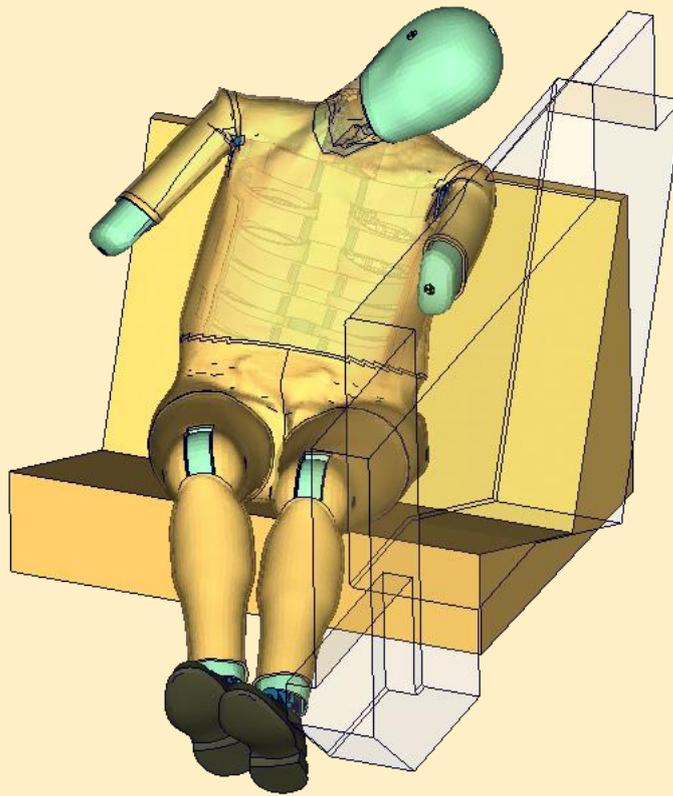


# Documentation

## PDB LS-DYNA

### WorldSID 50<sup>th</sup> – Version 5.0



#### **User's Manual**

Manual Release 0.0 for Model v5.0

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## 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 R7.1.3 MPP	05/19/2016	114888 Product ID 114888

**Table 1:** LS-DYNA versions

To offer a variety of LS-DYNA versions for the user to run the current WorldSID model, we tested the following releases with the barrier sled tests:

LS-DYNA Version	Date	Revision Nr.	recommended
971 R7.1.2 MPP	01/07/2015	97170 Product ID 97170	yes
971 R7.1.3 MPP	05/19/2016	114888 Product ID 114888	yes
971 R9 MPP	01/11/2018	123204 Product ID 123204	yes

**Table 2:** recommended LS-DYNA versions

With the version 5.0 of the WorldSID 50<sup>th</sup> model the following keyword files are delivered:

File name	Content
worldSID50_pdb_v5.0_mm_ms_kg.key	Dummy model; the file name might vary depending on the system of units
worldSID50_pdb_v5.0_arm_sleeve_v1.3.key	Arm_sleeve model for ENCAP Far-Side
Psg_v2.0_...	Script to generate pre-simulation input (chapter 3.2).
wsid50_v5.0_all_units_server.asc	License file; the file can be used in different system of units
wsid50_v5.0_all_units_load_curves_work.key	Work file used for pre-processing instead of license file. The file name might vary depending on the system of units
worldSID50_pdb_v5.0_H-Point_tool.key	H-Point measurement device
worldSID50_pdb_v5.0.X_mm_ms_kg_RibEye_v3.5.key	RibEye model; the file name might vary depending on the system of units

**Table 3:** Delivered Files

The work file `wsid50_pdb_vx.x_all_units_load_curves_work.key` can be used for pre-processing the dummy.

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.

The numbering scheme of the original model is shown in Table 4. On request, we deliver renumbered input decks, according to user specifications.

Component	Min ID	Max ID	Total number
Nodes	10000	300370	256375
Solids	12001	156971	142529
Beams	10000	361054	829
Shells	160001	360202	192057
Discrete elements	10036	10066	26
Accelerometer	1001	1023	22
Set node	1001	1301	19
Set shell	1029	1029	1
Set parts	1001	1582	46
Parts	1	818	776
Materials	1001	1096	83
Sections	1001	1114	111
Hourglass	1001	1010	6
Airbags	1	2	2
Joints	1024	1089	19
Joint stiffness	1001	1124	87
Contacts	1001	1050	18
Local coordinate systems	1001	1090	137
Load curves / tables	1001	1138	121
Define SD orientation	1001	1014	14
Time history nodes	10001	10756	69
Time history beam elements	10000	10256	22
Time history discrete elements	10040	10065	20

**Table 4:** Model numbering scheme

## 1.1 Keywords used

The following control and database keywords are used:

*CONTROL_ACCURACY	*CONTROL_SHELL
*CONTROL_BULK_VISCOSITY	*CONTROL_SOLID
*CONTROL_CONTACT	*CONTROL_SOLUTION
*CONTROL_MPP_IO_NODUMP	*CONTROL_TERMINATION
*CONTROL_MPP_DECOMPOSITION	*CONTROL_TIMESTEP
_ARRANGE_PARTS	
*CONTROL_ENERGY	*CONTROL_HOURLASS
*CONTROL_OUTPUT	

**Table 5:** Control cards used

The following database cards are defined:

*DATABASE_ABSTAT	*DATABASE_HISTORY_NODE_ID
*DATABASE_BINARY_D3PLOT	*DATABASE_HISTORY_NODE_LOCAL_ID
*DATABASE_BINARY_RUNRSF	*DATABASE_JNTFORC
*DATABASE_DEFORC	*DATABASE_MATSUM
*DATABASE_ELOUT	*DATABASE_NODOUT
*DATABASE_EXTENT_BINARY	*DATABASE_RBDOUT
*DATABASE_GLSTAT	*DATABASE_RCFORC
*DATABASE_HISTORY_BEAM_ID	*DATABASE_SBTOUT
*DATABASE_HISTORY_DISCRETE_ID	*DATABASE_SLEOUT

**Table 6:** Database cards used

The following material models are used:

*MAT_ELASTIC	*MAT_RIGID
*MAT_FU_CHANG_FOAM	*MAT_RIGID_DISCRETE
*MAT_FABRIC	*MAT_SHAPE_MEMORY
*MAT_LINEAR_ELASTIC_DISCRETE_BEAM	*MAT_SIMPLIFIED_RUBBER
*MAT_NONLINEAR_ELASTIC_DISCRETE_BEAM	*MAT_SIMPLIFIED_RUBBER_WITH_DAMAGE
*MAT_NULL	*MAT_SPRING_ELASTIC
*MAT_PLASTIC_KINEMATIC	*MAT_SPRING_NONLINEAR_ELASTIC
	*MAT_VISCOELASTIC

**Table 7:** Material models used

The following other keywords are used:

*CONSTRAINED_JOINT_CYLINDRICAL_ID	*ELEMENT_SOLID
*CONSTRAINED_JOINT_REVOLUTE_ID	*END
*CONSTRAINED_JOINT_SPHERICAL_ID	*HOURLASS
*CONSTRAINED_JOINT_STIFFNESS_	*INCLUDE

GENERALIZED *CONSTRAINED_JOINT_STIFFNESS_ TRANSLATIONAL *CONSTRAINED_RIGID_BODIES *CONTACT_AUTOMATIC_SINGLE_SURFACE *CONTACT_FORCE_TRANSDUCER_PENALTY *CONTACT_TIED_SHELL_EDGE_TO_ SURFACE_... *DAMPING_PART_STIFFNESS *DEFINE_COORDINATE_NODES *DEFINE_CURVE *DEFINE_SD_ORIENTATION_TITLE *DEFINE_TABLE *ELEMENT_BEAM *ELEMENT_DISCRETE *ELEMENT_SEATBELT_ ACCELEROMETER *ELEMENT_SHELL	*INITIAL_FOAM_REFERENCE_ GEOMETRY *KEYWORD *NODE *PART_... *PARAMETER  *PARAMETER_EXPRESSION *SECTION_BEAM *SECTION_DISCRETE *SECTION_SHELL  *SECTION_SOLID *SET_NODE_LIST *SET_PART_LIST *SET_PART_COLLECT *SET_SHELL_LIST *TITLE
---	---

**Table 8:** Other keywords used in the model

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

*ASSEMBLY *CONNECTION_HINGE *CONNECTION_LINE *DUMMY_END *DUMMY_START *H_POINT	*MECHANISM_START *MECHANISM_END *POINT_LOCATION *POSITION *UNITS
--	--

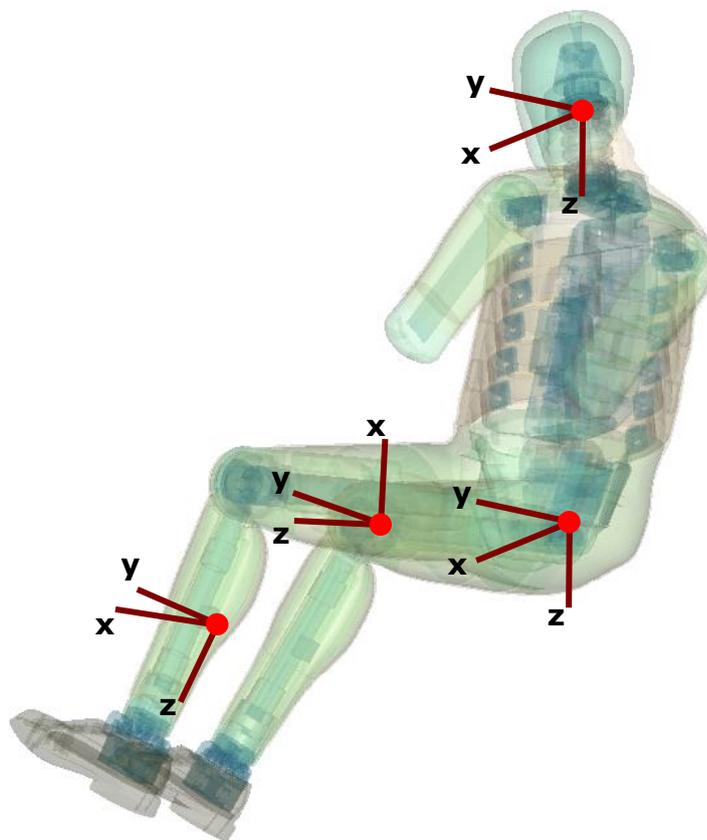
**Table 9:** Primer keywords used

## 2. Extraction of occupant injury criteria

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

### 2.1 Sign convention in the Model

All relevant coordinate systems are defined according to the SAEJ211 norm. This means that all coordinate axes in the dummy are oriented with respect to an upright standing dummy. Thus the x-axis of the coordinate systems in the upper legs points upwards as shown in Figure 1.

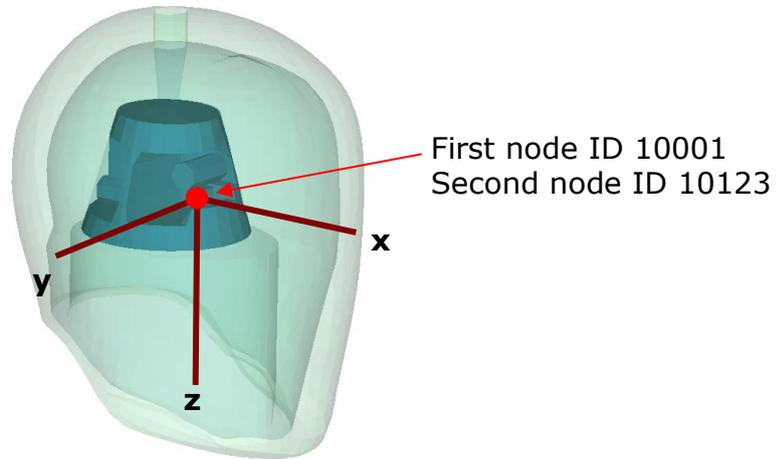


**Figure 1:** Orientation of the coordinate systems for accelerometers and load cells in the WORLD SID 50<sup>th</sup> model

Only the coordinate systems for evaluating injury criteria are oriented in this scheme. There are many more coordinate systems in the model which are sometimes oriented arbitrarily because of internal features in the dummy.

## 2.2 Accelerations

### 2.2.1 Head acceleration



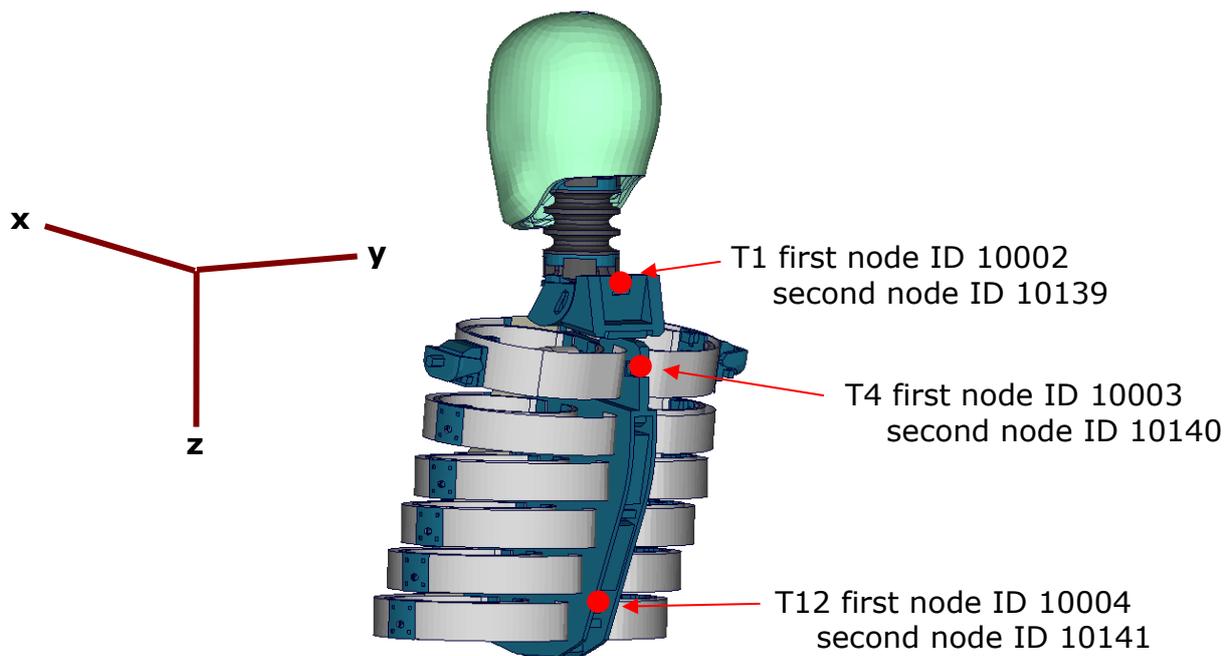
**Figure 2:** Head accelerometer and local coordinate directions

There are two nodes from the marked point for the head acceleration. An accelerometer is defined at the first node. The second node is for global acceleration. The first prints the results in the NODOUT file in the local coordinate system shown in Figure 2.

