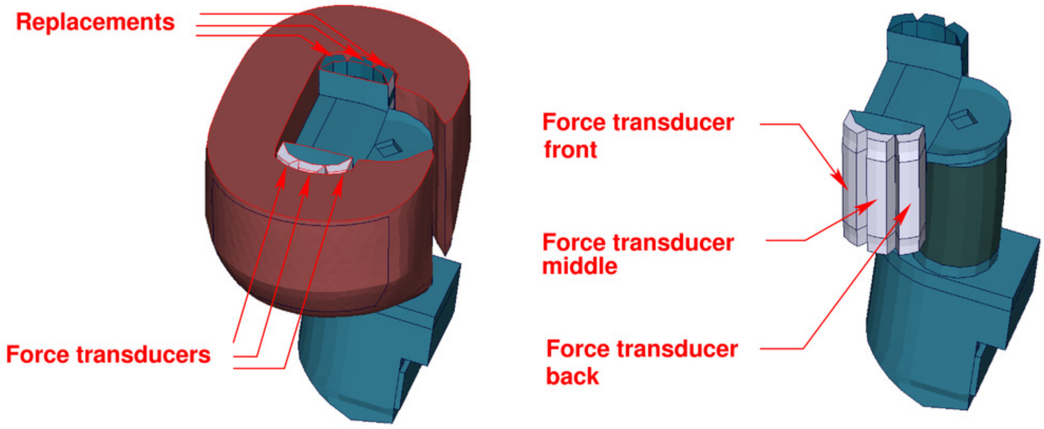


Figure 14: models of abdominal force transducers and replacements

The abdominal forces are determined by three load cells. Figure 14 shows the abdomen region. On the impact side the abdominal carrier is equipped with force transducers. On the other side replacements are located.

Three *CONTACT FORCE TRANSDUCER definitions are used in the model to represent the load cells. The title option is applied to find the interface number in the rcforc. The 3rd contact definition is the front force transducer. The 4th and 5th definition are measuring for the middle and back force. The sum of the three forces is the abdominal resultant force.

Remark: A renumbering or adding further contact definitions in the run may change the numbering and has to be considered in Post processing.

Item	Interface-ID	Label	Component
Abdominal force front	Interface 3	ABDOMINAL FORCE – FRONT	Magnitude
Abdominal force middle	Interface 4	ABDOMINAL FORCE – MIDDLE	Magnitude
Abdominal force back	Interface 5	ABDOMINAL FORCE - BACK	magnitude
Abdominal resultant force	Interfaces 3+4+5		magnitude

Table 21: Abdomen interface forces

As a new feature of the ES-2 version 4.5 there are discrete beam element for the evaluation of the abdominal forces available. Thus, it is possible to model an uni-axial load cell.

Item	Beam-ID	Label	Component
Abdominal force front	10014	abdomen load cell front	shear-S
Abdominal force middle	10015	abdomen load cell middle	shear-S
Abdominal force back	10016	abdomen load cell back	shear-S

Table 22: Abdomen forces beams

2.13 Femur load cells

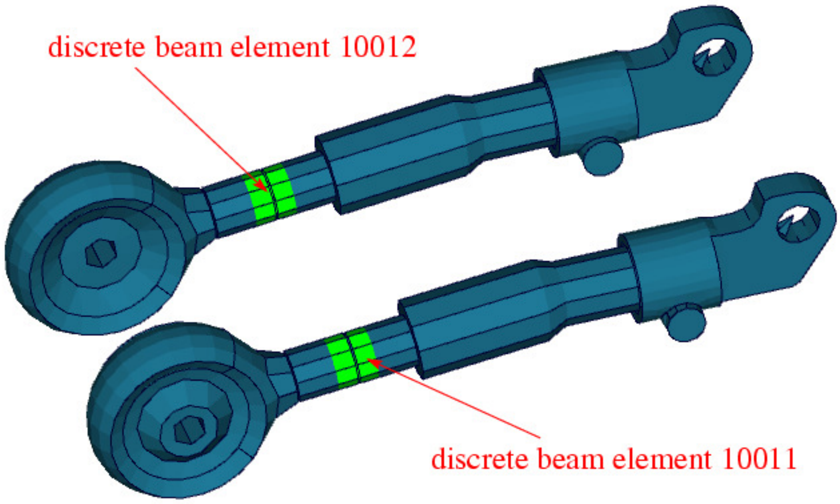


Figure 15: femur load cells

Figure 15 shows the femur area. Discrete beam elements 10011 & 10012 are located in the femur to determine forces and moments. The local directions are shown in table below.

Item	Beam-ID	Label	Component
Femur force left y-direction	10011	femur load cell leg left	force shear-S
Femur moment left about x-direction	10011	femur load cell leg left	moment torsion
Femur force right y-direction	10012	femur load cell leg right	force shear-S
Femur moment right about x-direction	10012	femur load cell leg right	moment torsion

Table 23: Femur forces and moment beams

2.14 ES-2re extension forces

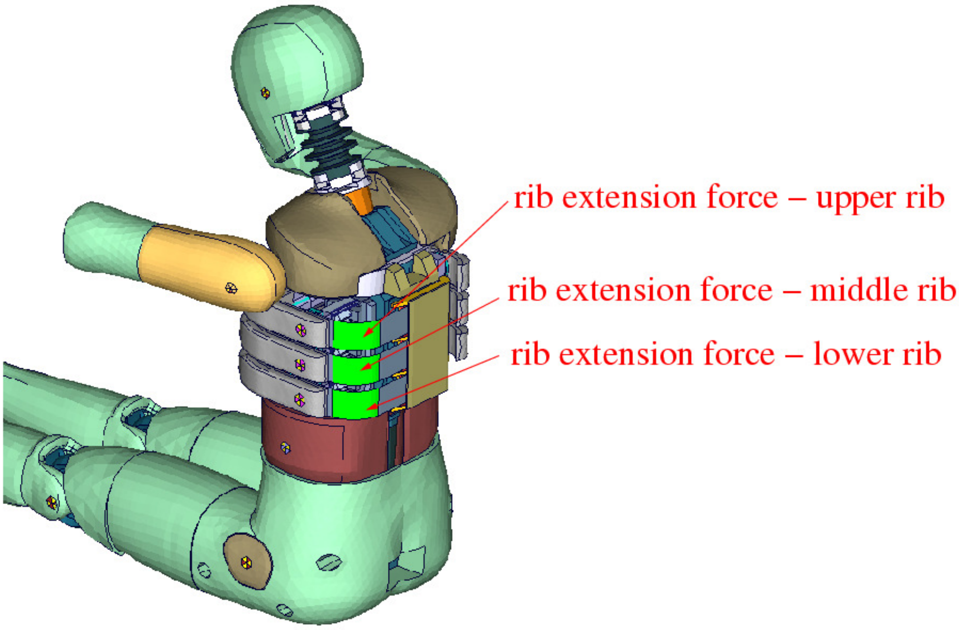


Figure 16: force transducer contacts of rib extension

Three *CONTACT FORCE TRANSDUCER definitions are used in the model to measure impact forces on the rib extensions of ES-2re model. The title option is applied to find the interface number in the rcforc.

Remark: A renumbering or adding further contact definitions in the run may change the numbering and has to be considered in Post processing.

Item	Interface-ID	Label	Component
Extension force upper rib	Interface 6	RIB EXTENSION FORCE - UPPER RIB	magnitude
Extension force middle rib	Interface 7	RIB EXTENSION FORCE - MIDDLE RIB	magnitude
Extension force lower rib	Interface 8	RIB EXTENSION FORCE - LOWER RIB	magnitude
Extension resultant force	Interfaces 6+7+8		magnitude

Table 24: rib extension interface forces

3. Accelerometers

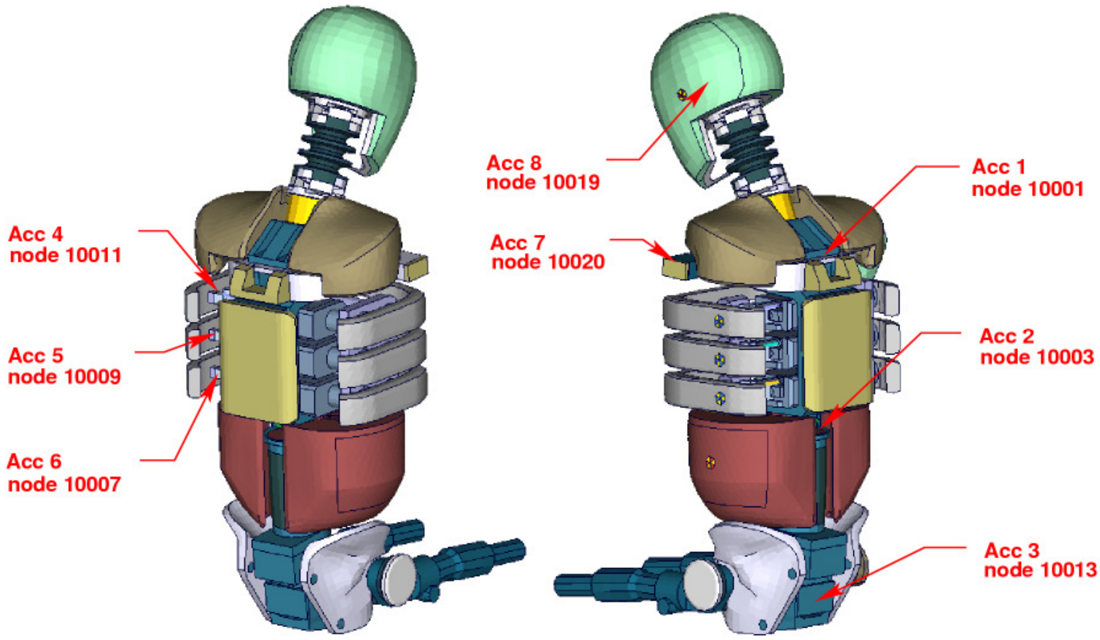


Figure 17: location of the accelerometers

Figure 17 shows the model from several views. The accelerometer and time history nodes are marked.
The accelerometer seven is an additional measurement used for validation. The following table shows the definition of the nodes.

Location	Acc-ID	1st node	2nd node	3rd node
Upper spine	1	10001	10100	10101
Lower spine	2	10003	10102	10103
Pelvis	3	10013	10104	10105
Upper rib	4	10011	10106	10060
Middle rib	5	10009	10108	10064
Lower rib	6	10007	10110	10069
Left arm joint	7	10020	10021	10022
Head	8	10019	10146	10145

Table 25: ES-2 accelerometers

4. Local Coordinate Systems

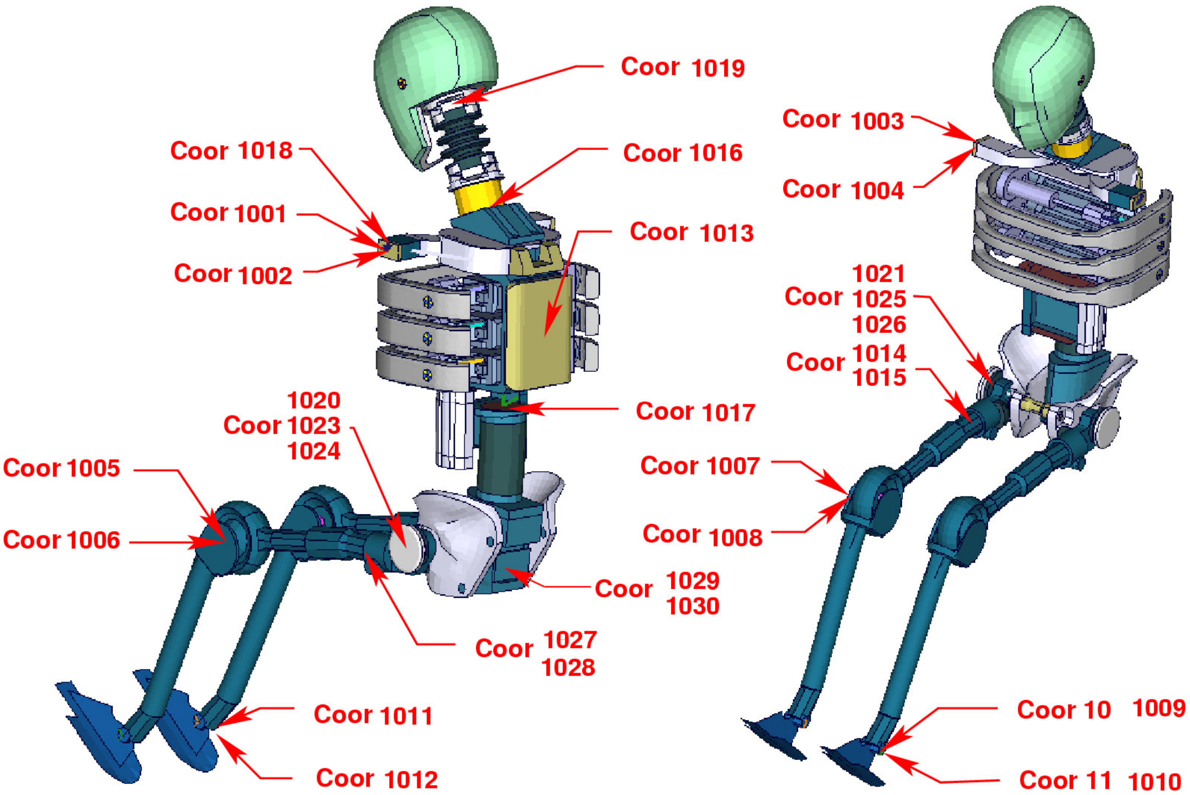


Figure 18: ES-2 skeleton with local coordinate systems

The model uses the local coordinate systems, which are shown in Figure 18, for definitions of joints or output of quantities in local systems.
The coordinate systems 1020 and 1021 are for validation purposes. The table below shows the definition.

Location	Coor-ID	1st node	2nd node	3rd node
Clavicle left	1001	10055	10099	10041
Arm left	1002	10030	10097	10046
Clavicle right	1003	10054	10078	10048
Arm right	1004	10068	10076	10049
Knee upper leg left	1005	10154	10159	10155
Knee lower leg left	1006	10148	10152	10149
Knee upper leg right	1007	10113	10135	10114
Knee lower leg right	1008	10057	10179	10158
Ankle lower leg left	1009	10157	10179	10158
Ankle foot left	1010	10170	10187	10169
Ankle lower leg right	1011	10162	10167	10161
Ankle foot right	1012	10172	10183	10171
Back plate	1013	10023	10024	10025
Femur bone left	1023	10042	10210	10211
	1024	10134	10212	10213
Femur bone right	1025	10045	10214	10215
	1026	10133	10216	10217

Upper leg bone left	1027	10039	10218	10219
	1028	10093	10220	10221
Upper leg bone right	1014	10139	10141	10140
	1015	10142	10144	10143
Lower neck	1016	10027	10026	10119
T12	1017	10038	10043	10032
Shoulder left	1018	10020	10021	10022
Upper neck	1019	10012	10018	10008
H-point left force	1020	10300	10308	10134
H-point right force	1021	10307	10309	10133
Global coordinate	1029	10228	10229	10231
H-point	1030	10201	10232	10234
Pubic symphysis load cell	1032	10255	10256	10257
femur load cell upper leg left	1033	10236	10237	10238
femur load cell upper leg right	1034	10241	10242	10243
Lumbar load cell	1035	10246	10247	10248
Abdomen load cell front				
Abdomen load cell middle				
Abdomen load cell back				

Table 26: coordinate systems of the dummy model

5. License file

The ES-2 v4.5 is distributed with a license file which uses an expiry date. The license file is sent to the user with the whole dummy package. Different license files are necessary for different systems of units.

In the license file, all load curves are encrypted. There are parameters defined which can be used to offset the numbering of the load curves. The load curves can be scaled by using parameters which are encrypted in the normal ES-2 input. The names of the parameters refer to the table or load curve ID of each material. So if the values of the table ID 1002 are to be scaled then the parameter s1002 must be used.

The principle structure is as follows:

Input data of the ES-2 file:

```
*PARAMETER
$ Load Curve offset
I lcoff          0

$ Load Curve scale values
R sTABID        1.0
             .
             .
             .
```

Input of the license file:

```
*PARAMETER_EXPRESSION
I lcTABID    TABID + &lcoff
R eTABID     1.0 * &sTABID


*DEFINE_CURVE
&lcTABID          0       1.0&eTABID           0.0         0.0
          <Values_x>          <Values_y>
             .
             .
             .
```

The license file must be included like a normal include file. But it is necessary that the license file is included **AFTER** the ES-2 file. LS-DYNA has to first read the ES-2 input data and then the PARAMETER_EXPRESSION in the license file. Otherwise LS-DYNA will terminate with an error because of missing parameters.

The expiry date, the owner of the license and the system of units are printed out in the d3hsp file of LS-DYNA. The name of the license file also includes the company name and the expiry date of the dummy.

For the work in a pre-processor, an additional file is delivered:

es2_v4.5_mm_ms_kg_load_curves_work.key

This work file includes the same input as the encrypted license file. The only difference is the scaling of the load curves in the work file. The load curves are scaled randomly in a wrong range and they are much too soft to be used for a LS-DYNA simulation. But the file can be used to observe the quality and course of the material curves.

A LS-DYNA simulation in use of the work file will give wrong results and is very unstable.

6. Incorporating the dummy in vehicle models

6.1 Positioning, tree file

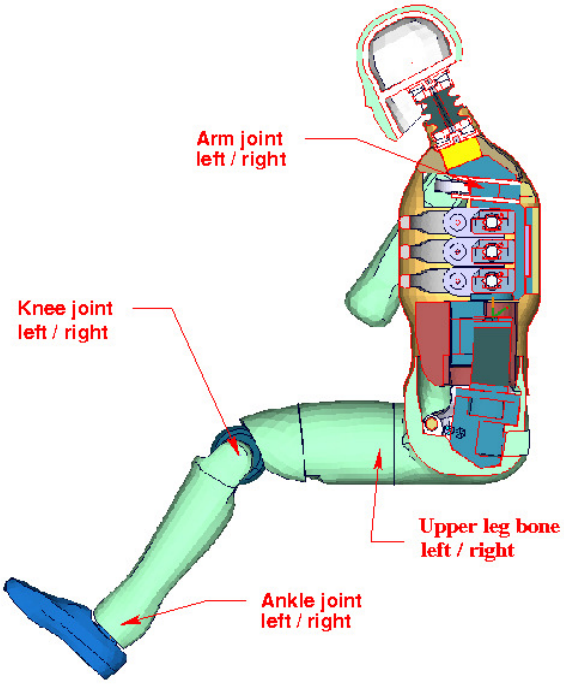


Figure 19: cut through the model with joints

The ES-2 model is delivered with a tree file for the Primer and LS-Prepost pre-processors (may work also for HyperMesh and ANSA, not verified by DYNAmore). This allows the user to position the dummy and adjust the parts according to their degree of freedom. Figure 19 shows the connections of movable parts via tree file.
The accompanying local coordinate systems are shown in Figure 18. All revolute joints are visualized by beams.

In the H-Point of the dummy model two coordinate systems are modeled. These coordinate systems are connected to each other by a spherical joint. One coordinate system is connected to global directions, e.g. only translations are possible, rotations are disabled. The other one is connected to the dummy, so it is possible to measure quickly and easily the pelvis angle of the ES-2 during the positioning simulation. These coordinate systems are also used to determine the initial pelvis angle with Primer.

Movable parts and revolute joints are:

- Foot, left and right about their ankle joints
  (stop angle: -30.0 and +30.0 degree)
- Lower leg, left and right about their knee joints
  (stop angle: -7.0 and 90.0 degree)
- Upper leg bone, left and right about x-axis

(stop angle: -40.0 and +40.0 degree)

- Upper leg bone, left and right about hip joints in y-,z-axis
  (stop angle y-axis: -5.0 and 5.0 degree)
  (stop angle z-axis: -1.0E-4 and 5.0 degree)
- Right arm about its arm joint
  (no stop angle)

Due to the continued modeling of the dummy jacket around the left shoulder, the rotation of the left arm by a preprocessor is obsolete. The rotation of the arm has to be done by a pre-simulation.

If the upper legs are rotated at the hip joints, initial penetrations would occur. This reaction is based on the hardware. In the hardware, the geometry is deformed if the position of the upper leg is changed with respect to the pelvis. That is the reason why the degrees of freedom for the upper legs are disabled in Primer tree-file. It is recommended to position the upper legs by a pre-simulation. A special positioning-file <positioning_es-2_v4.1_(re_1.0)_mm_ms_kg.key> is delivered to do this pre-simulation.
The positioning-file of ES-2 is very easy to use. At the top of this file you will find a set of parameters you have to set. These parameters are shown in the following table.

Parameter	Description
term	termination time
tmove	time to move parts
trans_x	x-translation of the whole dummy
trans_y	y-translation of the whole dummy
torsor	local y-rotation of torso
lfemry	left femur rotation about y
rfemry	right femur rotation about y
lfemrz	left femur rotation about z
rfemrz	right femur rotation about z

Table 27: positioning file parameters

In case you do not want to translate or rotate an assembly use a very small value like 1.0E-10. Please do not use zero as value, because zero as scaling factor is default 1 in LS-DYNA. As second step you have to add your include-files necessary for positioning the dummy model.
Usually only seat and dummy models are used for the positioning procedure. Please define a *CONTACT AUTOMATIC SURFACE TO SURFACE for the contact between the dummy and seat (environment). The ES-2(re) properties for this contact are prepared in the part set 1500.

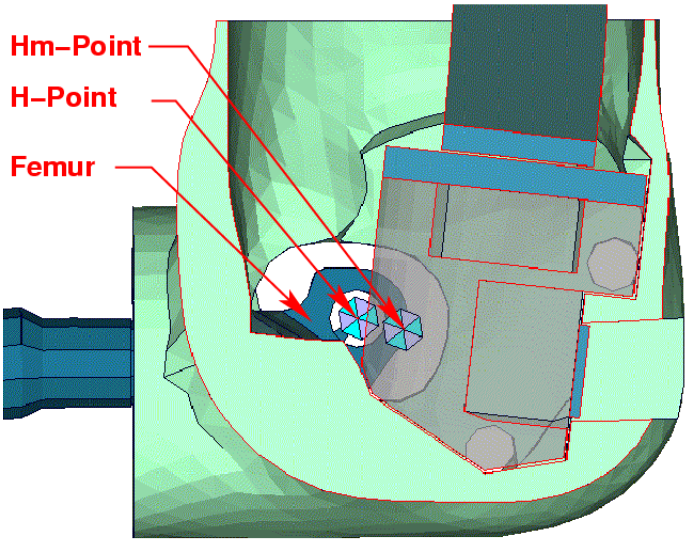


Figure 20: location of H- and Hm-point

Figure 20 shows the location of H- and Hm-Point. More details are give in the "User Manual ES-2; 2002, FTSS Inc.".

Following Nodes are used:

- The node 10200 is located at the H-Point.
- The Hm-Point, determined by the HIII Manikin, is located at node 10201.

The delivered coordinates are:

Location	x-coor	y-coor	z-coor
H-Point	-180.1	280	429.6
Hm-Point	-160.4	280	420.8

Table 28: H-Point coordinates

6.2 Measuring of pelvis and torso angle

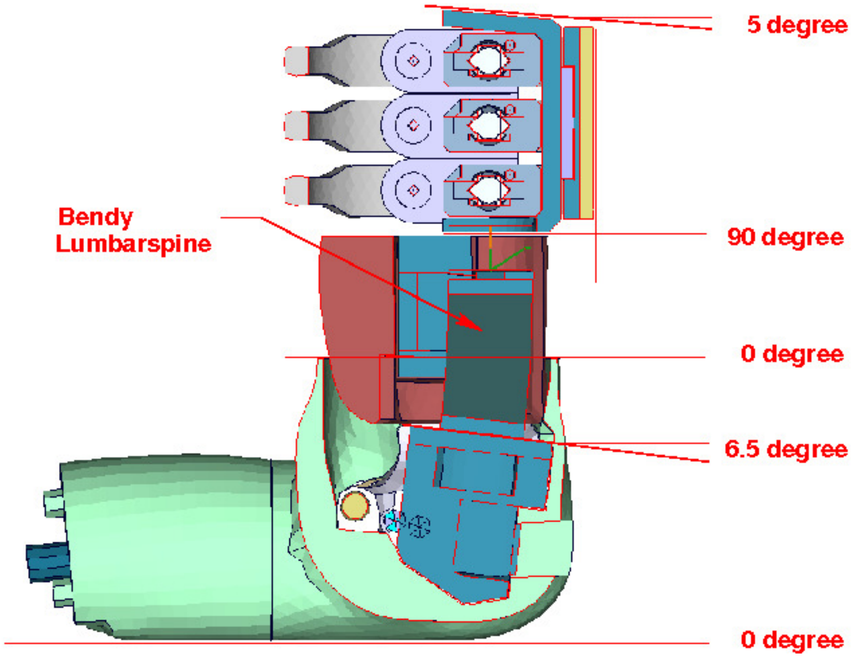


Figure 21: angles of important edges of the ES-2 dummy

Figure 21 shows the model in an upright position. The sacrum block and the spine box are rotated according to a 3D measurement of the fully assembled model.
There are different ways to measure the pelvis- and torso angle in the hardware model.

Angle	Device	Angle in upright position
Pelvis angle	Tilt sensor	6.5°
	H-Point device	0.0°
Torso angle	Tilt sensor	5.0°
	Measure at back plate	0.0°

Table 29: dummy angles

In the software model following parts should be used to identify pelvis- and torso angle.

Angle	Parts	Angle in upright position
Pelvis angle	Between PID 233 & 234	0.0°
Torso angle	Measure at back plate PID 55	0.0°

Table 30: dummy model angles

6.3 Numbering

- Nodes in the range of 10.000 to 11.000 are used for joints, accelerometers, etc. definitions.
- Nodes with node IDs above 11.000 are used only in *NODE and *ELEMENT cards.
- Elements in the range of 10.000 to 11.000 are used for history, discrete elements, etc. definitions.
- Elements with IDs above 11.000 are used only in *ELEMENT cards.

6.4 Contact definition

Dummy to Vehicle and Seat:

For the contact of the dummy model to the vehicle and the seat an automatic surface to surface contact is proposed. For this contact definition a property set (*SET PART, id: 1500) has been prepared in the dummy input-file. This property set includes all properties of the ES-2(re) model which are necessary for the dummy to environment contact definition.
The usage of a single surface contact is not recommended. This might interfere with the contact definitions of the dummy model itself. To remove the dummy model from used automatic single surface contact a second property set (*SET PART, id: 1501) has been prepared. This property set includes all properties of the dummy model, so it can be added easily to a used exclude list of the automatic single surface contact for whole vehicle.

The following figure depicts properties used in property sets 1500 & 1501:

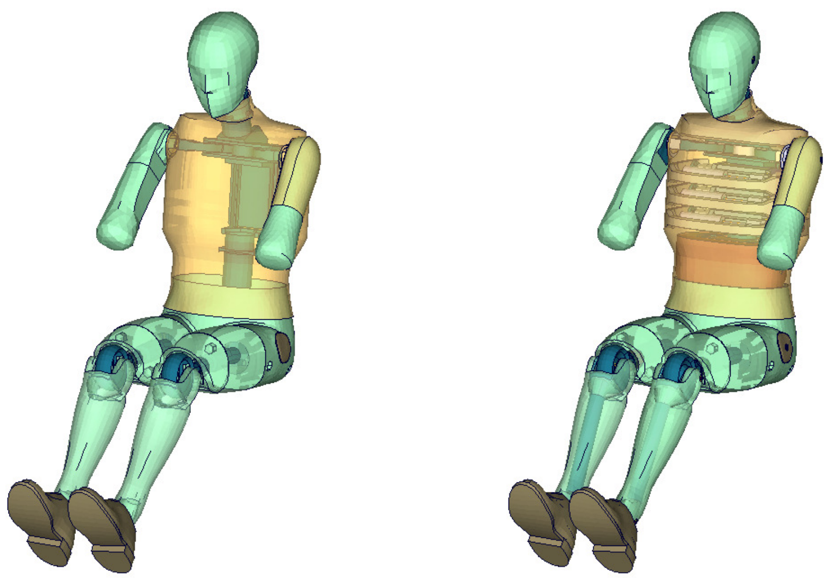


Figure 22: parts used in contact definition

The following table gives the part numbers used in property set 1500.

Item	Part-ID	Item	Part-ID
Head	65	Upper leg, left	158
Head	66	Upper leg, right	168
Jacket inner sleeve	24	Lower leg, left	174
Left Arm	3	Shoe, left	224
Right Arm	88	Shoe, right	178
Pelvis plug, right	133	Knee, left	179
Pelvis plug, left	134	Knee, right	184
Pelvis skin	136	Lower leg, right	226
Jacket	140	Shoe, right	188
Jacket outer sleeve	141	Contact shells	189
Jacket shoulder		Opt. contact shells	280

Table 31: properties for external contact

Optional Contact Shells:

A separate property (PID 280) has been defined. This property is used for nullshell elements closing physical gaps of the dummy model (for example between pelvis and jacket). DYNAmore prepared a separate include file. This include file is called es2 v4.1 nullshells.inc, it includes nullshell elements of property 280. These nullshells can be helpful for some contact problems of dummy to environment contact. The usage of this contact shells is optional and will not change the results of the ES-2 barrier tests. The figure 25 shows the nullshell contact elements (red-colored).

6.5 Additional remarks

- The modification of the *CONTROL cards of the dummy file may have influence on the performance and robustness of the model. Therefore, the *CONTROL cards of the dummy models are proposed for integrated simulations as well. Important flags on LS-DYNA control cards:

  *CONTROL ACCURACY flag INN=2
  *CONTROL BULK VISCOSITY flag TYPE=-1
  *CONTROL SHELL flag ESORT=1
  *CONTROL SOLID flag ESORT=1

- The model should be used with a time step size of 1 microsecond or less!
- If a model for right side impact is needed, please contact DYNAmore. RHD models in both systems of units are available.
- All nodes are connected to an element.
- No mass less nodes are in the input files of the dummy
- The model is free of initial penetrations.

7. Release notes from v4.1 to v4.5

The following major modifications are made:

7.1 Geometric modifications

- Neck assembly is completely remodeled. The new model uses only hexahedron and pentahedron elements. The neck buffers are included in the model as well as friction of the two neck joints.

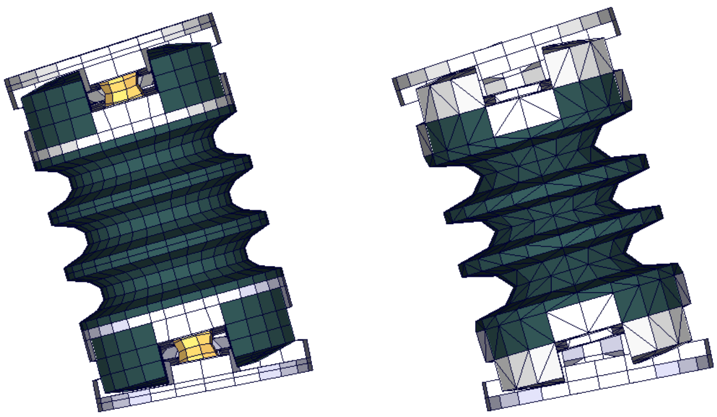


Figure 23: ES-2 v4.5 (left) and v4.1 (right) neck assembly

- The lumbar spine assembly is discretisized in completely new way. The mesh has been refined to catch the hardware geometry more accurately. The steel cable within the lumbar spine rubber is modeled and a contact between rubber and cable is defined.

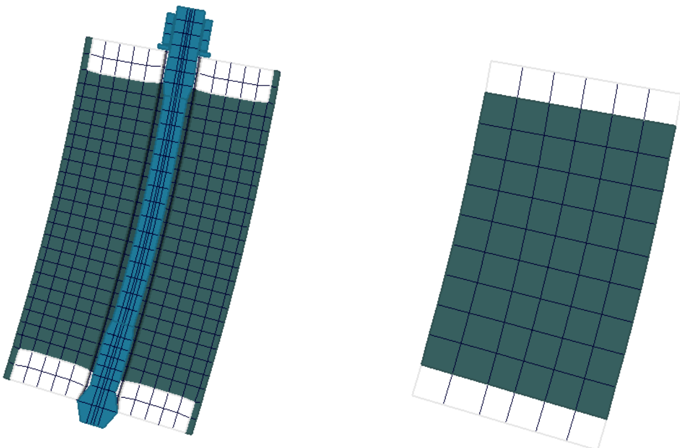


Figure 24: ES-2 v4.5 (left) and v4.1 (right) lumbar spine

- The dummy jacket is now closed in the shoulder area on the impact side. Furthermore the jacket is expanded in front and back and is connected to the pelvis flesh mesh.

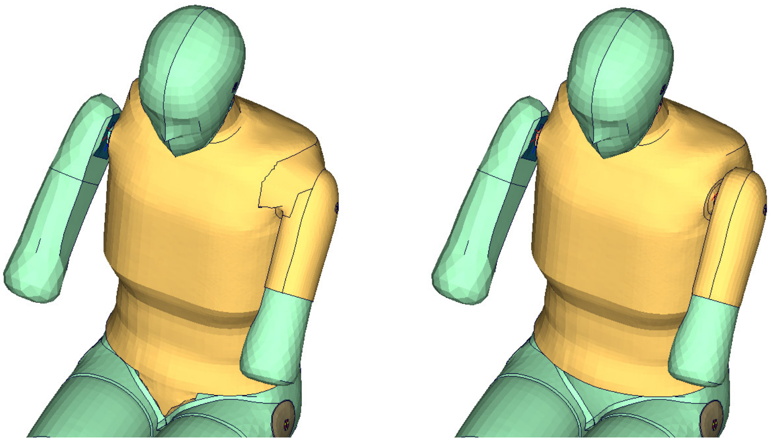


Figure 25: ES-2 v4.5 (left) and v4.1 (right) jacket at left shoulder area

- The abdomen carrier is being remeshed and now consists of hexahedron elements for better contact behavior.

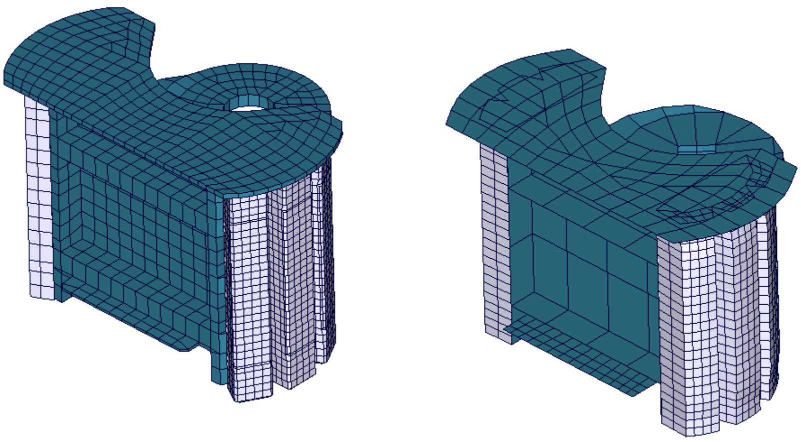


Figure 26: ES-2 v4.5 (left) and v4.1 (right) abdomen carrier

- The height of the T12 load cell is updated.
- The geometric modifications in the lumbar and abdomen area cause an increase of the dummy height of about 2.3 millimeters.

7.2 Non-geometric dummy model modifications

- Material modifications in the abdomen parts
- Material modifications in the pelvis foam and iliac wings

- Material modifications in the lumbar spine assembly

- Simplified Rubber material model for the neoprene jacked
- Modification of the T12 load cell beam to reduce the noise in the extraction data

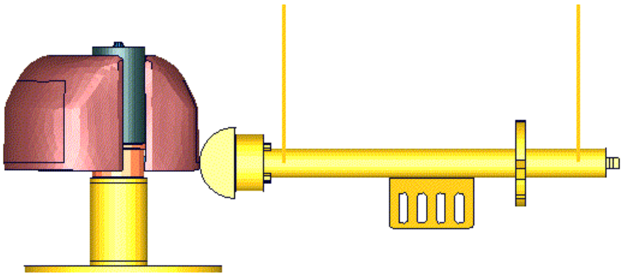
7.3 Additional remarks

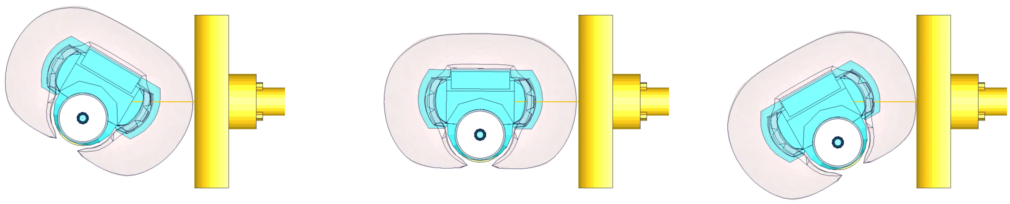
- new models of the certification pendulum tests
- validation of the lumbar spine including the certification test data

8. Limitations and further work

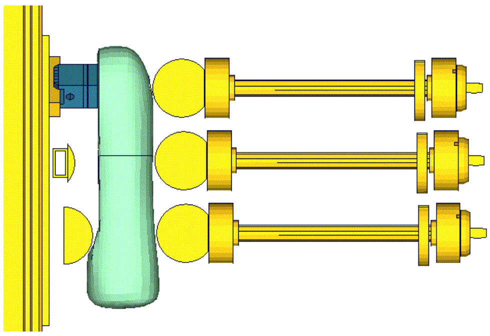
- Mesh refinement in the head an pelvis assembly

- Further improvement of the abdomen by using new test data for additional validation runs:

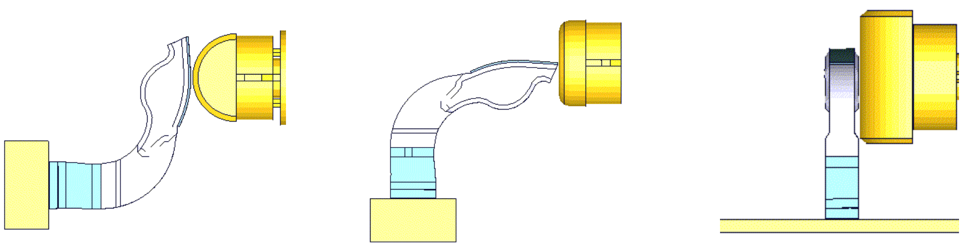




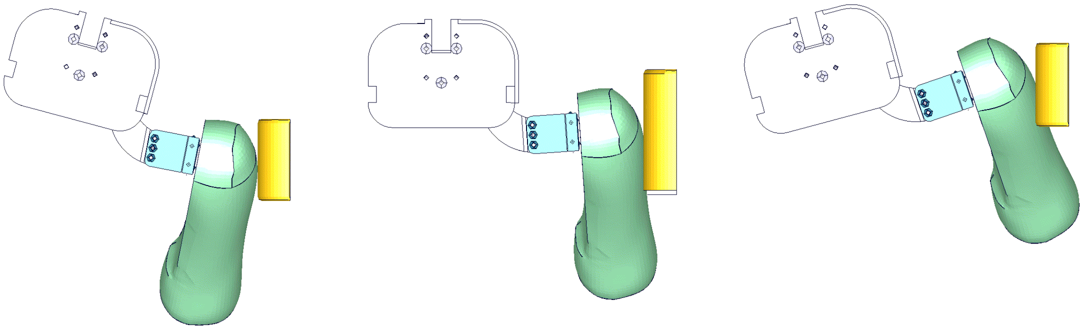
- Further improvement of the arm assembly by using new test data for additional validation runs

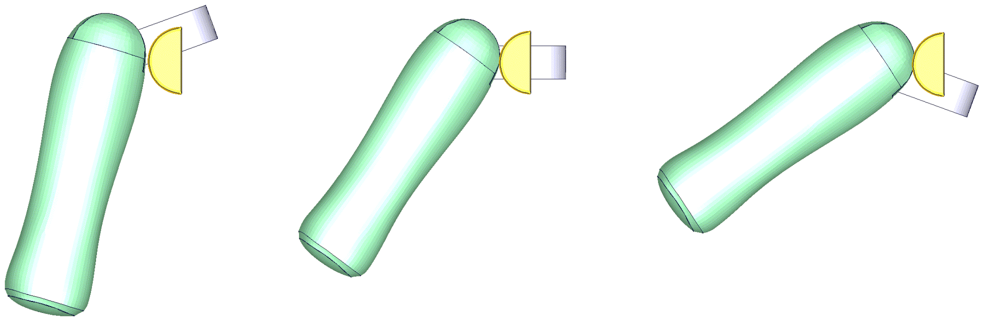


- Further improvement of the clavicle assembly by using new tests for validation

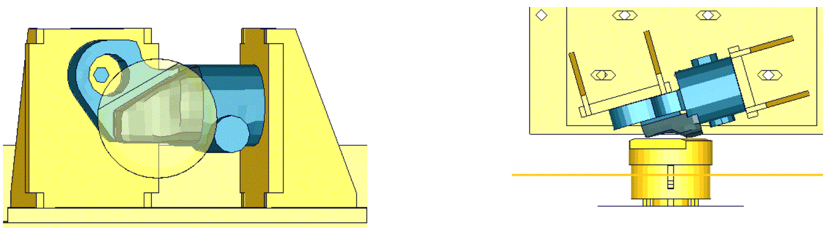


- More improvement of the clavicle mounted in the clavicle box assembly by using new tests for validation

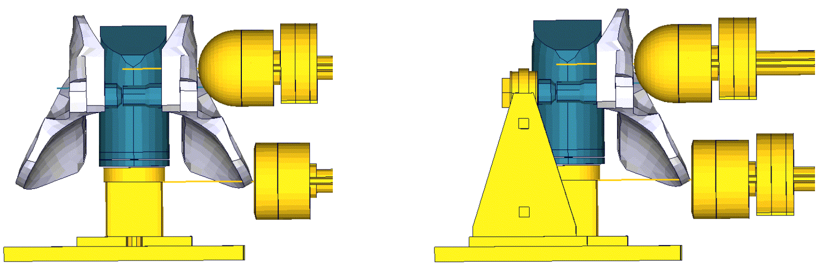




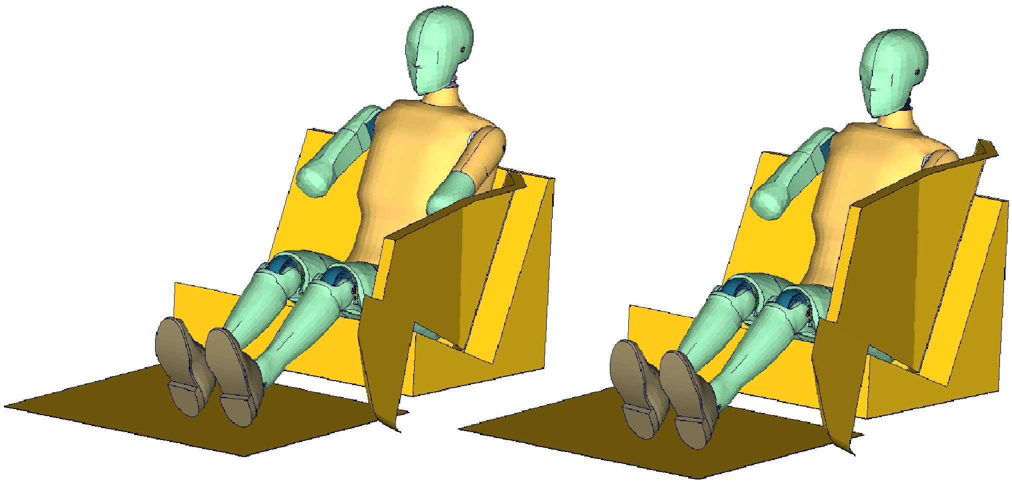
- More improvement of the femur stopper assembly by using new tests for validation



- More improvement of the iliac wings and pubic area by using new tests for validation



- Improvement of the whole ES-2re dummy by using new sled tests with new shapes of the sled.



9. Performance

9.1 Configuration D1: Plane Barrier

Boundaries:

- Rigid barrier (Figure 27)
- Impact speed: Low and high velocity
- Arms in 40 degree position
- Orthogonal impact

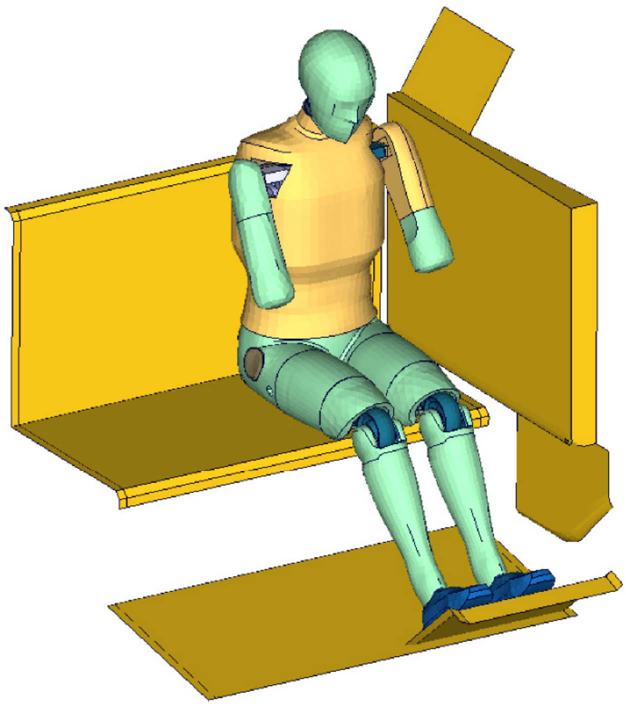
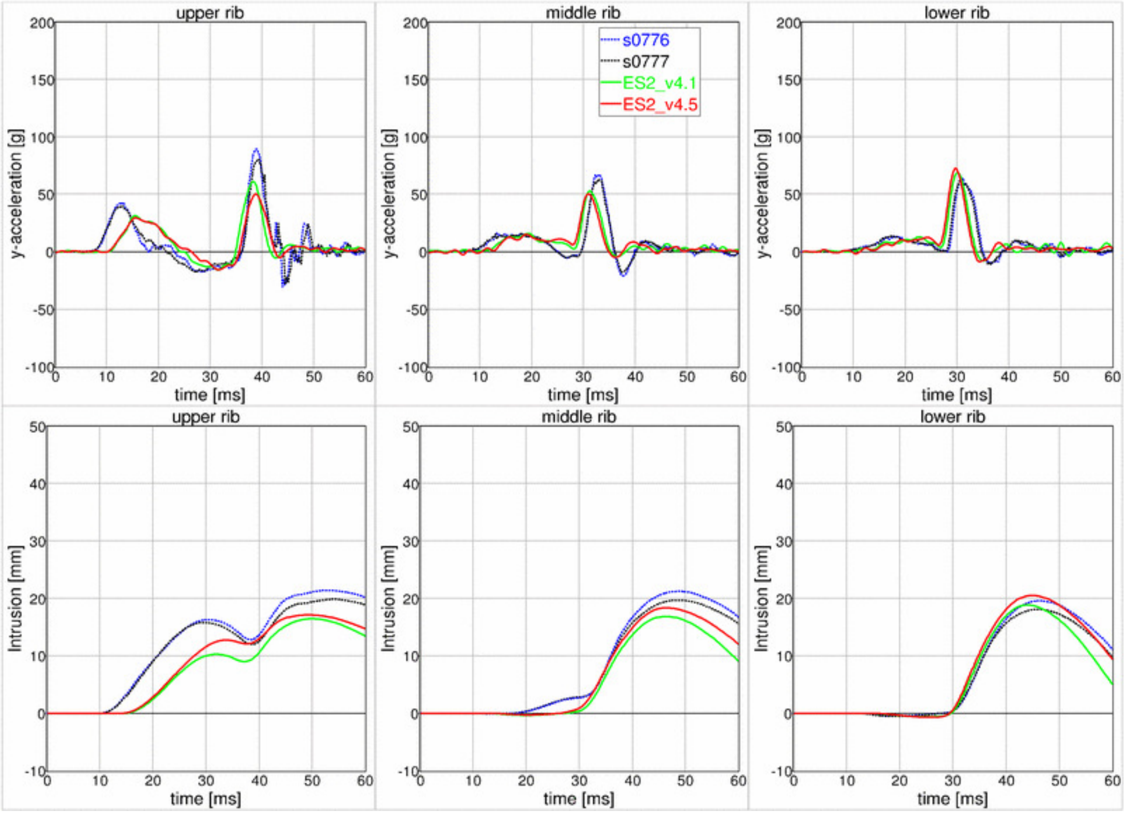
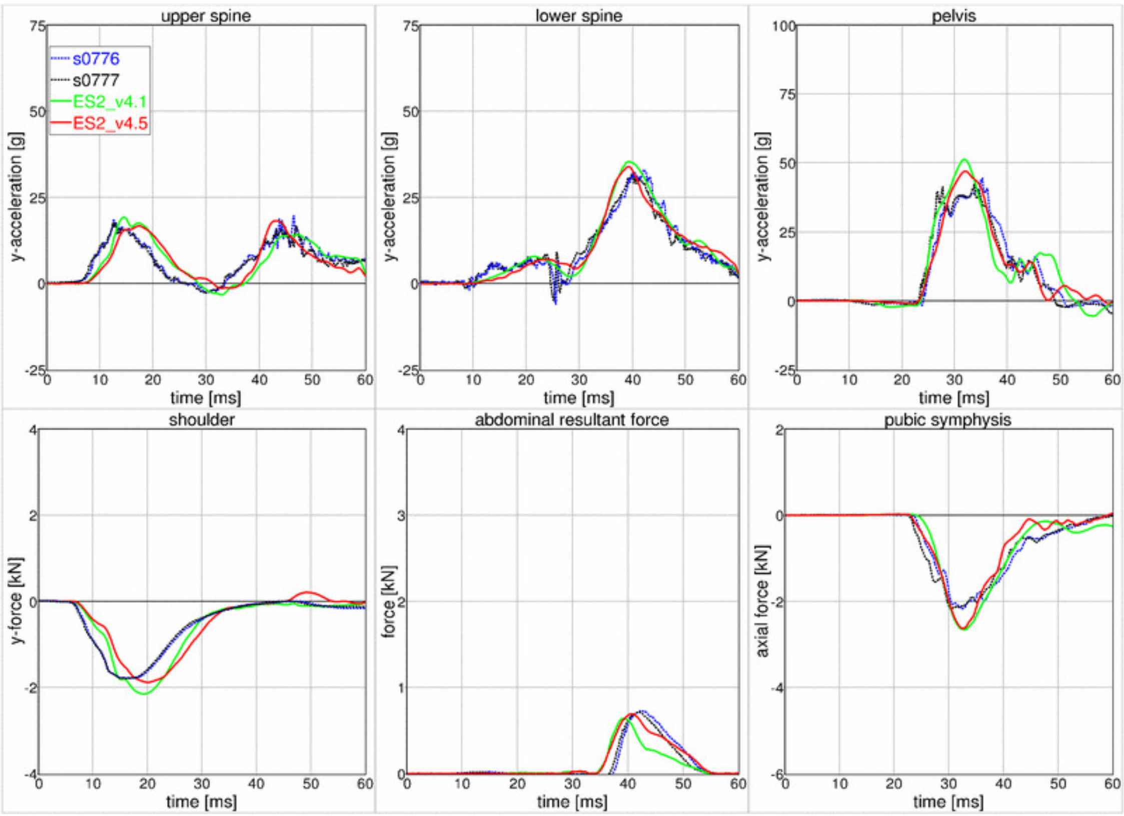
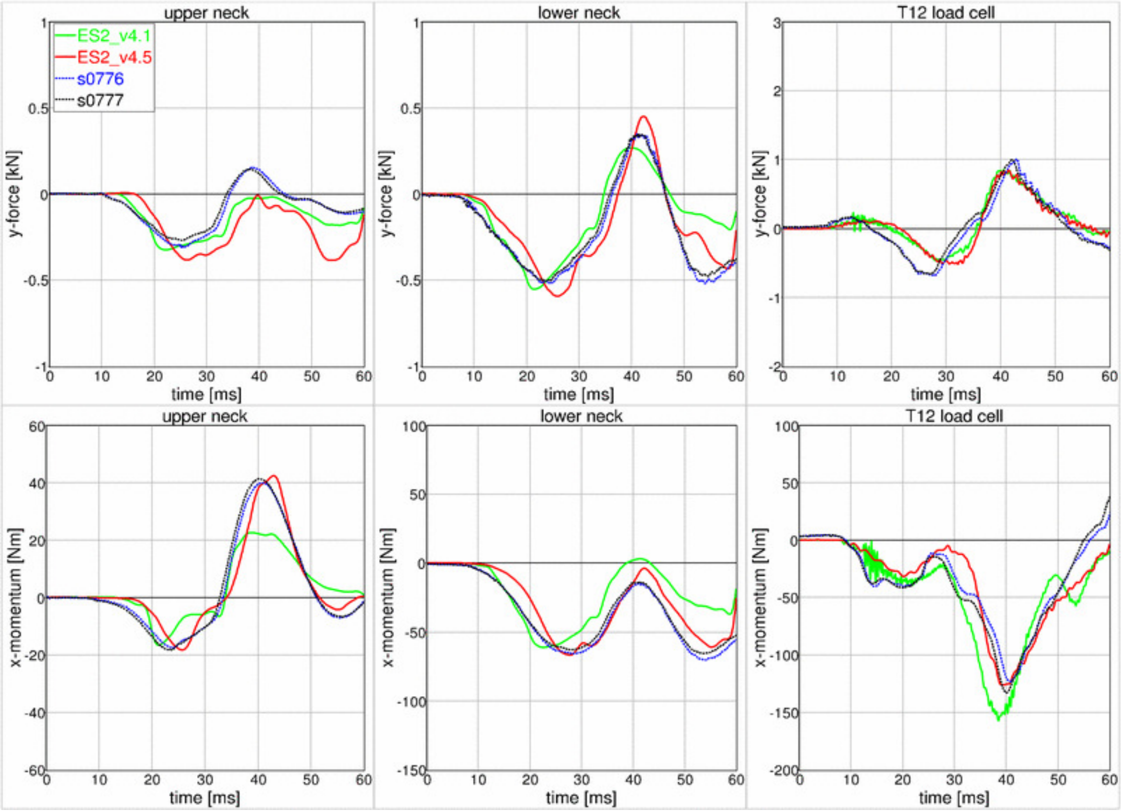


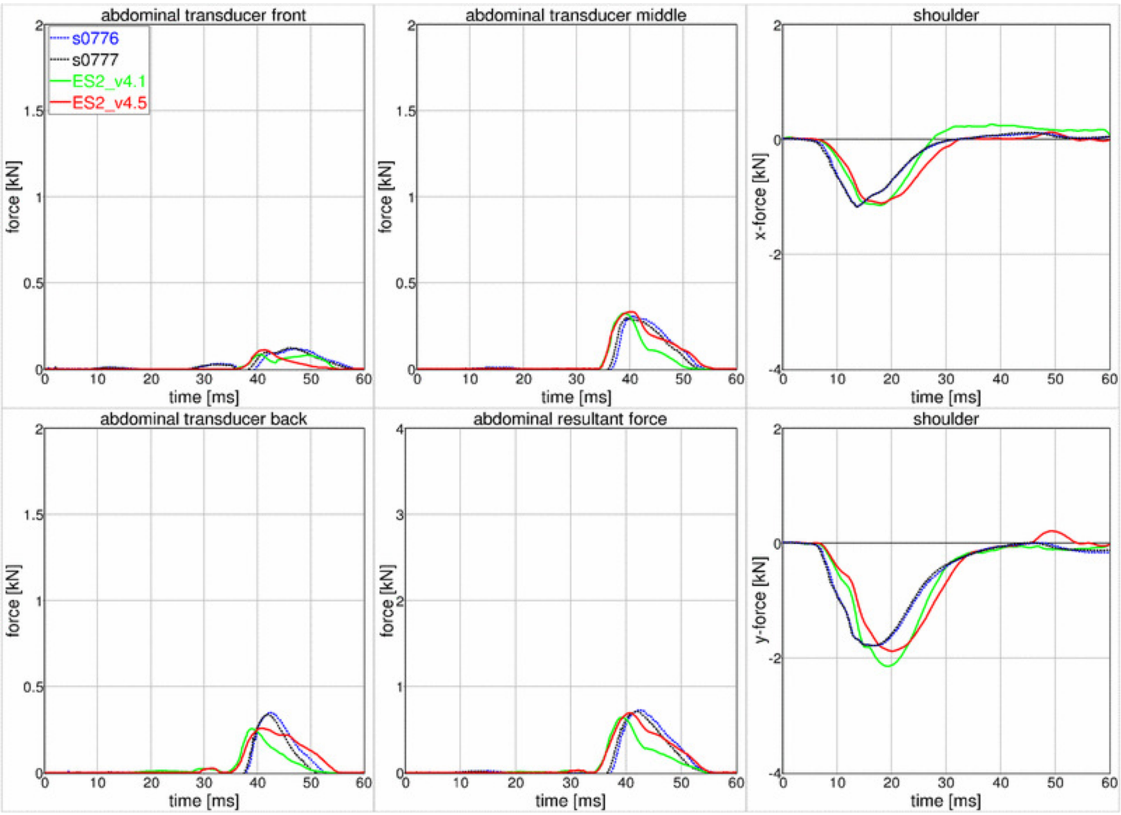
Figure 27: D1 plane barrier test setup

9.1.1 Results at low velocity impact

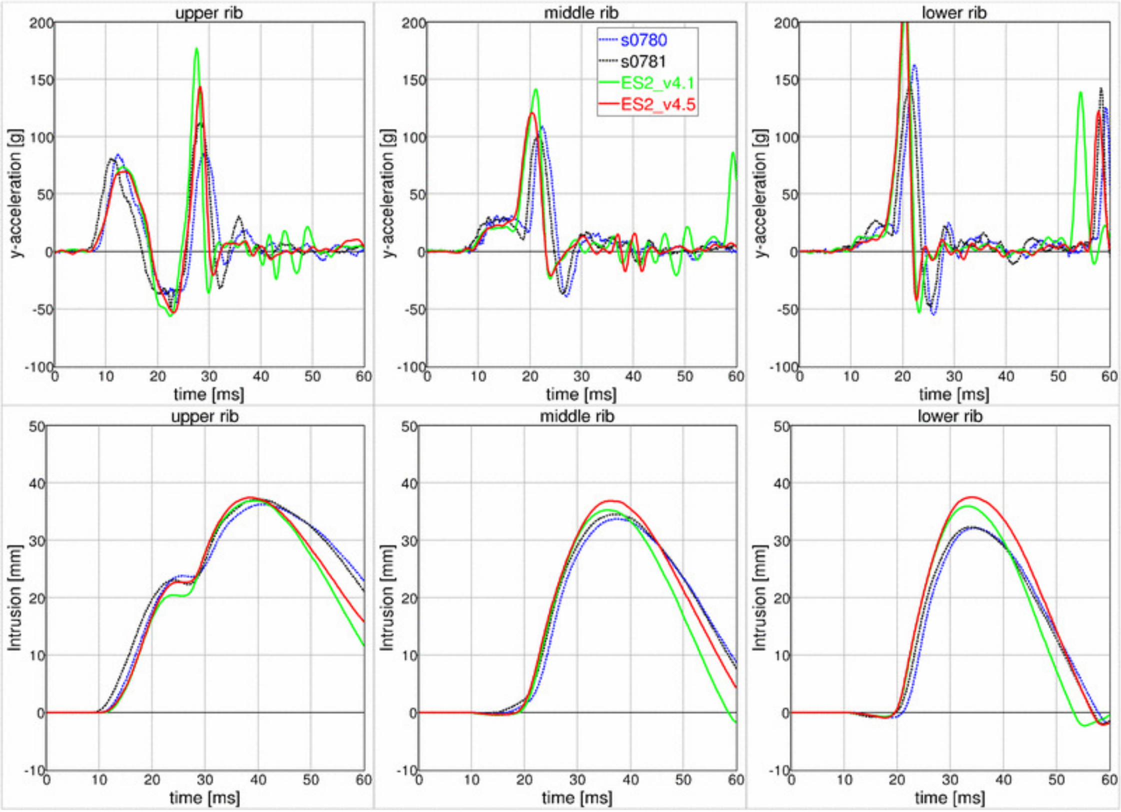


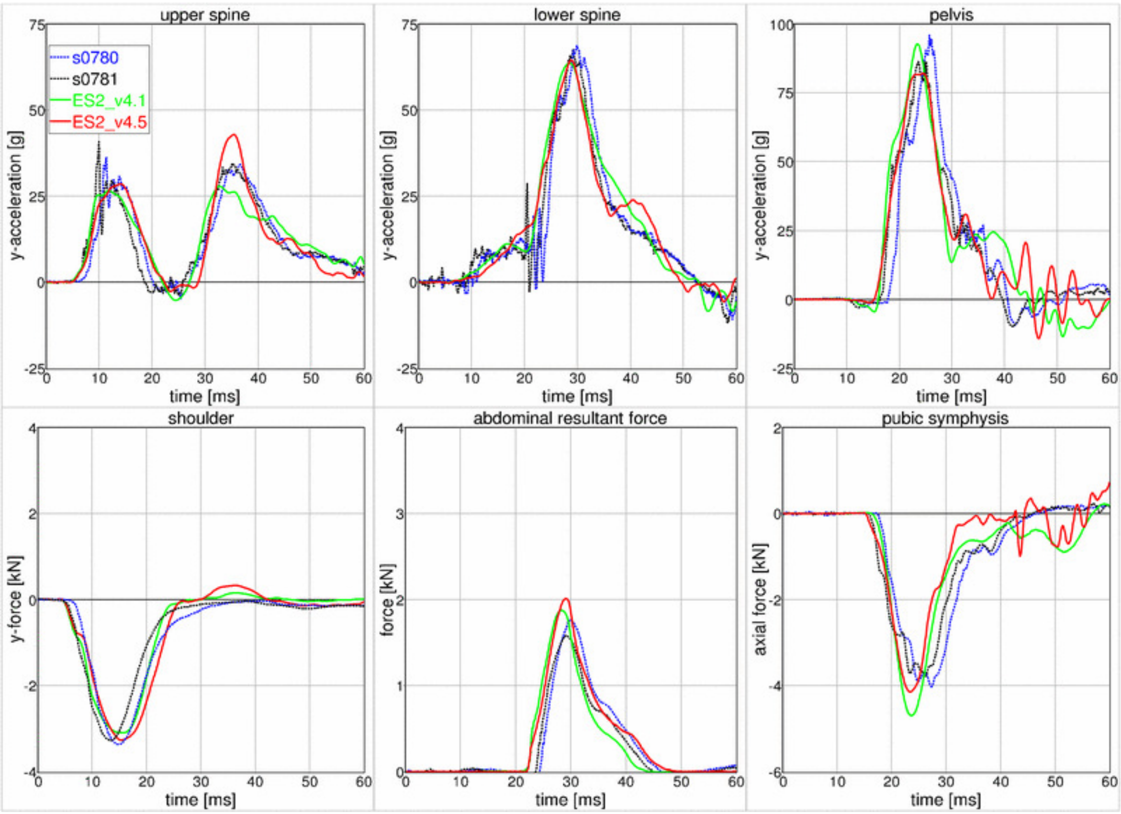


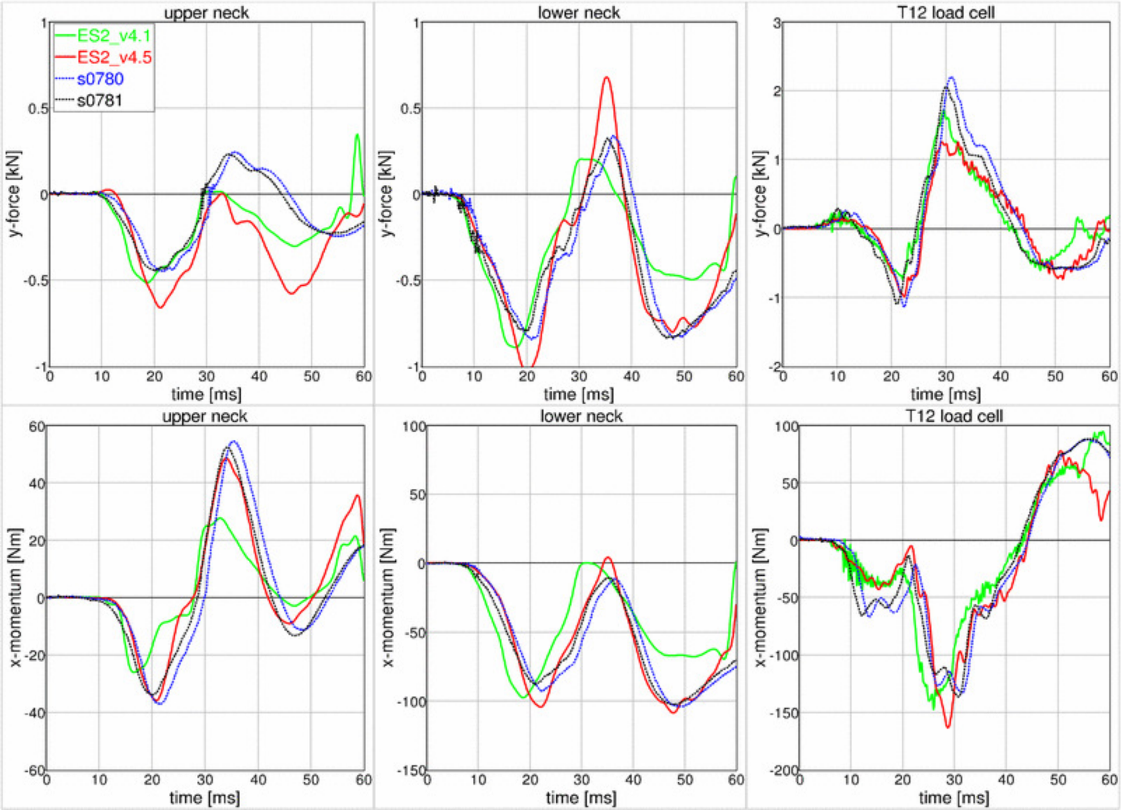

upper neck
lower neck
T12 load cell
ES2_v4.1
ES2_v4.5
s0776
s0777
y-force [kN]
x-momentum [Nm]
time [ms]

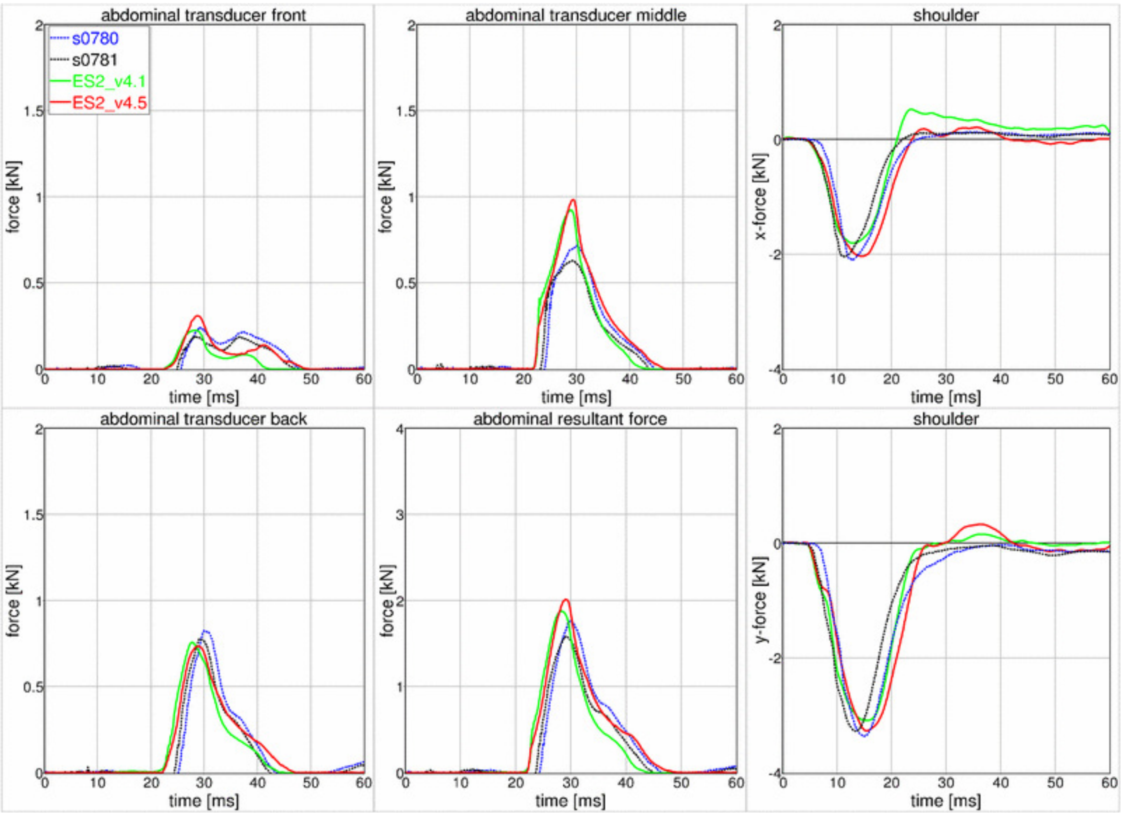

abdominal transducer front
abdominal transducer middle
shoulder
abdominal transducer back
abdominal resultant force
s0776
s0777
ES2_v4.1
ES2_v4.5
force [kN]
x-force [kN]
y-force [kN]
time [ms]

9.1.2 Results at high velocity impact






upper neck
lower neck
T12 load cell
ES2_v4.1
ES2_v4.5
s0780
s0781
y-force [kN]
x-momentum [Nm]
time [ms]


abdominal transducer front
abdominal transducer middle
shoulder
abdominal transducer back
abdominal resultant force
s0780
s0781
ES2_v4.1
ES2_v4.5
force [kN]
x-force [kN]
y-force [kN]
time [ms]

9.2 Configuration D2: Plane Barrier

Boundaries:

- Rigid barrier (Figure 28)
- Impact speed: Low velocity
- Arms in 0 degree position
- Orthogonal impact

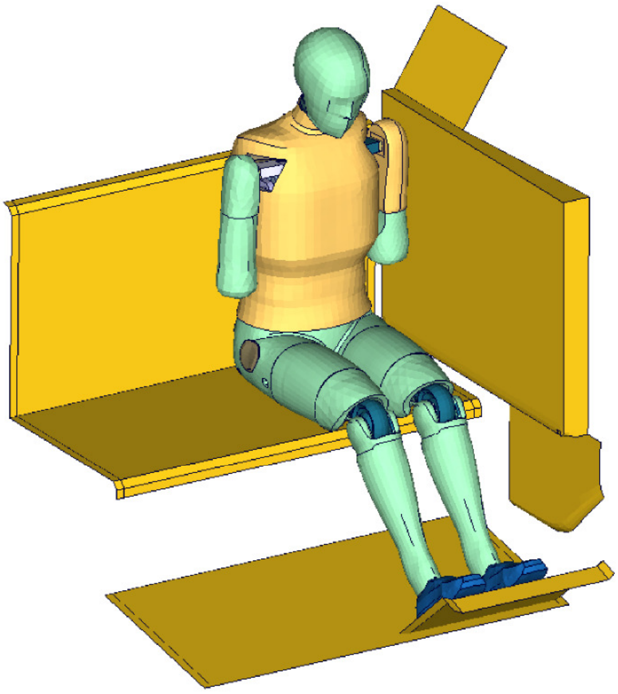
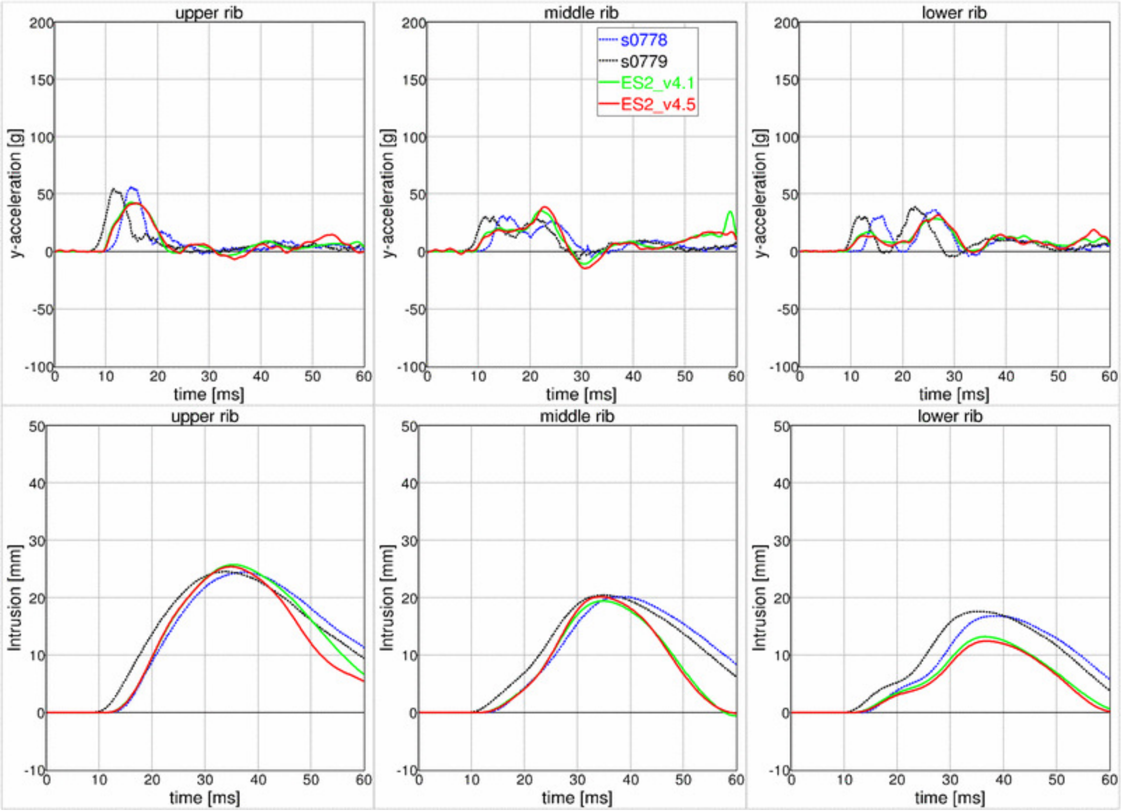
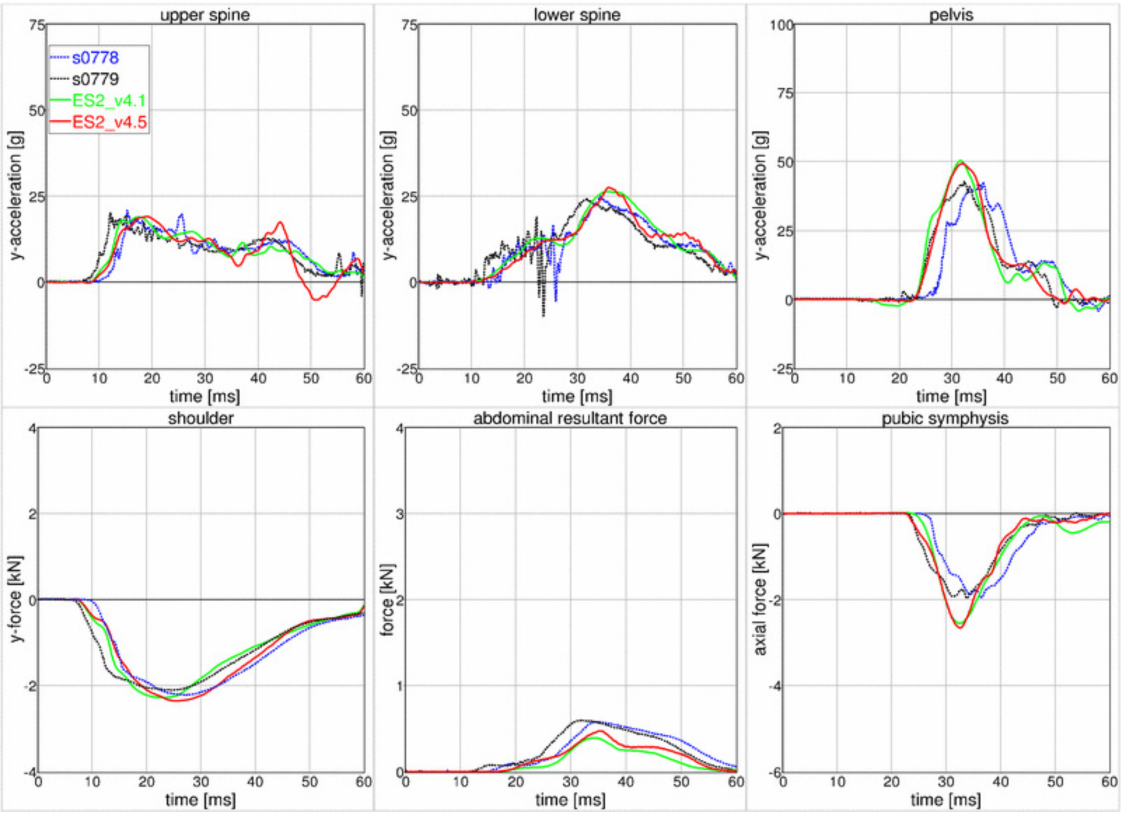
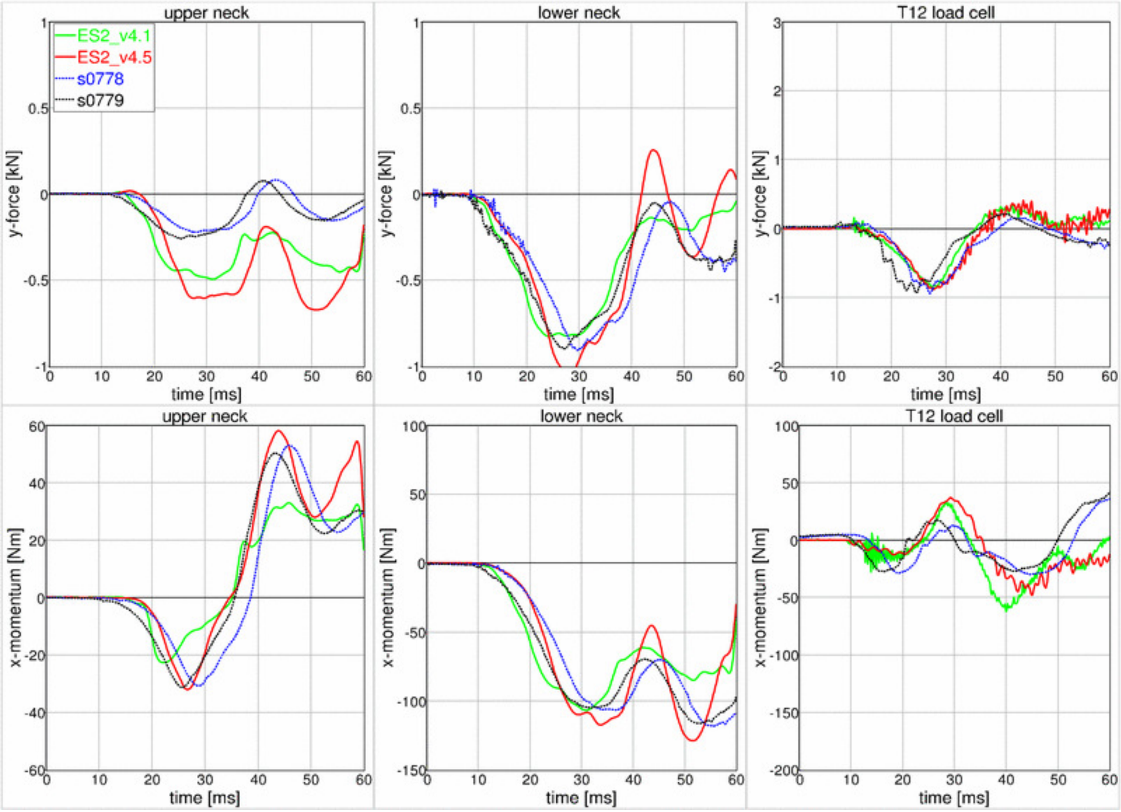