Item	Node-ID	Label	Available components
Head	10001	HEAD0000WSAC	local x-,y-,z- acceleration
Head global	10123	HEAD00GBWSAC	global x-,y-,z- acceleration

**Table 10:** Head accelerometer nodes

### 2.2.2 T1, T4 and T12 acceleration



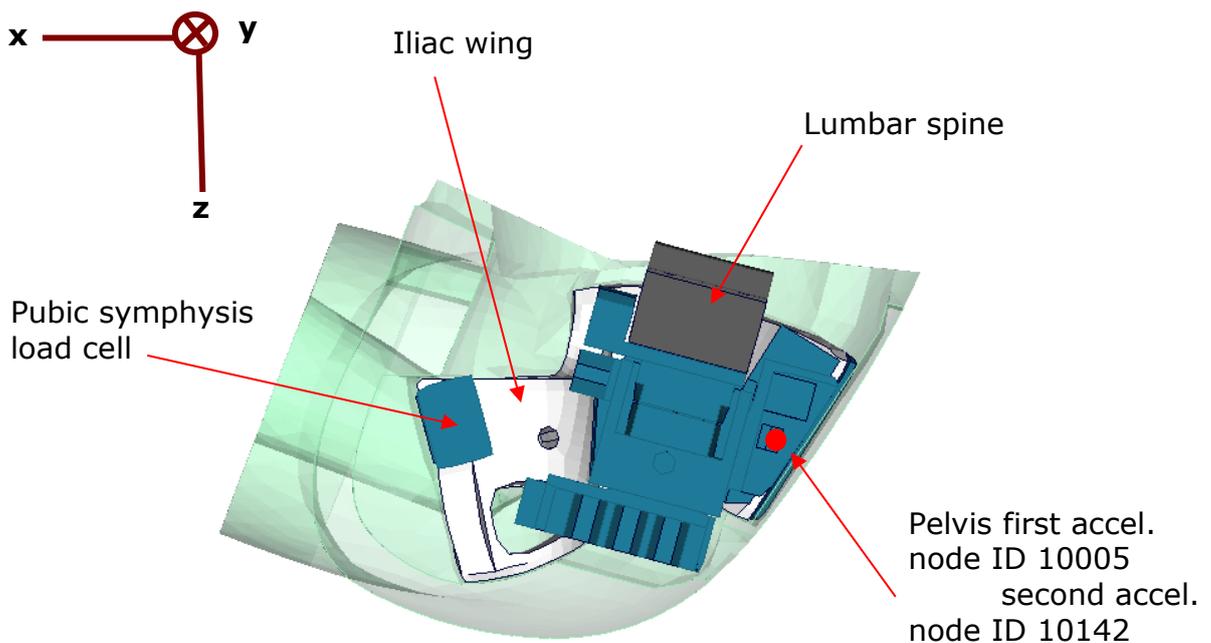
**Figure 3:** T1, T4 and T12 accelerometer nodes

The Figure 3 depicts the points, each point has two nodes which are used as output nodes in the NODOUT file for T1, T4 and T12 acceleration. For each first node, an accelerometer with the local directions is defined as shown in the Figure. For each second node is for global acceleration.

Item	Node-ID	Label	Available components
T1	10002	THSP0100WSAC	local x-,y-,z- acceleration
T1 global	10139	THSP01GBWSAC	global x-,y-,z- acceleration
T4	10003	THSP0400WSAC	local x-,y-,z- acceleration
T4 global	10140	THSP04GBWSAC	global x-,y-,z- acceleration
T12	10004	THSP1200WSAC	local x-,y-,z- acceleration
T12 global	10141	THSP12GBWSAC	global x-,y-,z- acceleration

**Table 11:** T1, T4 and T12 accelerometer nodes

### 2.2.3 Pelvis acceleration



**Figure 4:** Node to extract pelvis acceleration.

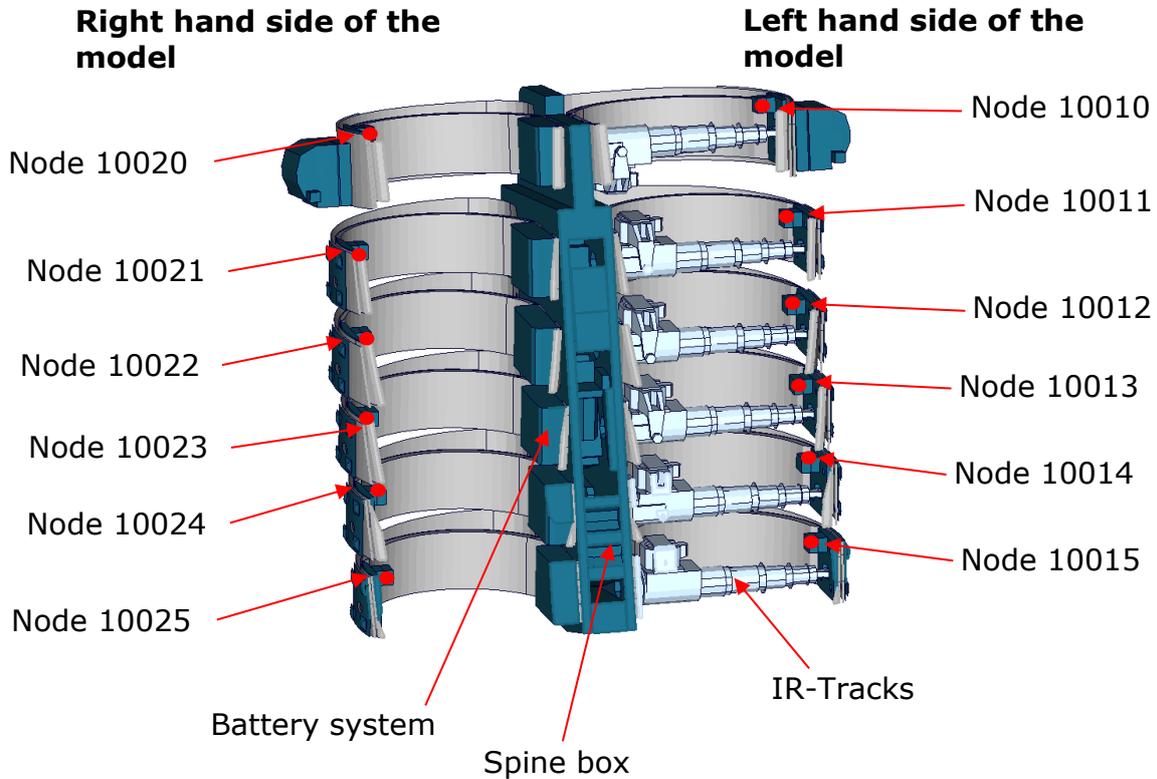
In Figure 4, a plate cut through the pelvis along the z-x-plane is shown. The pelvis accelerometer is located at the back of the sacrum block. The results of the node 10005 are printed in the NODOUT file in the local coordinate system which is shown in Figure 4. The node 10142 is for global acceleration.

Item	Node-ID	Label	Available components
Pelvis	10005	PELV0000WSAC	local x-,y-,z- acceleration
Pelvis global	10142	PELV00GBWSAC	global x-,y-,z- acceleration

**Table 12:** Pelvis accelerometer nodes

### 2.2.4 Rib accelerations

The WorldSID 50<sup>th</sup> model is equipped with twelve rib accelerometers. On each single rib, one accelerometer is mounted on the impact side and one on the opposite side.



**Figure 5:** Cut through upper torso and position of rib accelerometer nodes

The nodal results are printed in the NODOUT file in the local coordinate systems of the accelerometers. On the impact side (left hand side for the left handed driver model) the nodes are:

Item	Node-ID	Label	Available components
shoulder rib	10010	SHRILE00WSAC	local x-,y-,z- acceleration
1. thorax rib	10011	TRRILE01WSAC	local x-,y-,z- acceleration
2. thorax rib	10012	TRRILE02WSAC	local x-,y-,z- acceleration
3. thorax rib	10013	TRRILE03WSAC	local x-,y-,z- acceleration
1. abdomen rib	10014	ABRILE01WSAC	local x-,y-,z- acceleration
2. abdomen rib	10015	ABRILE02WSAC	local x-,y-,z- acceleration

**Table 13:** Rib accelerometer nodes on the side of impact

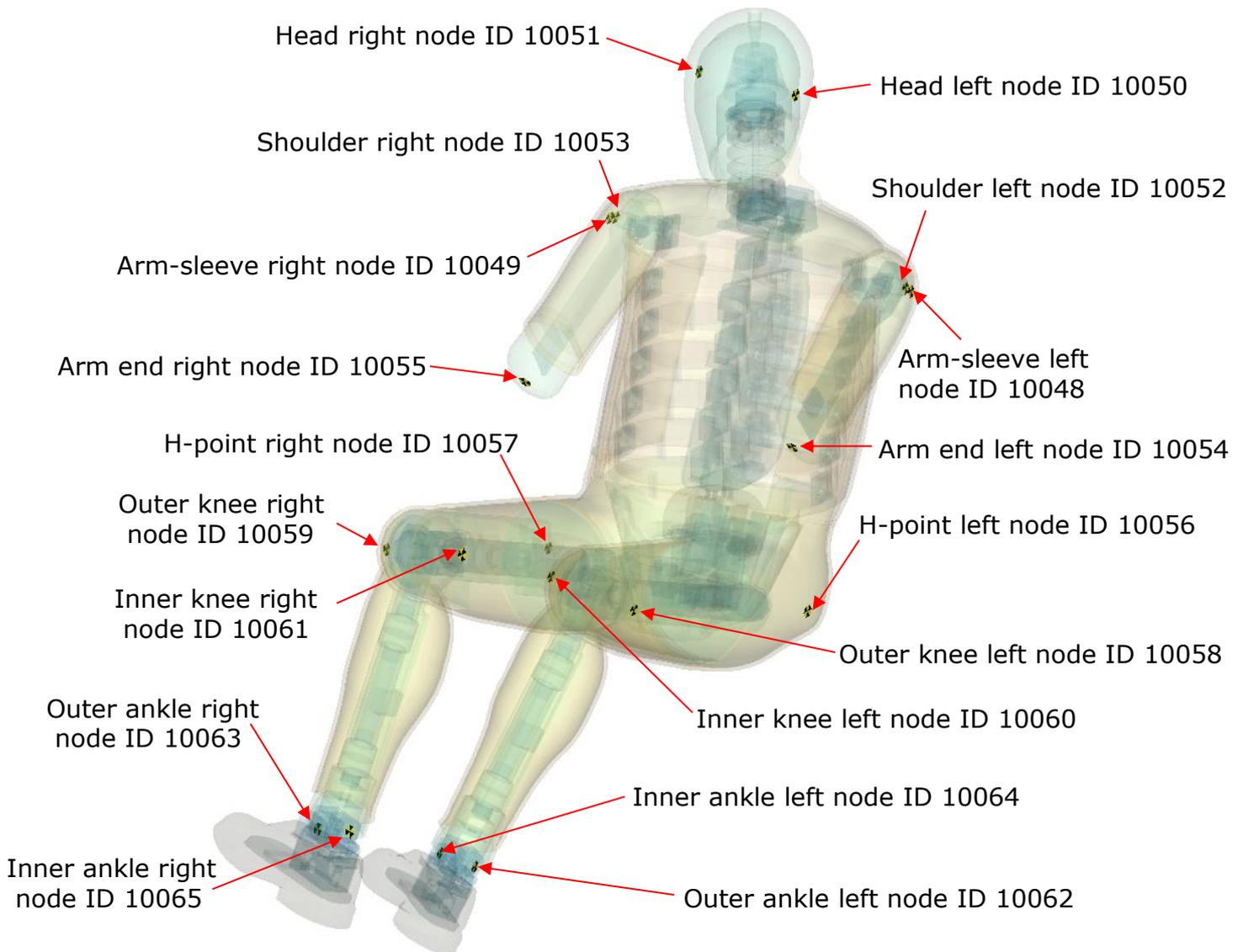
On the reverse side of impact (right hand side for the left handed driver model) the accelerometer nodes are:

Item	Node-ID	Label	Available components
shoulder rib	10020	SHRIRI00WSAC	local x-,y-,z- acceleration
1. thorax rib	10021	THRIRI01WSAC	local x-,y-,z- acceleration
2. thorax rib	10022	THRIRI02WSAC	local x-,y-,z- acceleration
3. thorax rib	10023	THRIRI03WSAC	local x-,y-,z- acceleration
1. abdomen rib	10024	ABRIRI01WSAC	local x-,y-,z- acceleration
2. abdomen rib	10025	ABRIRI02WSAC	local x-,y-,z- acceleration

**Table 14:** Rib accelerometer nodes on the side of impact

### 2.2.5 Marker evaluation

From WorldSID 50<sup>th</sup> v5.0, the model provide evaluation of marker. The Figure 6 depicts the nodes which are used as output nodes in the NODOUT file for marker in global system.