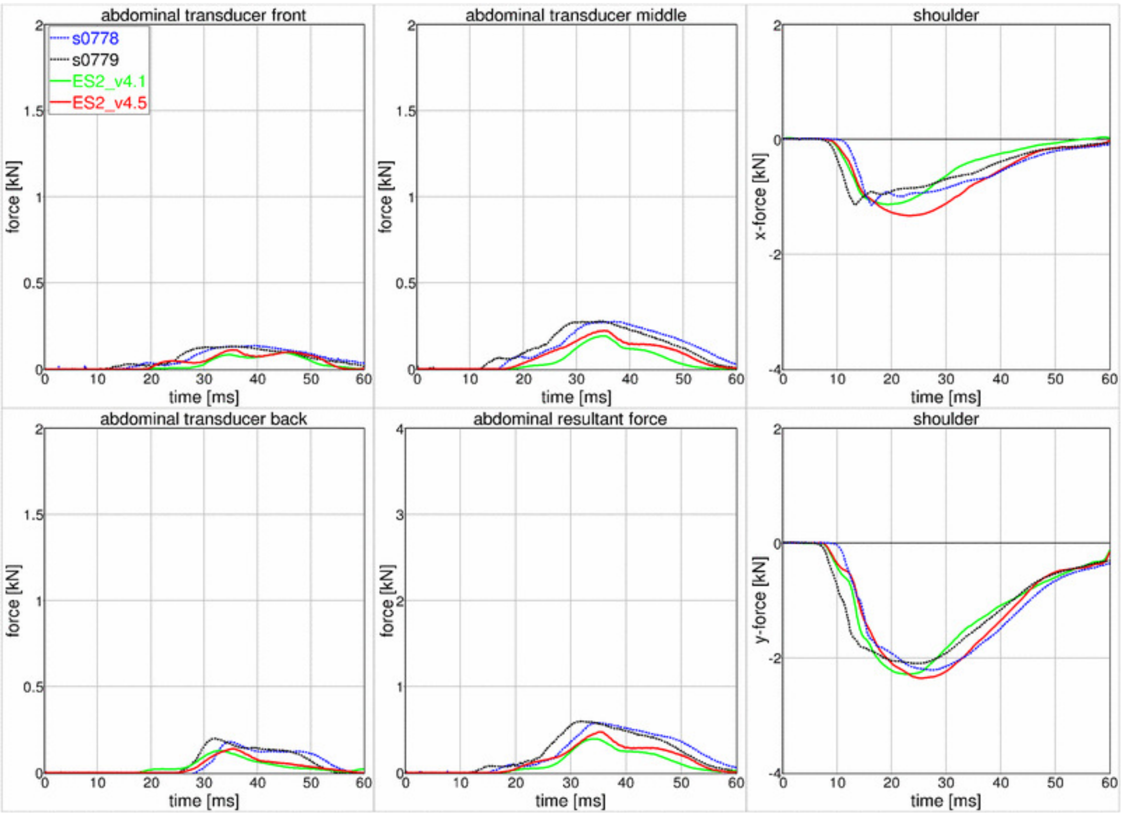
Figure 28: D2 plane barrier test setup

9.2.1 Results at low velocity impact






upper neck
lower neck
T12 load cell
ES2_v4.1
ES2_v4.5
s0778
s0779
y-force [kN]
x-momentum [Nm]
time [ms]


abdominal transducer front
abdominal transducer middle
shoulder
abdominal transducer back
abdominal resultant force
s0778
s0779
ES2_v4.1
ES2_v4.5
force [kN]
x-force [kN]
y-force [kN]
time [ms]

9.3 Configuration D3: Barrier with pelvis pusher

Boundaries:

- Rigid barrier (Figure 29)
- Impact speed: Low and high velocity
- Arms in 40 degree position
- Pelvis pusher
- Oblique impact

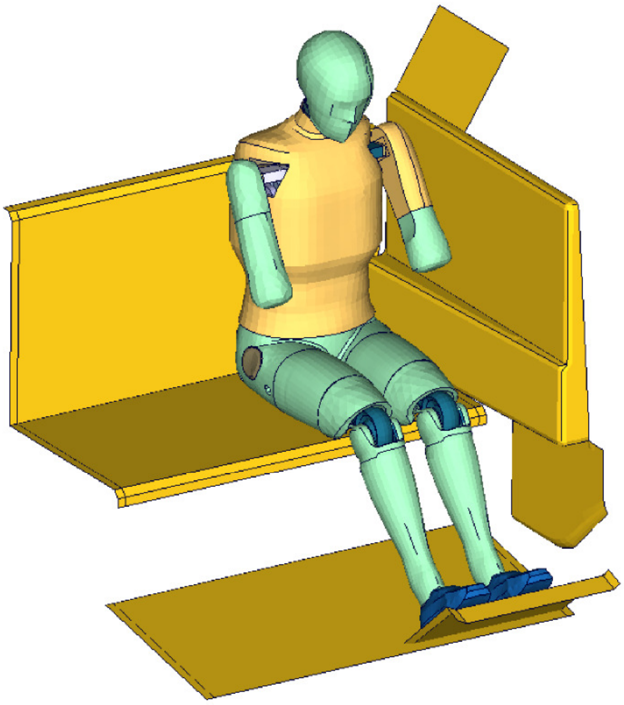
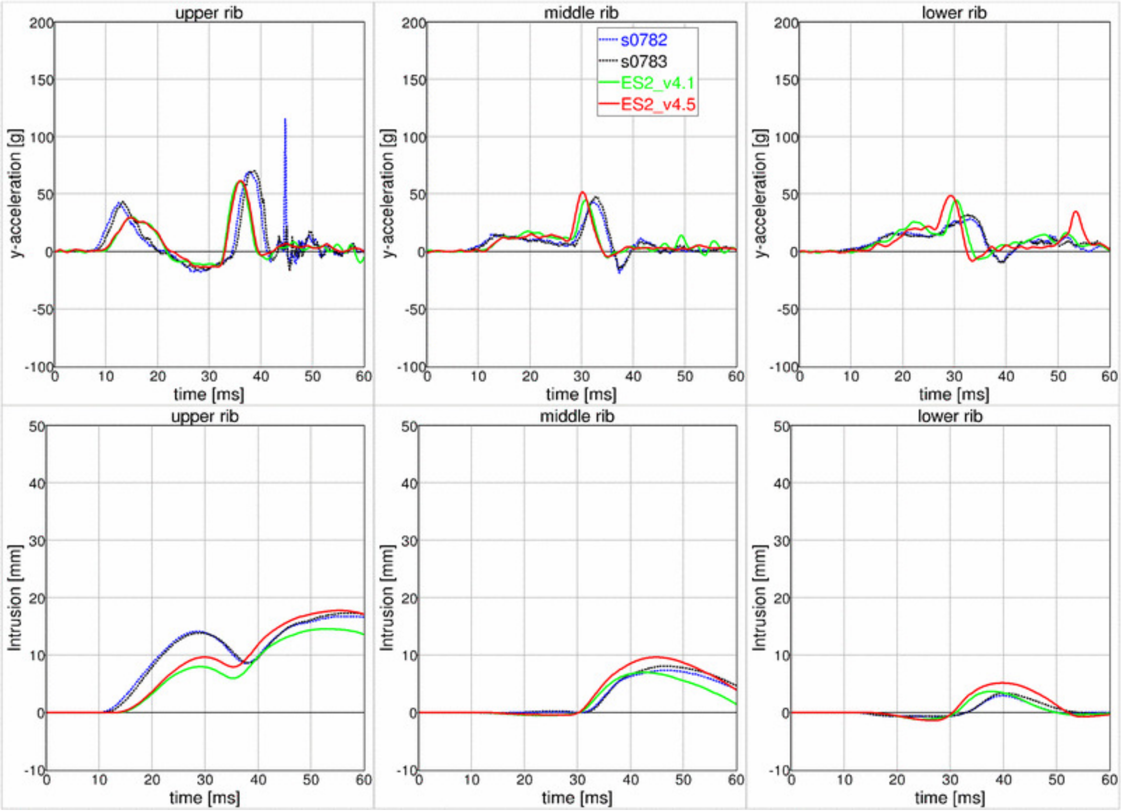
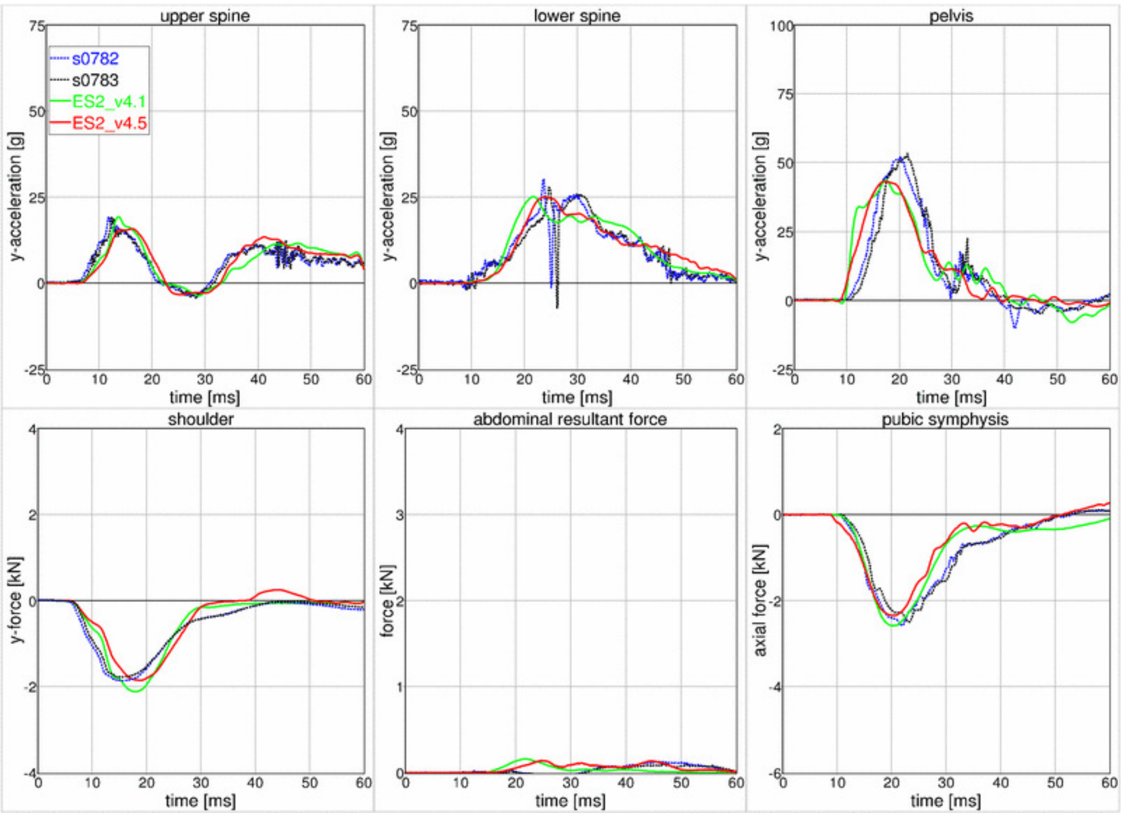
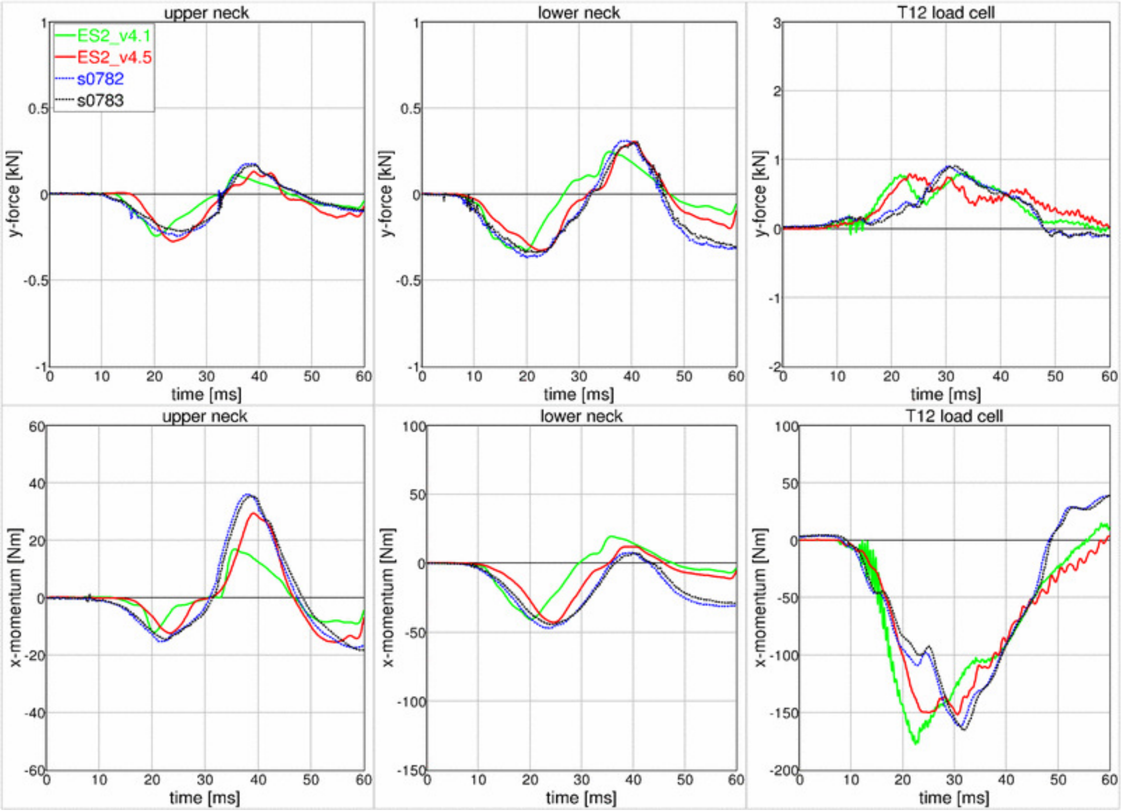


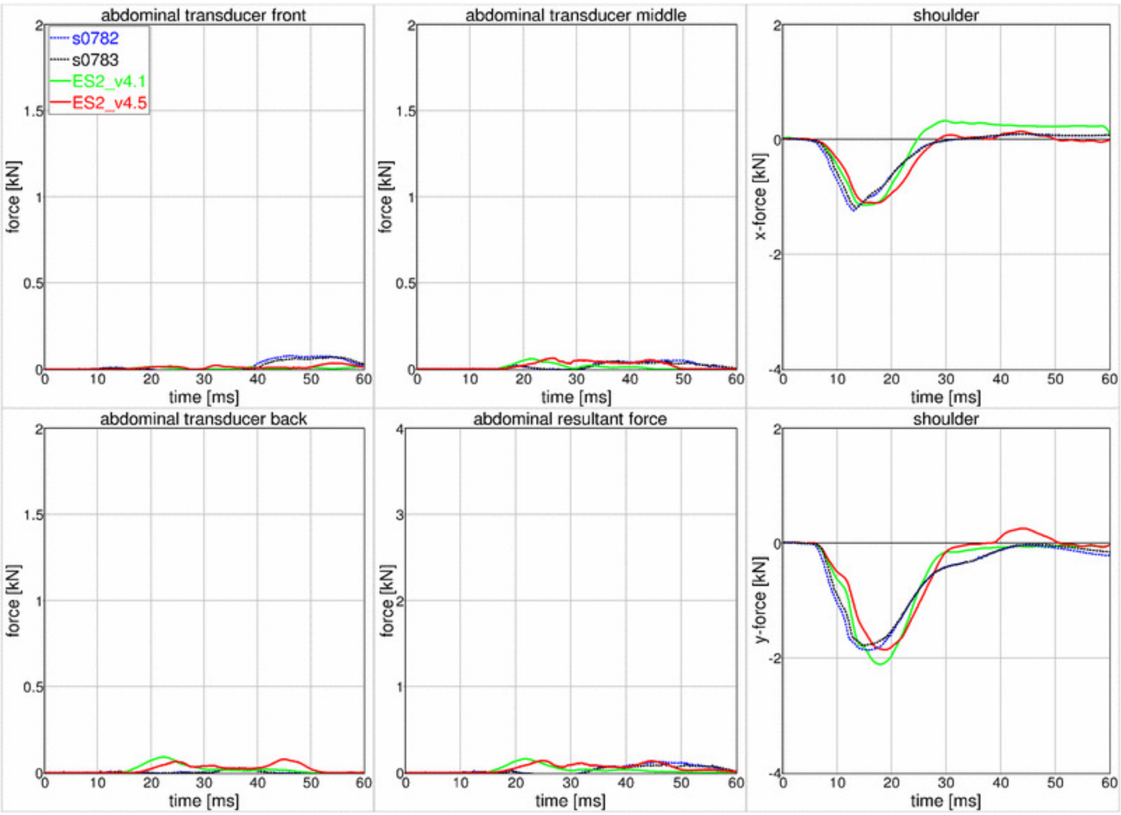
Figure 29: D3 barrier test setup

9.3.1 Results at low velocity impact

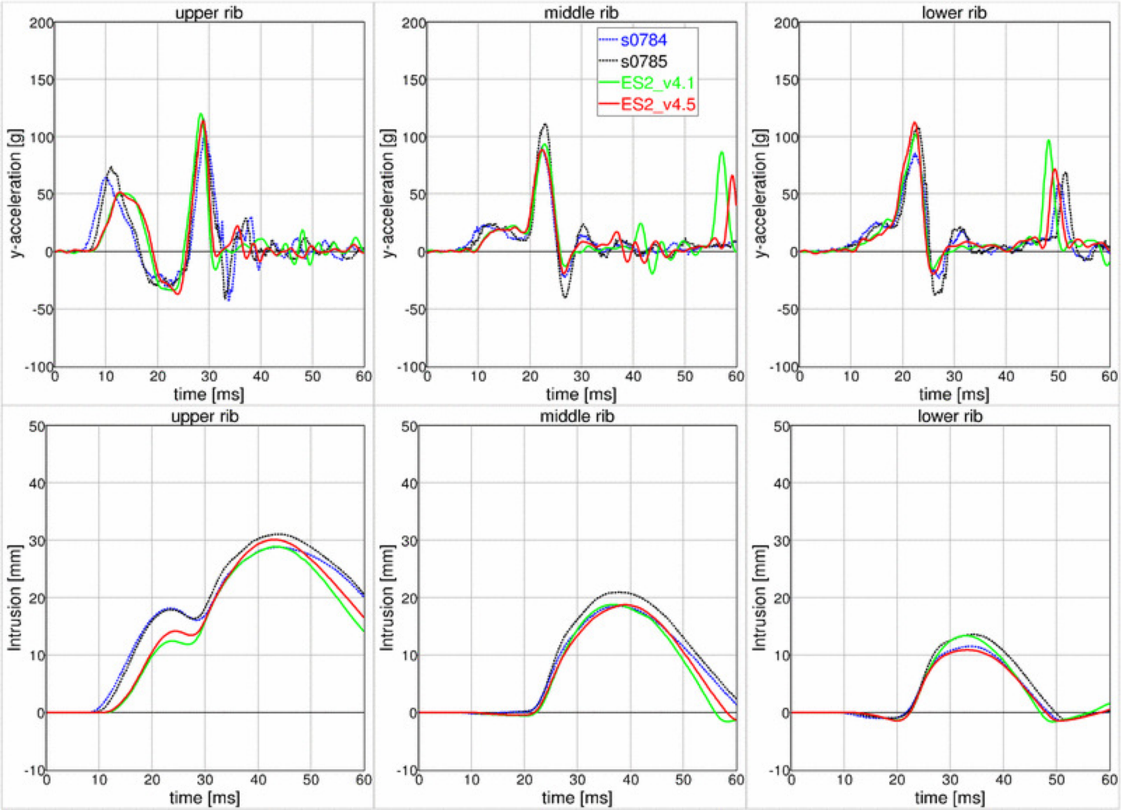


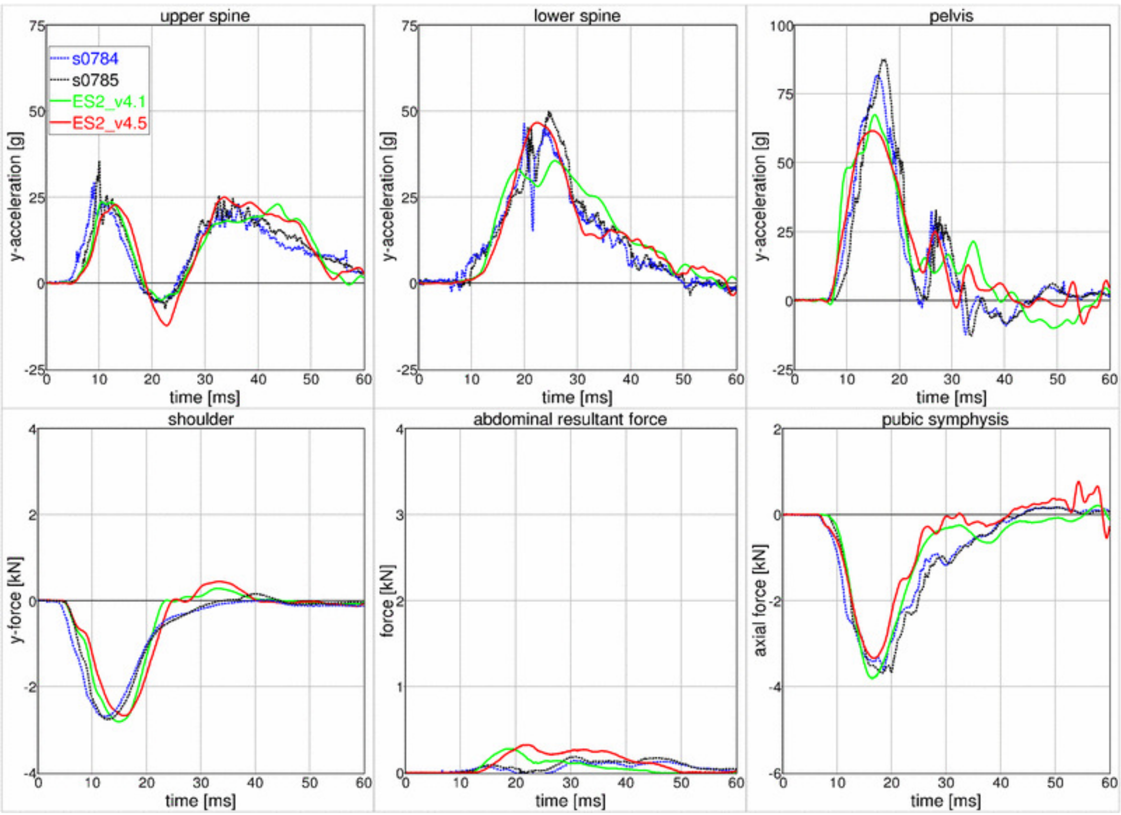


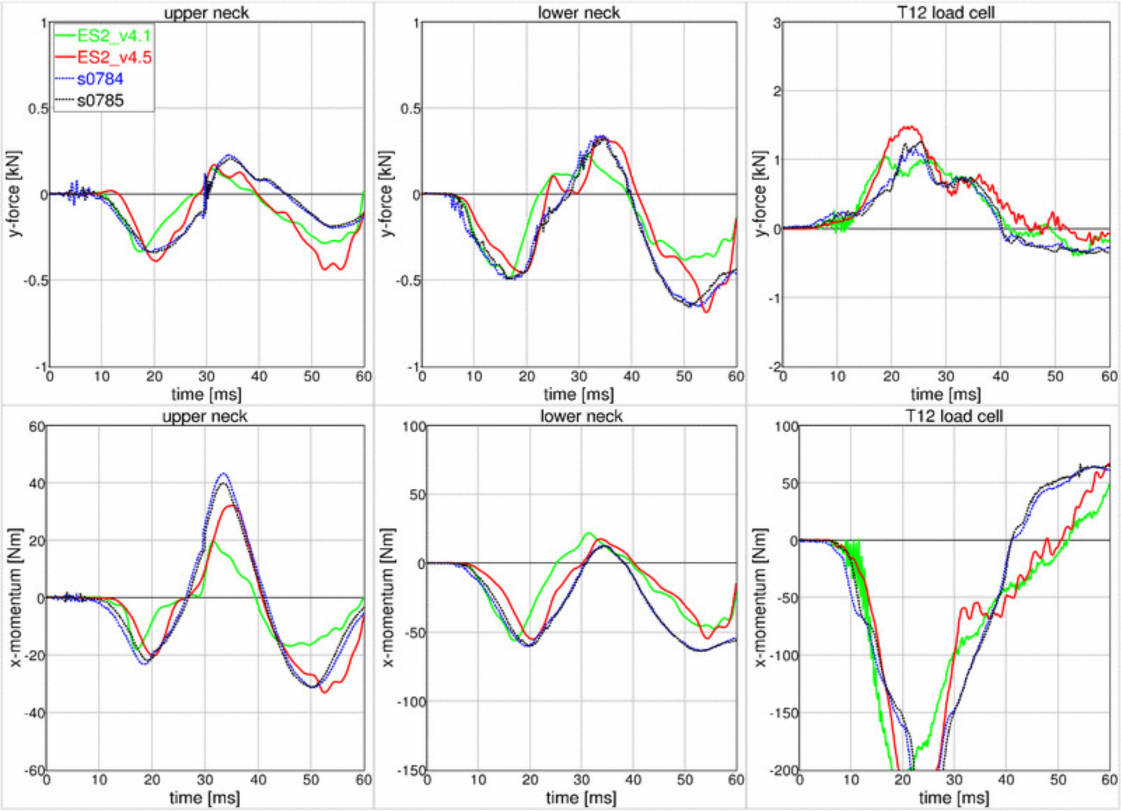

upper neck
ES2_v4.1
ES2_v4.5
s0782
s0783
y-force [kN]
time [ms]
lower neck
y-force [kN]
time [ms]
T12 load cell
y-force [kN]
time [ms]
upper neck
x-momentum [Nm]
time [ms]
lower neck
x-momentum [Nm]
time [ms]
T12 load cell
x-momentum [Nm]
time [ms]

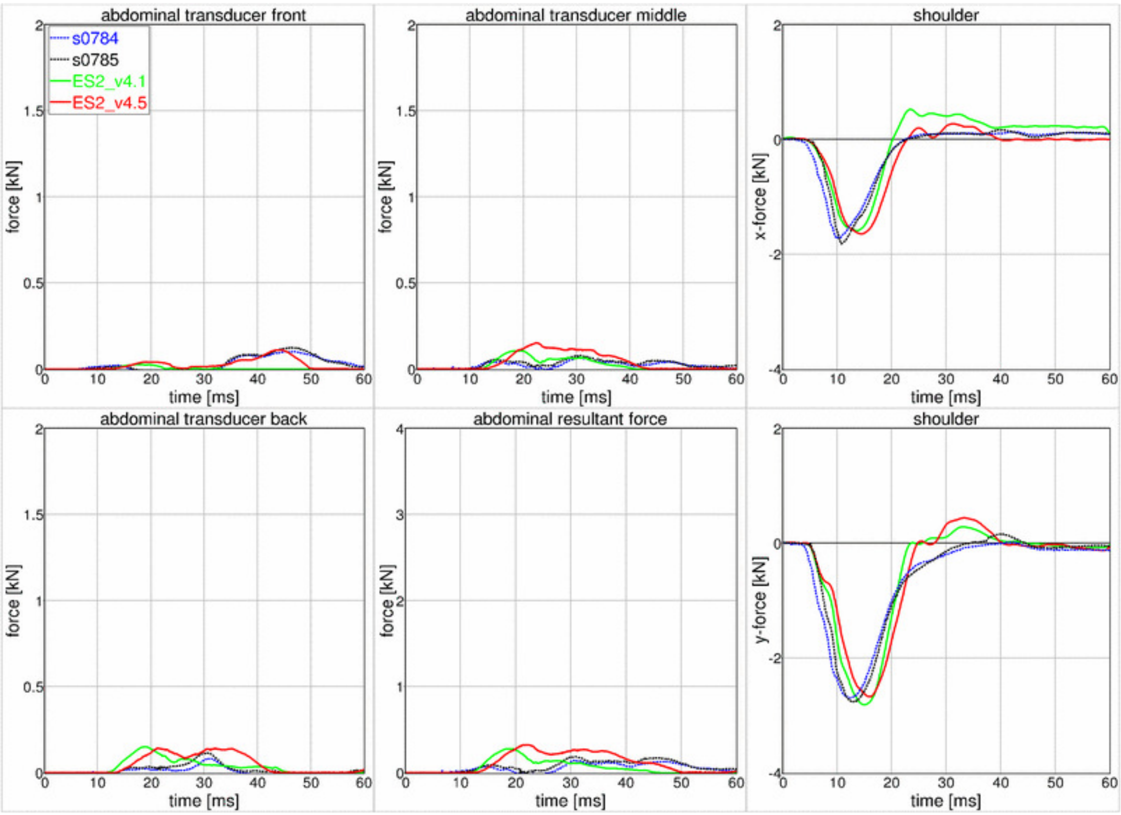

abdominal transducer front
s0782
s0783
ES2_v4.1
ES2_v4.5
force [kN]
time [ms]
abdominal transducer middle
force [kN]
time [ms]
shoulder
x-force [kN]
time [ms]
abdominal transducer back
force [kN]
time [ms]
abdominal resultant force
force [kN]
time [ms]
shoulder
y-force [kN]
time [ms]

9.3.2 Results at high velocity impact






upper neck
ES2_v4.1
ES2_v4.5
s0784
s0785
y-force [kN]
time [ms]
lower neck
y-force [kN]
time [ms]
T12 load cell
y-force [kN]
time [ms]
upper neck
x-momentum [Nm]
time [ms]
lower neck
x-momentum [Nm]
time [ms]
T12 load cell
x-momentum [Nm]
time [ms]


abdominal transducer front
s0784
s0785
ES2_v4.1
ES2_v4.5
force [kN]
time [ms]
abdominal transducer middle
force [kN]
time [ms]
shoulder
x-force [kN]
time [ms]
abdominal transducer back
force [kN]
time [ms]
abdominal resultant force
force [kN]
time [ms]
shoulder
y-force [kN]
time [ms]

9.4 Configuration D4: Door barrier

Boundaries:

- Rigid barrier (Figure 30)
- Impact speed: High velocity
- Arms in 40 degree position
- Curb edge
- Orthogonal impact

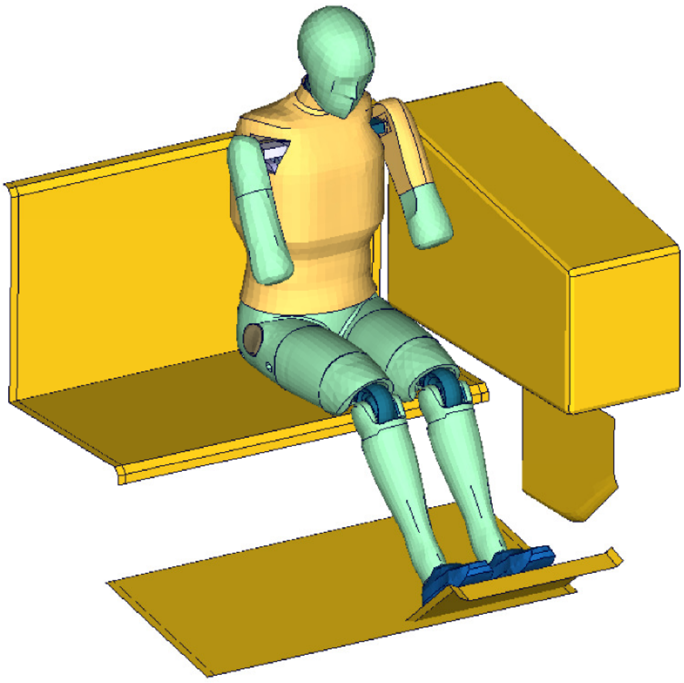
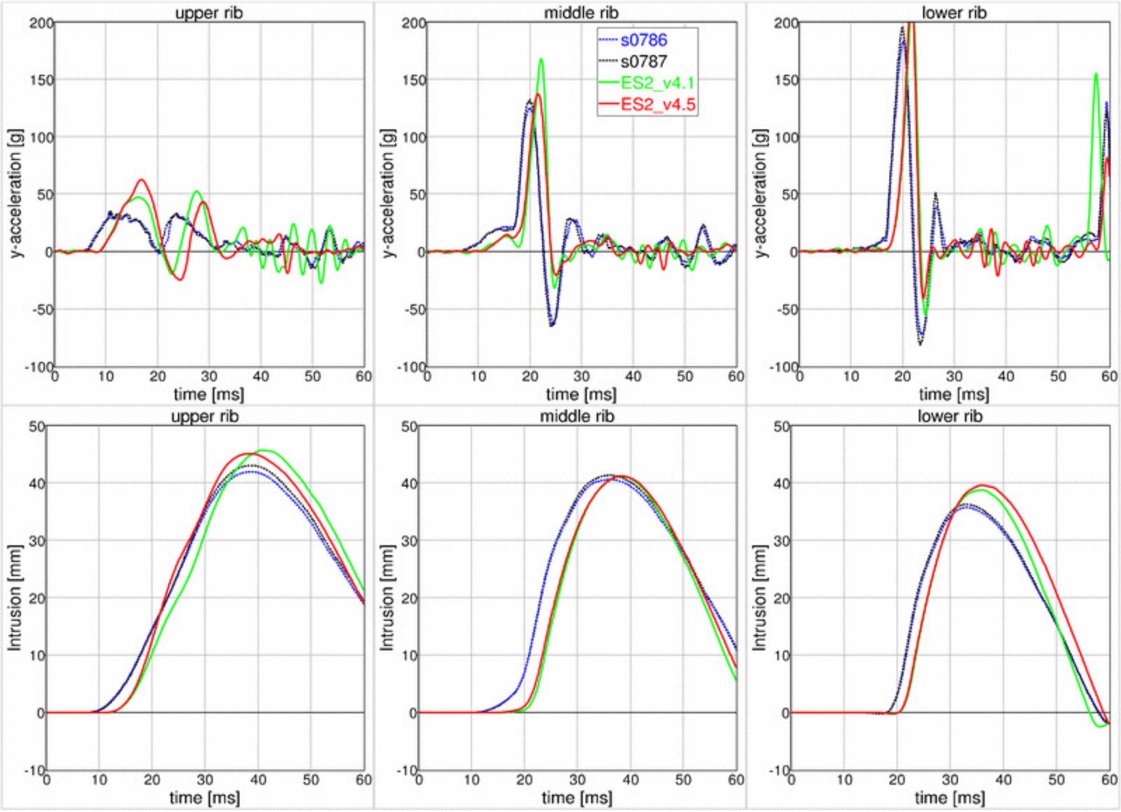
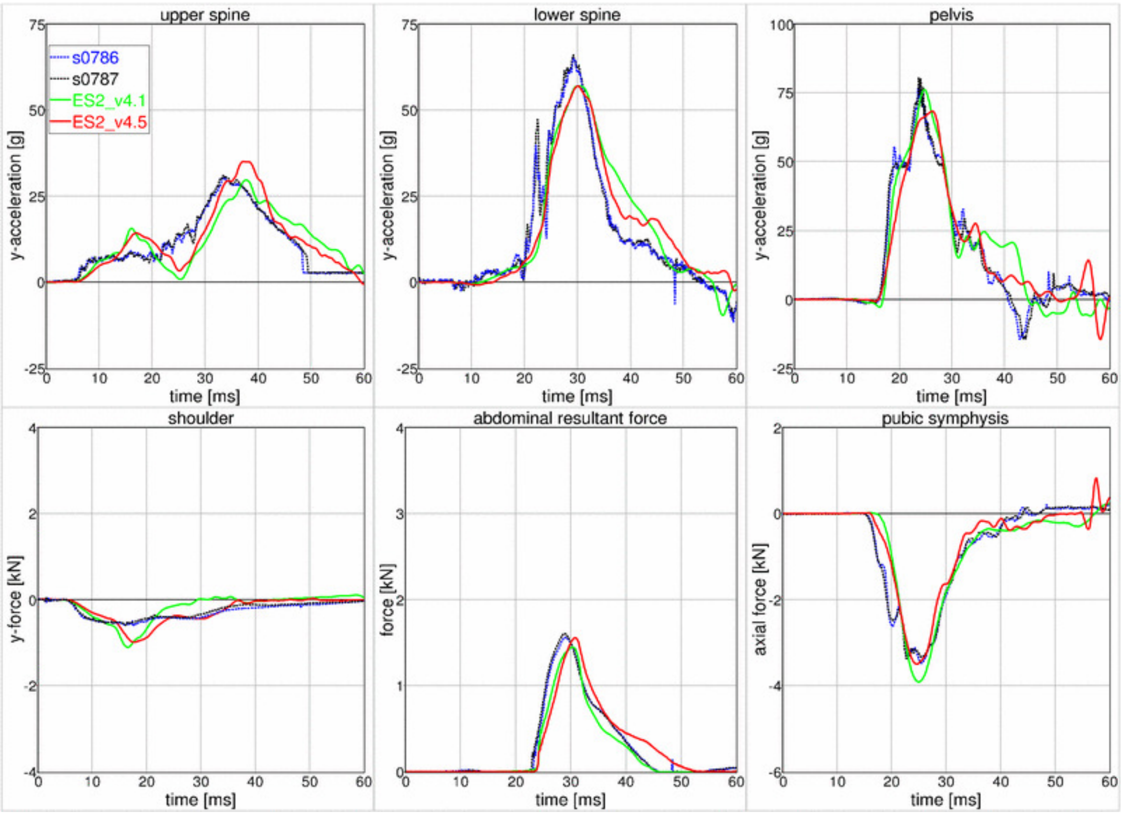
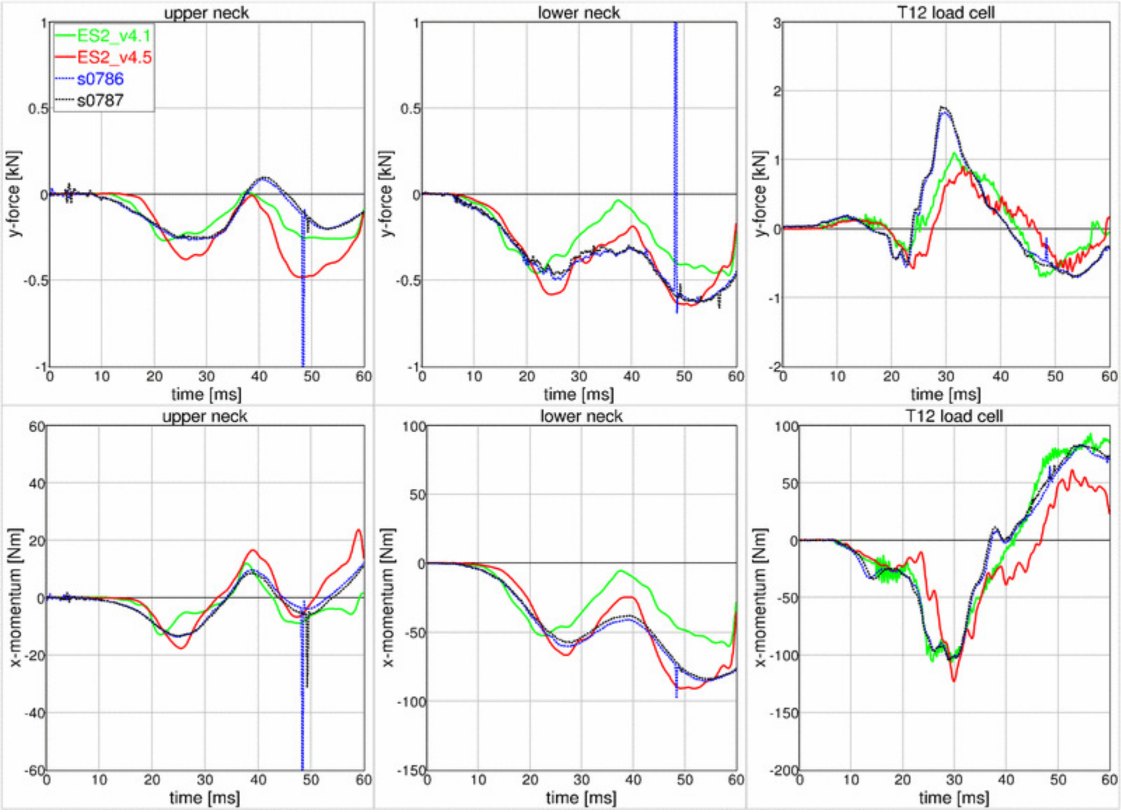


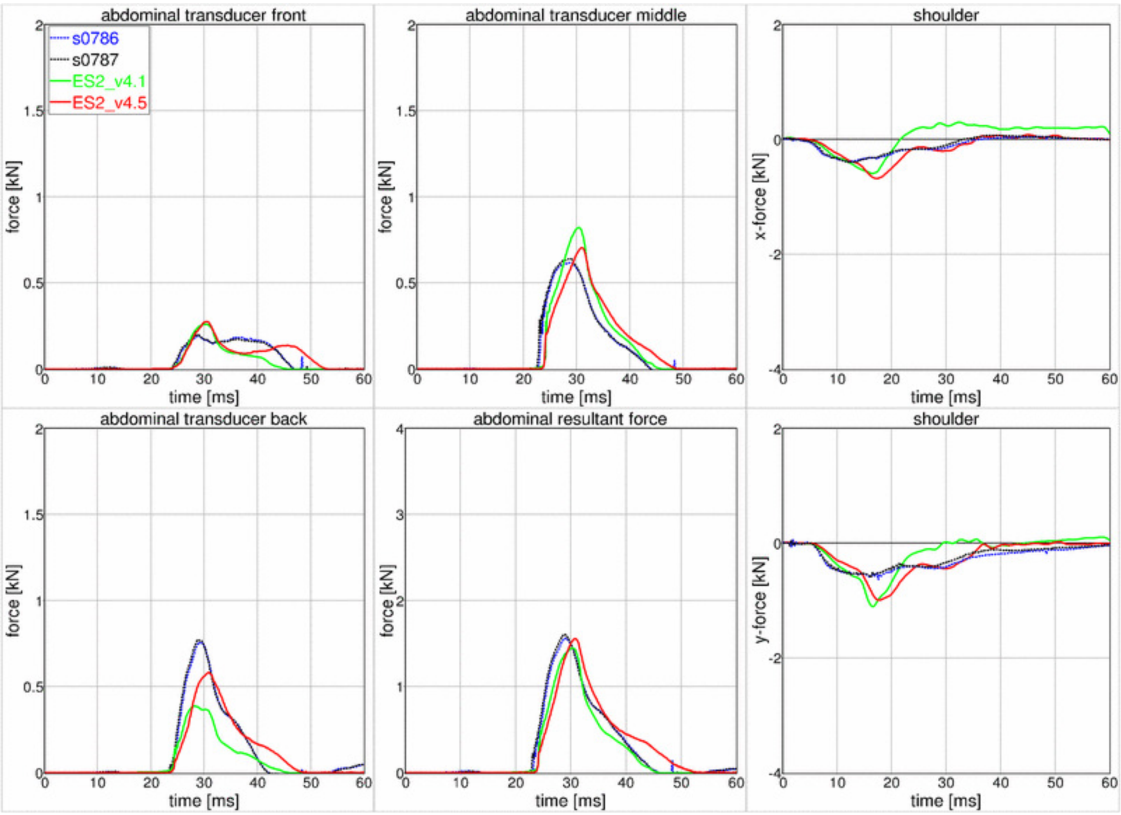
Figure 30: D4 door barrier test setup

9.4.1 Results at high velocity impact






upper neck
ES2_v4.1
ES2_v4.5
s0786
s0787
y-force [kN]
time [ms]
lower neck
y-force [kN]
time [ms]
T12 load cell
y-force [kN]
time [ms]
upper neck
x-momentum [Nm]
time [ms]
lower neck
x-momentum [Nm]
time [ms]
T12 load cell
x-momentum [Nm]
time [ms]


abdominal transducer front
s0786
s0787
ES2_v4.1
ES2_v4.5
force [kN]
time [ms]
abdominal transducer middle
force [kN]
time [ms]
shoulder
x-force [kN]
time [ms]
abdominal transducer back
force [kN]
time [ms]
abdominal resultant force
force [kN]
time [ms]
shoulder
y-force [kN]
time [ms]

9.5 Configuration D5: Flat barrier, oblique about +x

Boundaries:

- Rigid barrier (Figure 31)
- Impact speed: Low velocity
- Arms in 40 degree position
- Oblique impact barrier, positive angle about x-axis

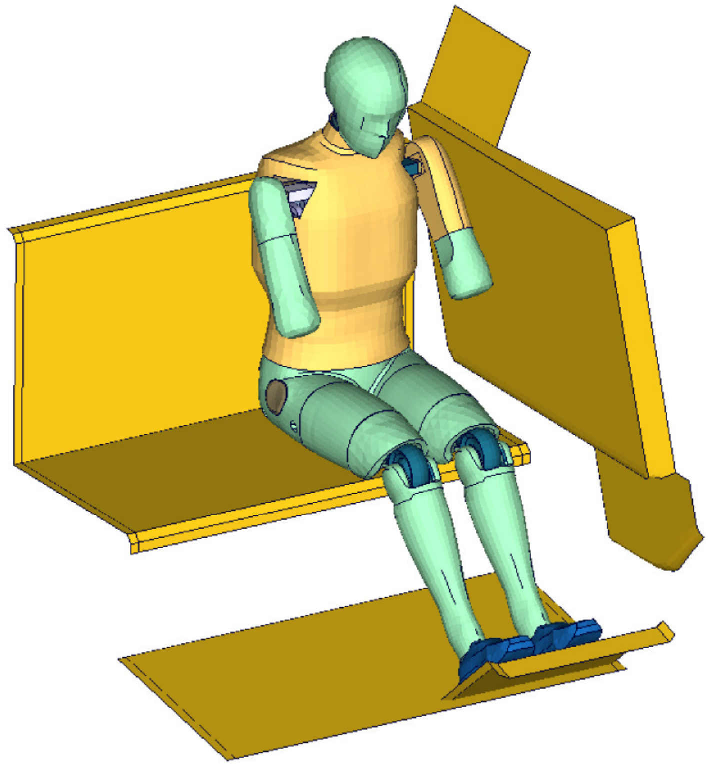
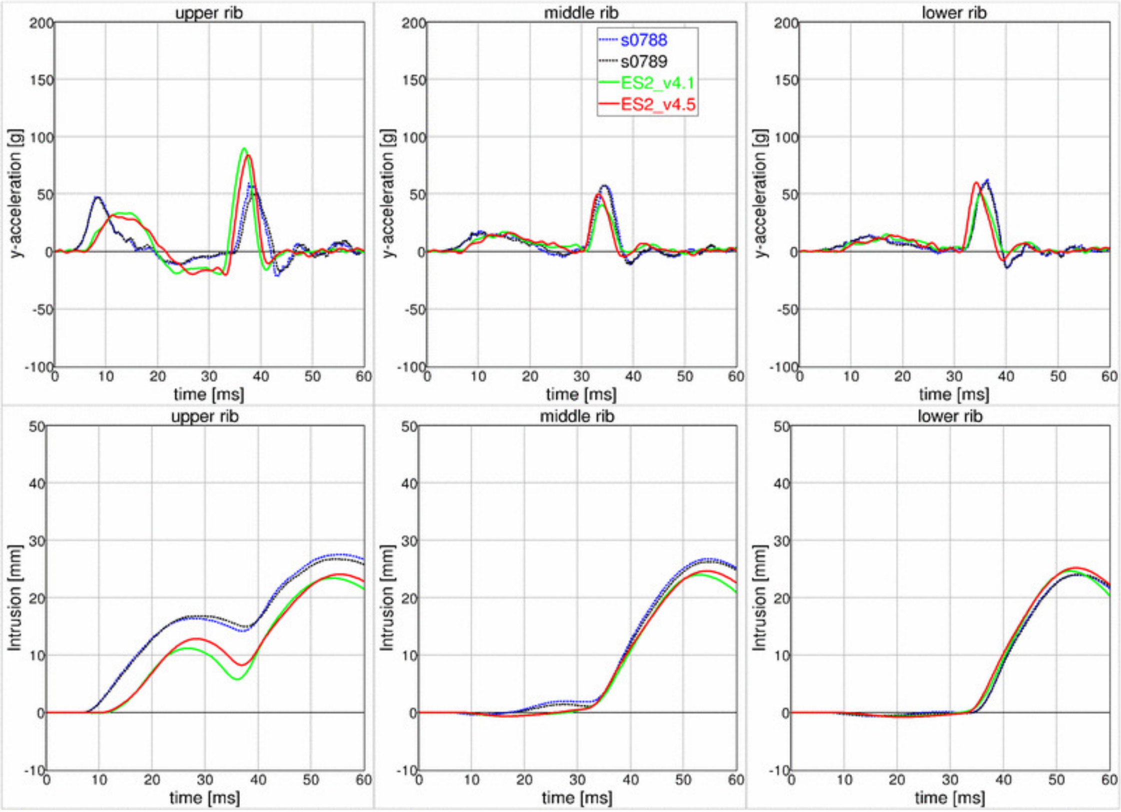
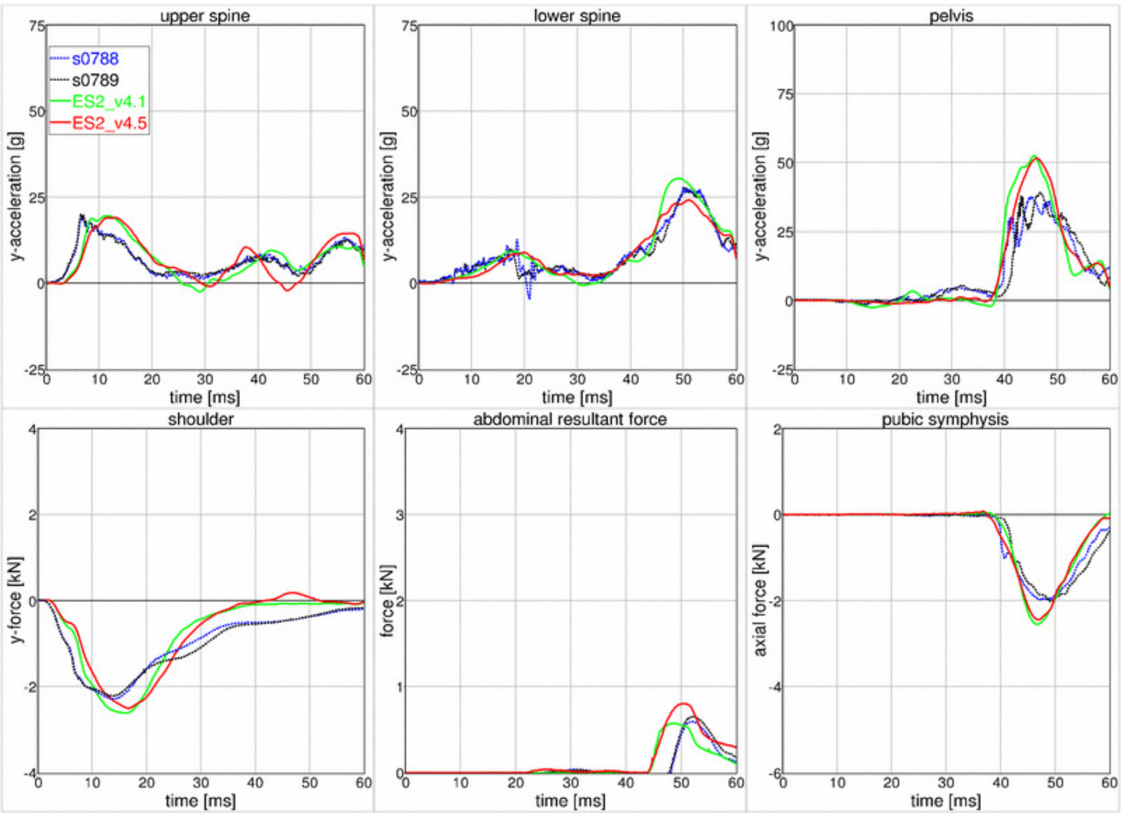
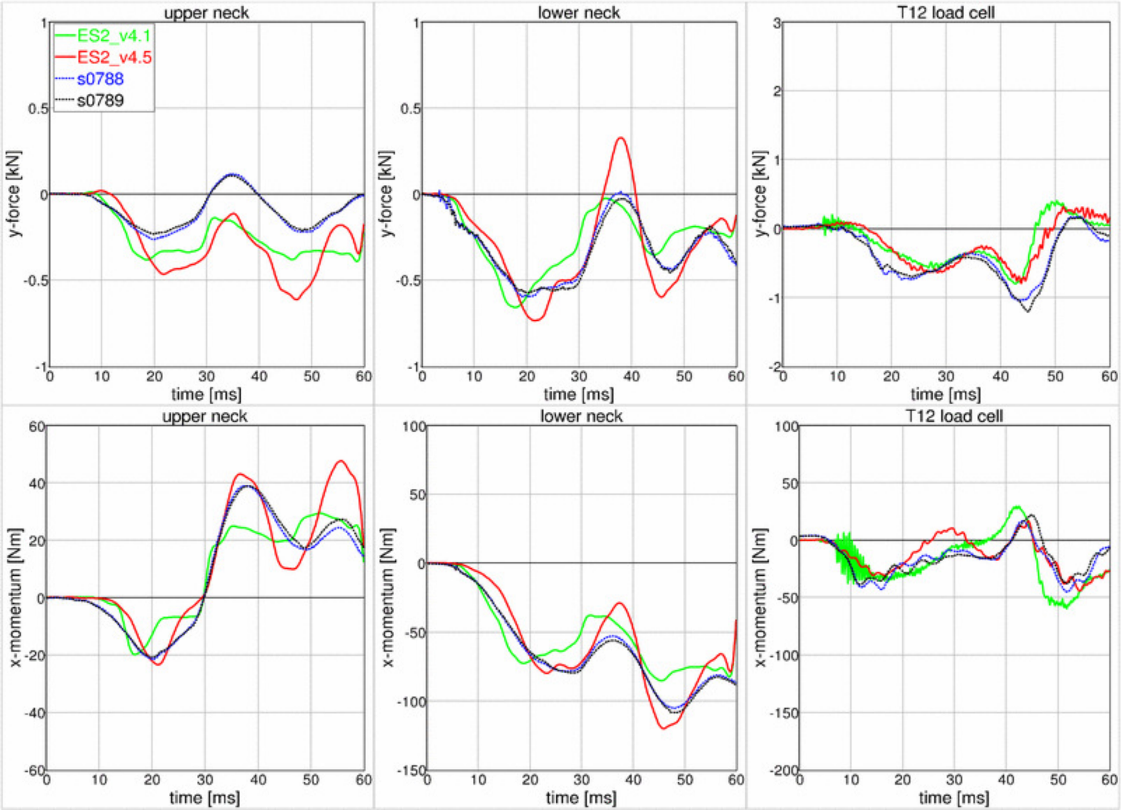


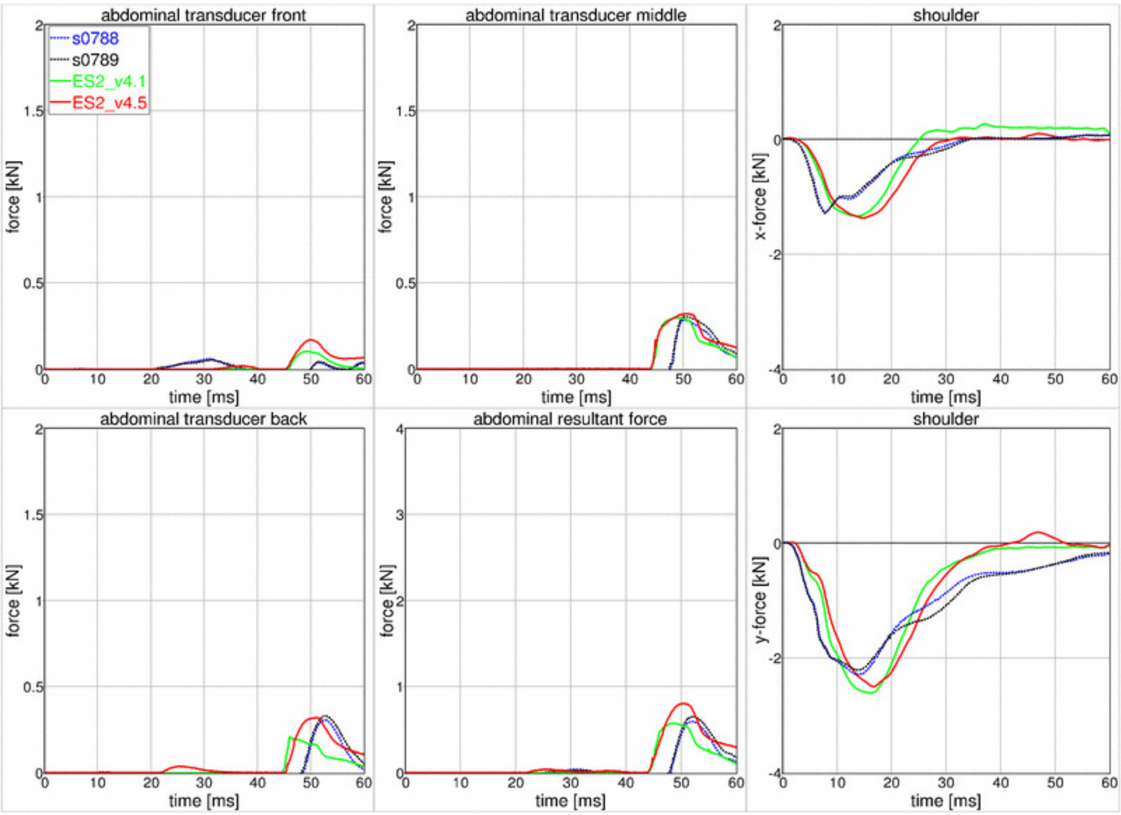
Figure 31: D5 flat barrier (oblique about +x) test setup

9.5.1 Results at low velocity impact






upper neck
lower neck
T12 load cell
ES2_v4.1
ES2_v4.5
s0788
s0789
y-force [kN]
x-momentum [Nm]
time [ms]


abdominal transducer front
abdominal transducer middle
shoulder
abdominal transducer back
abdominal resultant force
s0788
s0789
ES2_v4.1
ES2_v4.5
force [kN]
x-force [kN]
y-force [kN]
time [ms]

9.6 Configuration D6: Flat barrier, oblique about +z

Boundaries:

- Rigid barrier (Figure 32)
- Impact speed: Low and high velocity
- Arms in 40 degree position
- Oblique impact barrier, positive angle about z-axis

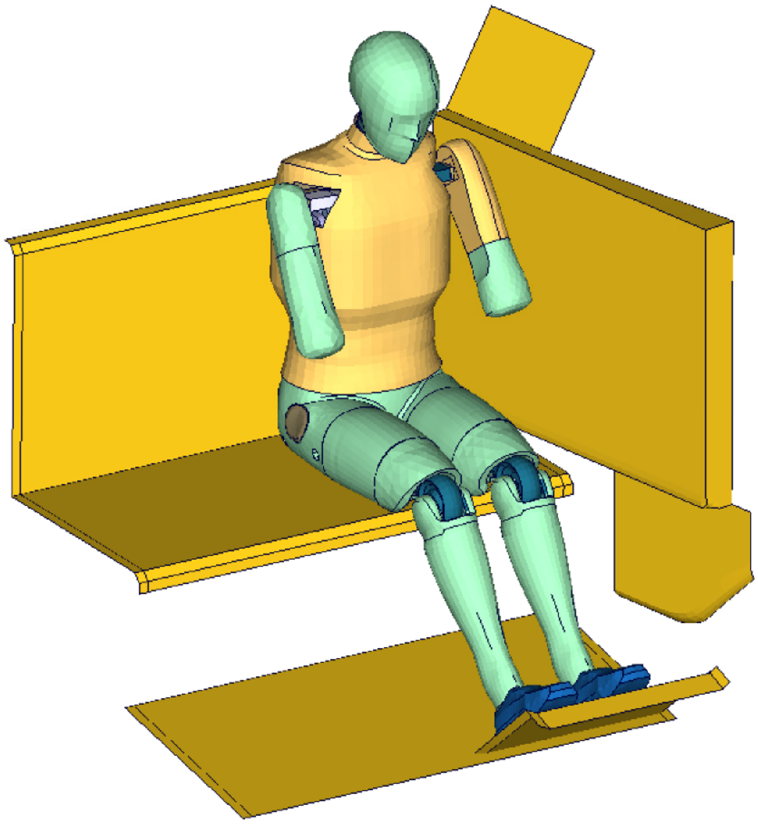
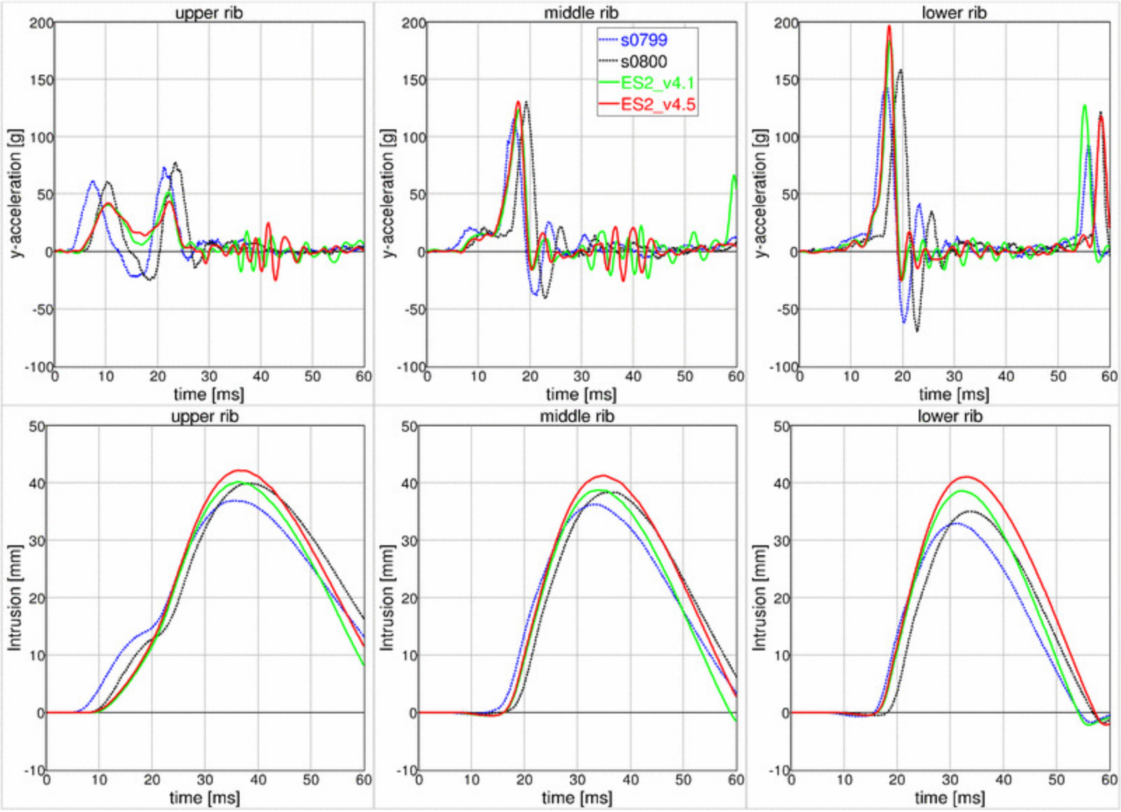
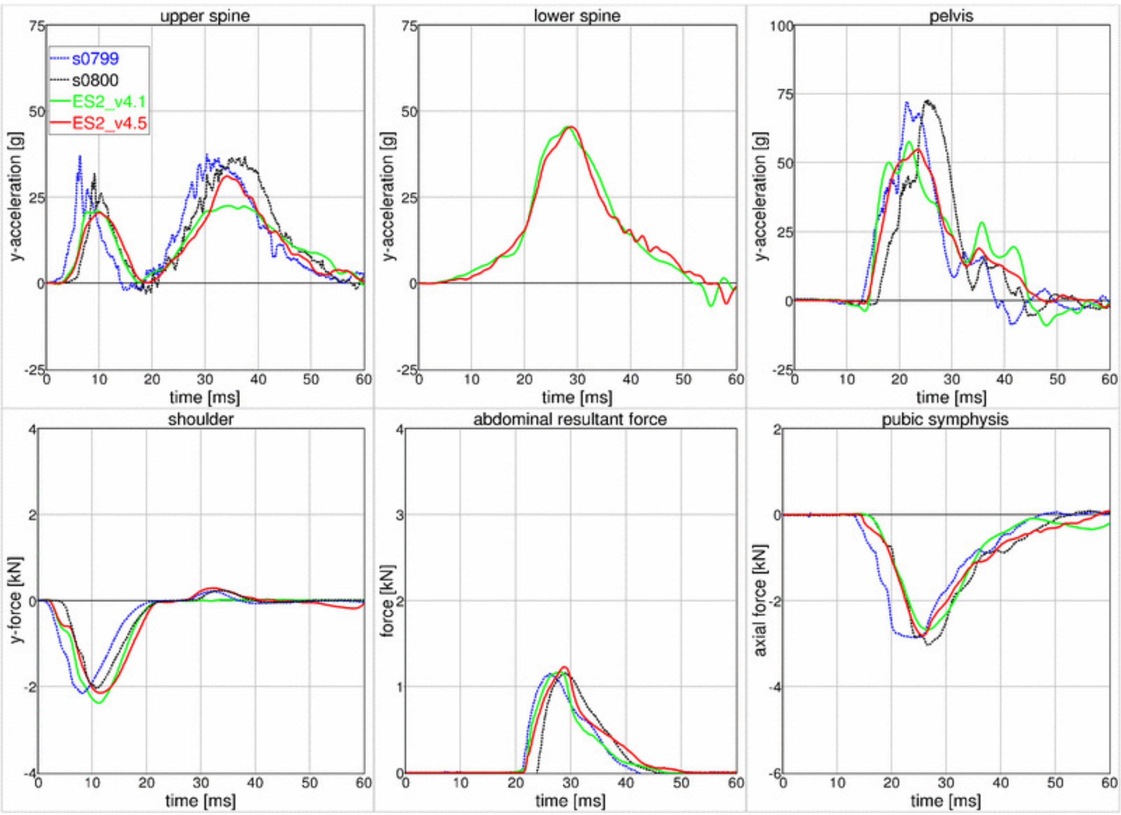
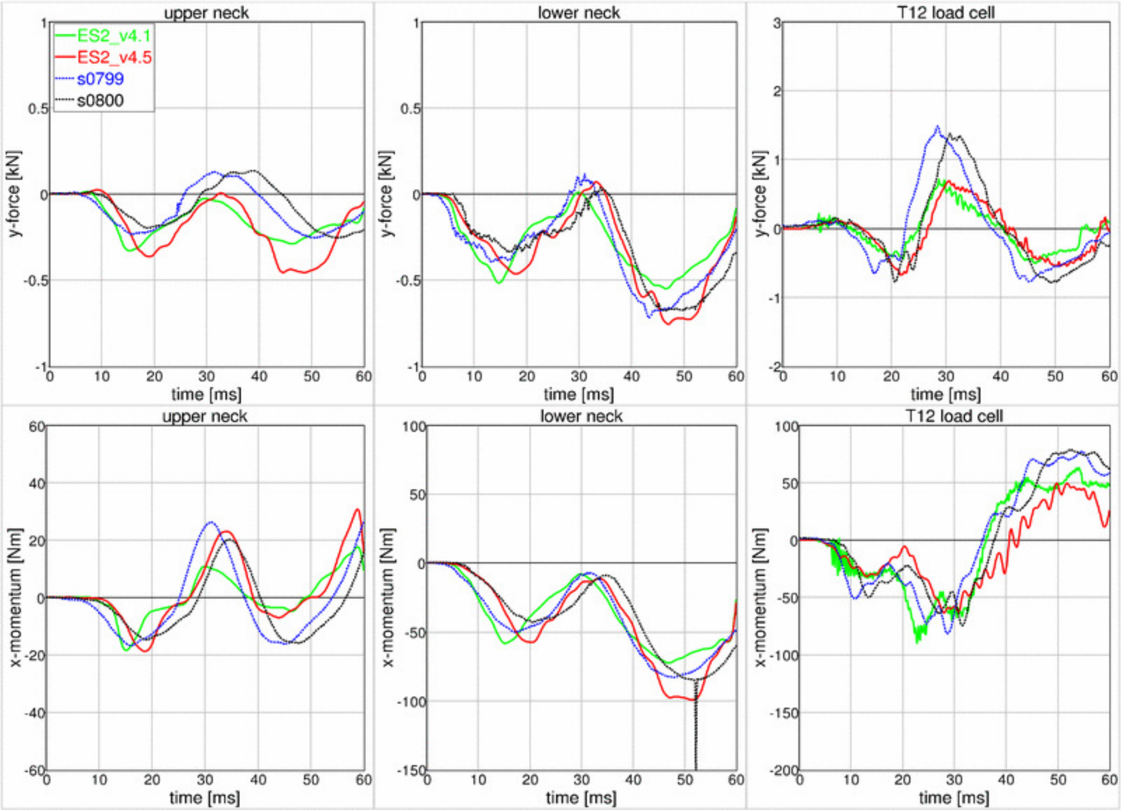


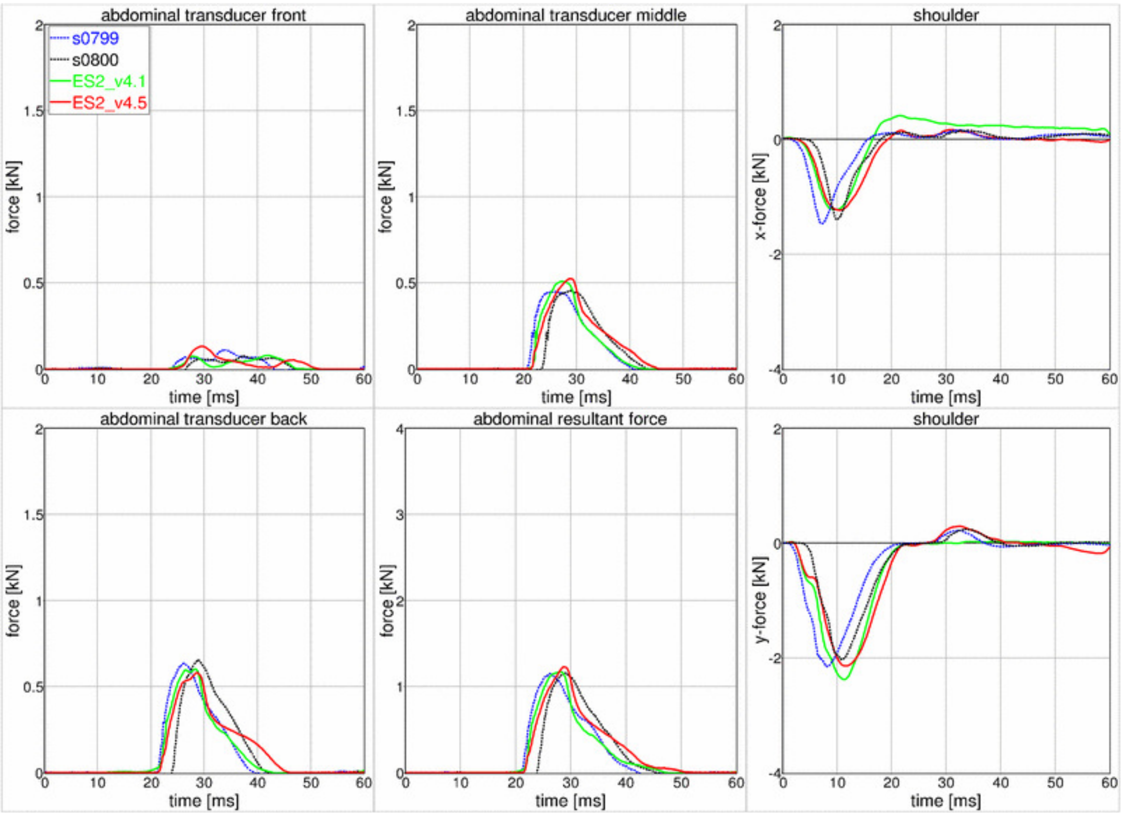
Figure 32: D6 flat barrier (oblique about +z) test setup

9.6.1 Results at low velocity impact

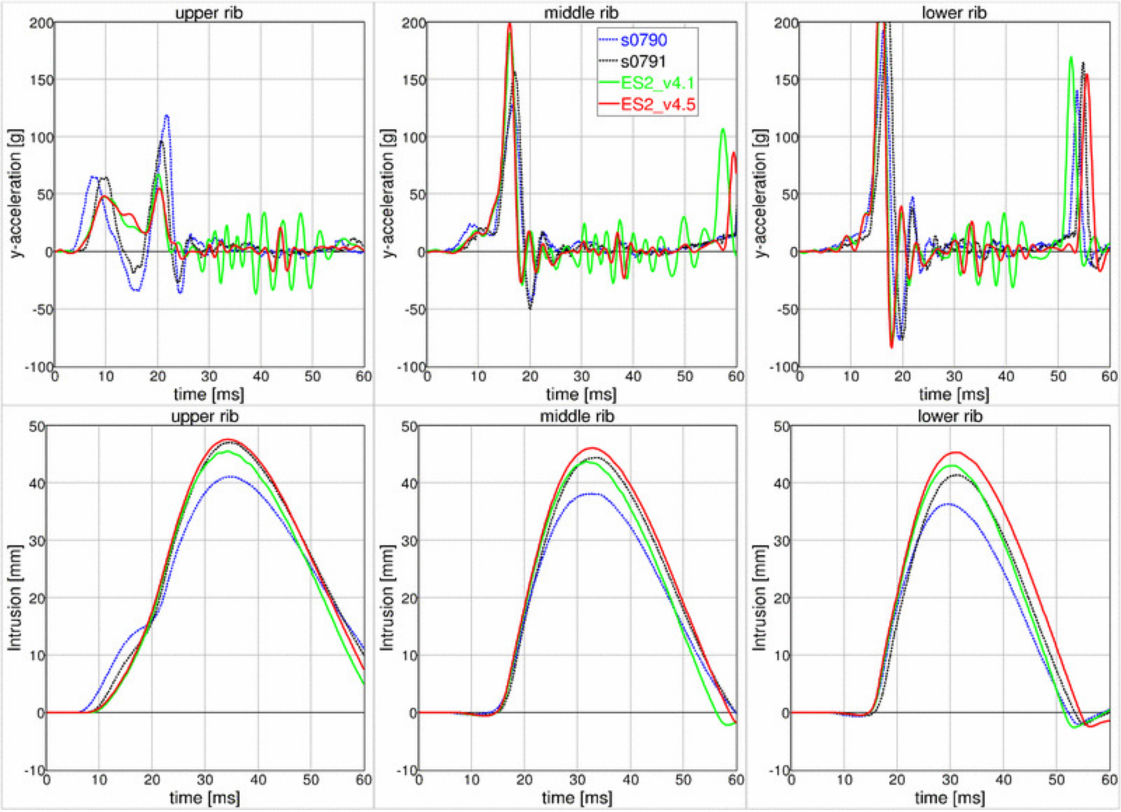


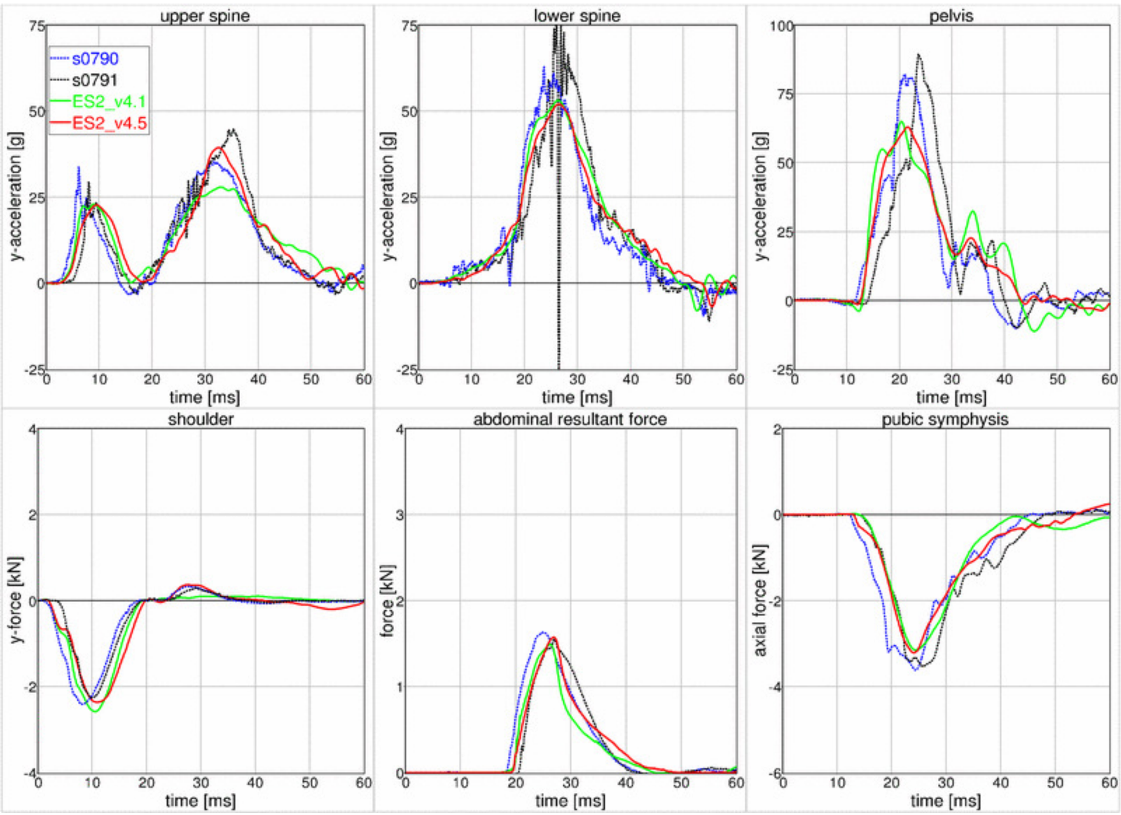


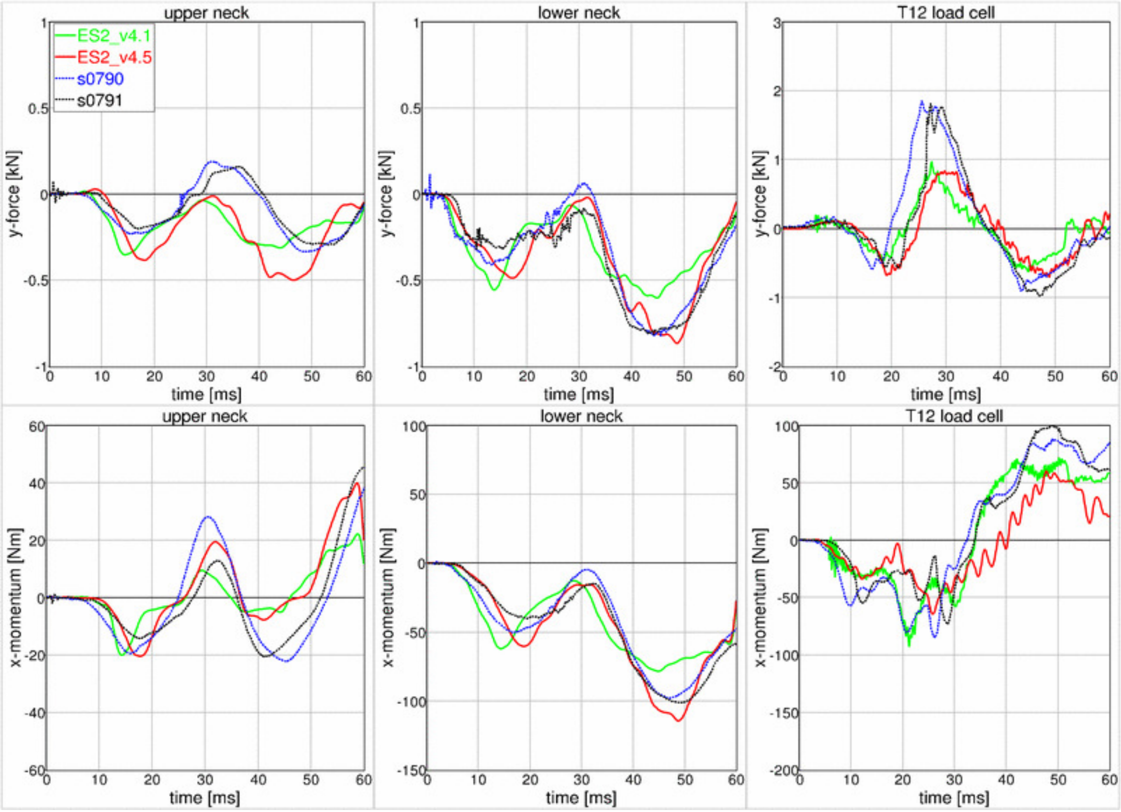

upper neck
lower neck
T12 load cell
ES2_v4.1
ES2_v4.5
s0799
s0800
y-force [kN]
x-momentum [Nm]
time [ms]


abdominal transducer front
abdominal transducer middle
shoulder
abdominal transducer back
abdominal resultant force
s0799
s0800
ES2_v4.1
ES2_v4.5
force [kN]
x-force [kN]
y-force [kN]
time [ms]

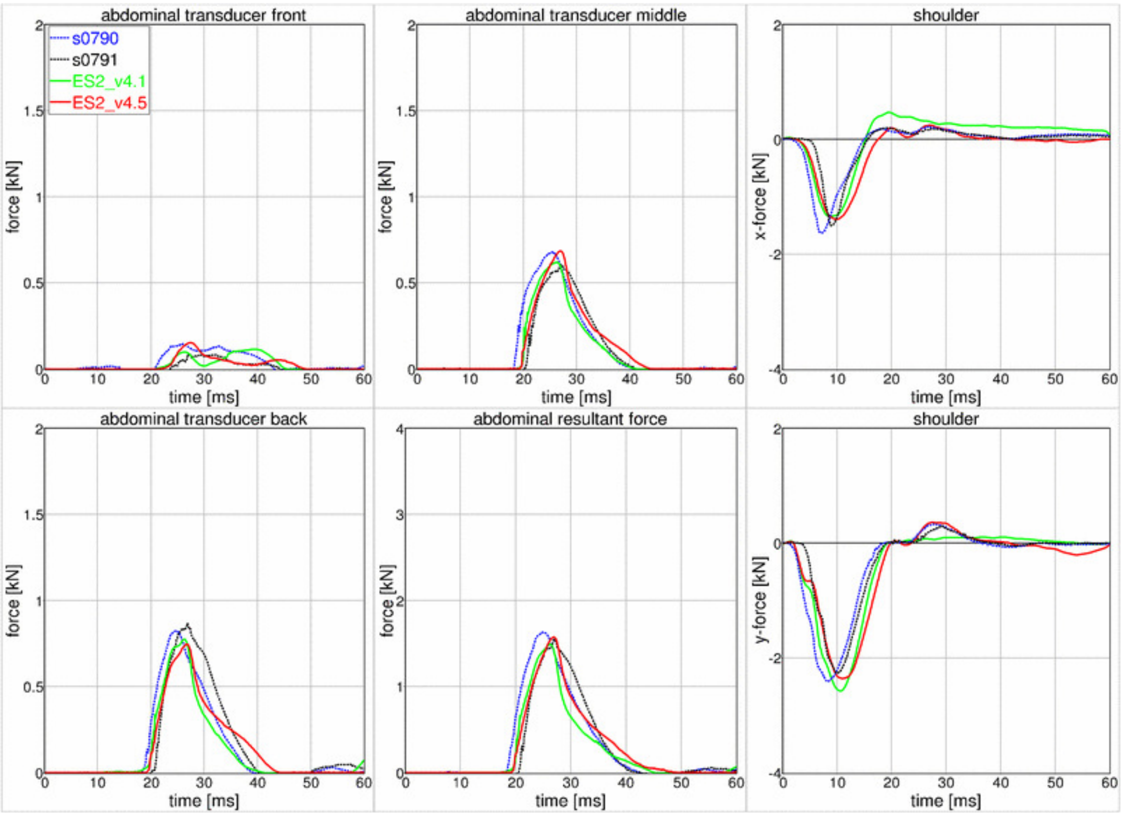
9.6.2 Results at high velocity impact







upper neck
lower neck
T12 load cell
ES2_v4.1
ES2_v4.5
s0790
s0791
y-force [kN]
x-momentum [Nm]
time [ms]



abdominal transducer front
abdominal transducer middle
shoulder
abdominal transducer back
abdominal resultant force
s0790
s0791
ES2_v4.1
ES2_v4.5
force [kN]
x-force [kN]
y-force [kN]
time [ms]