**Figure 6:** Nodes for evaluation of marker

The nodes' list is:

Item	Node-ID	Label	Available components
marker sleeve-shoulder left	10048	SLEELEMAWSAC	global node output
marker sleeve-shoulder right	10049	SLEERIMAWSAC	global node output
marker head left	10050	HEADLEMAWSAC	global node output
marker head right	10051	HEADRIMAWSAC	global node output
marker arm-shoulder left	10052	SHLDLEMAWSAC	global node output
marker arm-shoulder right	10053	SHLDRIMAWSAC	global node output
marker arm end left	10054	ARMOLEMAWSAC	global node output
marker arm end right	10055	ARMORIMAWSAC	global node output
marker H-point left	10056	PELVLEMAWSAC	global node output
marker H-point right	10057	PELVRIMAWSAC	global node output
marker outer knee left	10058	KNEELEMOWSAC	global node output
marker outer knee right	10059	KNEERIMOWSAC	global node output
marker inner knee left	10060	KNEELEMIWSAC	global node output
marker inner knee right	10061	KNEERIMIWSAC	global node output
marker outer ankle left	10062	ANKLLEMOWSAC	global node output
marker outer ankle right	10063	ANKLRIMOWSAC	global node output
marker inner ankle left	10064	ANKLLEMIWSAC	global node output
marker inner ankle right	10065	ANKLRIMIWSAC	global node output

**Table 15:** Marker evaluation nodes list

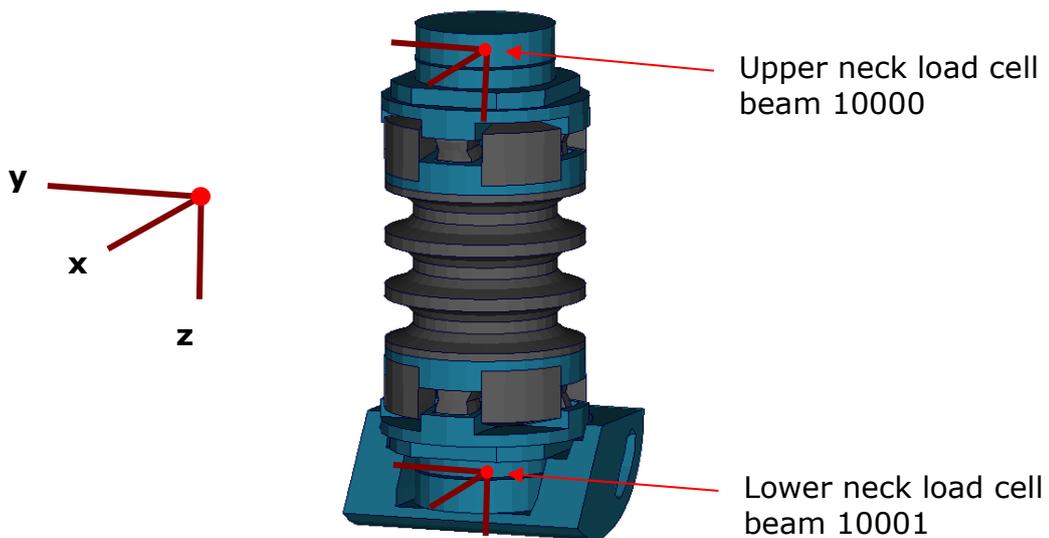
## 2.3 Load cells

All load cells in the model are defined in the same way beside spherical joint hip global force. They are modeled using a discrete beam in combination with a local coordinate system. The results of the discrete beam are printed in the ELOUT file with respect to the local coordinate system. The local axes to evaluate the results of the beam are listed in Table 16.

Item	Component in elout file
local x-force	axial
local y-force	shear-s
local z-force	shear-t
local x-moment	torsion
local y-moment	moment-s
local z-moment	moment-t

**Table 16:** Components of ELOUT file for evaluating load cell results

### 2.3.1 Upper and lower neck load cell



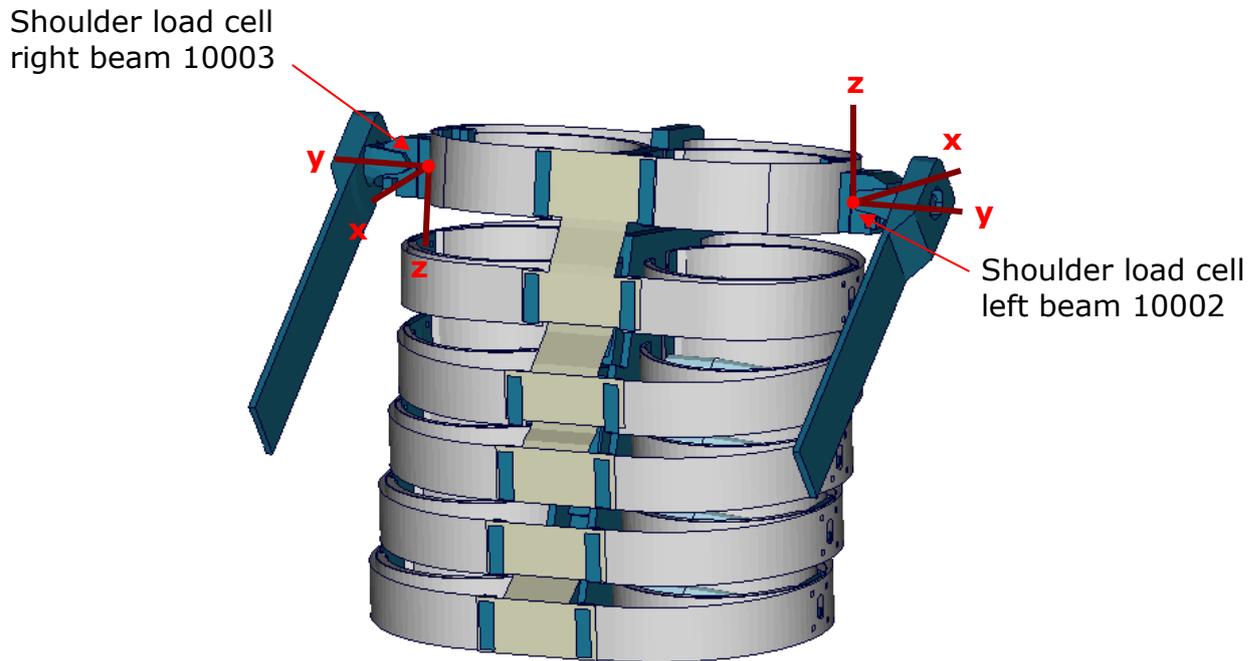
**Figure 7:** Upper and lower neck load cells

Item	Beam-ID	Label	Channels in physical dummy
Upper neck load cell	10000	NECKUP00WS	six-channel load cell
Lower neck load cell	10001	NECKLO00WS	six-channel load cell

**Table 17:** Upper and lower neck load cell beams

The neck load cells are six-channel load cells. This means that the forces and the moments in each direction of axis can be evaluated in the hardware.

### 2.3.2 Shoulder load cell left and right



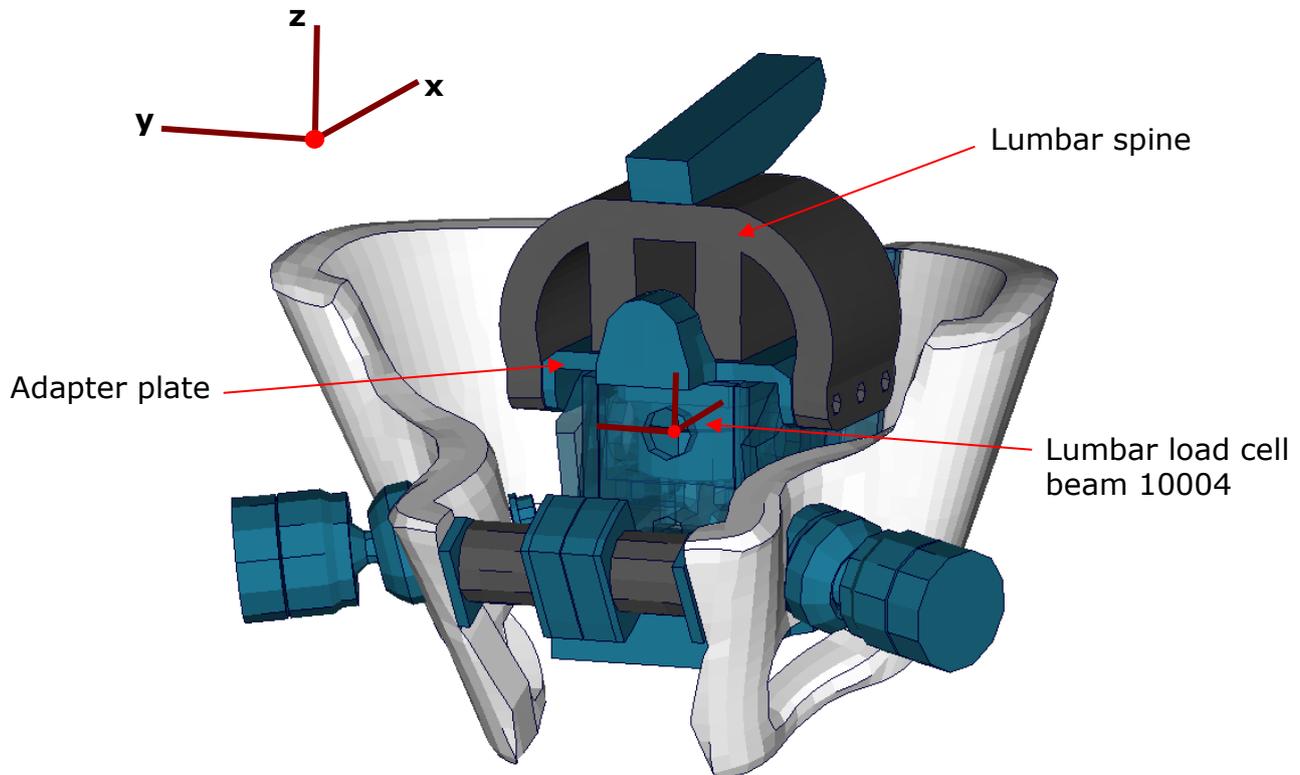
**Figure 8:** Shoulder load cells, left and right.

Item	Beam-ID	Label	Channels in physical dummy
Left shoulder load cell	10002	SHLDLE00WS	three-channel load cell
Right shoulder load cell	10003	SHLDRI00WS	three-channel load cell

**Table 18:** Shoulder load cell beams, left and right hand side

The shoulder load cells are three-channel load cells. This means that the forces in each direction of axis can be evaluated in the hardware.

### 2.3.3 Lumbar load cell



**Figure 9:** Lumbar load cell in Sacrum block

The lumbar load cell is adapted into the sacrum block. The load cell is connected to the adapter plate and the lumbar spine is connected on this adapter plate.

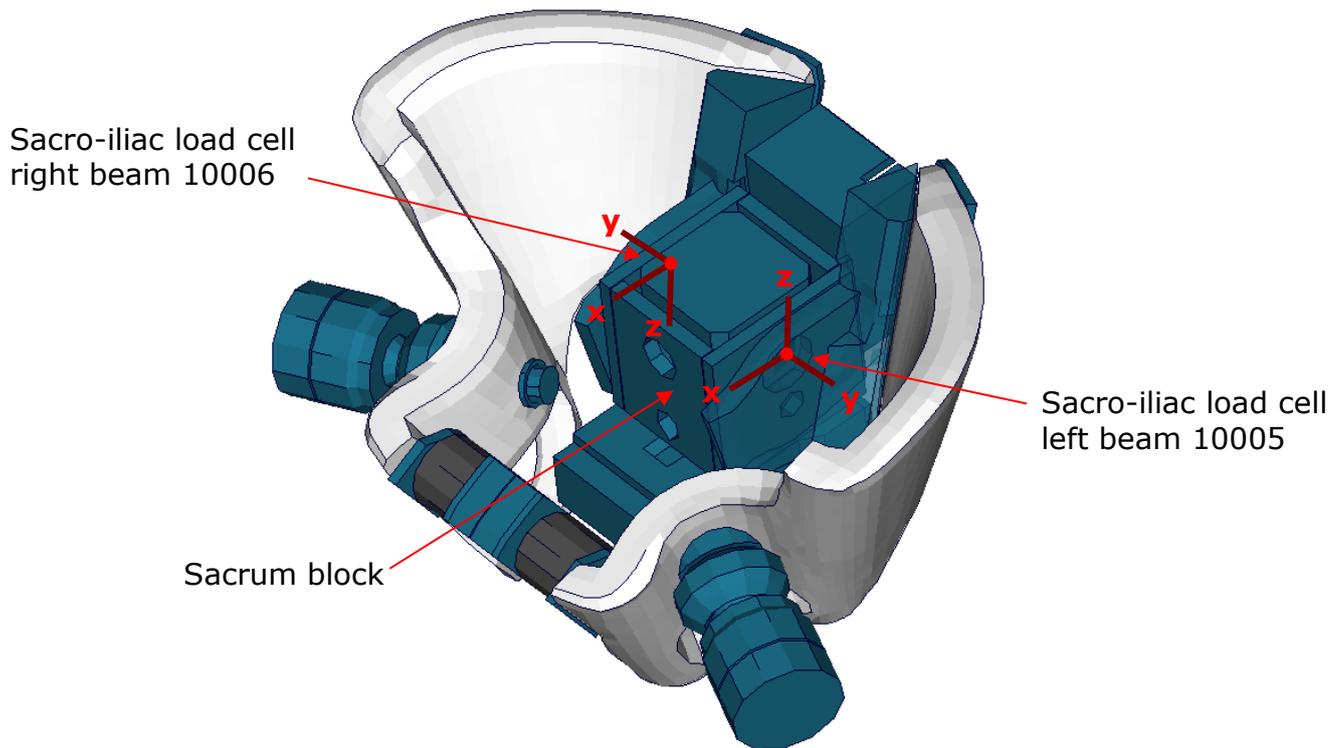
Item	Beam-ID	Label	Channels in physical dummy
Lumbar load cell	10004	LUSP0000WS	six-channel load cell

**Table 19:** Lumbar load cell beam

The lumbar load cell is a six-channel load cell. This means that the forces and the moments in each direction of axis can be evaluated in the hardware.

### 2.3.4 Sacro-iliac load cells

The Sacro-iliac load cells are positioned on the left and right hand side of the sacrum block. They are used to measure the forces and moments which come from the pelvis bones into the sacrum block. The load cells are shown in the figure.