9.7 Configuration D7: Flat barrier, oblique about -z

Boundaries:

- Rigid barrier (Figure 33)
- Impact speed: Low velocity
- Arms in 40 degree position
- Oblique impact barrier, negative angle about z-axis

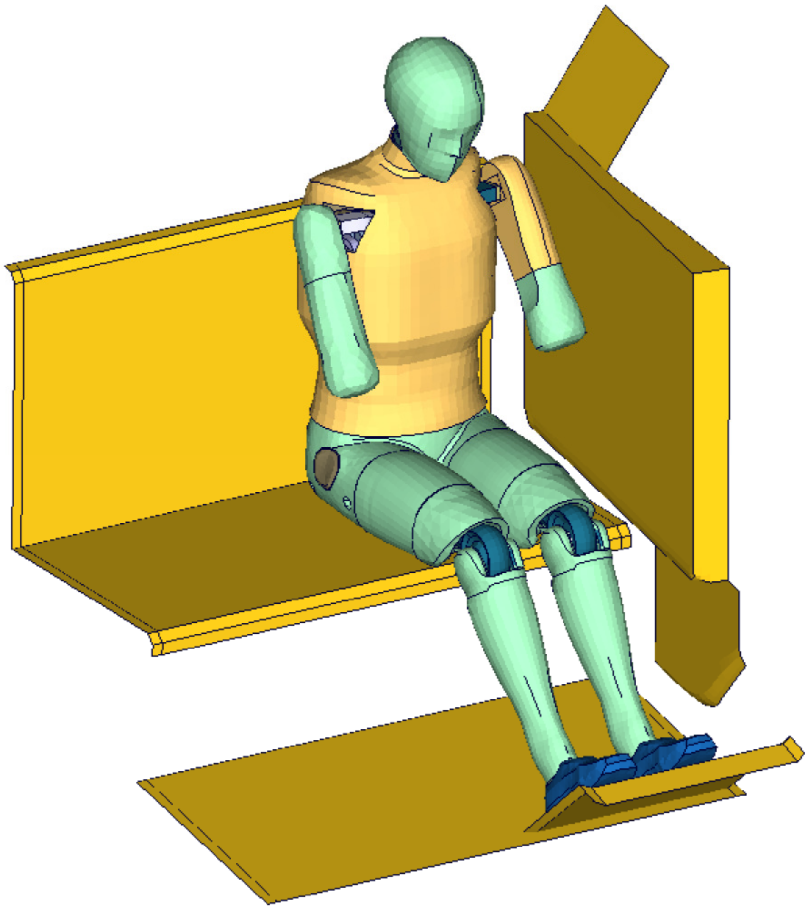
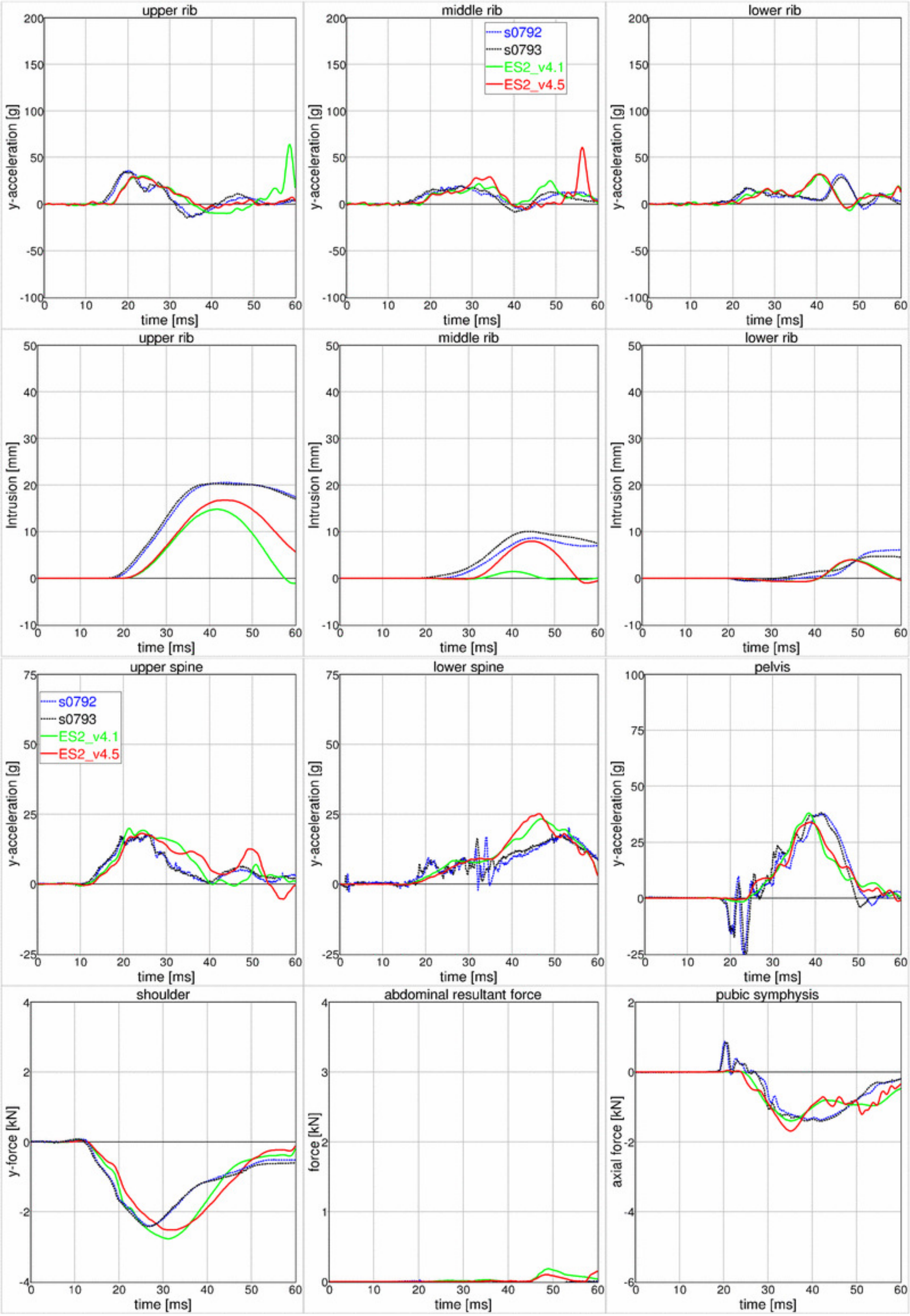
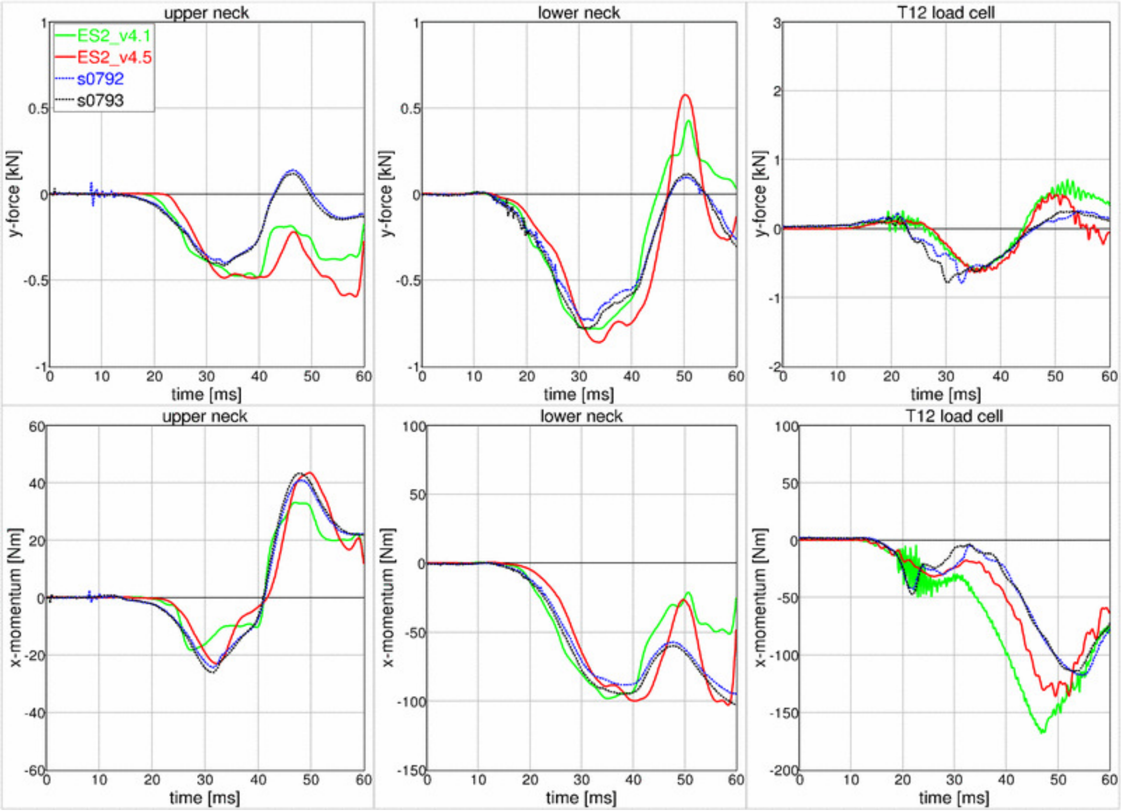
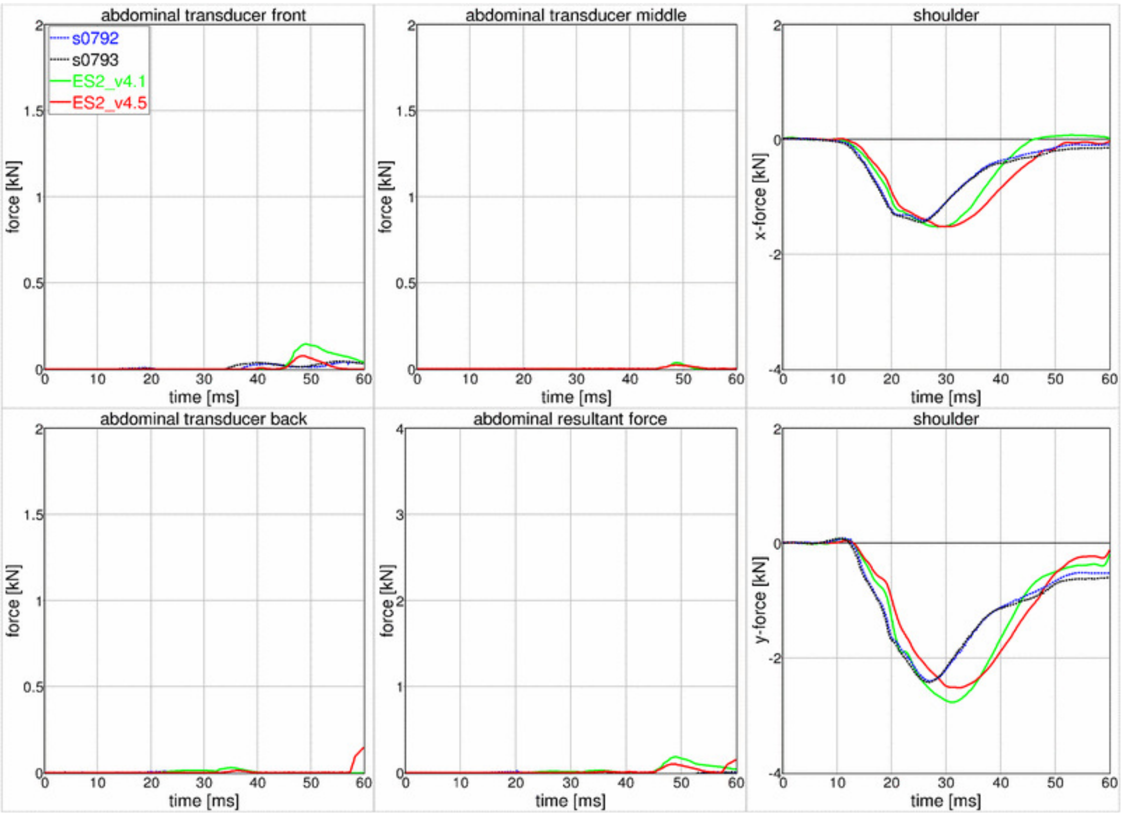


Figure 33: D7 flat barrier (oblique about -z) test setup

9.7.1 Results at low velocity impact




upper neck
lower neck
T12 load cell
ES2_v4.1
ES2_v4.5
s0792
s0793
y-force [kN]
x-momentum [Nm]
time [ms]


abdominal transducer front
abdominal transducer middle
shoulder
abdominal transducer back
abdominal resultant force
s0792
s0793
ES2_v4.1
ES2_v4.5
force [kN]
x-force [kN]
y-force [kN]
time [ms]

9.8 Shoulder Certification test of ES-2

Boundaries:

- Pendulum impacting the shoulder (Figure 34)
- Impact speed: 4.3 m/s
- Mass: 23.4 kg
- Arms in 40 degree position
- The pendulum hits the shoulder at the center pivot axis of the arm

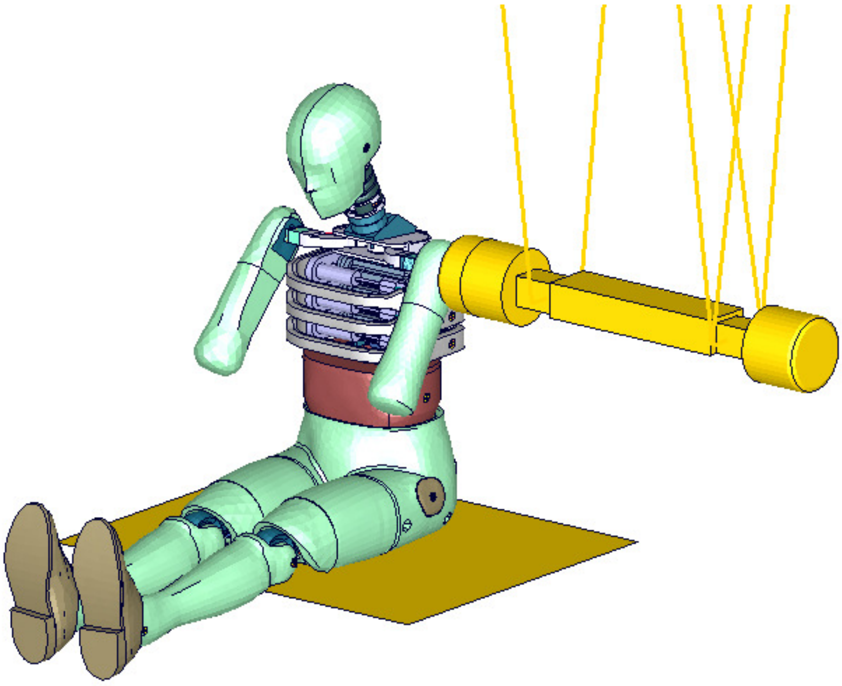
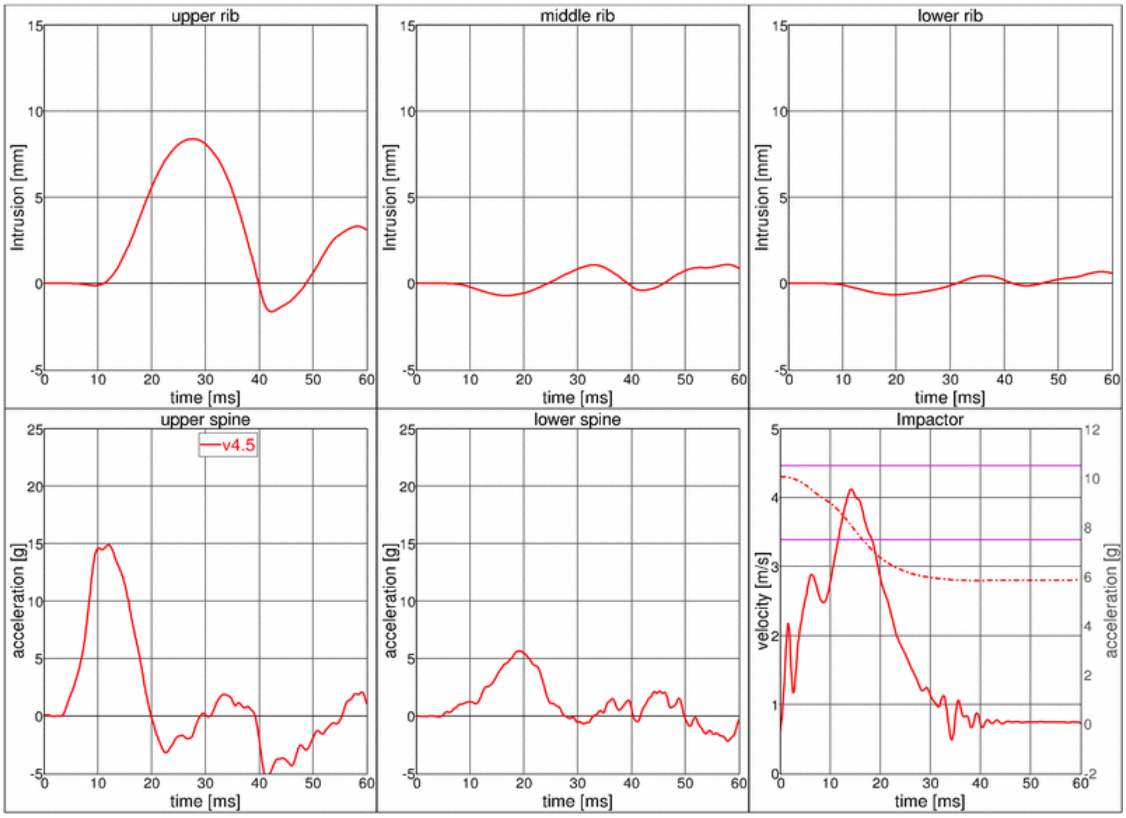


Figure 34: ES-2 shoulder certification test setup

9.8.1 Results



upper rib
middle rib
lower rib
Intrusion [mm]
time [ms]
upper spine
v4.5
lower spine
Impactor
acceleration [g]
velocity [m/s]

9.9 Abdomen Certification test of ES-2

Boundaries:

- Pendulum impacting the abdomen (Figure 35)
- Impact speed: 4.0 m/s
- Mass: 24.4 kg
- Arms in 90 degree position
- A wooden block is mounted in front of the pendulum

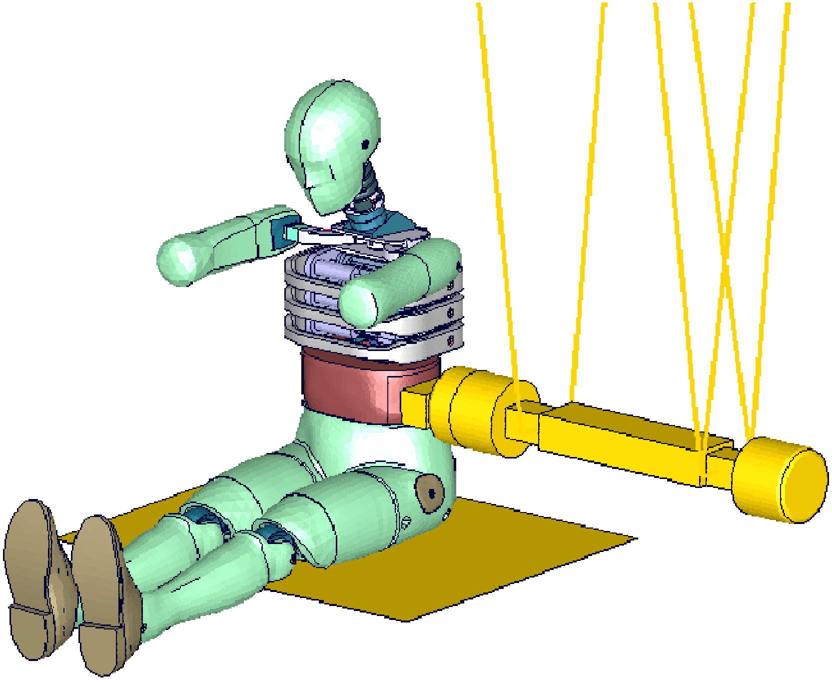
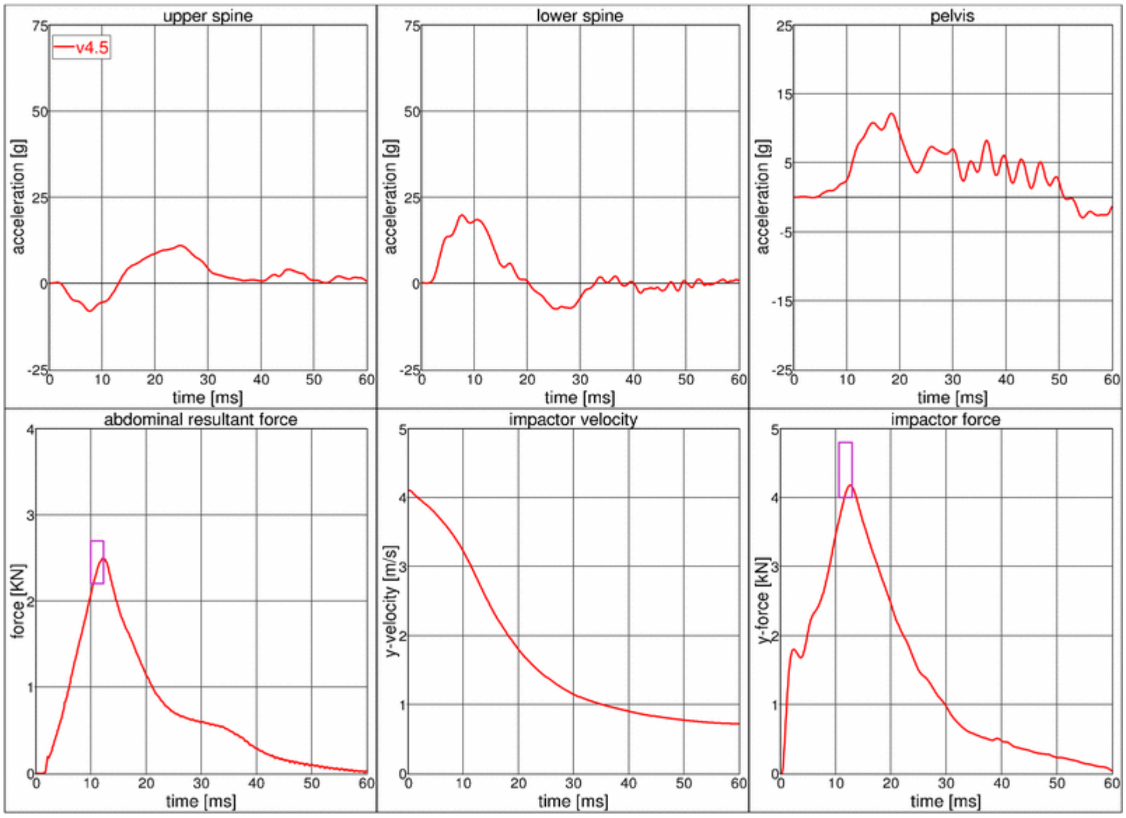


Figure 35: ES-2 abdomen certification test setup

9.9.1 Results


upper spine
v4.5
acceleration [g]
time [ms]
lower spine
acceleration [g]
time [ms]
pelvis
acceleration [g]
time [ms]
abdominal resultant force
force [KN]
time [ms]
impactor velocity
y-velocity [m/s]
time [ms]
impactor force
y-force [kN]
time [ms]

9.10 Pelvis Certification test of ES-2

Boundaries:

- Pendulum impacting the pelvis (Figure 36)
- Impact speed: 4.3 m/s
- Mass: 23.4 kg
- Arms in 90 degree position
- The pendulum impact is aligned to the H-point

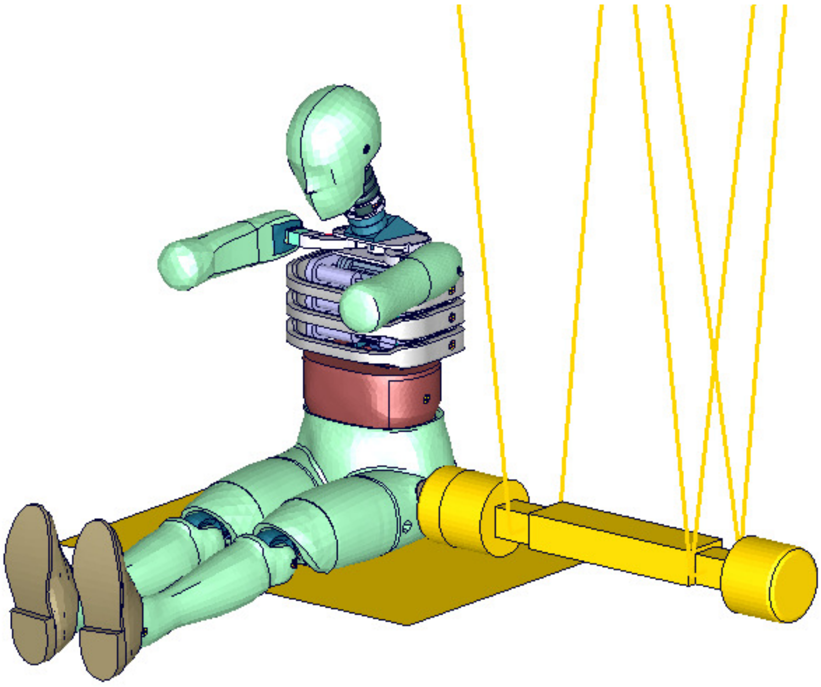
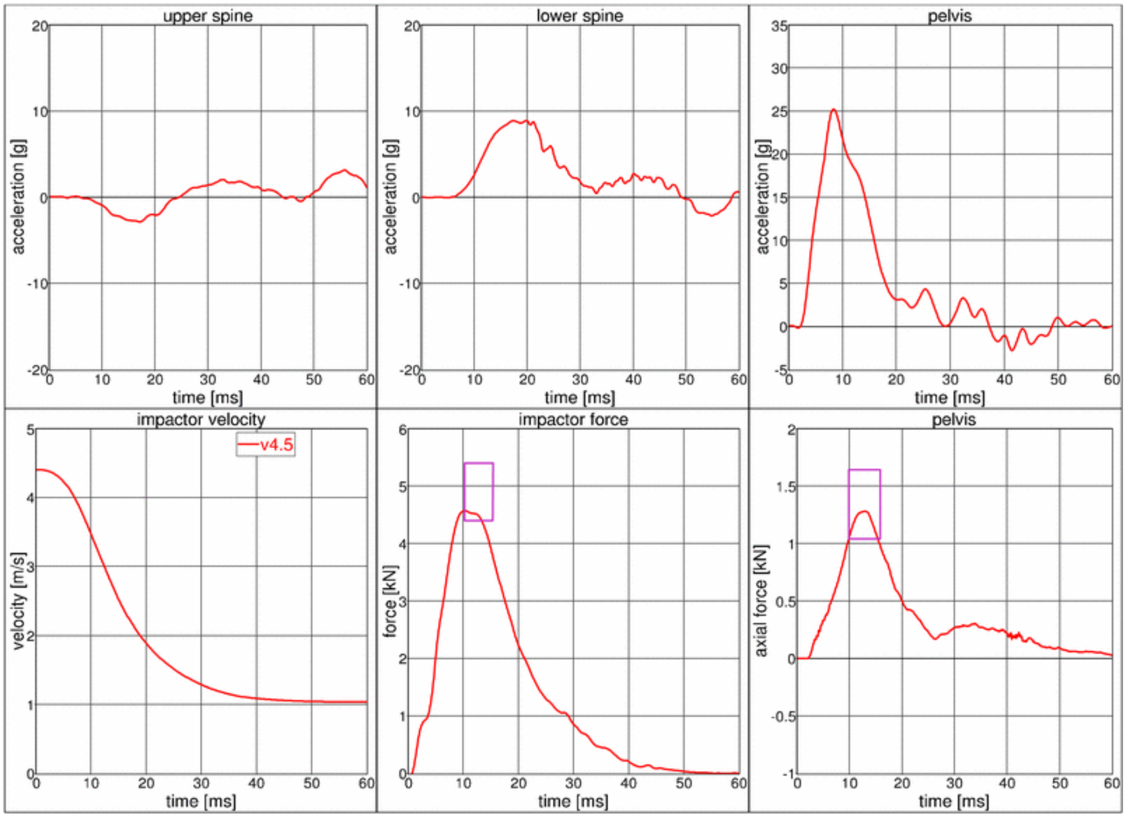


Figure 36: ES-2 pelvis certification test setup

9.10.1 Results



9.11 Rib module tests

9.11.1 Test setup 1

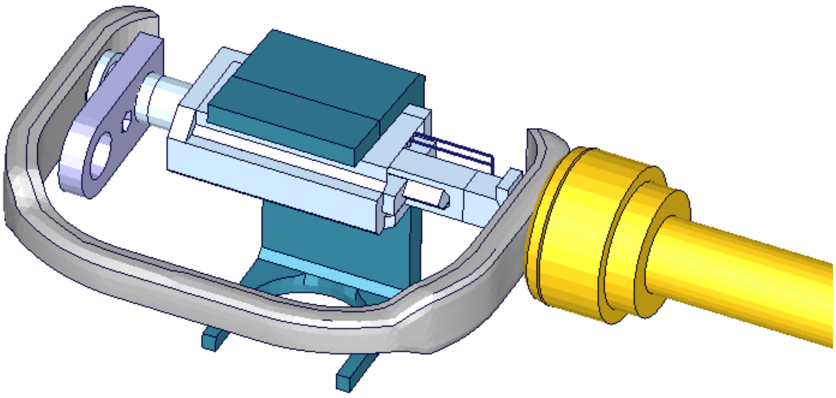
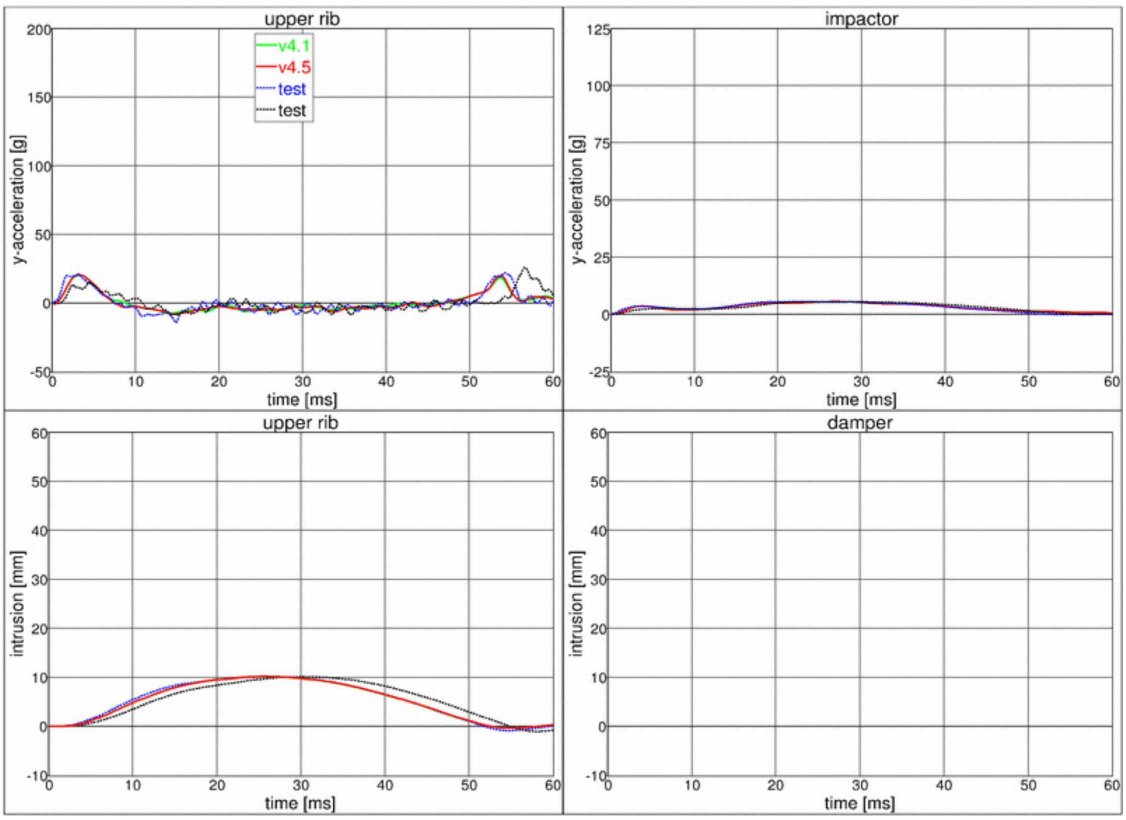


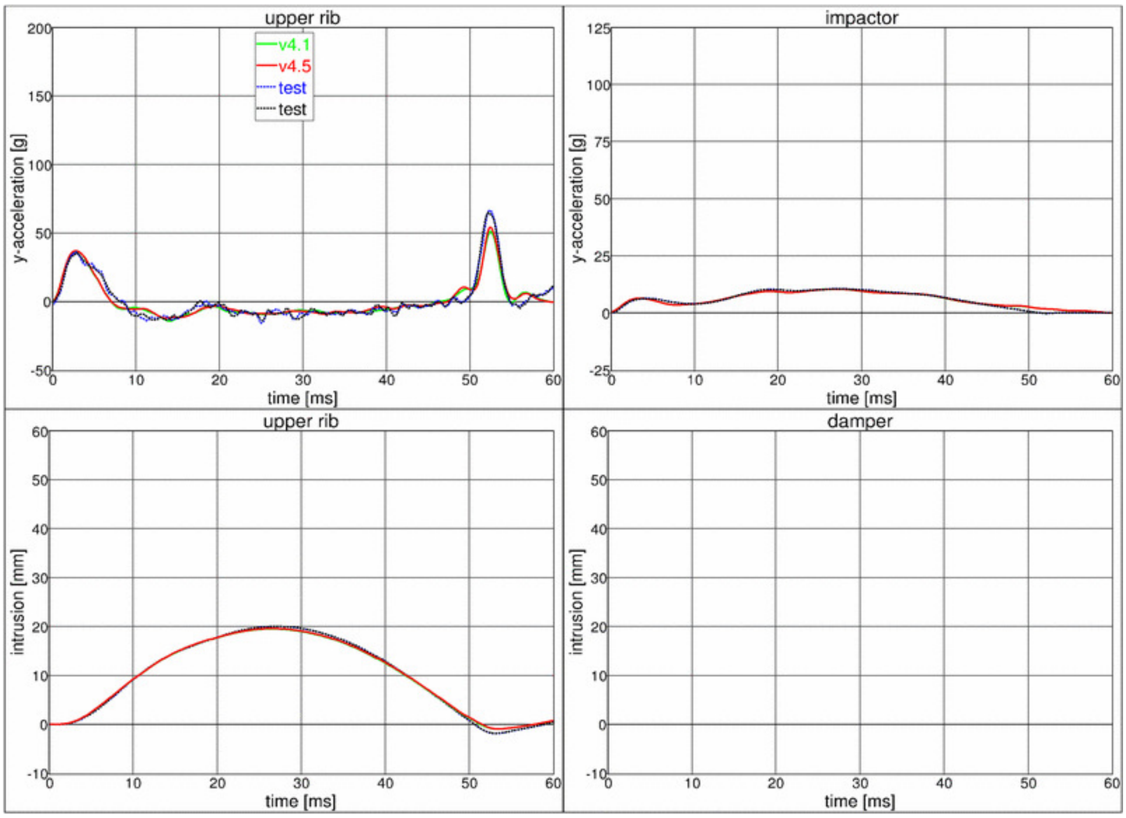
Figure 37: ES-2 rib module test setup 1

- Pendulum impacting the assembly at the rib guidance
- 5 impact velocities
- Damper assembly is removed