**Figure 10:** Sacro-iliac load cells, left and right hand side

Item	Beam-ID	Label	Channels in physical dummy
Sacro-iliac load cell left hand side	10005	SACRLE00WS	six-channel load cell
Sacro-iliac load cell right hand side	10006	SACRRI00WS	six-channel load cell

**Table 20:** Sacro-iliac load cell beams

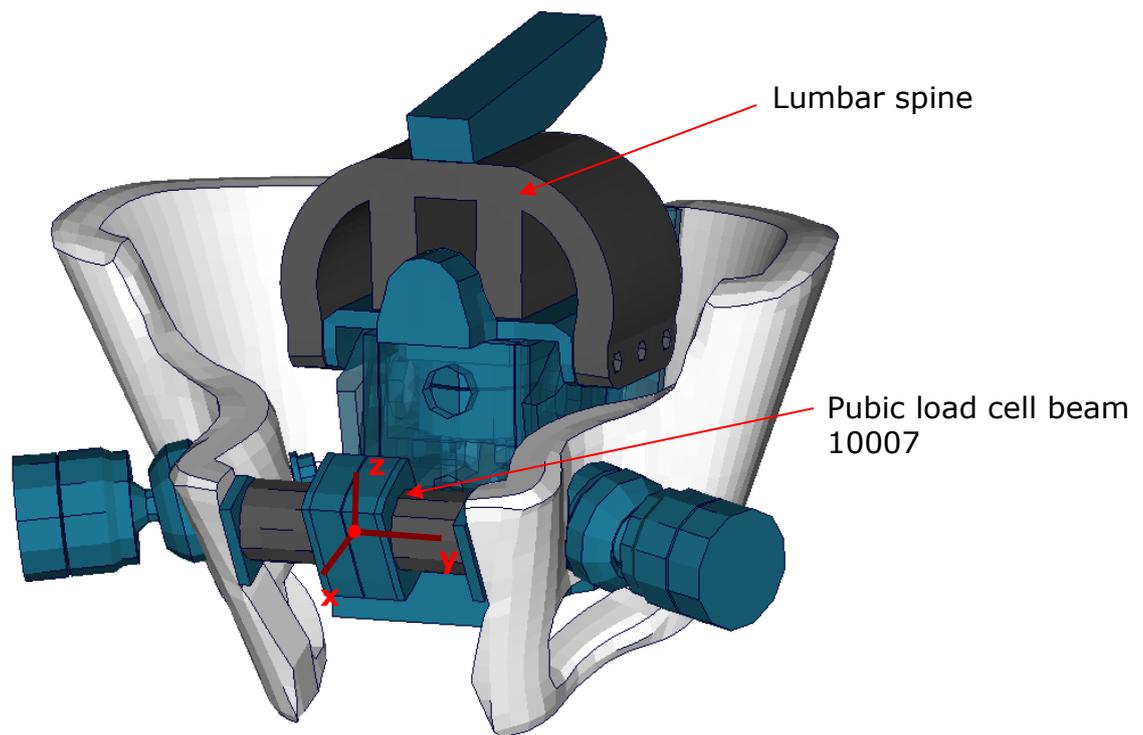
The sacro-iliac load cells are six-channel load cells. This means that the forces and the moments in each direction of axis can be evaluated in the hardware.

### 2.3.5 Pubic symphysis load cell

Item	Beam-ID	Label	Channels in physical dummy
Pubic symphysis load cell	10007	PUBC0000WS	one-channel load cell

**Table 21:** Pubic symphysis load cell beam

The pubic load cell is a one-channel load cell. This means that only the force in the local y-direction can be evaluated in the hardware.



**Figure 11:** Pubic load cell adapted to pelvis bones

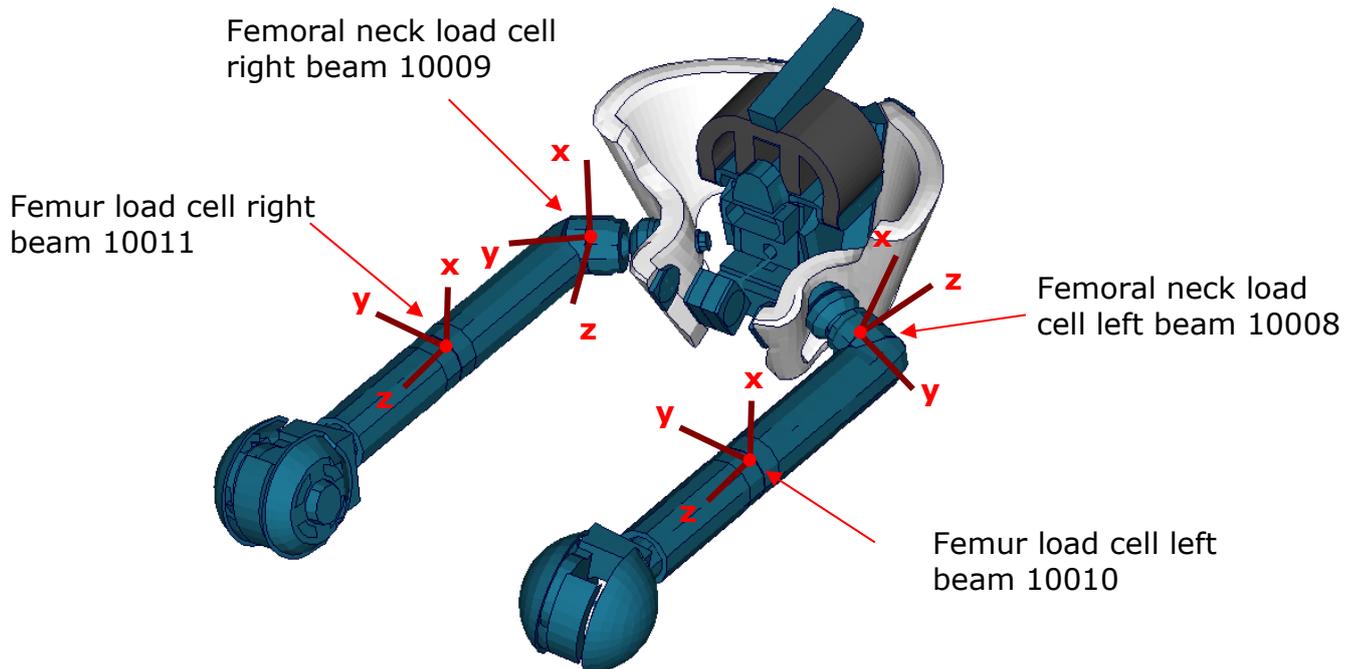
### 2.3.6 Femoral load cells

The upper legs of the WorldSID are equipped with four load cells: at the femoral neck of the left and right hand side, and in the middle of the left and right hand side femur.

Item	Beam-ID	Label	Channels in physical dummy
Femoral neck load cell left hand side	10008	FEACLE00WS	three-channel load cell
Femoral neck load cell right hand side	10009	FEACRI00WS	three-channel load cell
Femur load cell left hand side	10010	FEMRLE00WS	six-channel load cell
Femur load cell right hand side	10011	FEMRRI00WS	six-channel load cell

**Table 22:** Femoral load cell beams

The results of the load cells can be extracted as described in the following Table. The exact location of the load cells is shown in the figure below:



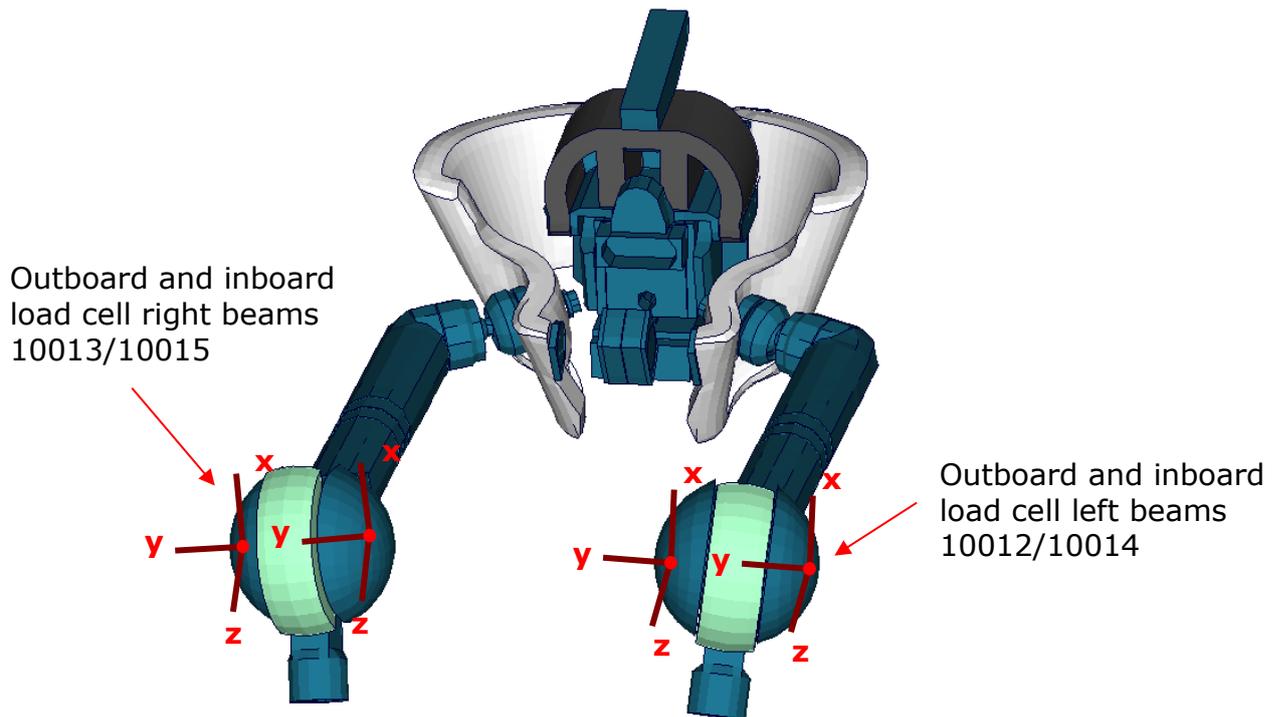
**Figure 12:** Upper and lower femur load cells

### 2.3.7 Knee load cells

The knee load cells can be used to determine the contact times. The load cells in the hardware are only one channel load cells.

Item	Beam-ID	Label	Channels in physical dummy
outboard knee load cell left	10012	KNEELEOUWS	one-channel load cell
outboard knee load cell right	10013	KNEERIOUWS	one-channel load cell
inboard knee load cell left	10014	KNEELEINWS	one-channel load cell
inboard knee load cell right	10015	KNEERIINWS	one-channel load cell

**Table 23:** Knee load cell beams



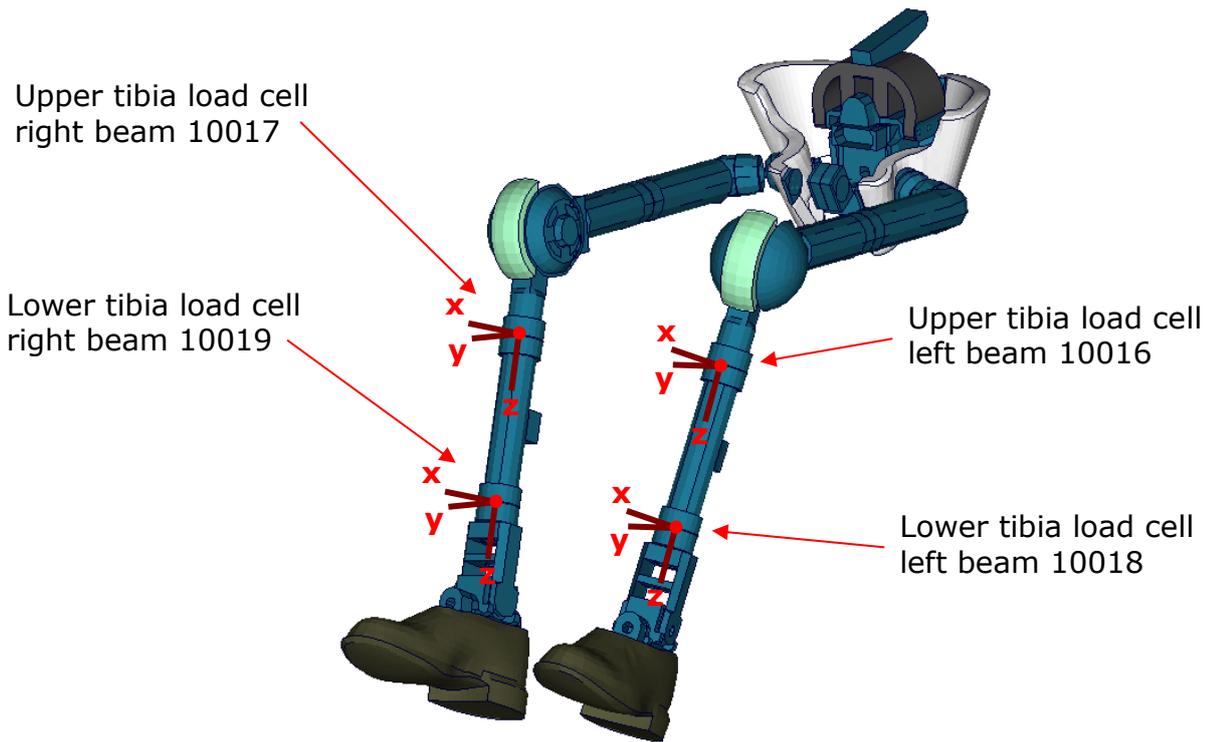
**Figure 13:** Knee load cell beams

### 2.3.8 Tibia load cells

The tibias are also equipped with four load cells. Each tibia consists of two load cells, in the upper and the lower tibia. They are listed in the Table 24. The location of the load cells is depicted in the figure below:

Item	Beam-ID	Label	Channels in physical dummy
Upper tibia load cell left	10016	TIBILEUPWS	six-channel load cell
Upper tibia load cell right	10017	TIBIRIUPWS	six-channel load cell
Lower tibia load cell left	10018	TIBILELOWS	six-channel load cell
Lower tibia load cell right	10019	TIBIRILOWS	six-channel load cell

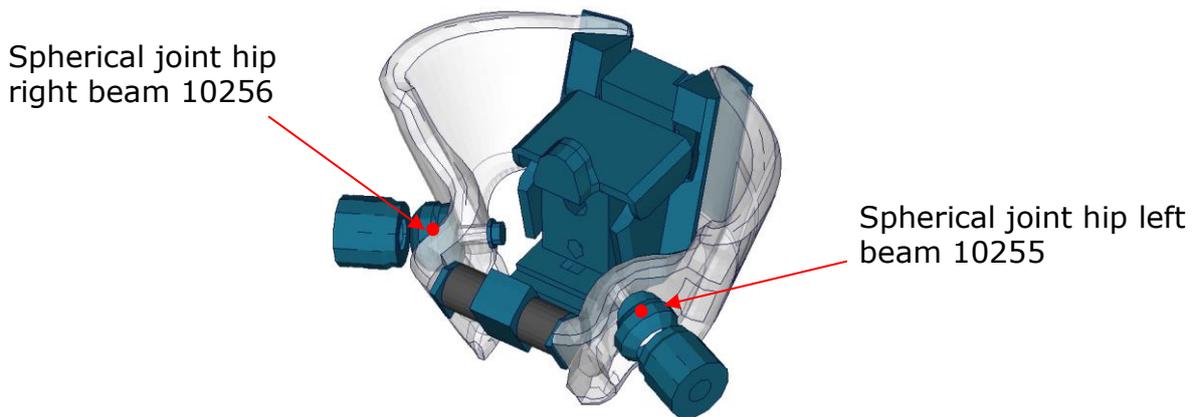
**Table 24:** Tibia load cell beams, left and right hand side



**Figure 14:** Tibia load cell beams

### 2.3.9 Spherical joint hip global force

The global force of the spherical joint hip left and right are new force and moment signals for WorldSID v5.0 in global coordinate system by beam 10255 and 10256.