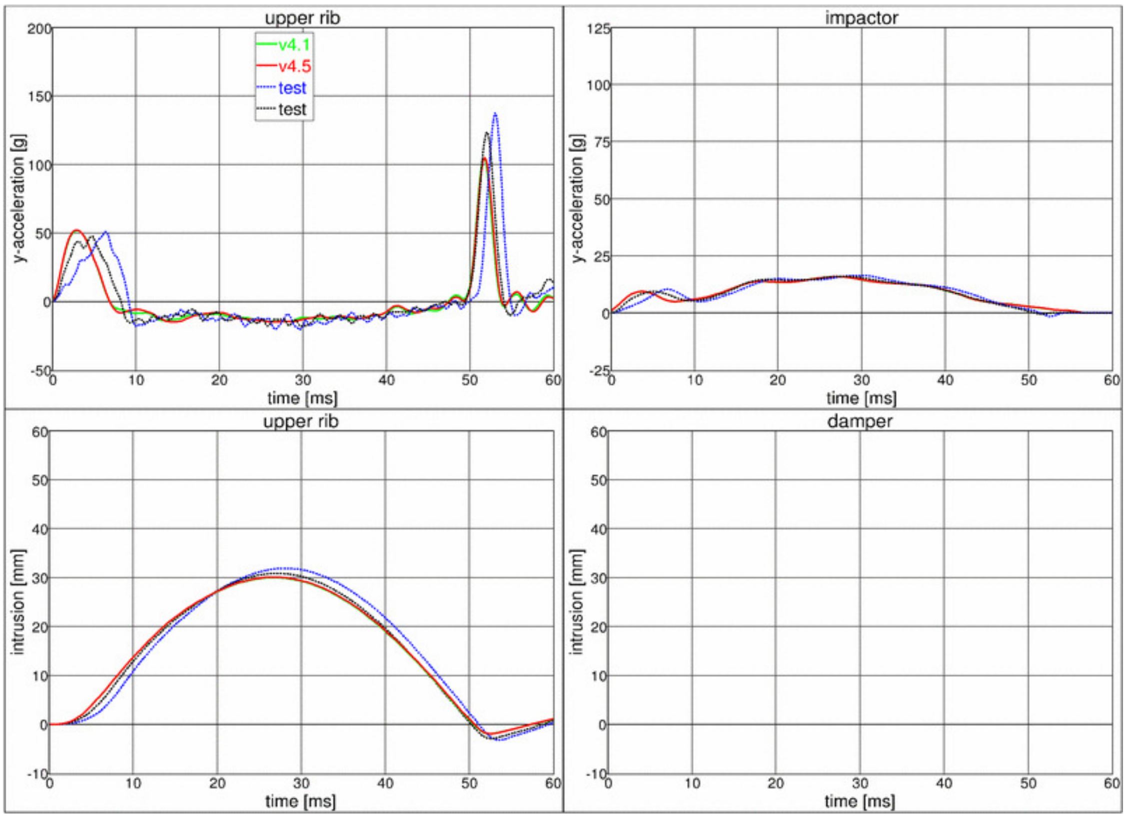
9.11.2 Test setup 1: velocity 1



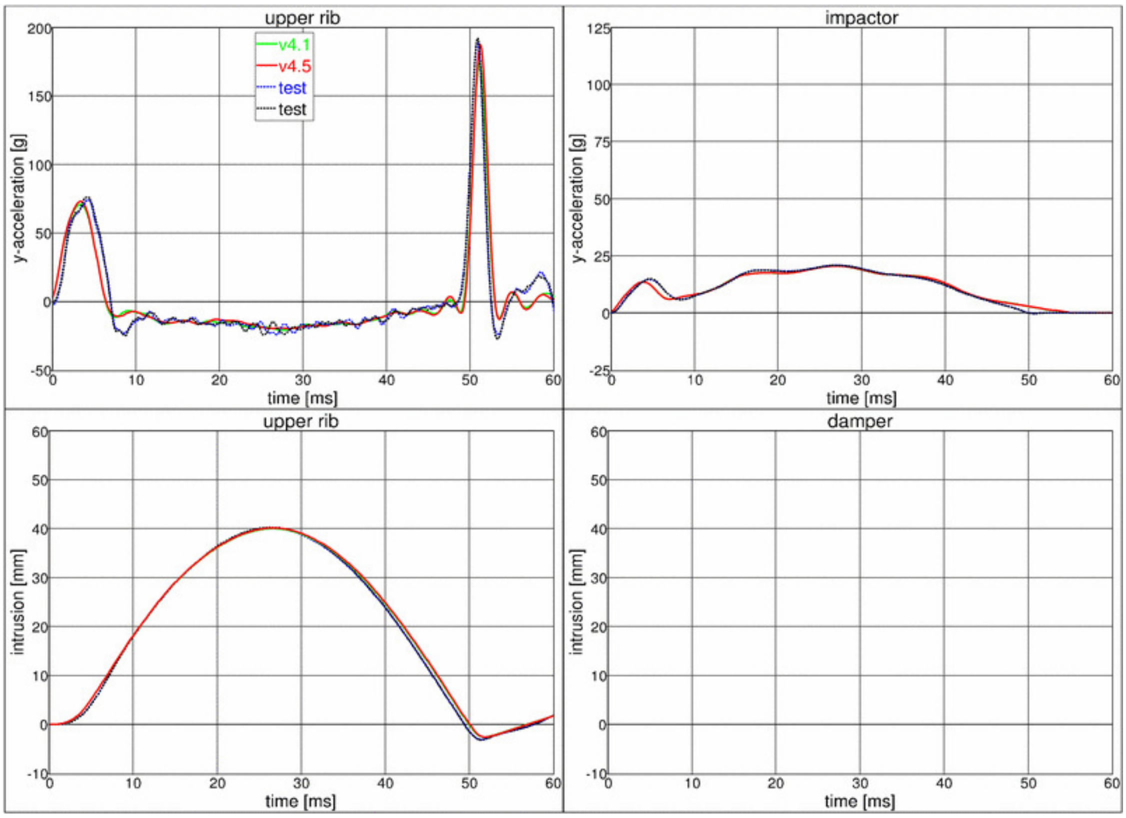
9.11.3 Test setup 1: velocity 2



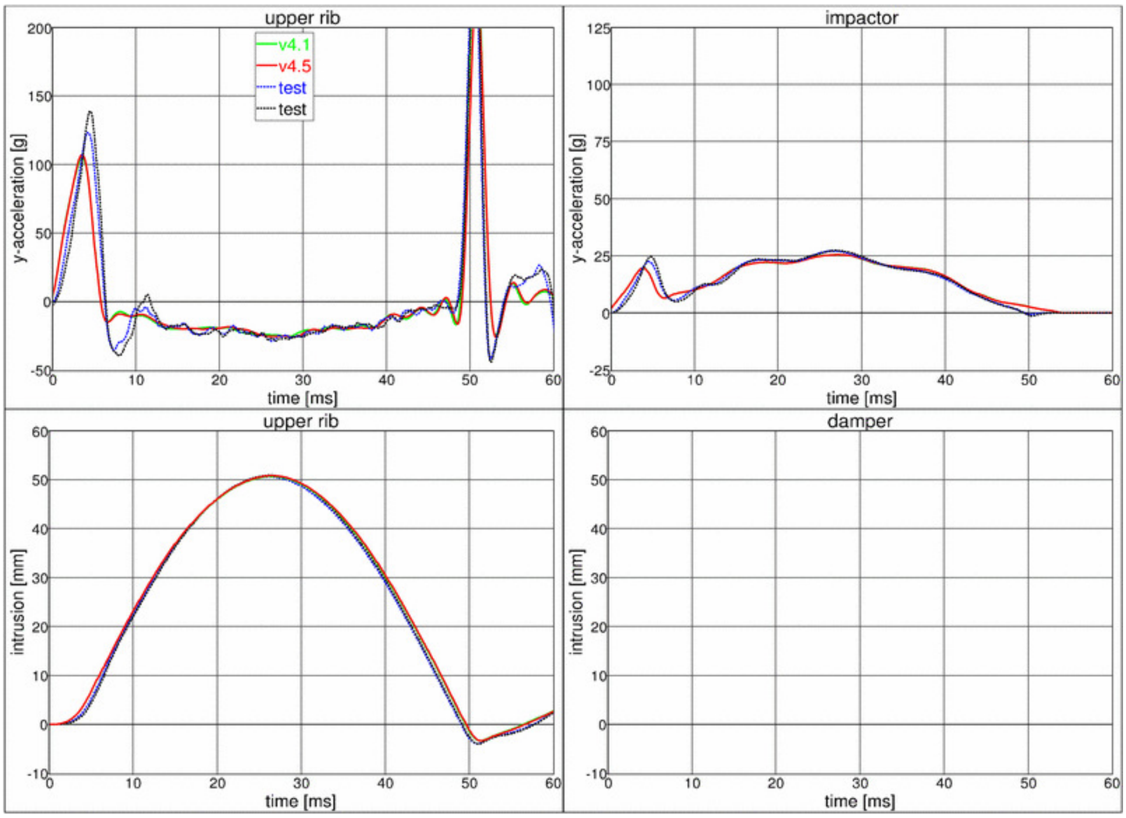
9.11.4 Test setup 1: velocity 3



9.11.5 Test setup 1: velocity 4



9.11.6 Test setup 1: velocity 5



9.11.7 Test setup 2

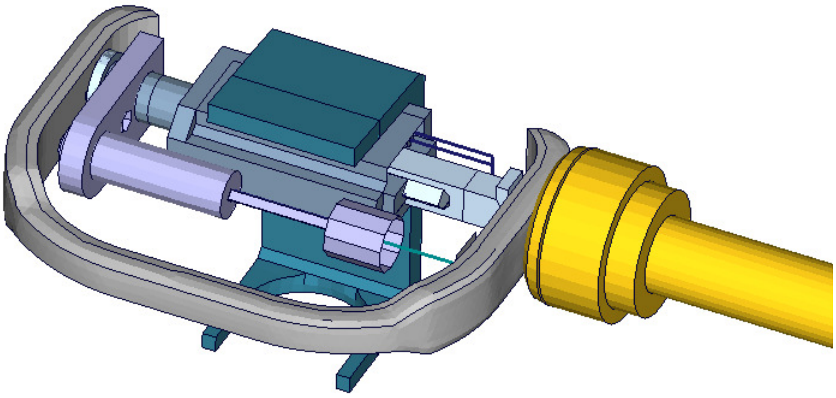
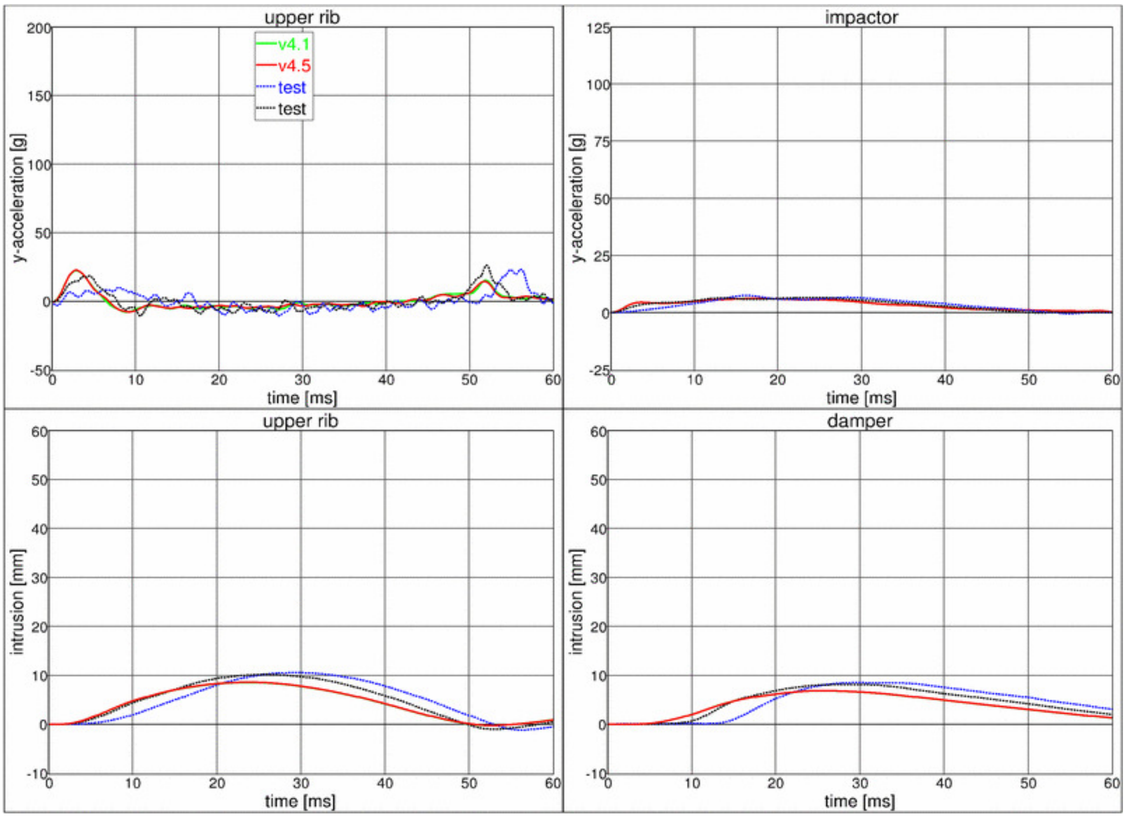


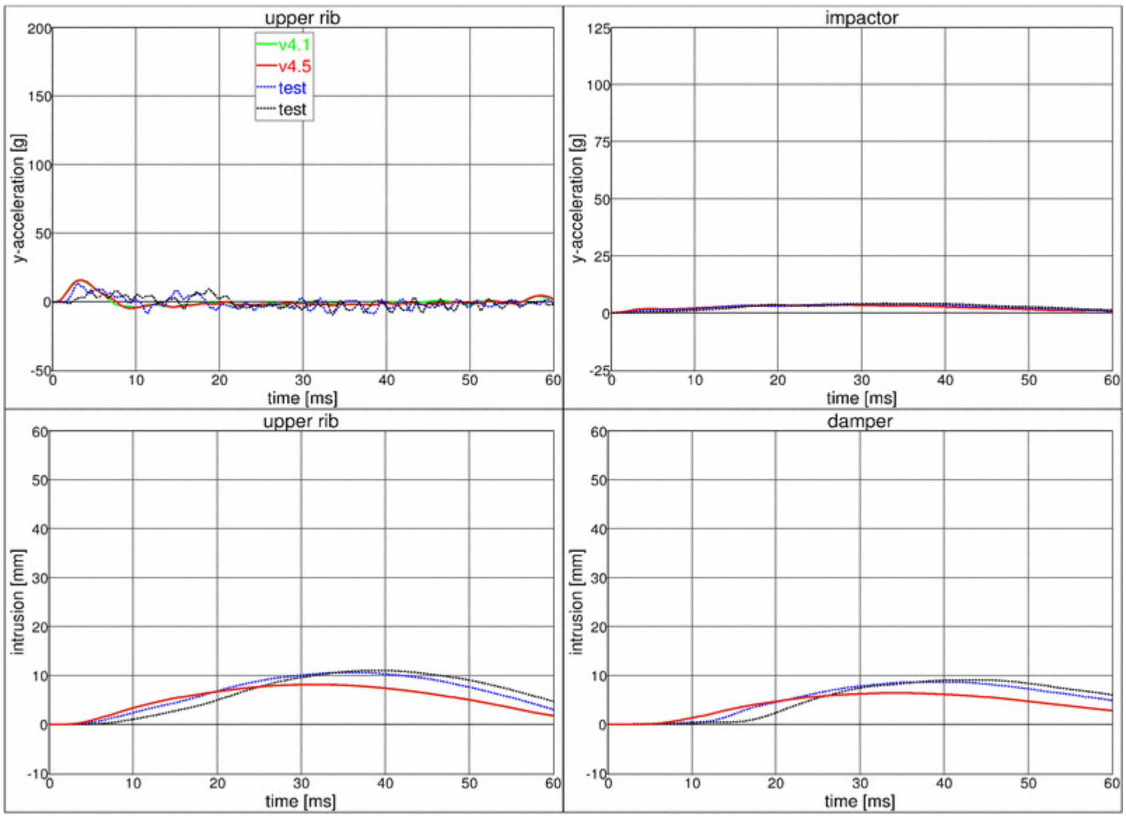
Figure 38: ES-2 rib module test setup 2

- Pendulum impacting the assembly at the rib guidance
- 5 impact velocities
- Damper assembly is included

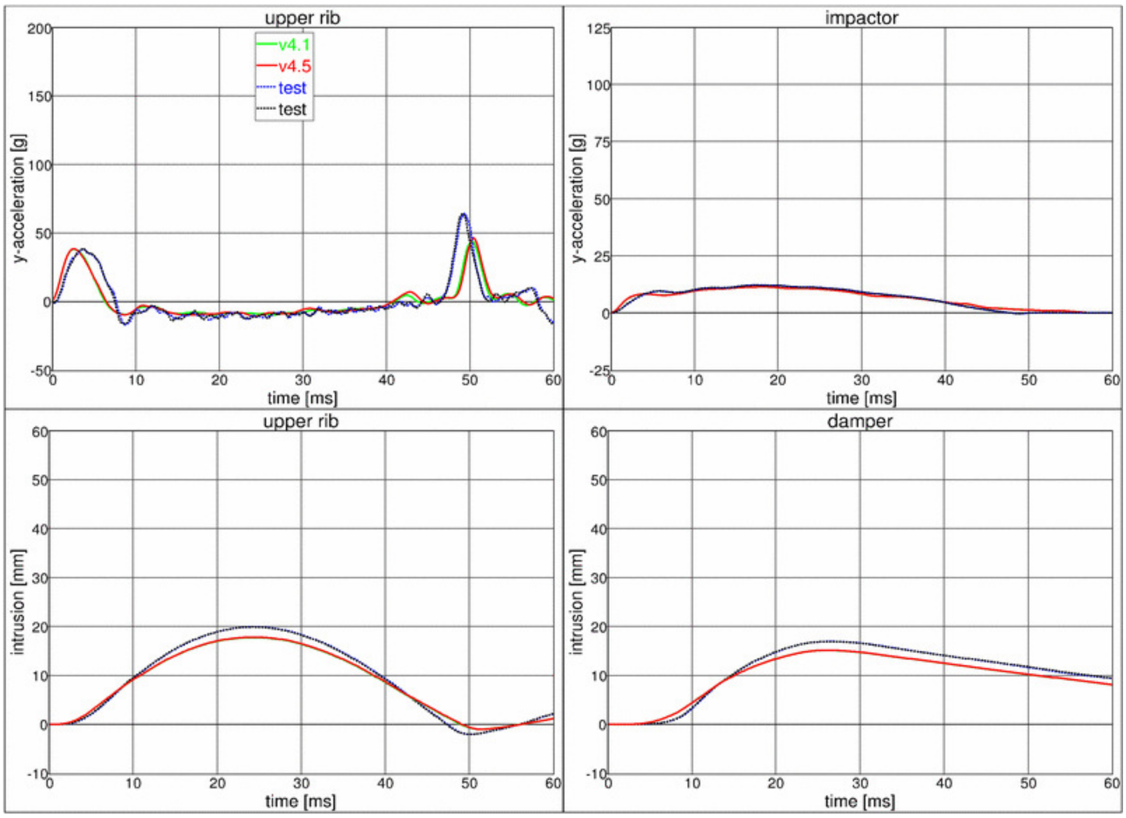
9.11.8 Test setup 2: velocity 1 low mass



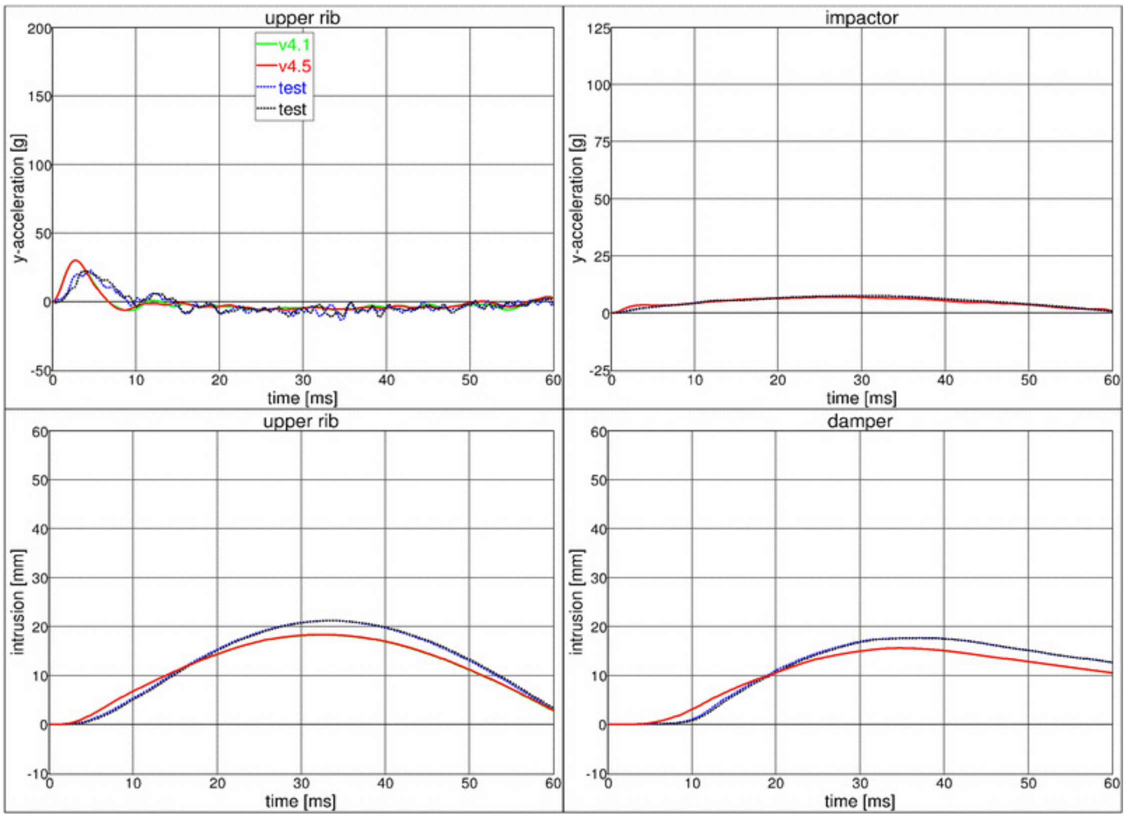
9.11.9 Test setup 2: velocity 1 high mass



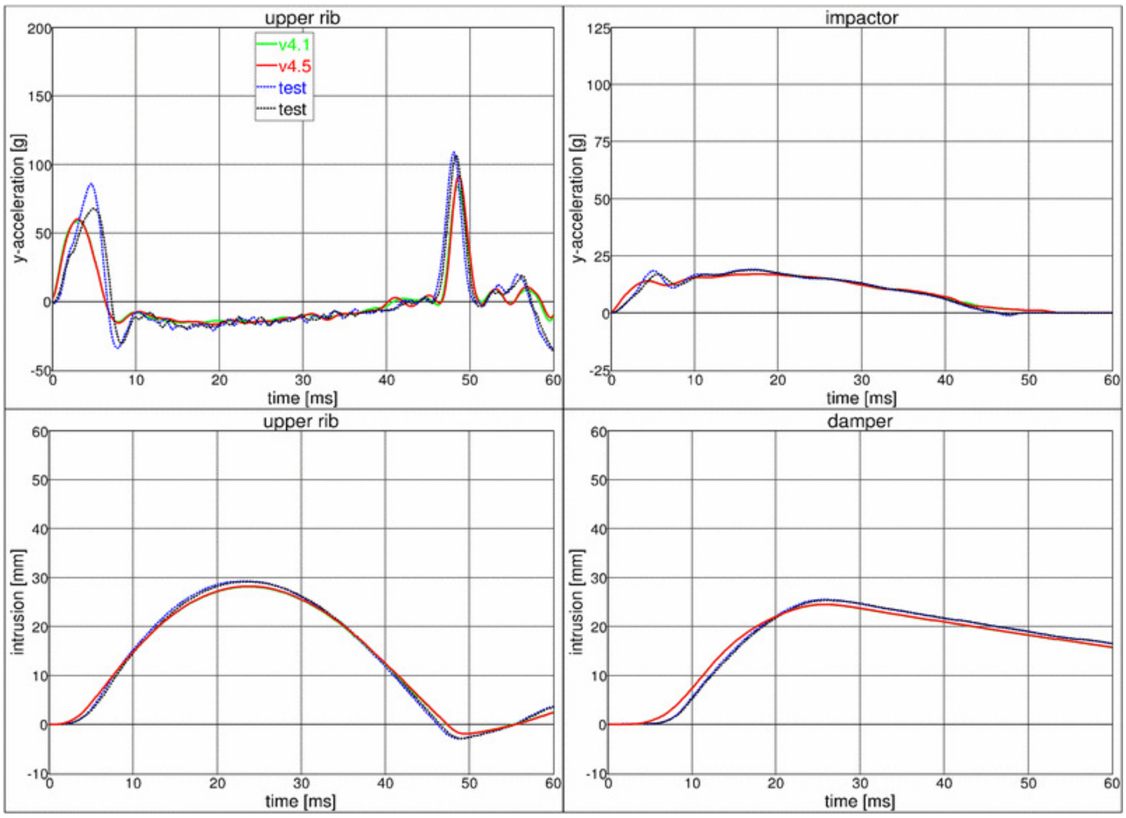
9.11.10 Test setup 2: velocity 2 low mass



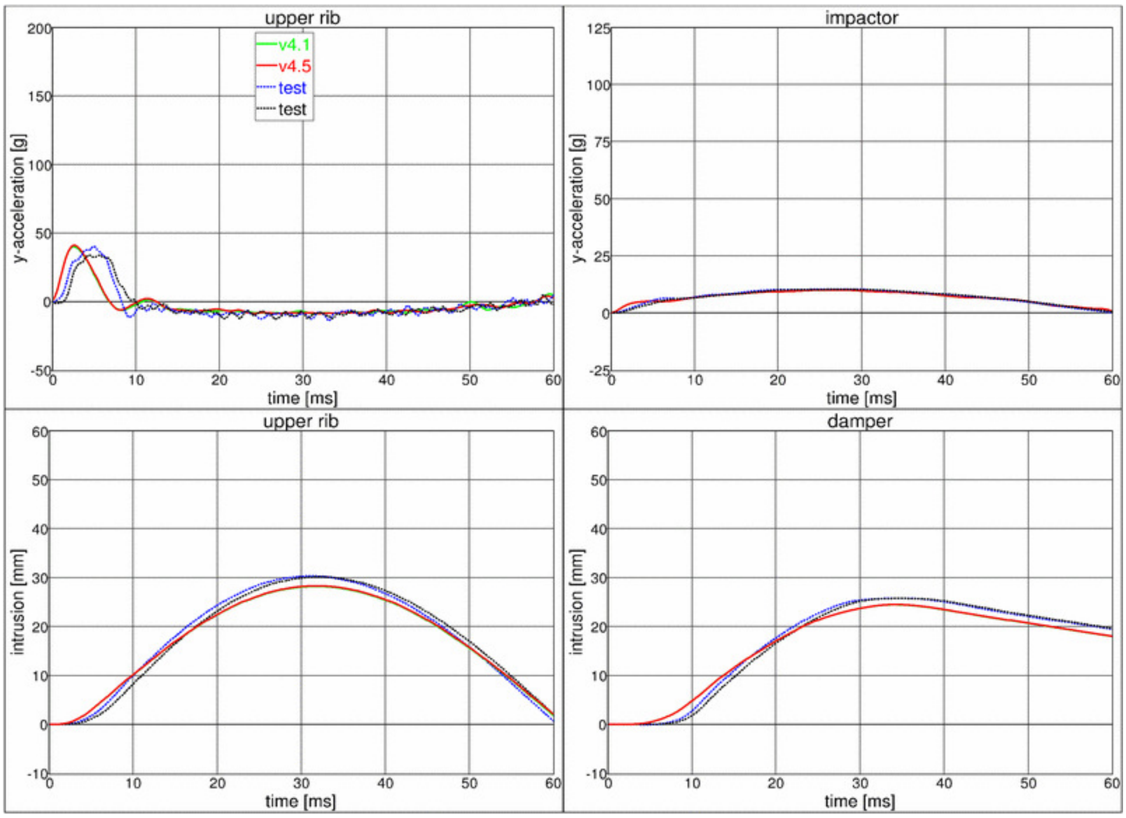
9.11.11 Test setup 2: velocity 2 high mass



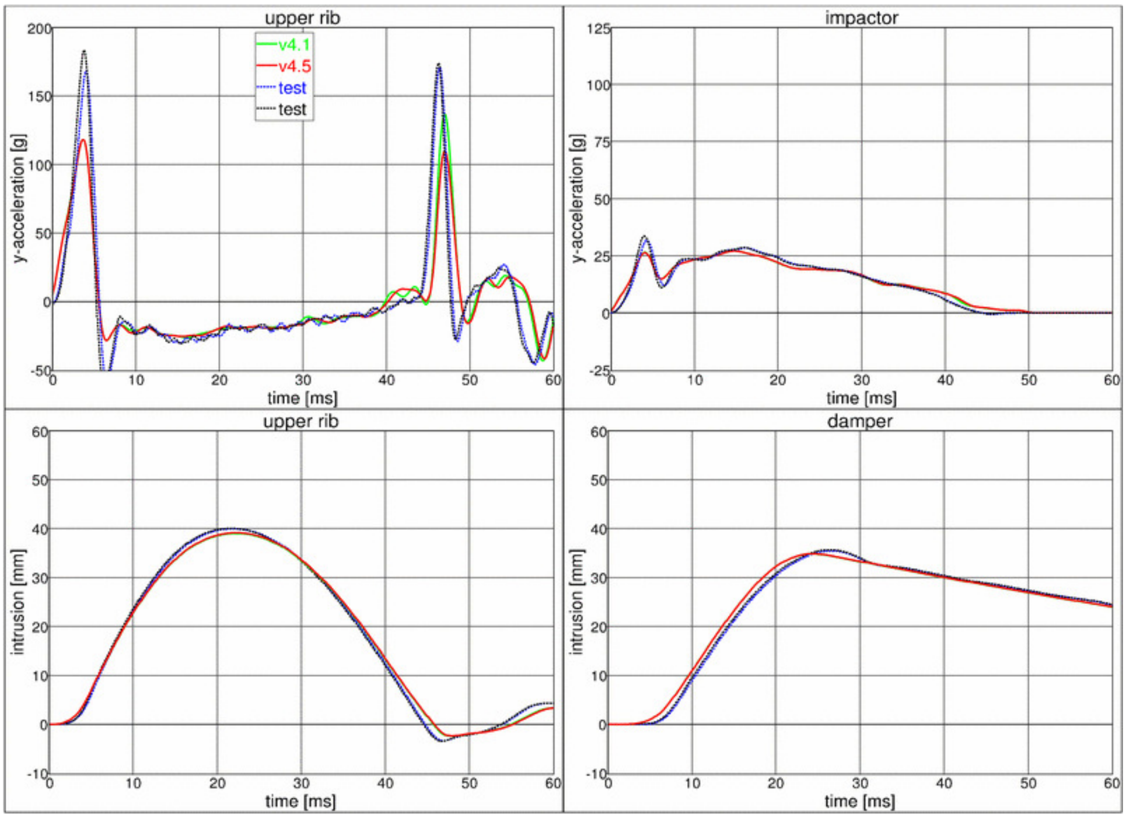
9.11.12 Test setup 2: velocity 3 low mass



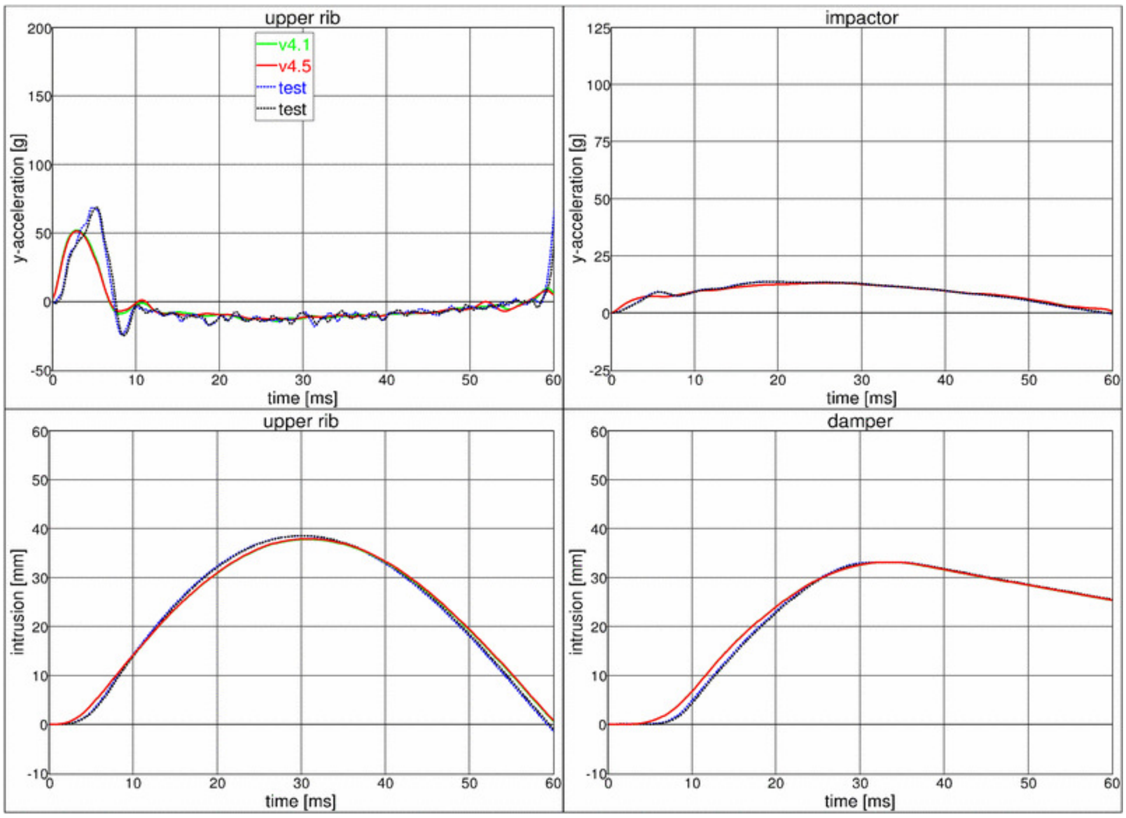
9.11.13 Test setup 2: velocity 3 high mass



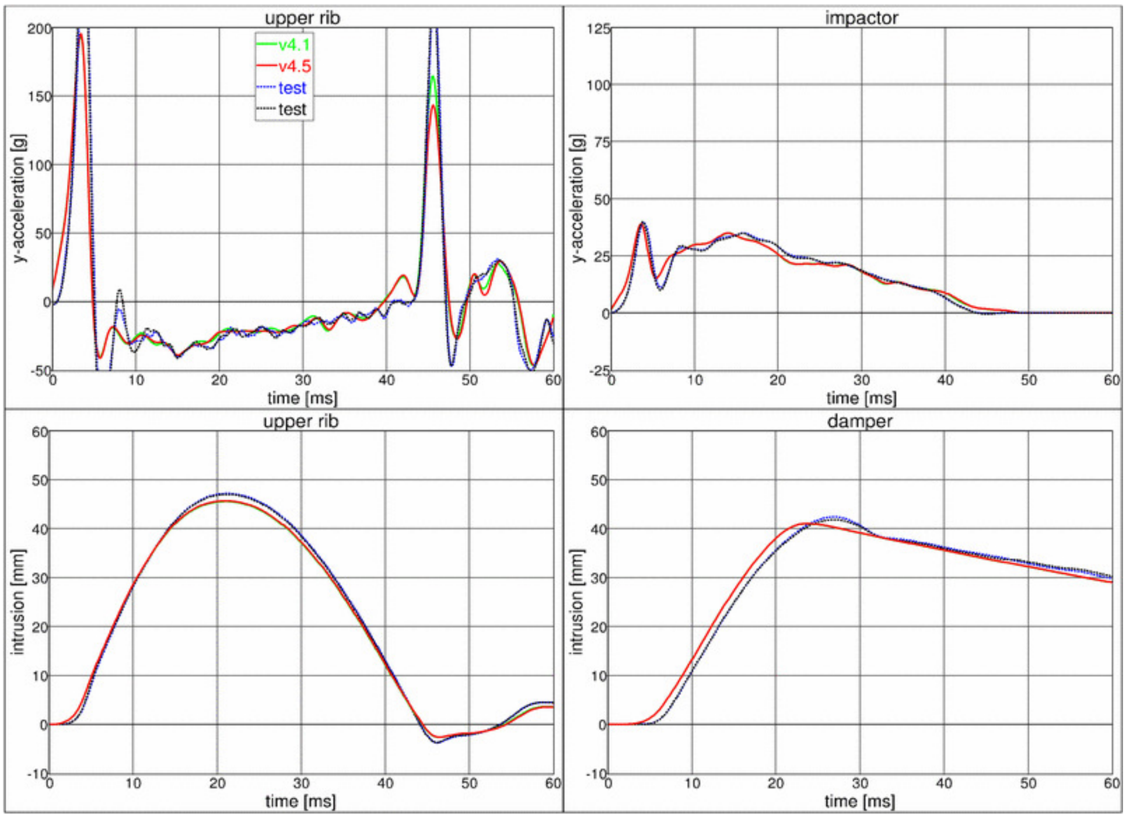
9.11.14 Test setup 2: velocity 4 low mass



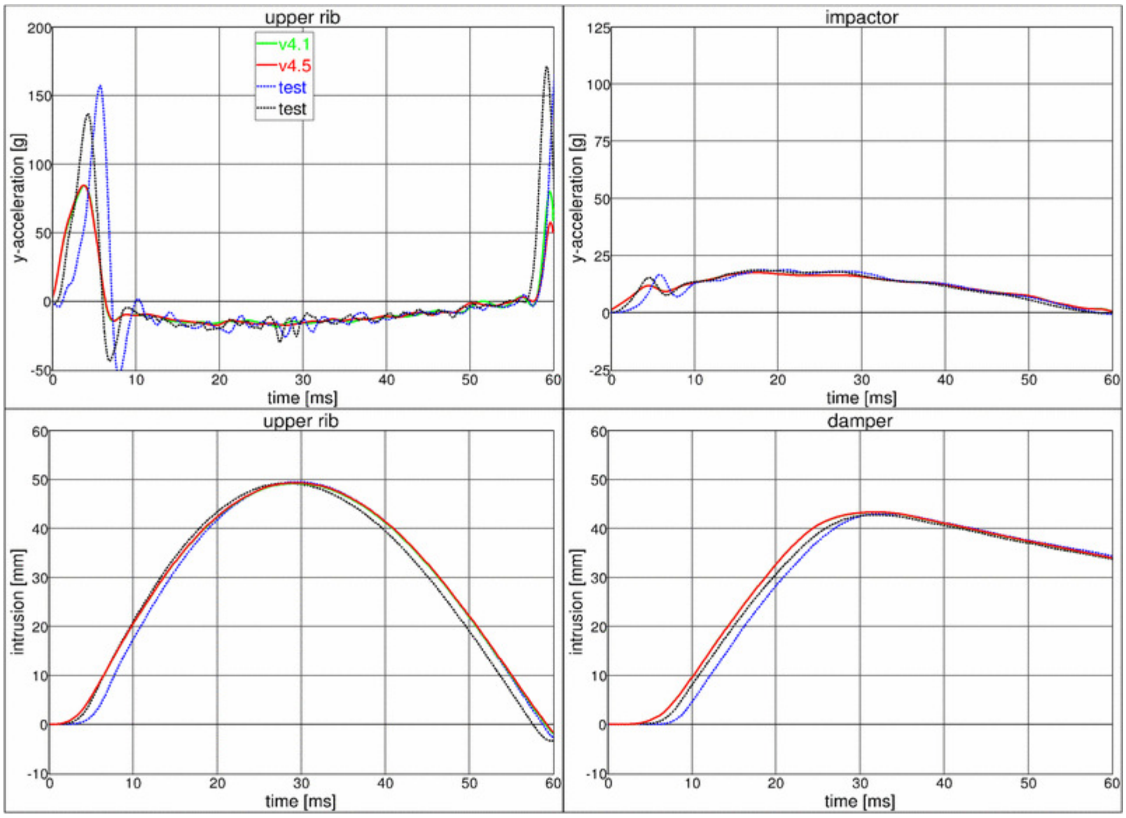
9.11.15 Test setup 2: velocity 4 high mass



9.11.16 Test setup 2: velocity 5 low mass



9.11.17 Test setup 2: velocity 5 high mass



9.11.18 Test setup 3

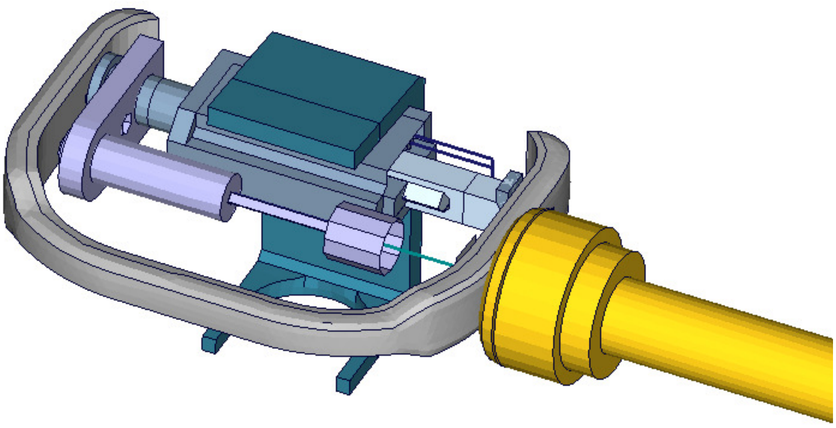
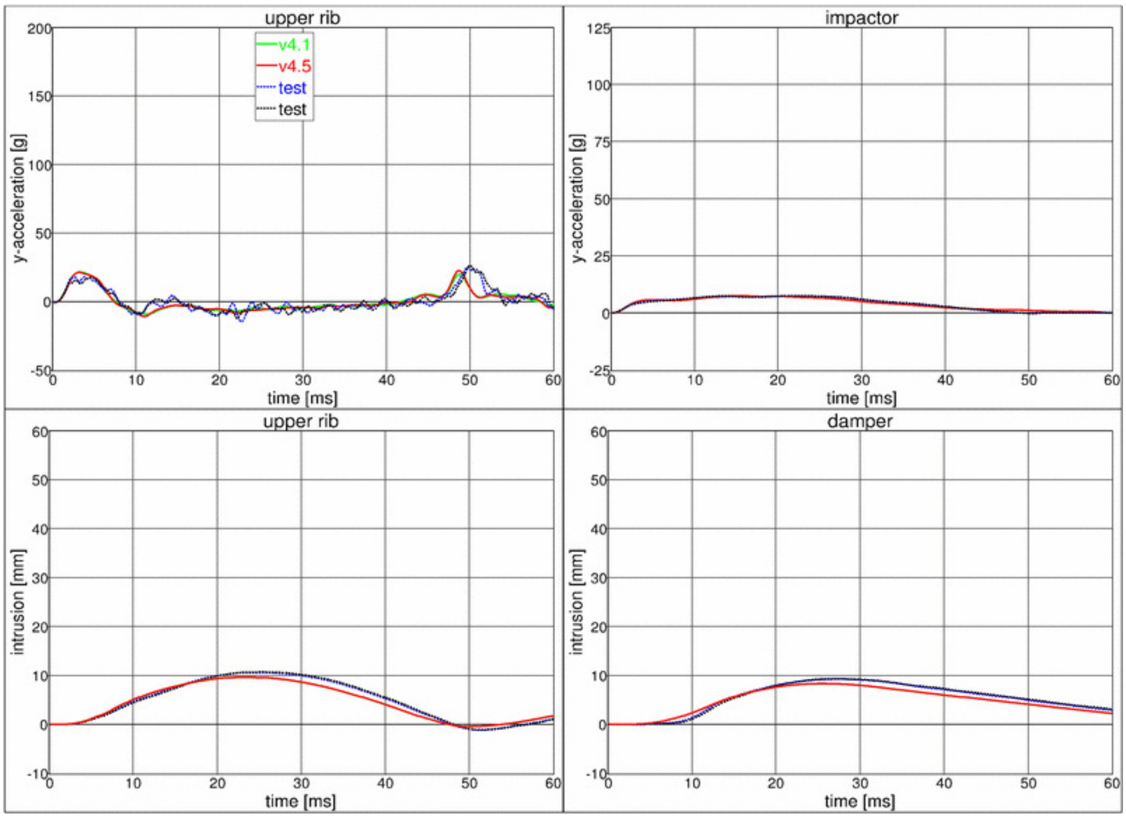