**Figure 15:** Spherical joint hip global force beams

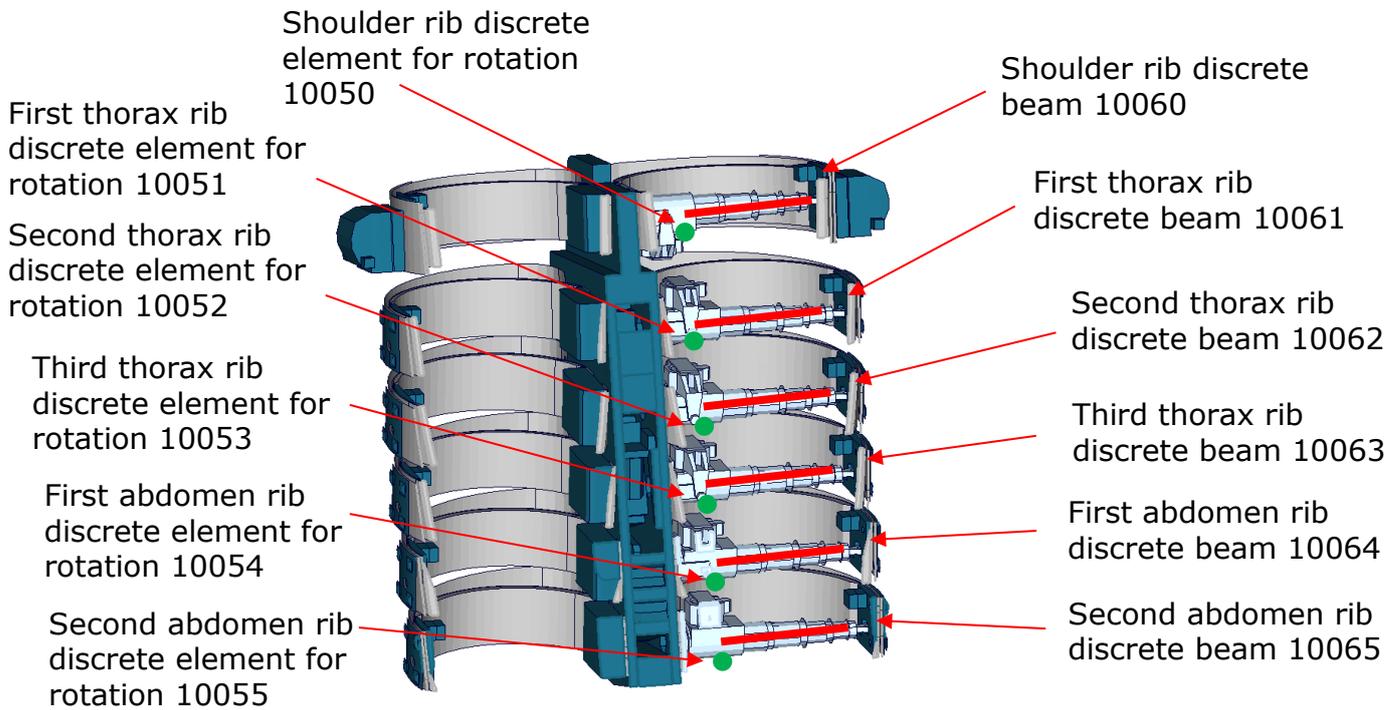
Item	Beam-ID	Label	Available components
Spherical joint hip left	10255	HIPJLE00WS	global force and moment
Spherical joint hip right	10256	HIPJRI00WS	global force and moment

**Table 25:** Spherical joint hip global force beams, left and right hand side

## 2.4 Deflections and rotations

In the WorldSID model, it is possible to measure deflections and also rotations of some parts. Therefore discrete elements, which have no stiffness, are used. The elements are only used for the purpose of measurement and do not influence the results of the model. The output of these elements is included in the DEFORC file. From the hardware SBL E1 the WorldSID is equipped with the 2D IR-TRACCs, i.e. the deflection and the rotation of the rib is measured. The LS-DYNA WorldSID v5.0 model offers the 2D IR-TRACC measurement devices.

### 2.4.1 Rib deflections 2D (from hardware SBL E1)



**Figure 16:** Cut through upper torso and location of rib deflection measurement springs

Item	Discrete beam-ID	Label	Available components
shoulder rib	10060	SHRILE00WSDS0	change in length
1. thorax rib	10061	TRRILE01WSDS0	change in length
2. thorax rib	10062	TRRILE02WSDS0	change in length
3. thorax rib	10063	TRRILE03WSDS0	change in length
1. abdomen rib	10064	ABRILE01WSDS0	change in length
2. abdomen rib	10065	ABRILE02WSDS0	change in length

**Table 26:** Rib deflection measurement using discrete elements (2D IR-TRACCs)

Item	Discrete beam-ID	Label	Available components
shoulder rib	10050	SHRILE00WSANZ	rotation
1. thorax rib	10051	TRRILE01WSANZ	rotation
2. thorax rib	10052	TRRILE02WSANZ	rotation
3. thorax rib	10053	TRRILE03WSANZ	rotation
1. abdomen rib	10054	ABRILE01WSANZ	rotation
2. abdomen rib	10055	ABRILE02WSANZ	rotation

**Table 27:** Rib rotation measurement using discrete elements (2D IR-TRACCs)

For EuroNCAP evaluation the local x- and y- deflections in respect to the spine box is calculated by an equation.

In simulation model we also added possibility to evaluate the local x- and y- deflections directly from the nodout file. Therefore the following Nodes are defined:

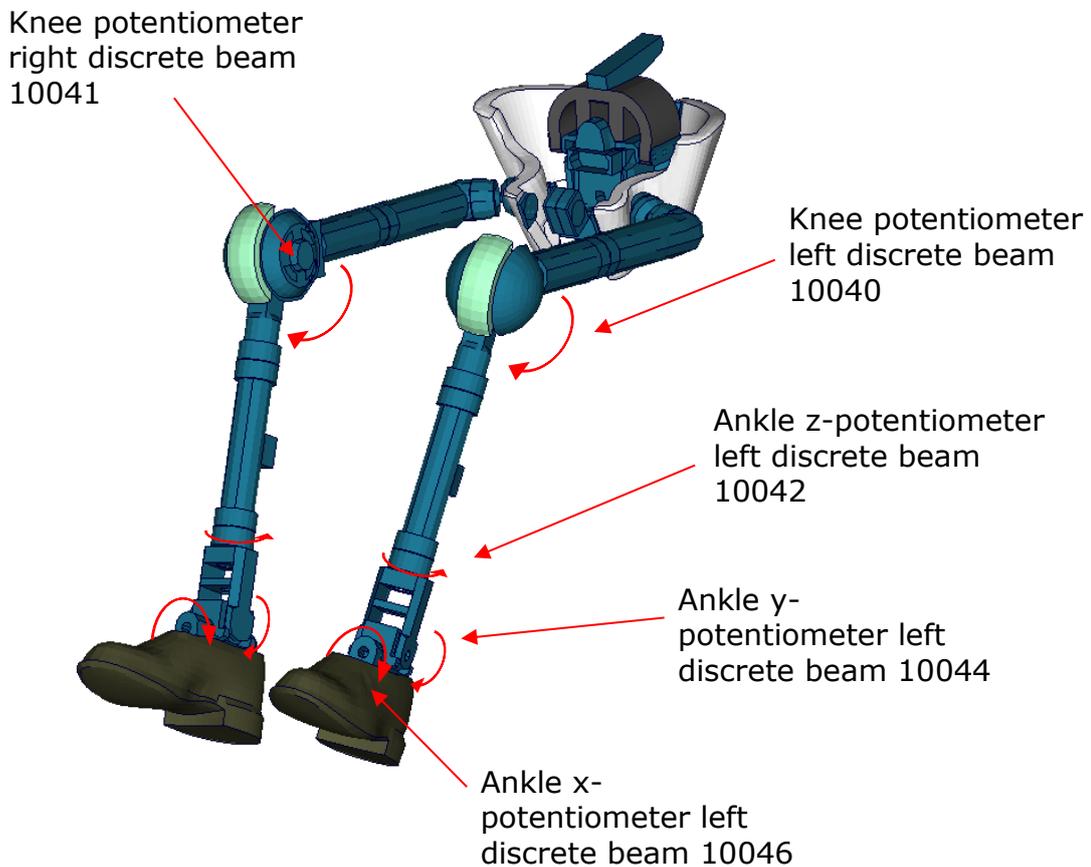
Item	Node-ID	Label	Available components
shoulder rib	10751	shoulder rib deformation Local X/Y/Z	x-, y-, z-displacement
1. thorax rib	10752	1 thorax rib deformation Local X/Y/Z	x-, y-, z-displacement
2. thorax rib	10753	2 thorax rib deformation Local X/Y/Z	x-, y-, z-displacement
3. thorax rib	10754	3 thorax rib deformation Local X/Y/Z	x-, y-, z-displacement
1. abdomen rib	10755	1 abdomen rib deformation Local X/Y/Z	x-, y-, z-displacement
2. abdomen rib	10756	2 abdomen rib deformation Local X/Y/Z	x-, y-, z-displacement

**Table 28:** Rib local measurements in respect to Torso using nodout (2D IR-TRACCs)

The results of these nodes should give the same output than calculation the local deflections from resultant deflection and rotation of 2D IR-TRACCs.

### 2.4.2 Knee and ankle rotation

The WorldSID also offers the possibility to measure the relative rotations between the upper legs and the lower legs and also between the lower legs and the feet. Therefore discrete elements are additionally used to measure these rotations. The location of the elements in the model is depicted in the following figure.



**Figure 17:** Location of rotation measurement discrete beams in the WorldSID model

Item	Discrete beam-ID	Label	Available components
knee potentiometer y-rotation left	10040	KNEELE00WSANY	rotation
knee potentiometer y-rotation right	10041	KNEERI00WSANY	rotation
ankle potentiometer z-rotation left	10042	ANKLLE00WSANZ	rotation
ankle potentiometer z-rotation right	10043	ANKLRI00WSANZ	rotation
ankle potentiometer y-rotation left	10044	ANKLLE00WSANY	rotation
ankle potentiometer y-rotation right	10045	ANKLRI00WSANY	rotation
ankle potentiometer x-rotation left	10046	ANKLLE00WSANX	rotation
ankle potentiometer x-rotation right	10047	ANKLRI00WSANX	rotation

**Table 29:** Knee and ankle rotation measurement discrete beams

## 2.5 IR-TRACCs length and relative rotation

In the WorldSID model from version 5.0, it is possible to measure the length and relative rotation of IR-TRACCs.

These are measured by key word  
 CONSTRAINED\_JOINTSTIFFNESS\_TRANSLATIONAL\_TITLE and  
 CONSTRAINED\_JOINTSTIFFNESS\_GENERALIZED\_TITLE.

For evaluating signals of length use the output of the jntforc File. Then use type 0 and evaluate y- displacement.

For evaluating signals of relative rotation use the output of the jntforc File. Then use type 1 and evaluate z- displacement.

Some post processors show different component output name. In this case evaluate as follows:

For CONSTRAINED\_JOINTSTIFFNESS\_TRANSLATIONAL:  
 theta\_degree = y-displacement, length of 2D IR-TRACCs

For CONSTRAINED\_JOINTSTIFFNESS\_GENERALIZED:  
 psi\_degree = z-displacement, relative rotation degree of 2D IR-TRACCs

The CONSTRAINED\_JOINT\_STIFFNESS\_TRANSLATIONAL cards IDs are as follows:

ID	Title	Local direction	component
1043	IR Tracc Shoulder rib length	y-coordinate	theta_degree
1044	IR Tracc 1st Thorax rib length	y-coordinate	theta_degree
1045	IR Tracc 2nd Thorax rib length	y-coordinate	theta_degree
1046	IR Tracc 3rd Thorax rib length	y-coordinate	theta_degree
1047	IR Tracc 1st Abdomen rib length	y-coordinate	theta_degree
1047	IR Tracc 2nd Abdomen rib length	y-coordinate	theta_degree

**Table 30:** IR-TRACCs length evaluation

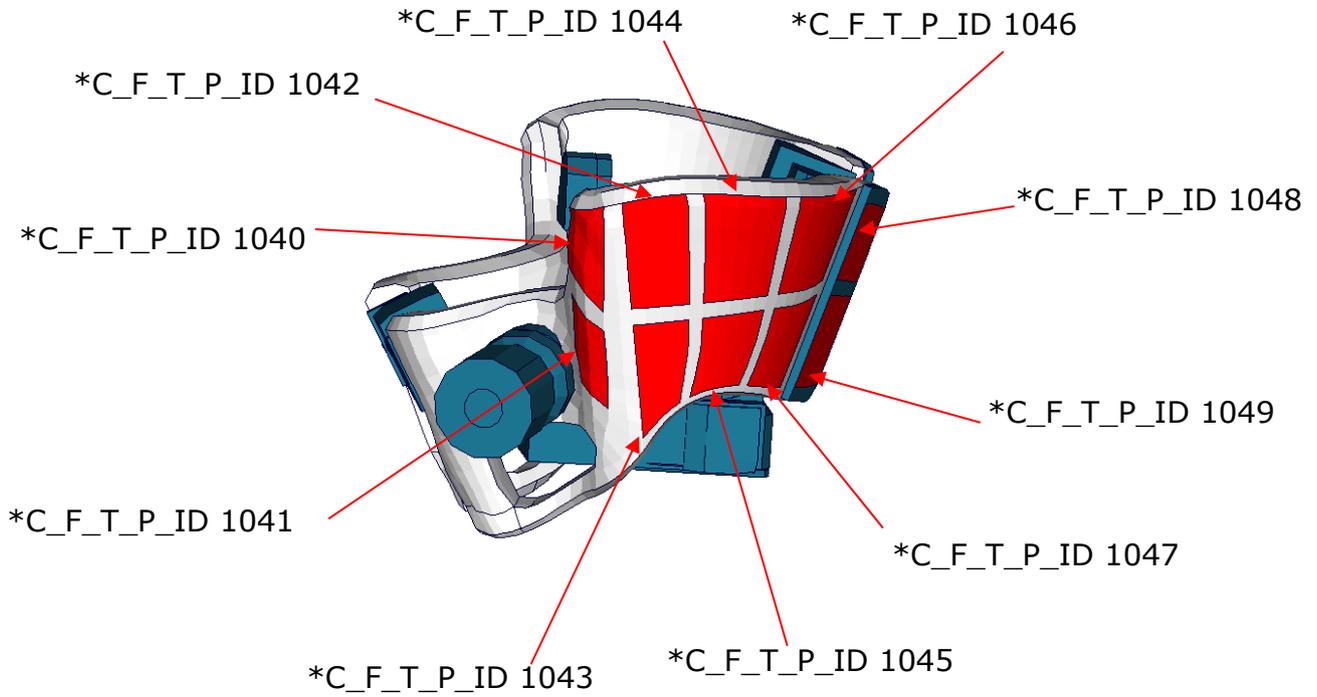
The CONSTRAINED\_JOINT\_STIFFNESS\_GENERALIZED cards IDs are as follows:

ID	Title	Local rotation's direction	component
1051	IR Tracc Shoulder rib Rotation	z-coordinate	psi_degree
1052	IR Tracc 1st Thorax rib Rotation	z-coordinate	psi_degree
1053	IR Tracc 2nd Thorax rib Rotation	z-coordinate	psi_degree
1054	IR Tracc 3rd Thorax rib Rotation	z-coordinate	psi_degree
1055	IR Tracc 1st Abdomen rib Rotation	z-coordinate	psi_degree
1056	IR Tracc 2nd Abdomen rib Rotation	z-coordinate	psi_degree

**Table 31:** IR-TRACCs relative rotation evaluation

## 2.6 Pelvis Force

In the WorldSID model from version 5.0, it is possible to measure the pelvis force with more details. Pelvis bone is separated into small parts for evaluations over \*CONTACT\_FORCE\_TRANSUDCER\_PENALTY\_ID. The small parts and \*C\_FT\_P\_ID are show in the following figure.