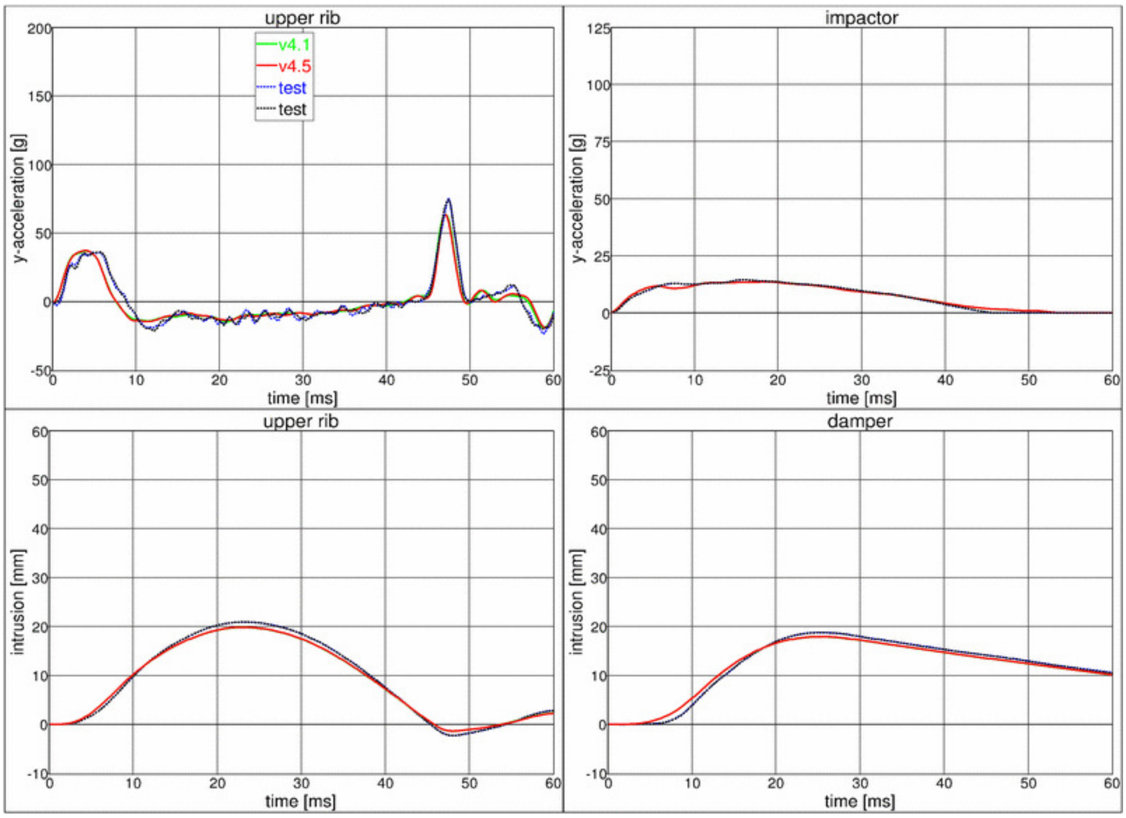
Figure 39: ES-2 rib module test setup 3

- Pendulum impacting the assembly at the damper connection
- 5 impact velocities
- Damper assembly is included

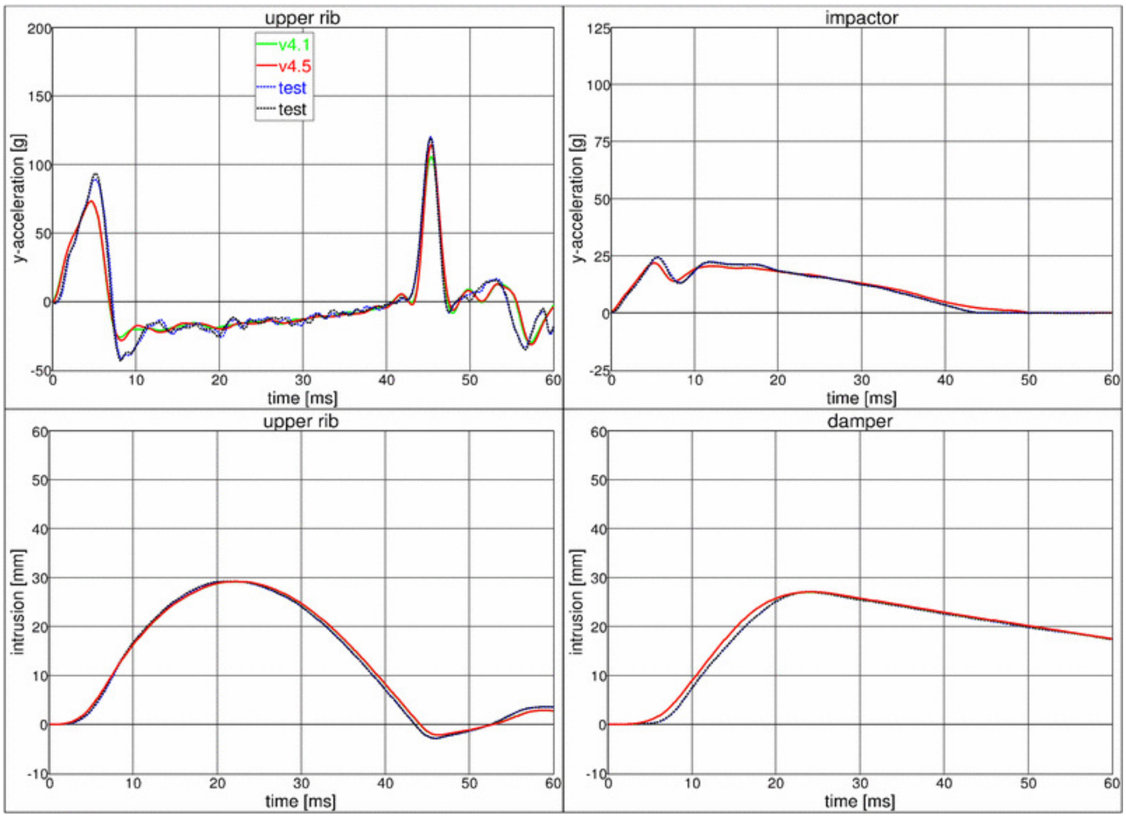
9.11.19 Test setup 3: velocity 1



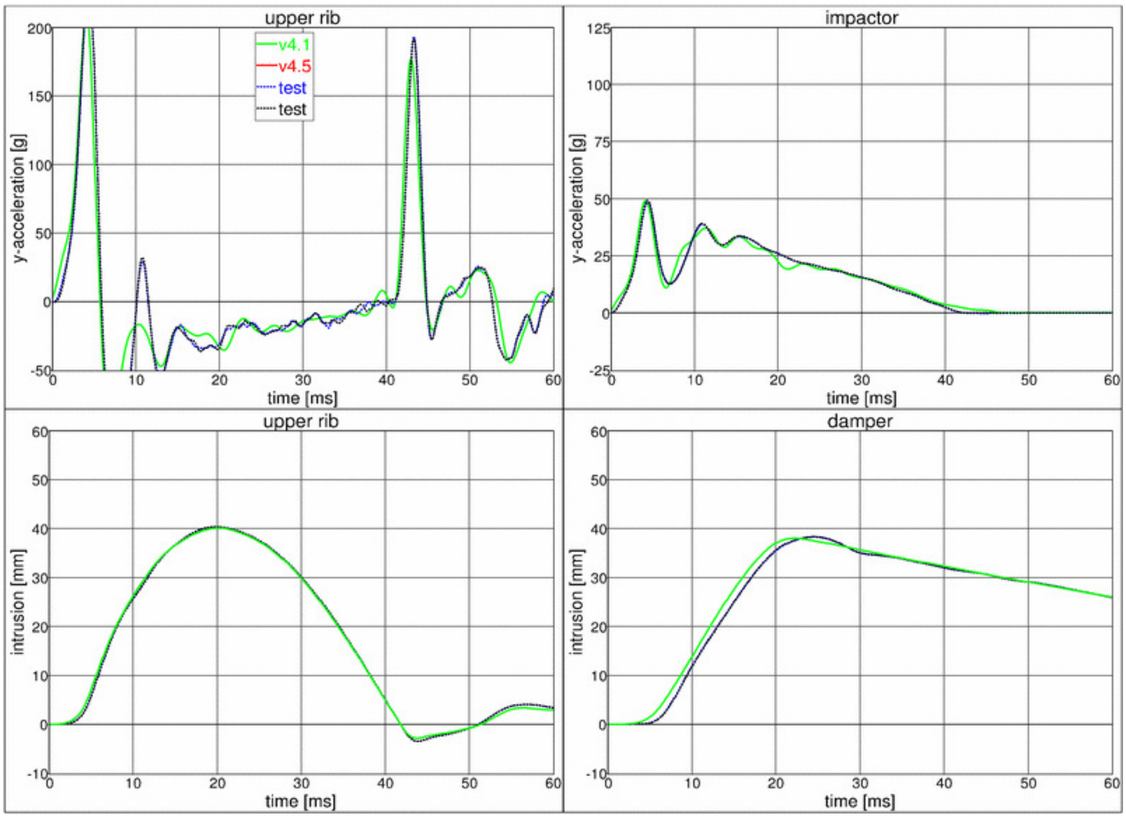
9.11.20 Test setup 3: velocity 2



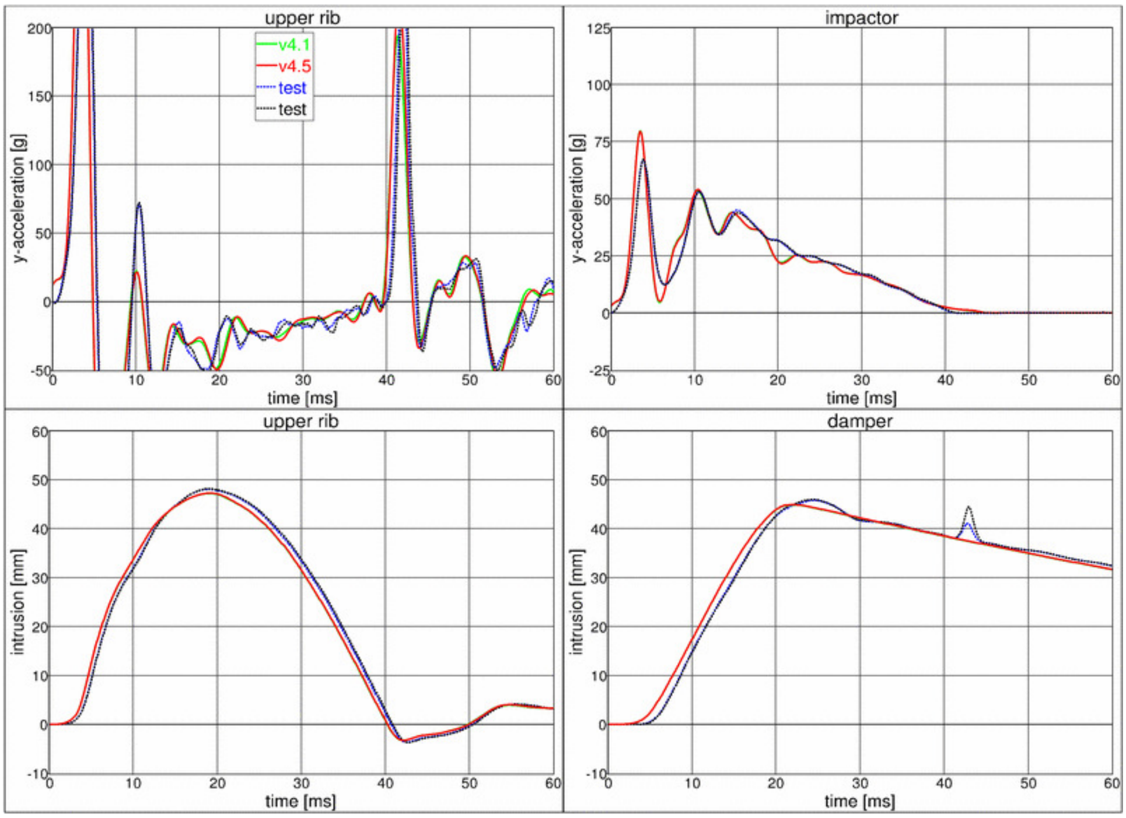
9.11.21 Test setup 3: velocity 3



9.11.22 Test setup 3: velocity 4



9.11.23 Test setup 3: velocity 5



9.11.24 Test setup 4

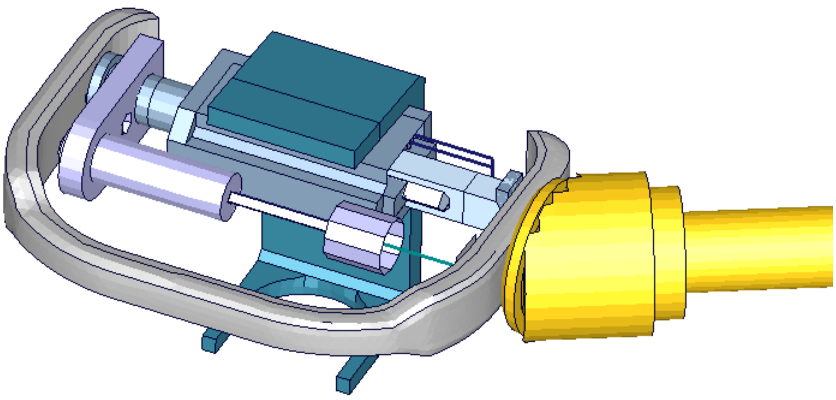
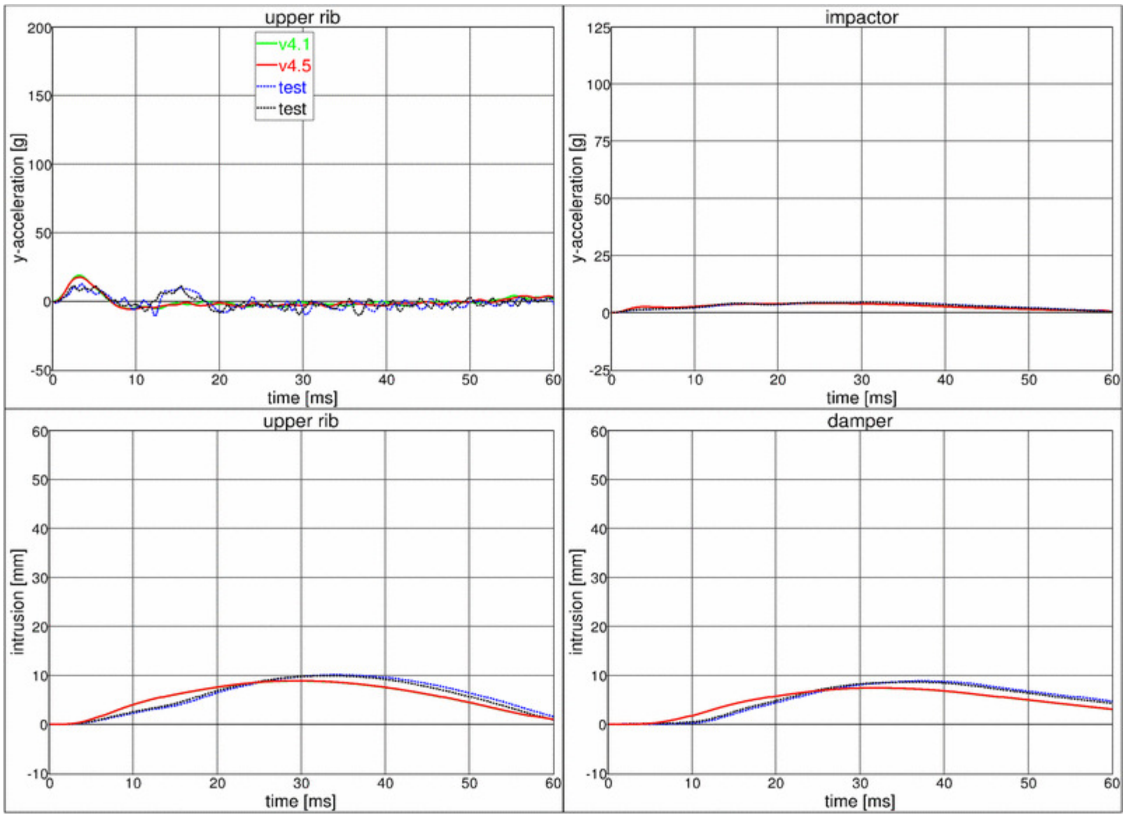


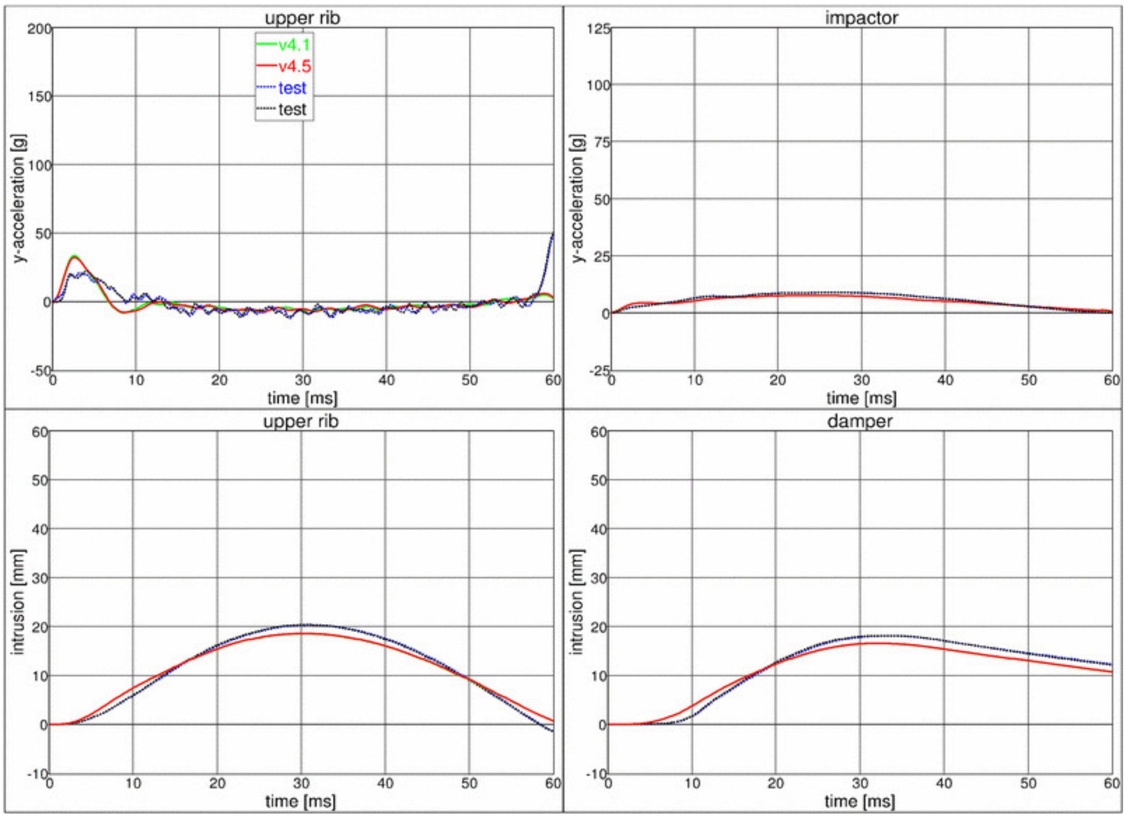
Figure 40: ES-2 rib module test setup 4

- Pendulum impacting the assembly at between damper and guidance
- 5 impact velocities
- Damper assembly is included
- The impact direction is oblique

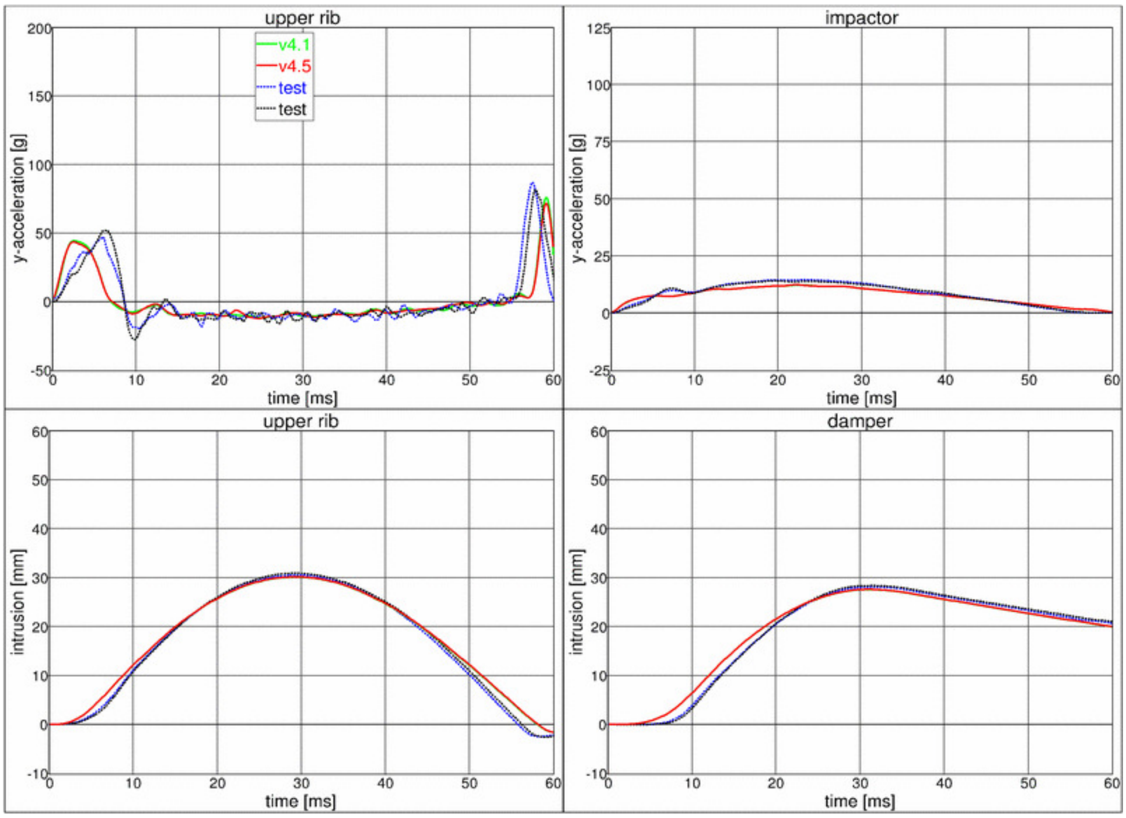
9.11.25 Test setup 4: velocity 1



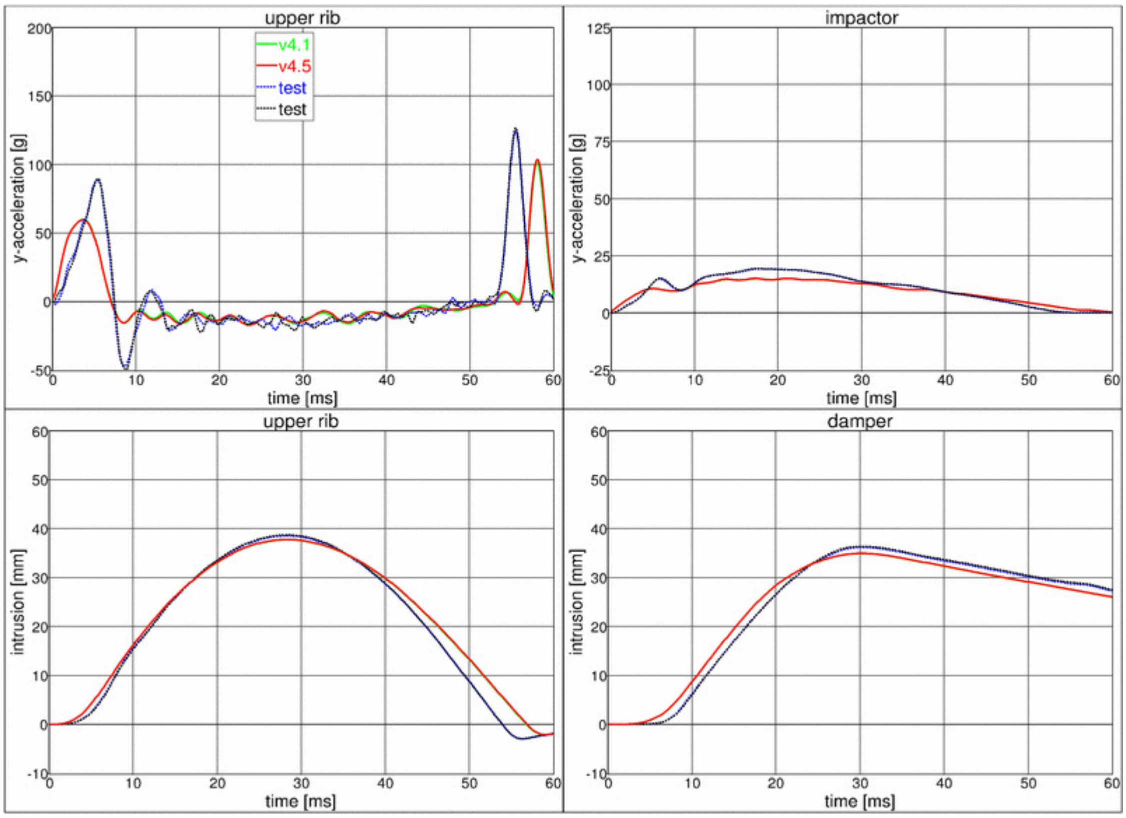
9.11.26 Test setup 4: velocity 2



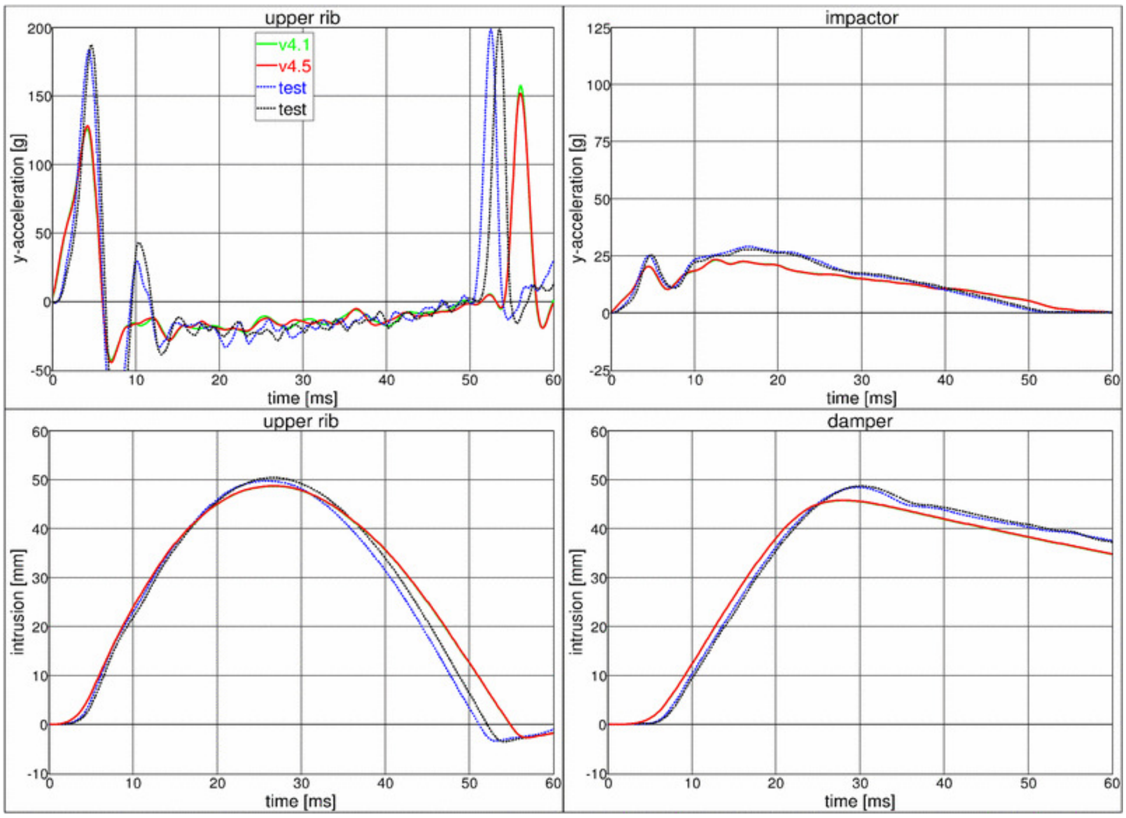
9.11.27 Test setup 4: velocity 3



9.11.28 Test setup 4: velocity 4



9.11.29 Test setup 4: velocity 5



9.12 Performance under SMP & MPP

The results of two different runs on SMP and MPP machines are depicted below.

SMP results obtained on:

- Platform: Intel Xeon Linux Workstation (8 CPUs)
- OS-level: CentOS 5
- Version: ls971 R3.2.1 revision 47756 single precision

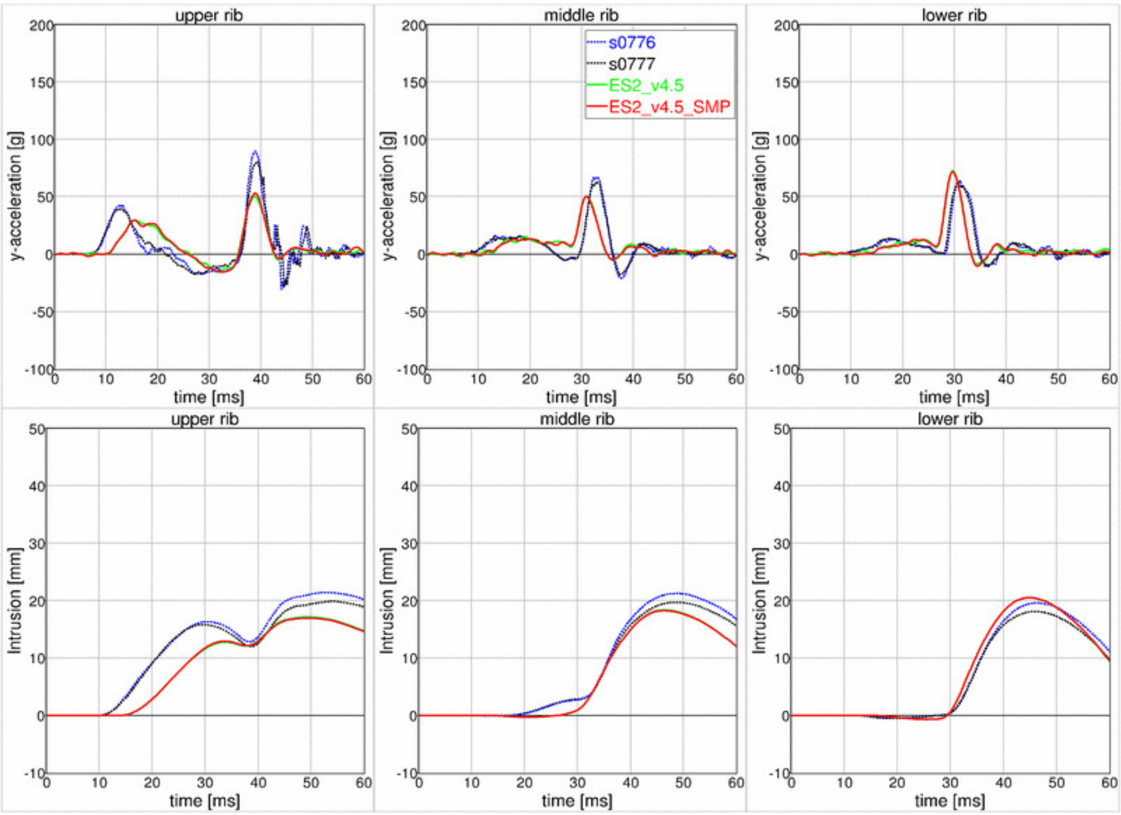
MPP results obtained on:

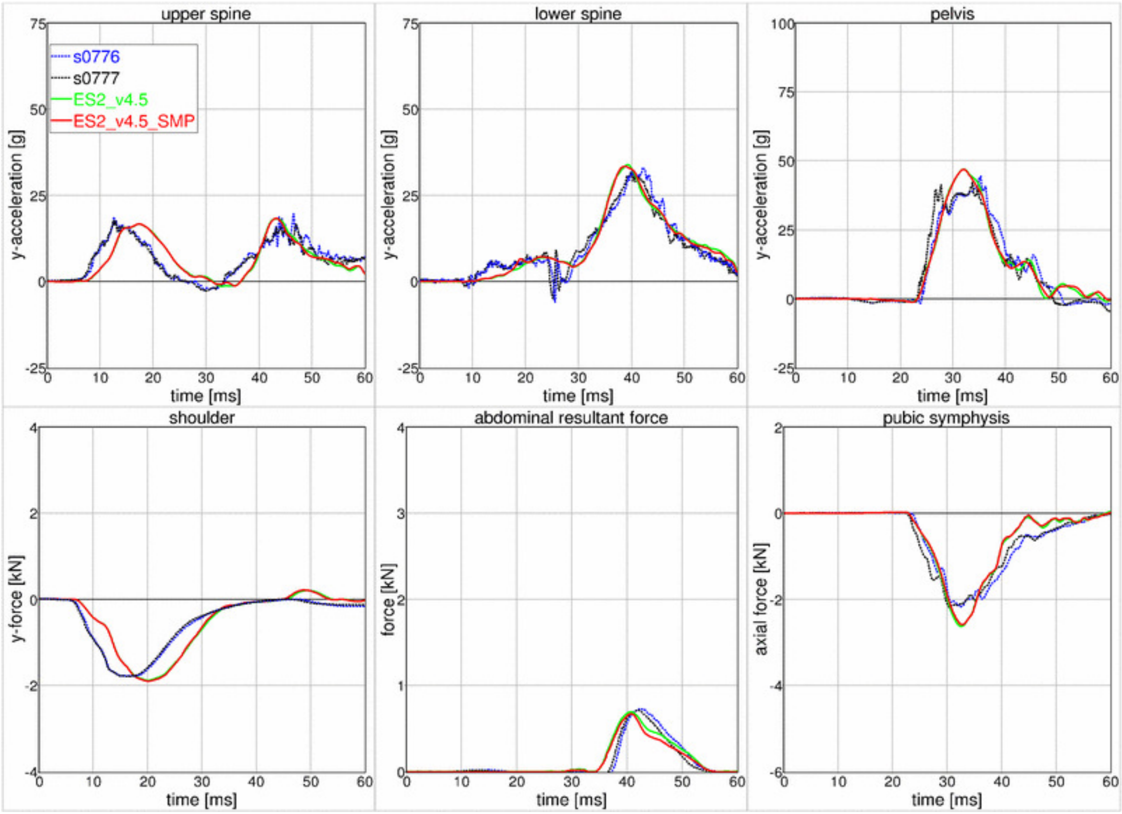
- Platform: Linux Cluster AMD-Opteron (64 CPUs)
- OS-level: Red Hat 4
- Version: mpp971 R3.2.1 revision 47756 single precision

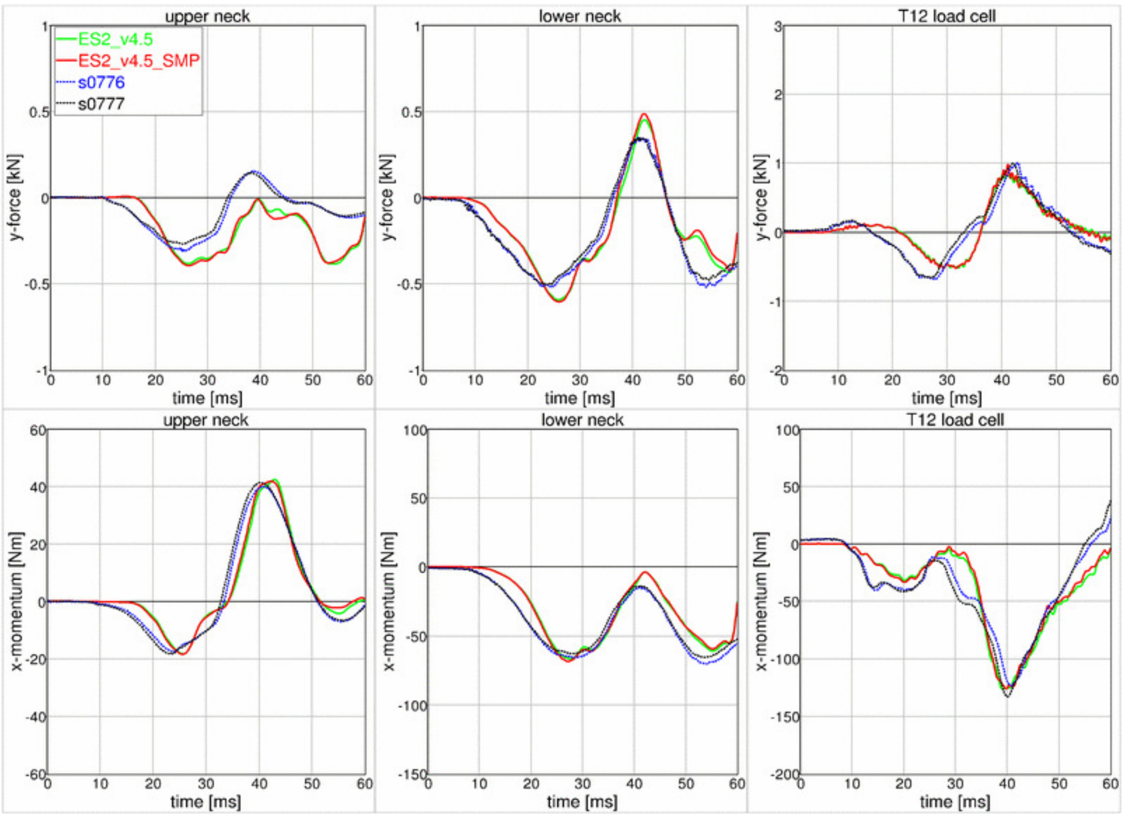
Boundaries:

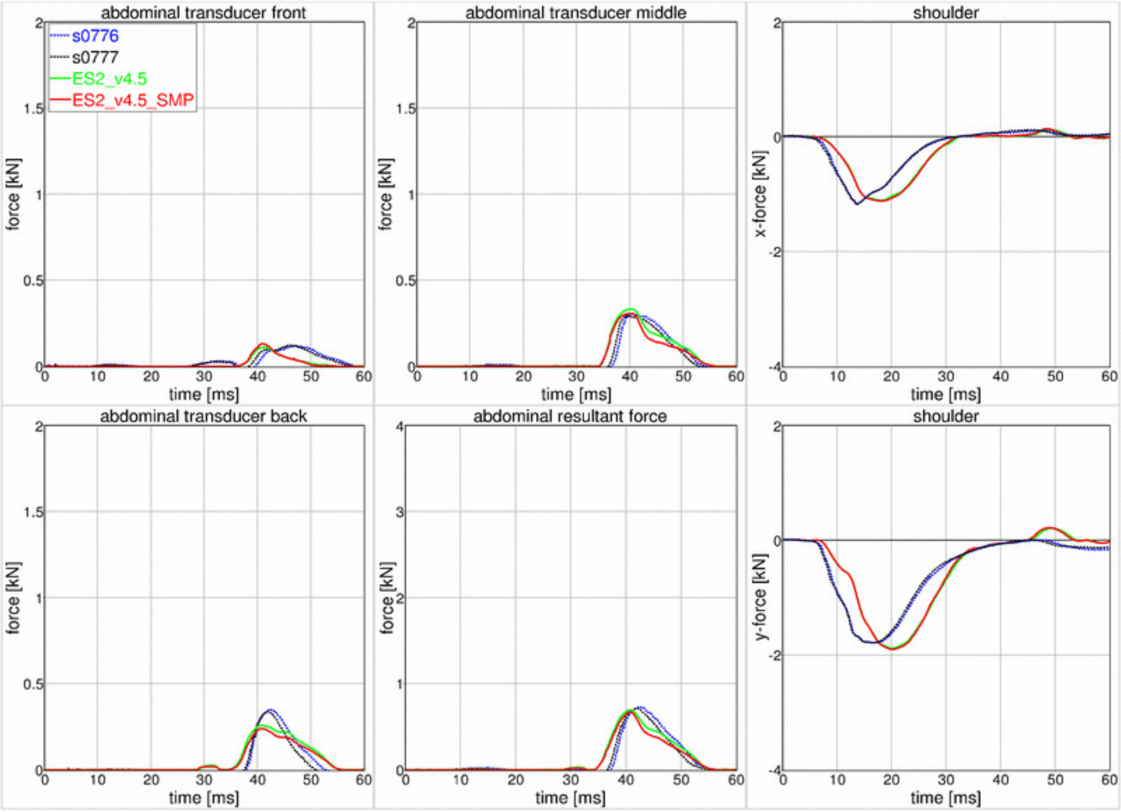
- Rigid barrier (Figure 27)
- Speed: high and low speed
- Arms in 40 degree position
- Orthogonal impact