**Figure 18:** Pelvis bone is separated into small parts for evaluations

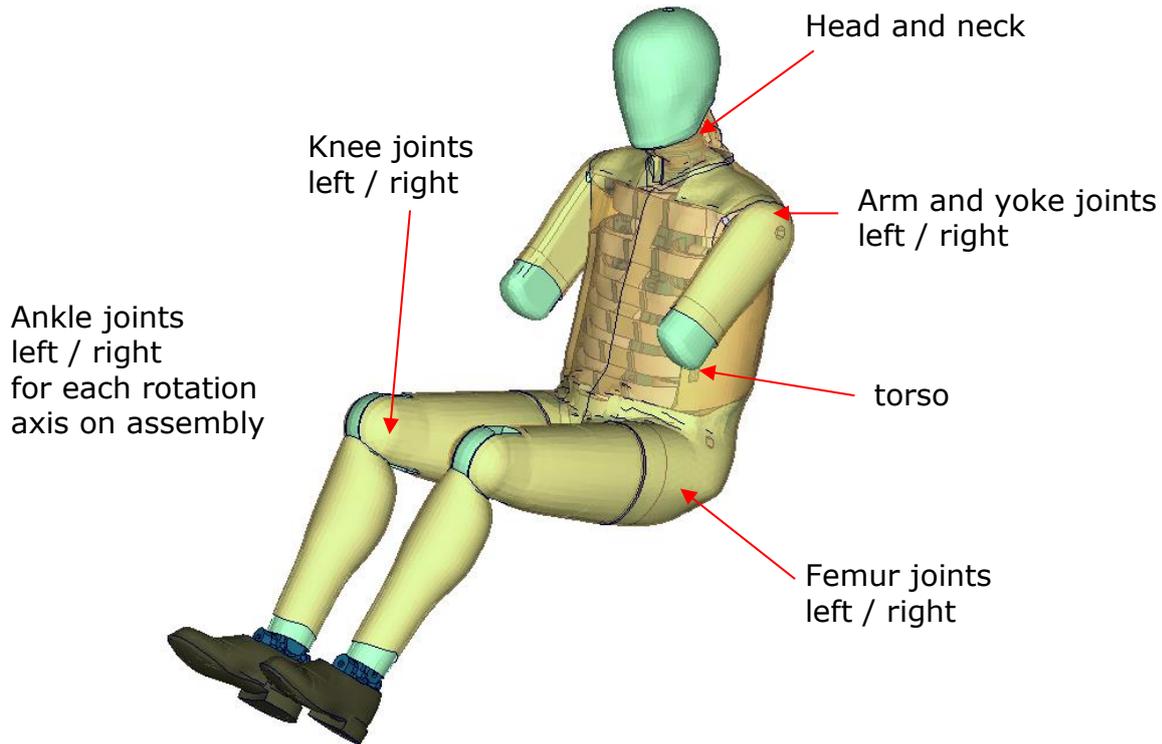
Item	C_F_T_P_ID	Label	Available components
Pelvis Force	1040	pelvis bone force left - upper front	global contact force x-,y-,z-, resultant ;
Pelvis Force	1041	pelvis bone force left - lower front	global contact force x-,y-,z-, resultant ;
Pelvis Force	1042	pelvis bone force left - upper side forward	global contact force x-,y-,z-, resultant ;
Pelvis Force	1043	pelvis bone force left - lower side forward	global contact force x-,y-,z-, resultant ;
Pelvis Force	1044	pelvis bone force left - upper side middle	global contact force x-,y-,z-, resultant ;
Pelvis Force	1045	pelvis bone force left - lower side middle	global contact force x-,y-,z-, resultant ;
Pelvis Force	1046	pelvis bone force left - upper side rear	global contact force x-,y-,z-, resultant ;
Pelvis Force	1047	pelvis bone force left - lower side rear	global contact force x-,y-,z-, resultant ;
Pelvis Force	1048	pelvis bone force left - connection plate - upper	global contact force x-,y-,z-, resultant ;
Pelvis Force	1049	pelvis bone force left - connection plate - lower	global contact force x-,y-,z-, resultant ;

**Table 32:** Pelvis force evaluations by \*CONTACT\_FORCE\_TRANSUDCER\_PENALTY\_ID

### 3. Incorporating the dummy into vehicle models

#### 3.1 Positioning by preprocessor

The WorldSID model is delivered with a tree file for the Primer pre-processor (may also work for ALTAIR Hypermesh, BETA CAE-Systems ANSA and LS-PrePost, not verified by DYNAmore). This allows the user to position the dummy and adjust the parts according to their degrees of freedom. The Figure below shows the connections of movable parts via tree file. All revolute joints are visualized by beams.



**Figure 19:** Tree-file assemblies of the WorldSID model.

Two coordinate systems are modelled at the H-Point of the dummy model. These coordinate systems are connected to each other by a spherical joint. One coordinate system is constrained to global directions, which means only translations are possible, rotations are disabled. The other one is connected to the dummy, thus making it possible to measure the pelvis angle of the WorldSID during the positioning simulation quickly and easily. These coordinate systems are also used to determine the initial pelvis angle with Primer.

Movable parts and revolute joints are:

assembly	stop angles
Foot, left and right about their ankle joints local z-axis	stop angle: -29.0 and 29.0 degrees
Lower leg, left and right about their knee joints: local y-axis	stop angle: -0.1 and 145.0 degrees
Upper leg bone, left and right about hip joint: local x-axis	no stop angle
local y-axis	no stop angle
local z-axis	no stop angle
Torso	no stop angle
Head and neck	no stop angle

Upper arm	no stop angle
Yoke	no stop angle

**Table 33:** Movable parts of WorldSID by a pre-processor

The stop angles of the feet and the knees are adjusted to the physical range of motion of the individual components.

However it might be possible that some pre-processors do not support the stop function of this tree-file structure. In this case, initial penetrations can occur if the upper legs are rotated at the hip joints beyond the values given in Table 33. 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.

The arms cannot be rotated in a pre-processor, because the jacket has to be deformed when the arms rotate. Here we recommend a pre-simulation to rotate the arm in the desired position.

The WorldSID V5.0 or high version model is also delivered with a MECHANISM in Primer for the position of 2D IR-TRACCs. This allows the user to position the 2D IR-TRACCs and adjust the parts according to their degrees and displacements freedom. This MECHANISM work for pre-processor (Primer, ALTAIR Hypermesh, BETA CAE-Systems ANSA...).

### 3.2 Positioning by pre-simulation

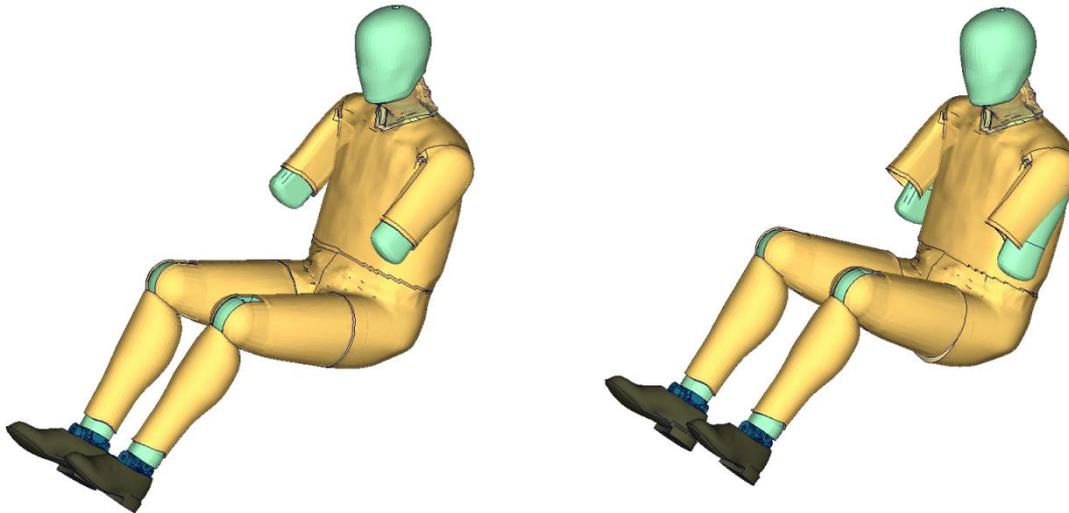
For the WorldSID v4.0 DYNAmore developed a new positioning pre-simulation procedure. The basic idea for this was to improve and simplify the usability of the dummy model. There are only a few steps necessary to achieve a correct positioned and ready-to-run WorldSID dummy model.

For the WorldSID v5.0 DYNAmore provide a new positioning pre-simulation procedure for 2D IR-TRACCs and optional thickness of damping material of thorax rib.

## **The procedure of positioning must be carried out strict as followed step:**

The first step is to choice an optional thickness of damping material of thorax rib. This can be done by changing the parameter & trd\_opt. Please see the detail in chapter 5.1 Release notes of WorldSID v5.0.

The second step is to adapt the posture of the dummy to your desired position besides the position of 2D IR-TRACCs in your car by using the preprocessor of your choice. You should not take care of penetrating parts and highly distorted elements. Save this dummy model to a separate file.



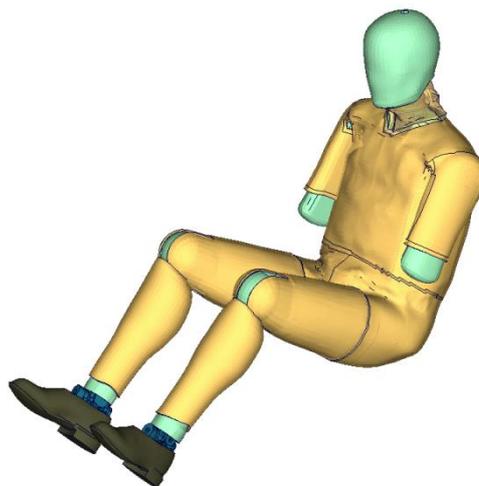
**Figure 20:** WorldSID origin position (left) and target position (right), besides 2D IR-TRACCS

The third step is to run the enclosed positioning script which is enclosed to the delivery package. The script needs the dummy model inputs of the origin and the target position. Run

```
psg_vX.X_... -d dummyinput_origin.key -t target_pos_dummy.key
```

The script generates a pre-simulation input for LS-DYNA. This one refers to the origin dummy model input (and also the license file) as a include file. The script is generating a BOUNDARY\_PRESCRIBED\_FINAL\_GEOMETRY Card for the positions of Pelvis, Torso, Head/Neck and upper legs. For all other limbs, there are generated spring and damper elements which pull the limbs in position.

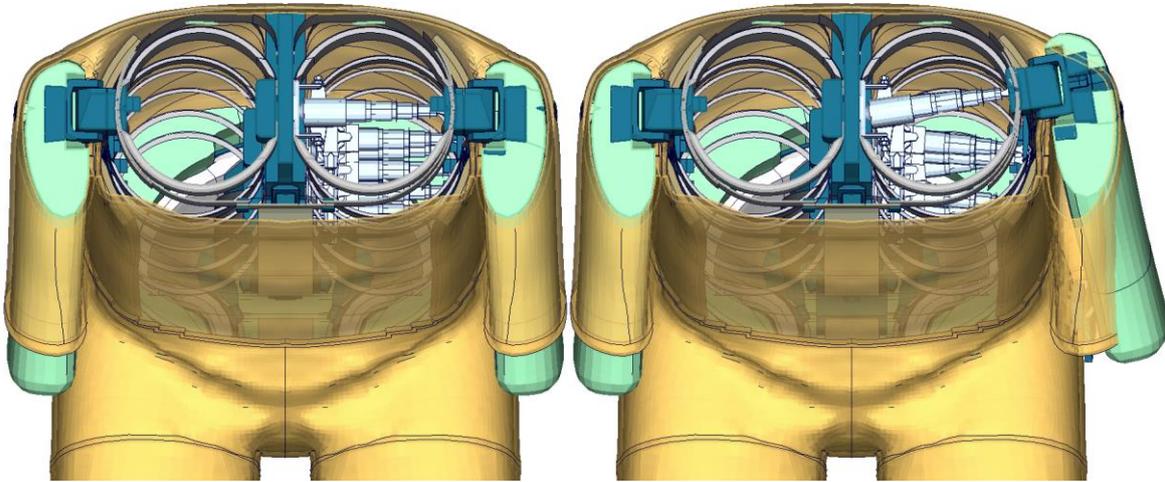
The fourth step is to run the generated input in LS-DYNA and use the results for your actual car model or the position of 2D IR-TRACCS as the initial geometry when there isn't necessary to take care about the position of 2D IR-TRACCS.



**Figure 21:** WorldSID position after pre-simulation, besides 2D IR-TRACCS

The Results can be extracted by using any post processors. Only the new nodal coordinates are needed for the new position.

The fifth step is to adapt the posture of the dummy to your desired the position of 2D IR-TRACCs in your car by using the preprocessor of your choice. The same as the second step, you should not take care of penetrating parts and highly distorted elements. Save this dummy model also to a separate file.

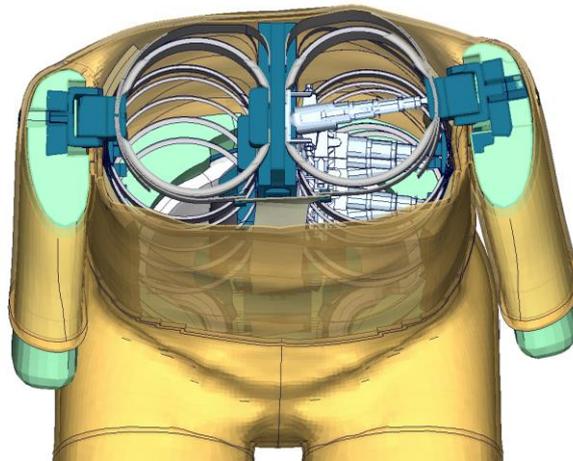


**Figure 22:** WorldSID IR-TRACCs origin position (left) and target position (right)

The sixth step is the same the third step to run the enclosed positioning script which is enclosed to the delivery package. The script needs the dummy model inputs of the origin and the target position. Run

```
psg_vX.X_... -d dummyinput_origin.key -t target_pos_dummy.key
```

The seventh step is to run the generated input from the sixth step in LS-DYNA and use the results for your actual car model as the initial geometry.



**Figure 23:** WorldSID position after 2D IR-TRACCs pre-simulation

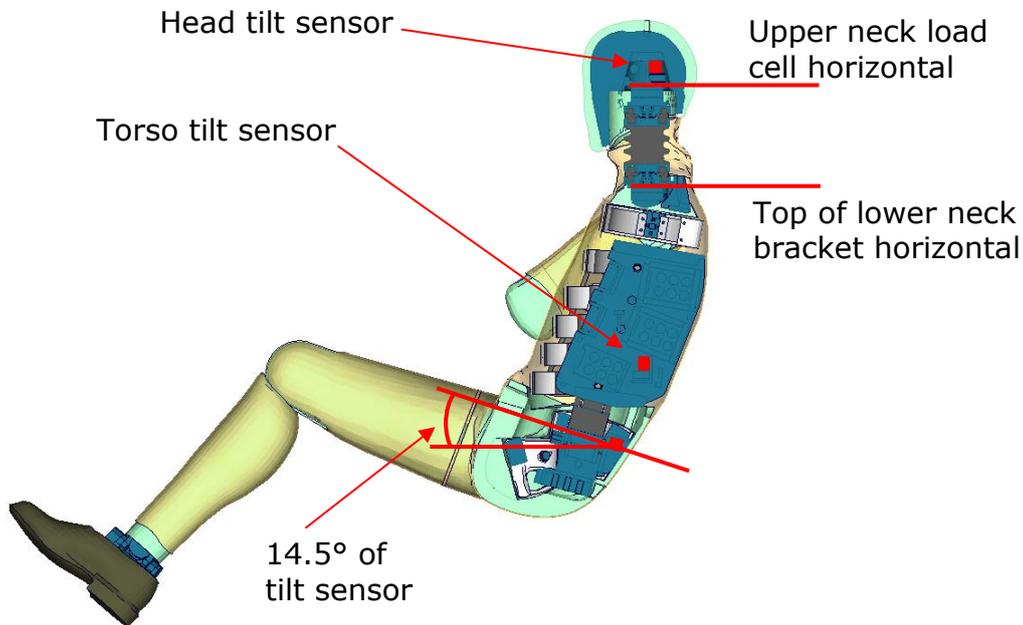
A very helpful tool to replace the nodal coordinates in the original Input is plot2coor from the DYNAmore LS-DYNA Tools. This Tool can be requested on our Webpage here:

<http://www.dynamore.de/en/products/tools>

Pretensions are automatically applied by reference geometry so you do not have to take care about this.

### 3.3 Measurement of pelvis and torso angle

The pelvis, torso and head angles are measured in the physical WorldSID by three tilt sensors. These three sensors are also included in the model. They can be used to measure the pelvis and torso angle as shown in the following figure.



**Figure 24:** Cut through WorldSID model with positions of tilt sensors

The initial position of the WorldSID model uses a pelvis angle of 14.5 degrees. For this position the H-Point tool, which is used to measure the pelvis angle without tilt sensor, has an angle of 45 degrees below the horizontal. For this pelvis angle, the torso (top of the lower neck bracket is horizontal) and head (upper neck load cell is horizontal) angle is zero degrees.

### 3.4 Numbering

- Nodes in the range of 10.000 to 11.000 are used for joints, accelerometers, ... 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, ... definitions.
- Elements with IDs above 11.000 are used only in \*ELEMENT cards.

The numbering of the material tables and load curves is defined by parameters. The default range is given in Table 4: Model numbering scheme Table 4. If the model should be renumbered all tables and load curves must be renumbered by using the parameter **wlcoff**. This parameter gives a numbering offset on all table IDs and load curve IDs.

### 3.5 Contact Definition

Please define a \*CONTACT\_AUTOMATIC\_SURFACE\_TO\_SURFACE for the contact between dummy and seat (environment). We recommend the use of the SOFT 1 option of LS-DYNA, because this option shows a high robustness for contact between very stiff and very soft components. The WorldSID properties for this contact are defined in the part set 1500.

The second part set defined in the model (Part Set ID 1501) includes all parts of the model in it. This set can be used to exclude the model out of contacts, which are defined by the use of exclude part sets.

### 3.6 Additional Remarks

- The modification of the \*CONTROL cards of the dummy file may have an 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
  - CONTROL\_MPP\_DECOMPOSITION\_ARRANGE\_PARTS
- If the CONTROL\_MPP\_DECOMPOSITION\_ARRANGE\_PARTS is erased from the model the simulation time in large models can be two or three times longer. It is strongly recommended to use this control card in MPP simulations.
  - The model should be used with a time step size of 0.9 microseconds 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, except the third beam nodes of the beam elements.
  - No mass less nodes are present in the input file of the dummy except the third beam nodes of the beam elements.
  - The model is free of initial penetrations.
  - The Version 4.0 and higher of the WorldSID provides parameters to scale the friction of the joint off all limbs. As default a 1 g adjustment of the joints is included. The user is now able to increase or decrease the friction values of the joints. The scale factors are used for the left and right hand

side assemblies. So it is not possible to scale left and right assembly different.

Parameter name	Joint
Sfarmx	Scale factor arms local x-rotation
sfarmy	Scale factor arms local y-rotation
sffemr	Scale factor upper legs all directions
sfknee	Scale factor knees
sfankl	Scale factor ankle joints all directions

**Table 34:** Parameters to scale joint friction

## 4. License file and usage

The WorldSID is distributed with a license file which uses an expiry date. The license file is sent to the user with the whole dummy package. It is a PGP encrypted part of the dummy model input and includes all load curves referenced in the WorldSID model. For the WorldSID there is a general license file for any unit system provided.

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 provided in the main WorldSID 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 should be used.

The principle structure is as follows:

Input data in the WorldSID license file:

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

$ Load Curve scale values
R wsXXXX        1.0
R wsxXXXX       1.0
```

Input of the license file:

```
*PARAMETER_EXPRESSION
I lcTABID      TABID + &wloff
R eTABID       1.0 * & wsXXXX

*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 **IN** the WorldSID model main file **AFTER** the \*PARAMETER block. If you get error messages like "missing parameter" you should check if the license file is included at the correct position in the file.

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

We recommend storing the license file of dummy models in a central place as read only. Furthermore the name of the license include should be simple like for instance

`wsid50_v5.0_all_units_server.asc.`

With a symbolic link from the current license to this name it is possible to keep older input decks running without updating the input data of them.

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

`wsid50_pdb_v5.0_all_units_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. So if you observe dummy model crashes without appreciable load you should check if you included the load-curves-work file instead of the license file.

## 5. Release Notes

### 5.1 Release notes of WorldSID v5.0

- 1D IR-TRACCs are deleted from WorldSID v5.0. 1D IR-TRACC is the old standard hardware. Rib deflection is measured by 2D IR-TRACCs right now for WorldSID 50th, both of hardware and software.
- \*CONSTRAINED\_JOINT\_STIFFNESS... of 2D IR-TRACCs are modified to deal with the blocked and NAN problem in IR-TRACCs.
- MECHANISM for IR-TRACCs are created. This is for IR-TRACCs initial position and work for pre-processor (Primer, ALTAIR Hypermesh, BETA CAE-Systems ANSA...).
- Thickness of thorax-rib's damping material is variable by parameter.

The control-parameter is &trd\_opt and located at the first place of block \*PARAMETER. There are 4 difference optional thickness for thorax-rib which can be chosen by changing the parameter &trd\_opt.

&trd\_opt == 1: The thickness of thorax rib (Damp-MAT) is 3.00mm.

&trd\_opt == 2: The thickness of thorax rib (Damp-MAT) is 3.45mm.

&trd\_opt == 3: The thickness of thorax rib (Damp-MAT) is 3.90mm.

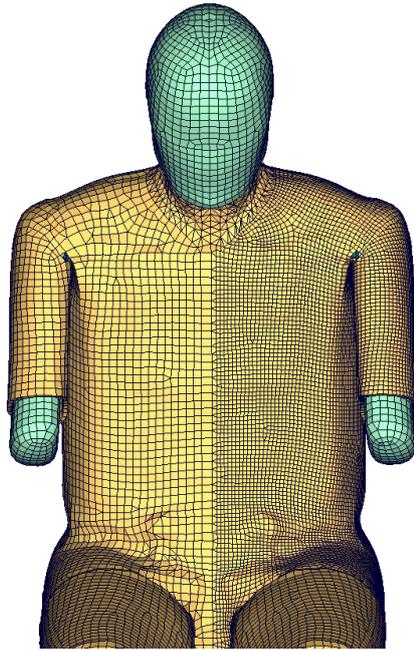
&trd\_opt == 4: The thickness of thorax rib (Damp-MAT) is 4.35mm.

Original thickness of thorax-rib's damping material is 3.00mm after calibration.

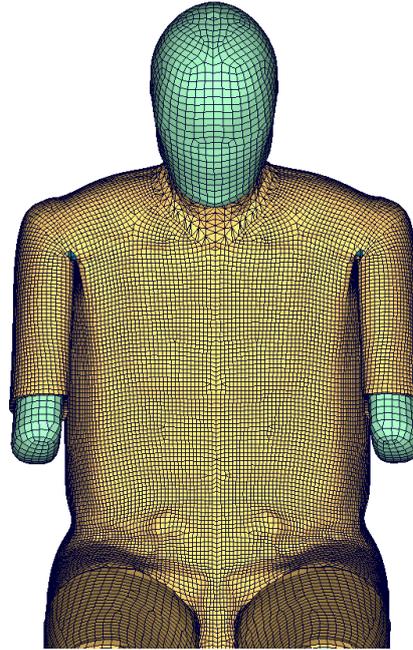
Very important comment: !!!!!

- WorldSID v5.0 is defined with control parameter of thickness of thorax-rib's damping material. The nodes ID and elements ID in WorldSID v5.0 can't be renumbered. For number crash problem and number range distribution: WorldSID v5.0 must be included by keyword \*INCLUDE\_TRANSFORM.
- WorldSID v5.0 provide the function of pre-position for 2D IR-TRACCs (rib pre-position). Before the simulation of rib pre-position, the thickness of thorax-rib's damping material must be chosen. After the simulation of rib pre-position, the control-parameter &trd\_opt can't be changed anymore, one simulation of rib pre-position according to just only one thickness of thorax-rib's damping material.
- Geometric modifications
  - Symmetry jacket, This finer jacket is optimal for EuroNCAP Far-Side simulation.

WSID v4.0

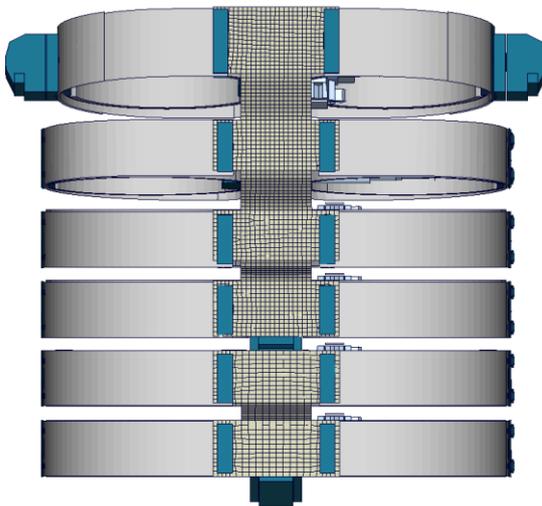


v5.0

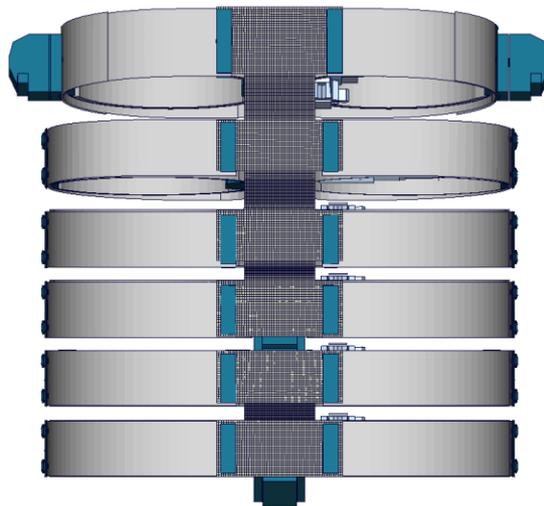


- Thorax rib coupler geometric update

WSID v4.0

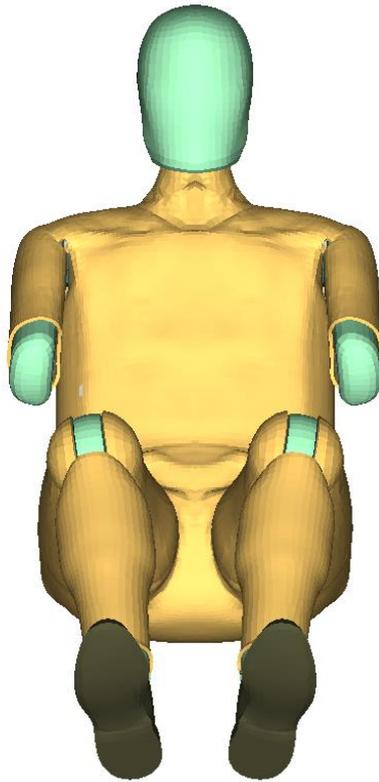


v5.0

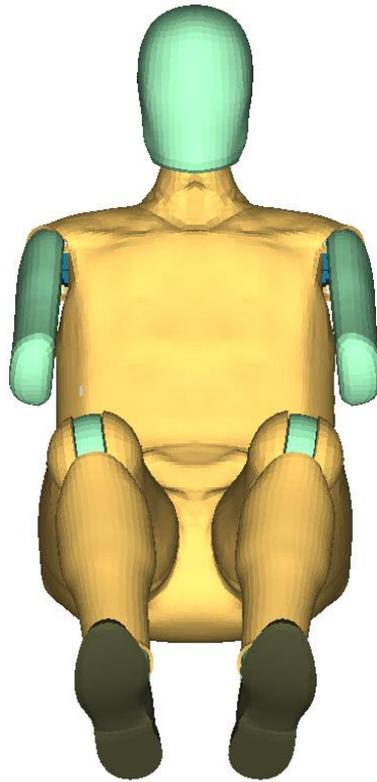


- Arm-sleeve is a include key-file in WorldSID v5.0. This can be switched very easy in dummy-key-file. Without arm-sleeve model is stander model for EuroNCAP Far-side test.