9.12.1 Results at low speed

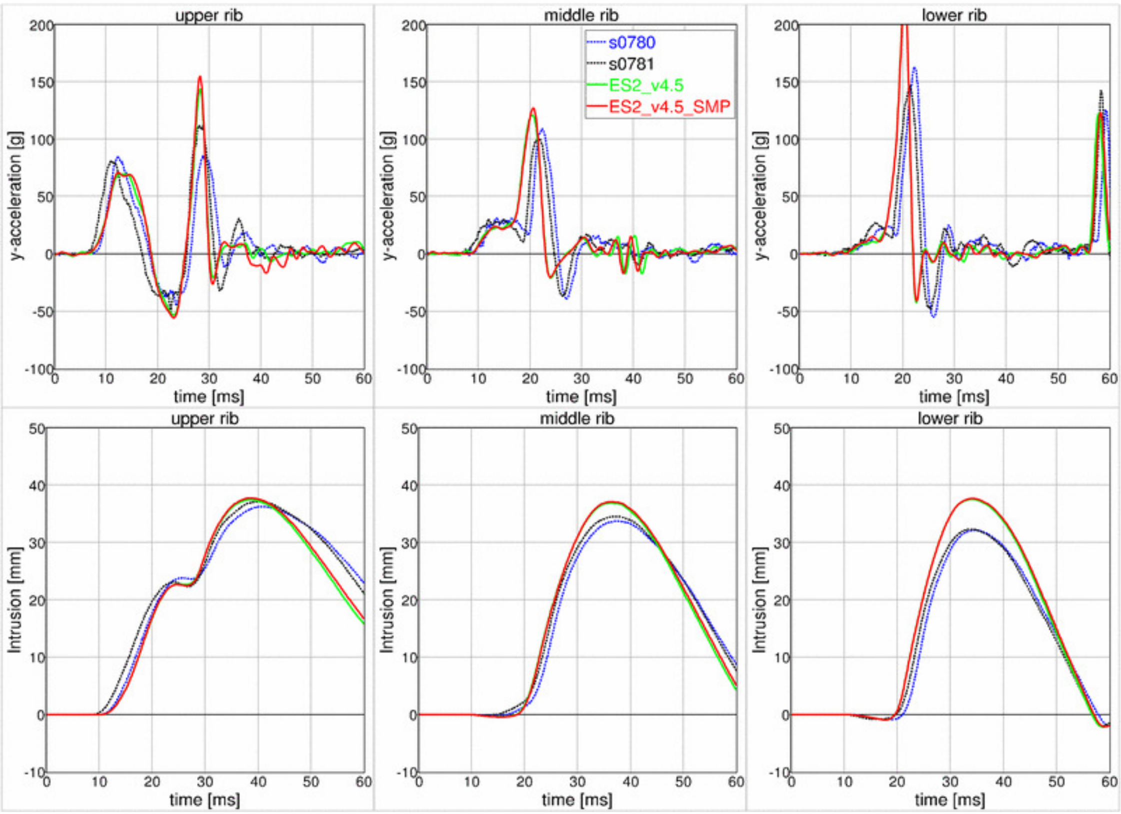


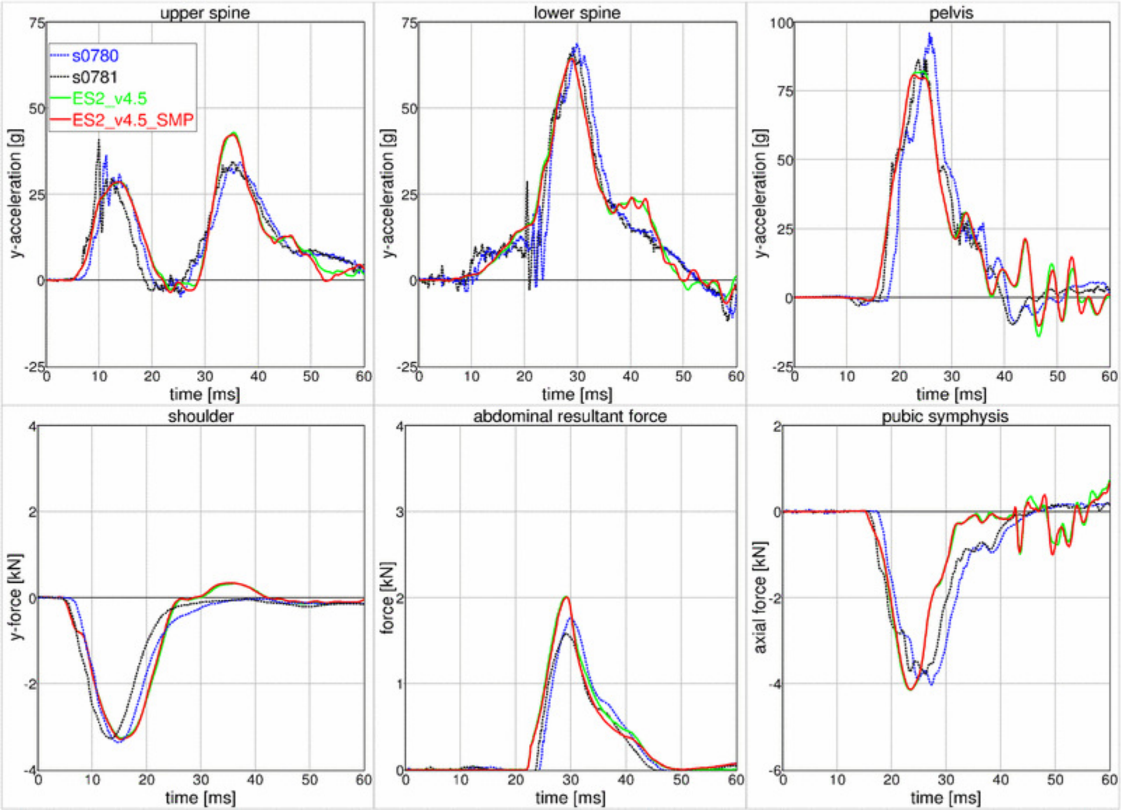

upper spine
lower spine
pelvis
s0776
s0777
ES2_v4.5
ES2_v4.5_SMP
y-acceleration [g]
time [ms]
shoulder
abdominal resultant force
pubic symphysis
y-force [kN]
force [kN]
axial force [kN]

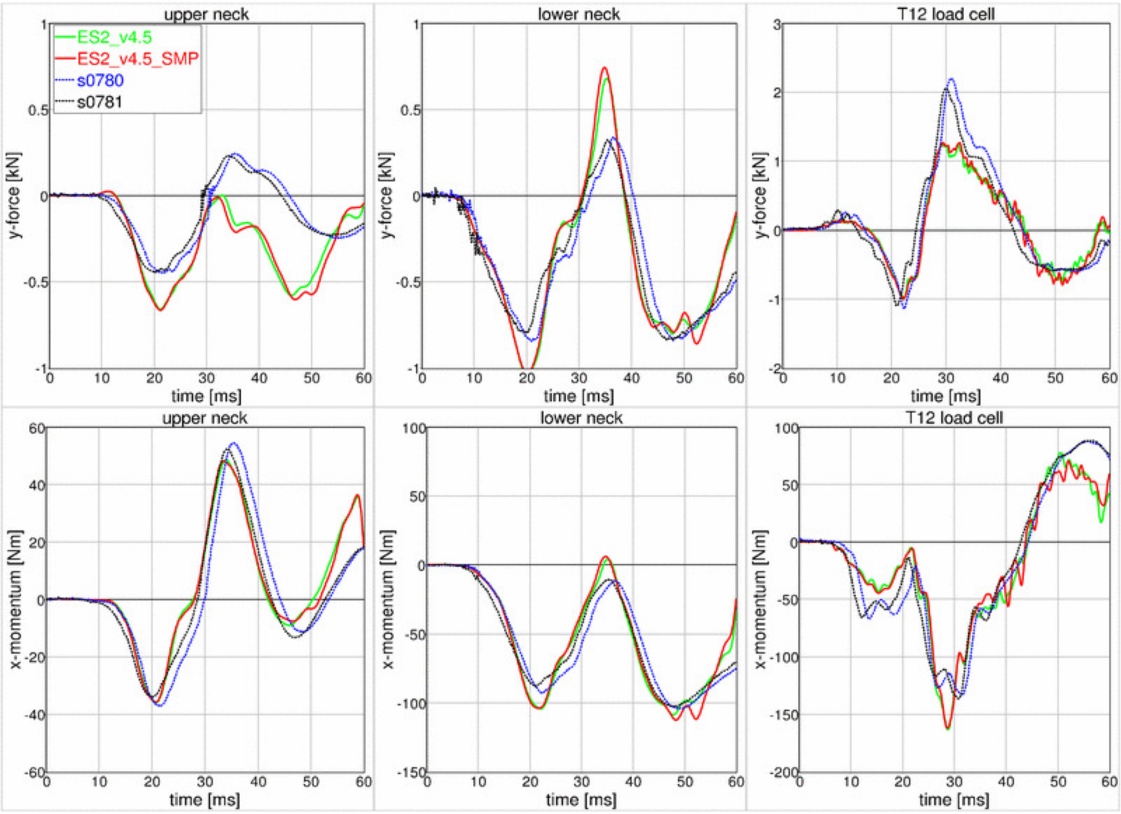

upper neck
lower neck
T12 load cell
ES2_v4.5
ES2_v4.5_SMP
s0776
s0777
y-force [kN]
x-momentum [Nm]
time [ms]

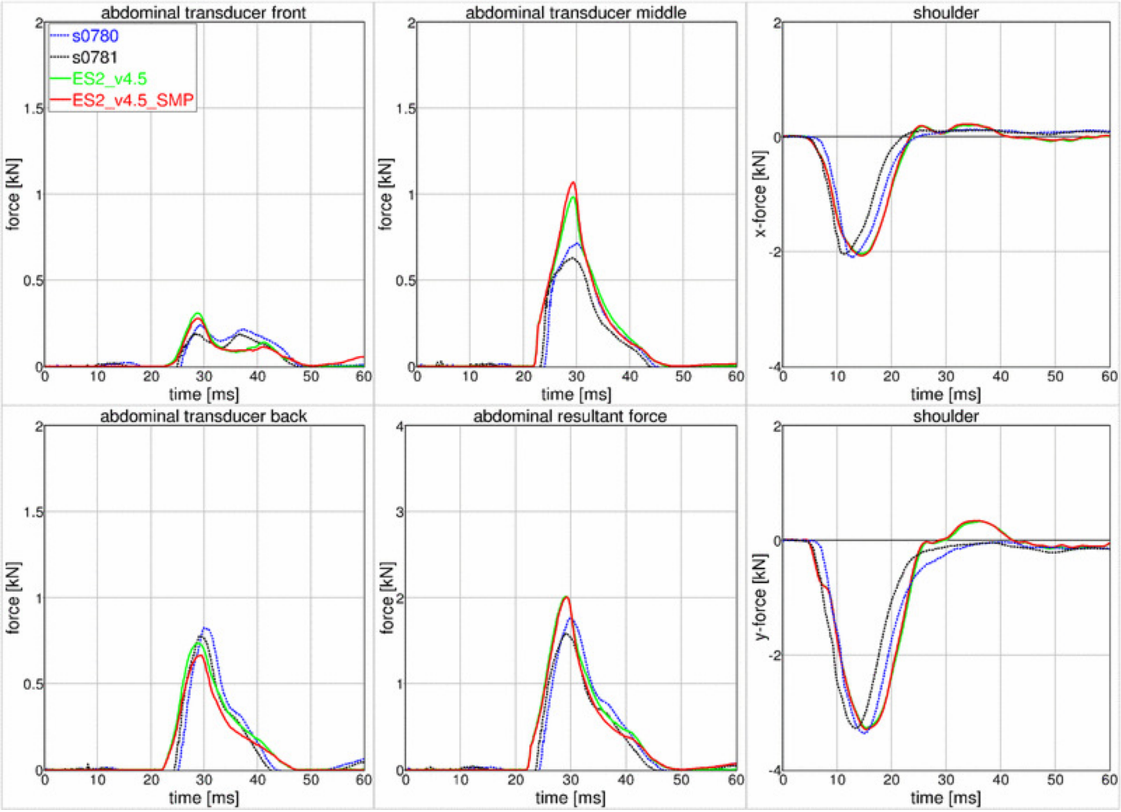


9.12.2 Results at high speed




upper spine
lower spine
pelvis
s0780
s0781
ES2_v4.5
ES2_v4.5_SMP
y-acceleration [g]
time [ms]
shoulder
abdominal resultant force
pubic symphysis
y-force [kN]
force [kN]
axial force [kN]
time [ms]


upper neck
lower neck
T12 load cell
ES2_v4.5
ES2_v4.5_SMP
s0780
s0781
y-force [kN]
time [ms]
x-momentum [Nm]
time [ms]


abdominal transducer front
s0780
s0781
ES2_v4.5
ES2_v4.5_SMP
force [kN]
time [ms]
abdominal transducer middle
force [kN]
time [ms]
shoulder
x-force [kN]
time [ms]
abdominal transducer back
force [kN]
time [ms]
abdominal resultant force
force [kN]
time [ms]
shoulder
y-force [kN]
time [ms]

9.13 Additional test of ES-2re – Pendulum at 90 degree without jacket and arm

Boundaries:

- Pendulum at 90 degrees (Figure 41)
- Speed: low and high velocity
- Pendulum mass: 24.1 kg
- No jacket and left arm is not attached

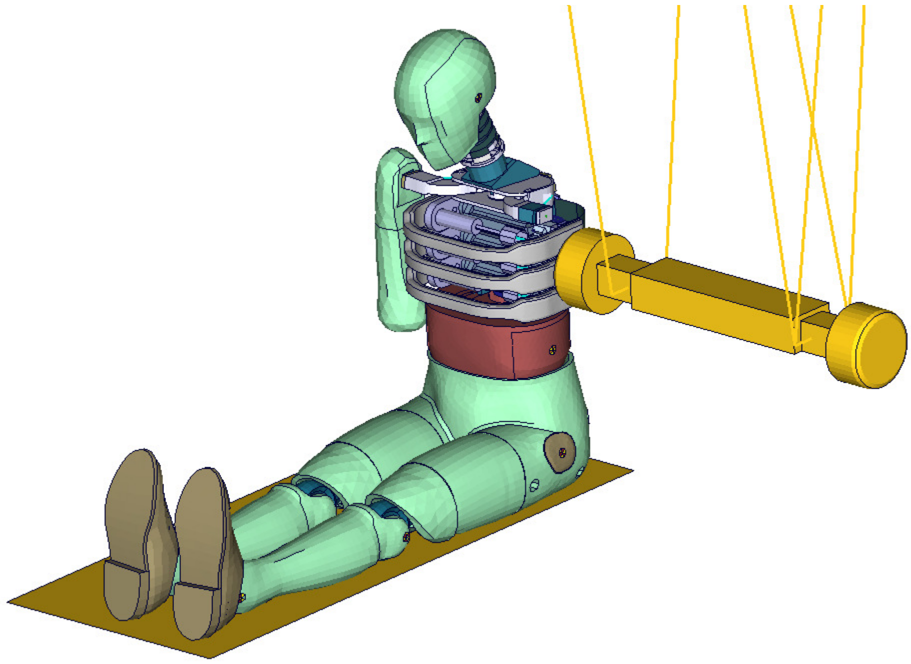
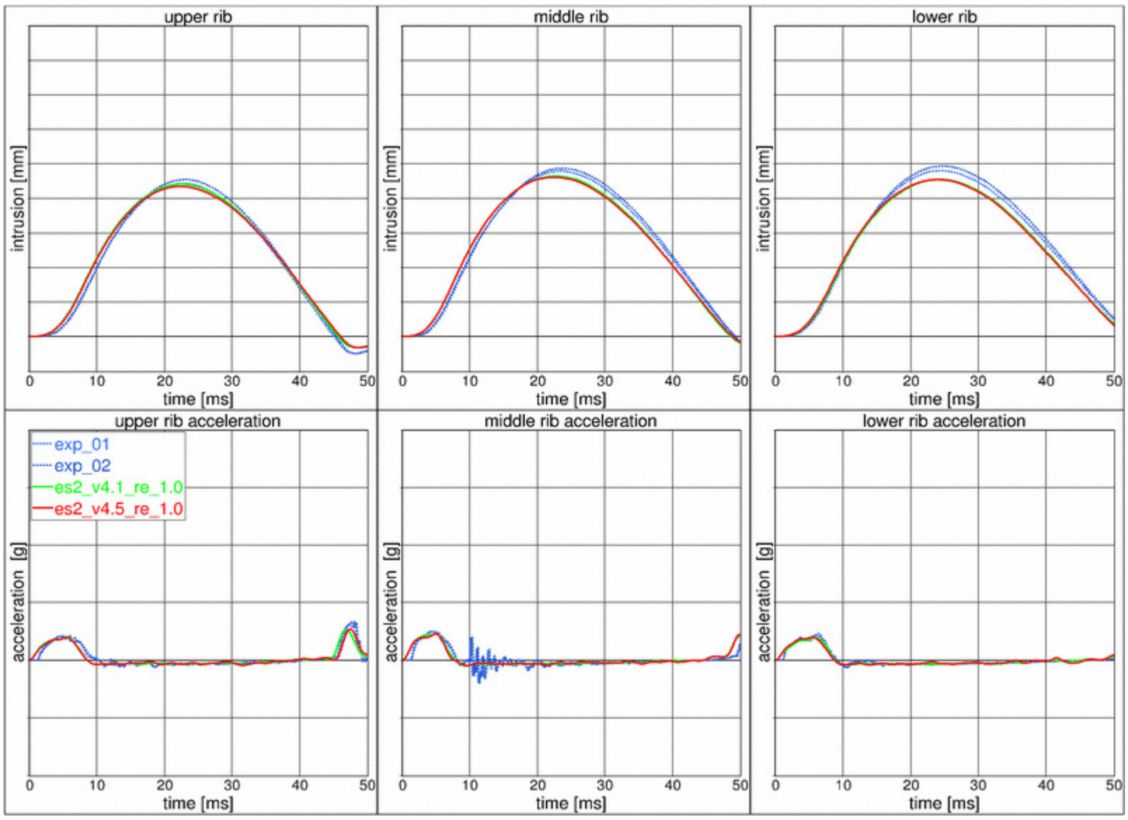
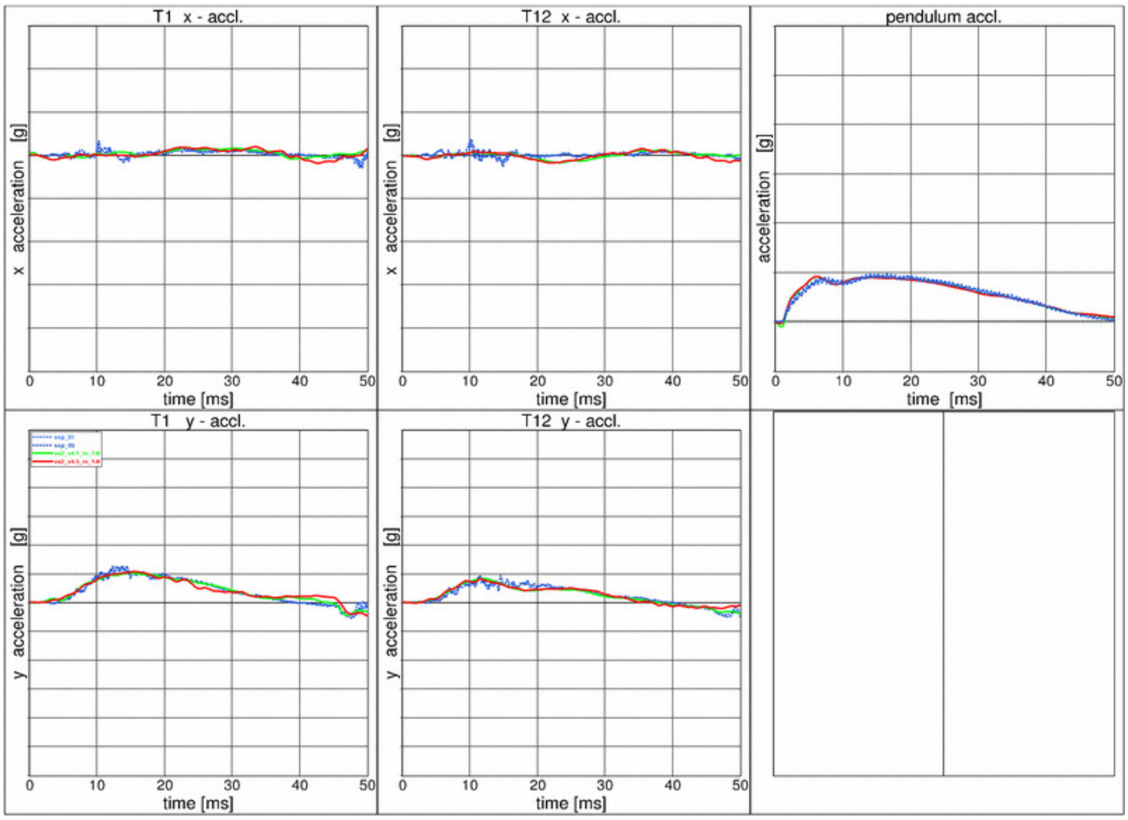


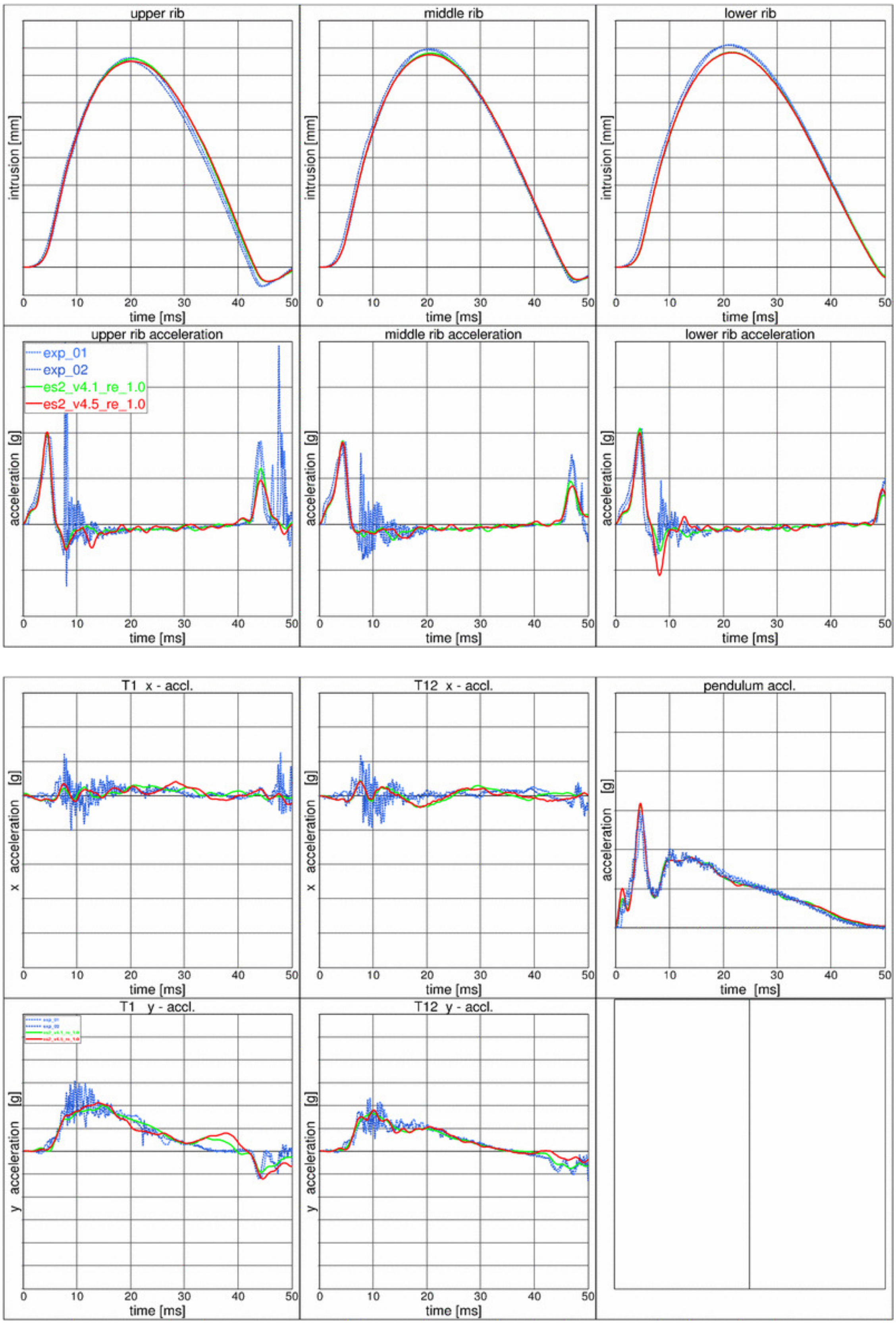
Figure 41: Pendulum impacting the ribs at 90 degrees; without arm and jacket

9.13.1 Results at low velocity





9.13.2 Results at high velocity



9.14 Additional test of ES-2re – Pendulum at 45 degree without jacket and arm

Boundaries:

- Pendulum at 45 degrees (Figure 42)
- Speed: low and high velocity
- Pendulum mass: 24.1 kg
- No jacket and left arm is not attached
- An ensolite foam is mounted in front of the pendulum

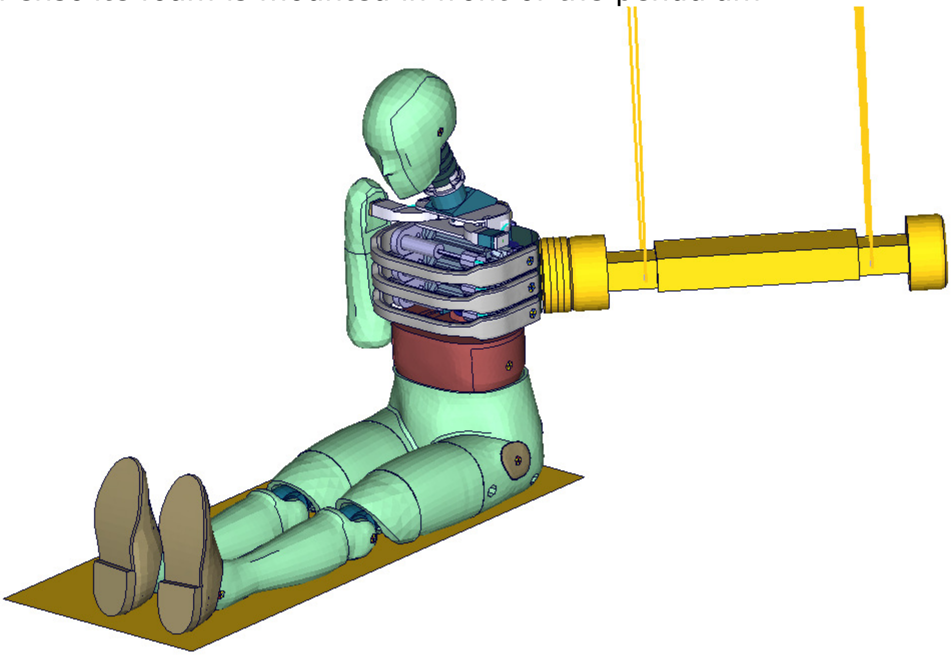
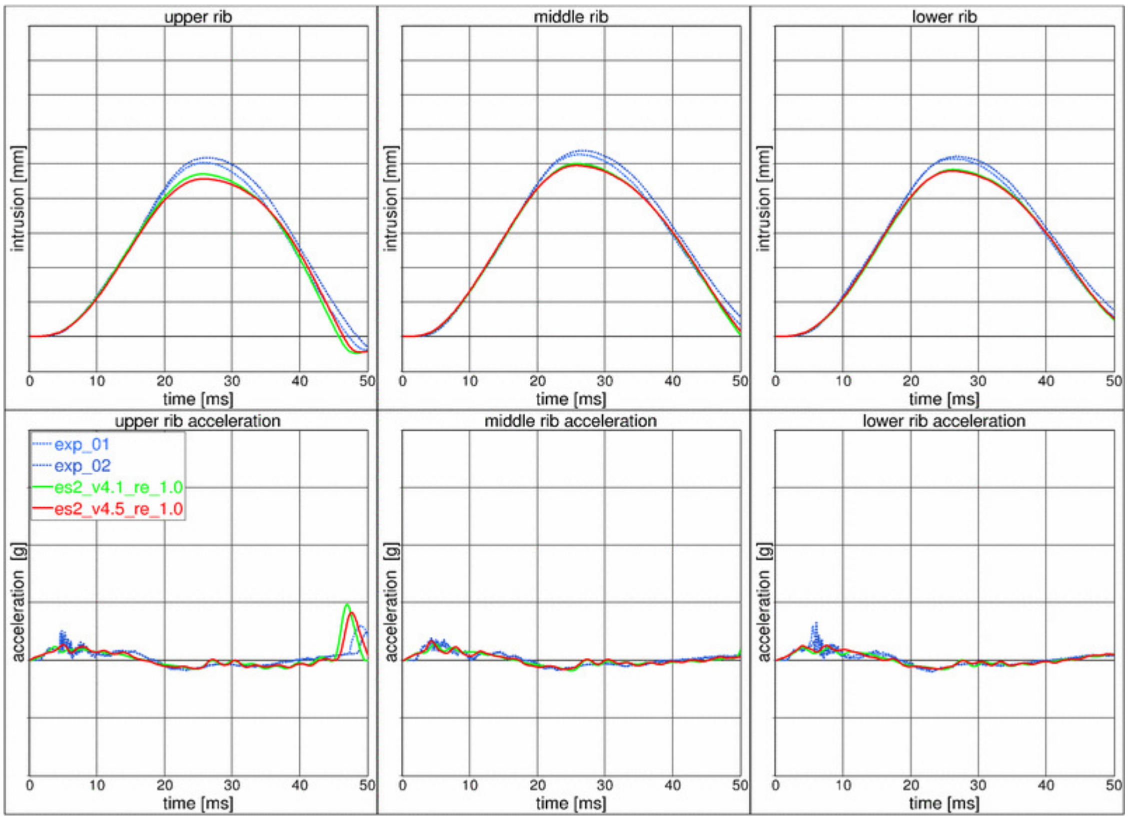
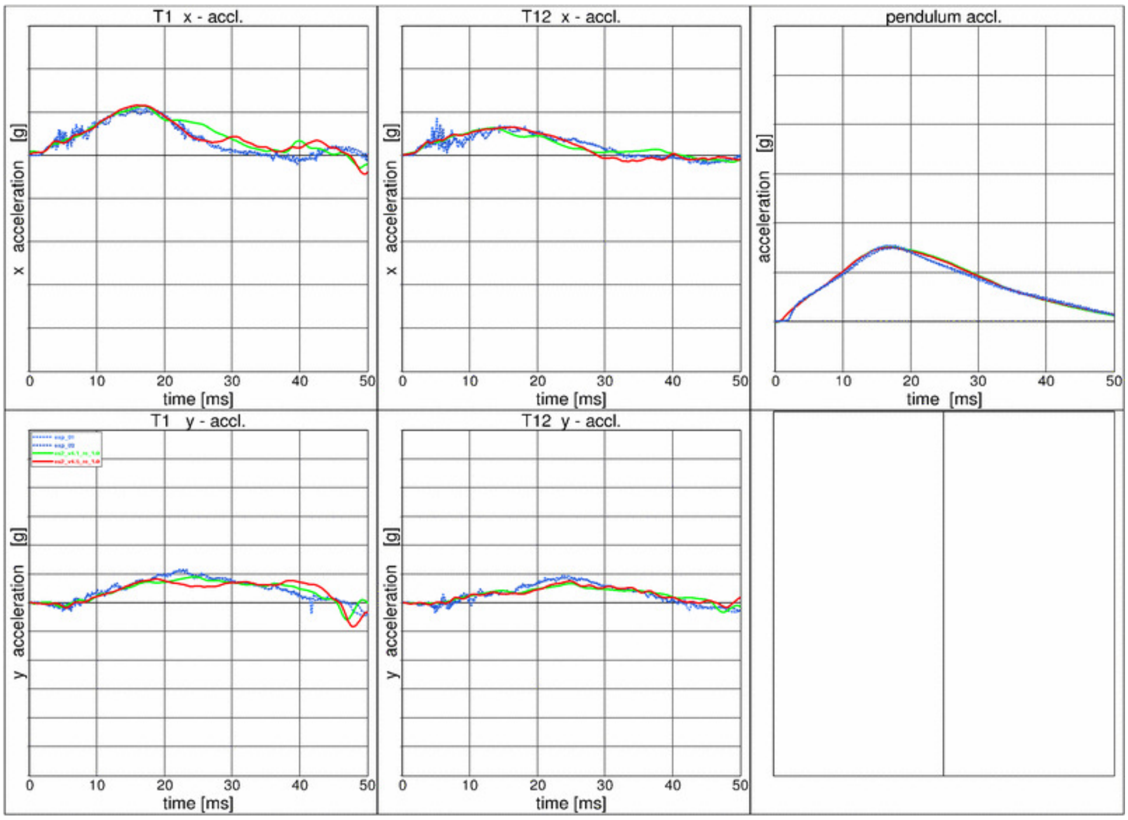


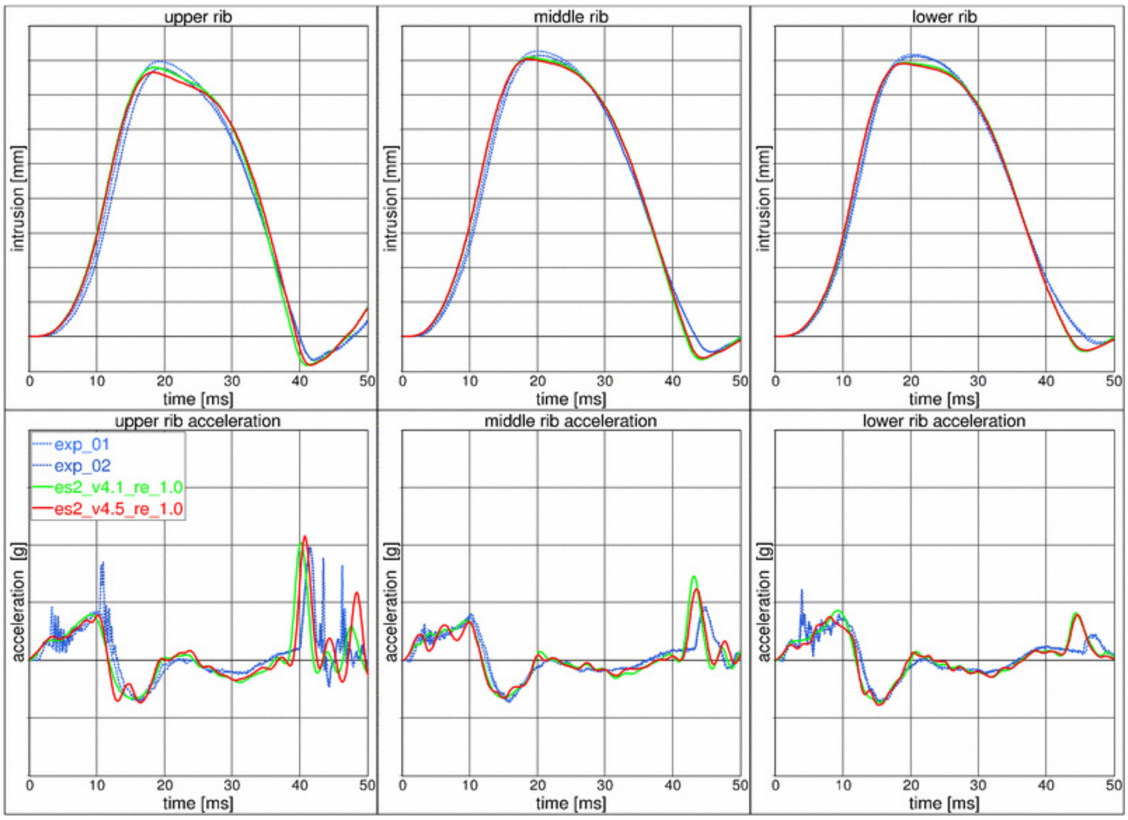
Figure 42: Pendulum impacting the ribs at 45 degrees; without arm and jacket

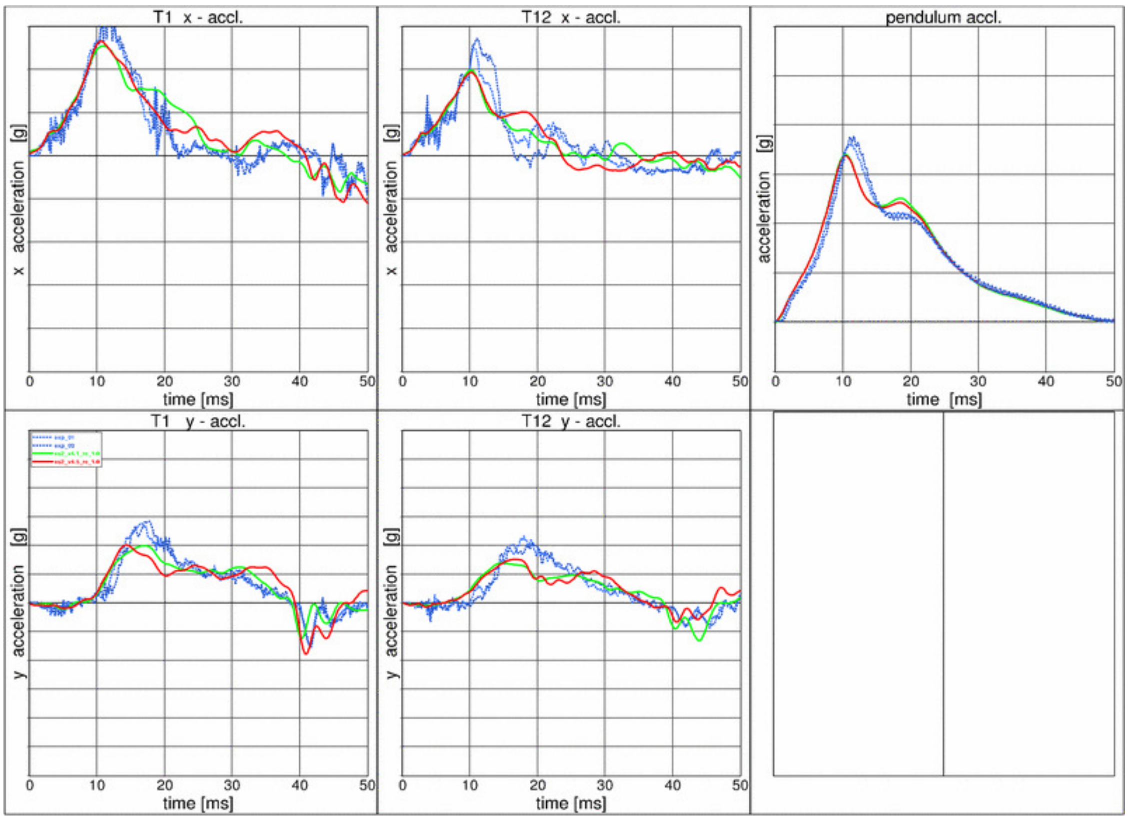
9.14.1 Results at low velocity





9.14.2 Results at high velocity





9.15 Additional test of ES-2re – Pendulum at 45 degree without jacket and arm

Boundaries:

- Pendulum at 45 degrees (Figure 43)
- Speed: high velocity
- Pendulum mass: 24.1 kg
- Arms in 90 degree position
- The pendulum hits the rib extension at an angle of 45 degrees
- ES-2 is equipped with arms and jacket

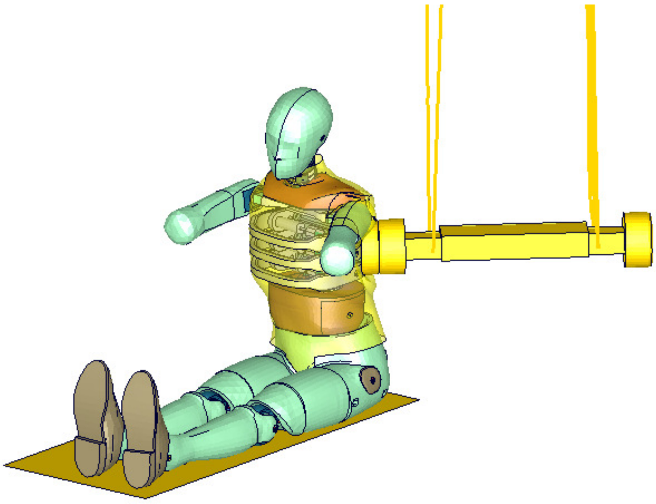


Figure 43: Pendulum impacting the ribs at 45 degrees; with arm and jacket

9.15.1 Results