This include file is: worldSID50\_pdb\_vx.x\_arm\_sleeve\_vx.x.key



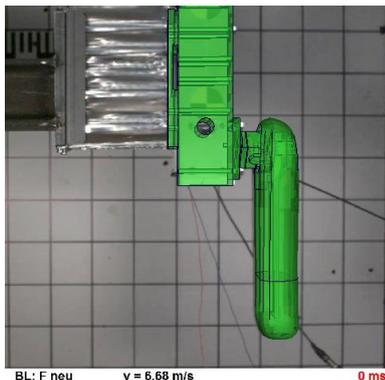
With arm-sleeve



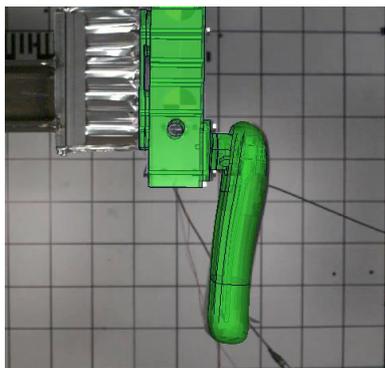
Without arm-sleeve

- Arm validation is improved. WSID v4.0 still has a relative soft half arm. The bending behavior of arm is improved in WSID v5.0. In the following a half-arm component test is shown for both versions of WorldSID:

WSID v4.0



BL: F neu v = 6,68 m/s 0 ms

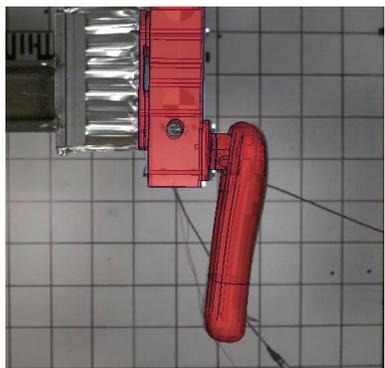


BL: F neu v = 6,68 m/s 10 ms

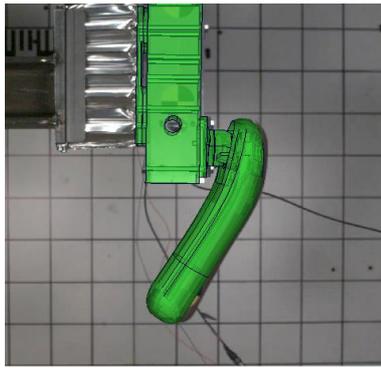
v5.0



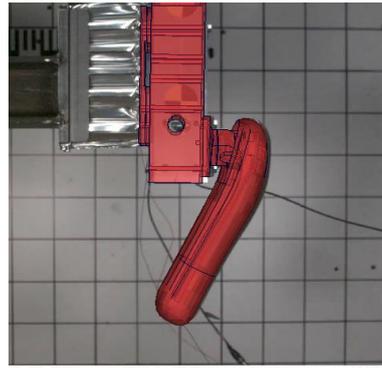
BL: F neu v = 6,68 m/s 0 ms



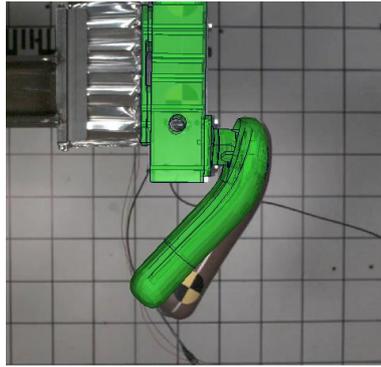
BL: F neu v = 6,68 m/s 10 ms



BL: F neu v = 6,68 m/s 20 ms



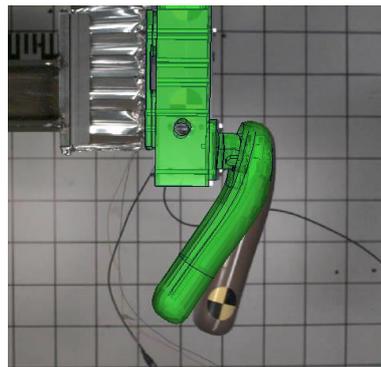
BL: F neu v = 6,68 m/s 20 ms



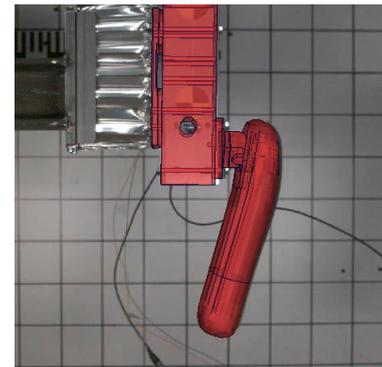
BL: F neu v = 6,68 m/s 30 ms



BL: F neu v = 6,68 m/s 30 ms



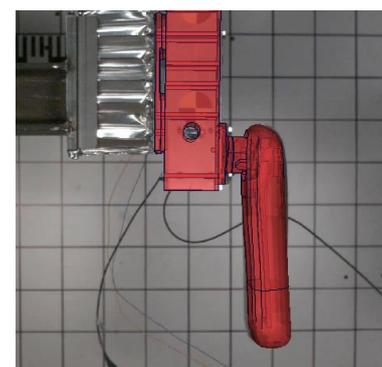
BL: F neu v = 6,68 m/s 40 ms



BL: F neu v = 6,68 m/s 40 ms



BL: F neu v = 6,68 m/s 50 ms



BL: F neu v = 6,68 m/s 50 ms

- ISO-CODE-Label are created for evaluation to instead of the old evaluation's label.
  - \*DATABASE\_HISTORY\_NODE\_ID, evaluation for acceleration or angel.

Item	Node-ID	Old Label	ISO-CODE
Head	10001	accelerometer head	HEAD0000WSAC
T1	10002	accelerometer T1	THSP0100WSAC
T4	10003	accelerometer T4	THSP0400WSAC
T12	10004	accelerometer T12	THSP1200WSAC
Pelvis	10005	accelerometer pelvis	PELV0000WSAC
Head	10006	rotational accelerometer Head	HEAD0000WSAA
Thorax	10007	rotational accelerometer Thorax	THSP0000WSAA
Pelvis	10008	rotational accelerometer Pelvis	PELV0000WSAA
shoulder rib	10010	accelerometer shoulder rib left	SHRILE00WSAC
1. thorax rib	10011	accelerometer upper thorax rib left	TRRILE01WSAC
2. thorax rib	10012	accelerometer middle thorax rib left	TRRILE02WSAC
3. thorax rib	10013	accelerometer lower thorax rib left	TRRILE03WSAC
1. abdomen rib	10014	accelerometer upper abdomen rib left	ABRILE01WSAC
2. abdomen rib	10015	accelerometer lower abdomen rib left	ABRILE02WSAC
shoulder rib	10020	accelerometer shoulder rib right	SHRIRI00WSAC
1. thorax rib	10021	accelerometer upper thorax rib right	THRIRI01WSAC
2. thorax rib	10022	accelerometer middle thorax rib right	THRIRI02WSAC
3. thorax rib	10023	accelerometer lower thorax rib right	THRIRI03WSAC
1. abdomen rib	10024	accelerometer upper abdomen rib right	ABRIRI01WSAC
2. abdomen rib	10025	accelerometer lower abdomen rib right	ABRIRI02WSAC
Tibia	10101	accelerometer tibia left	TIBILE00WSAC
Tibia	10102	accelerometer tibia right	TIBIRI00WSAC

- \*DATABASE\_HISTORY\_BEAM\_ID, evaluation for force and moment.

Item	Beam-ID	Old Label	ISO-CODE
Upper neck load cell	10000	upper neck load cell	NECKUP00WS
Lower neck load cell	10001	lower neck load cell	NECKLO00WS
Left shoulder load cell	10002	shoulder load cell left	SHLDLE00WS
Right shoulder load cell	10003	shoulder load cell right	SHLDRI00WS
Lumbar load cell	10004	lumbar load cell	LUSP0000WS
Sacro-iliac load cell left hand side	10005	sacro-iliac load cell left	SACRLE00WS
Sacro-iliac load cell right hand side	10006	sacro-iliac load cell right	SACRRI00WS
Pubic symphysis load cell	10007	pubic load cell	PUBC0000WS

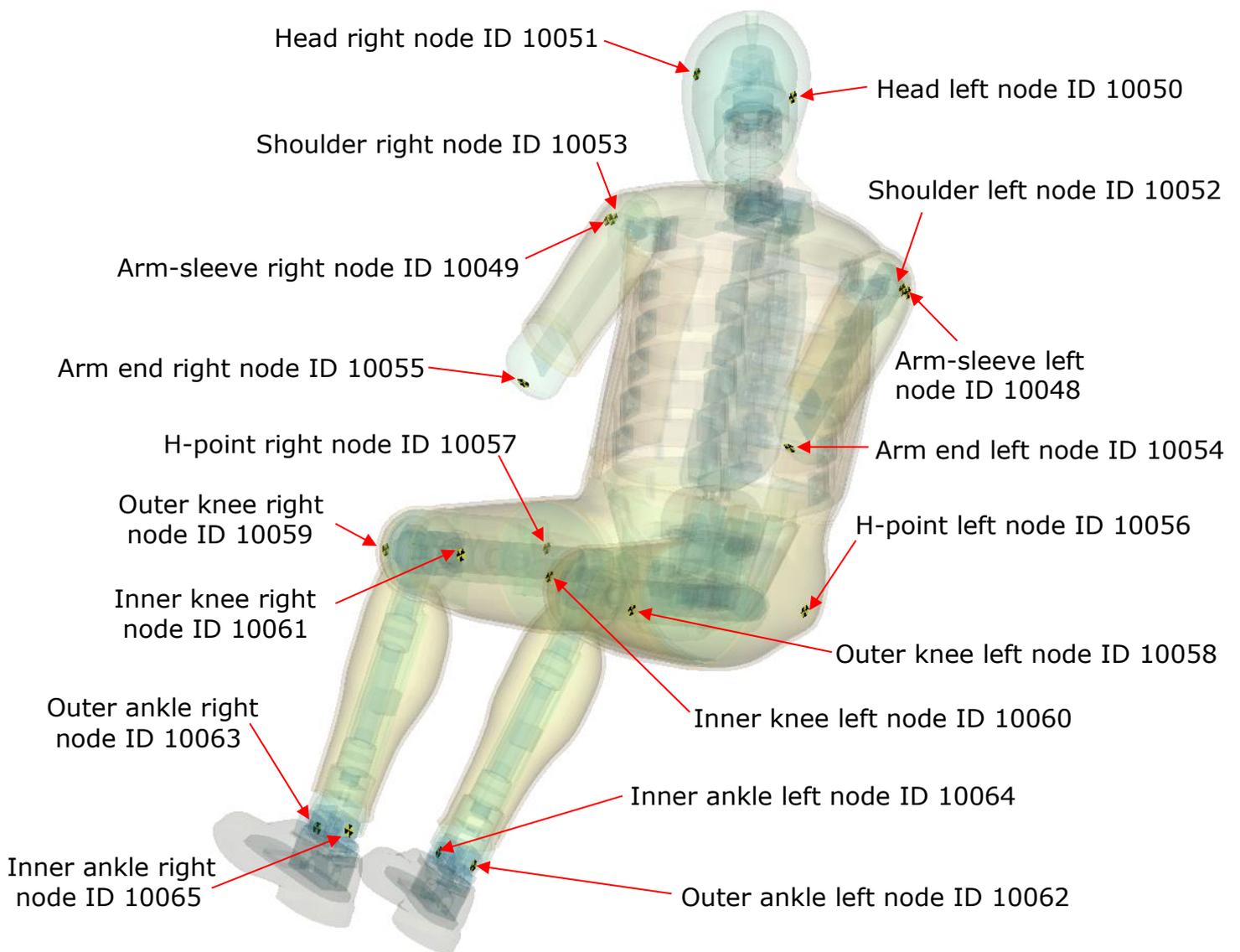
Femoral neck load cell left hand side	10008	femoral neck load cell left	FEACLE00WS
Femoral neck load cell right hand side	10009	femoral neck load cell right	FEACRI00WS
Femur load cell left hand side	10010	femur load cell left	FEMRLE00WS
Femur load cell right hand side	10011	femur load cell right	FEMRRI00WS
outboard knee load cell left	10012	outer knee contact load cell left	KNEELEOUWS
outboard knee load cell right	10013	outer knee contact load cell right	KNEERIOUWS
inboard knee load cell left	10014	inner knee contact load cell left	KNEELEINWS
inboard knee load cell right	10015	inner knee contact load cell right	KNEERIINWS
Upper tibia load cell left	10016	upper tibia load cell left	TIBILEUPWS
Upper tibia load cell right	10017	upper tibia load cell right	TIBIRIUPWS
Lower tibia load cell left	10018	lower tibia load cell left	TIBILELOWS
Lower tibia load cell right	10019	lower tibia load cell right	TIBIRILOWS

- \*DATABASE\_HISTORY\_DISCRETE\_ID instead of \*DATABASE\_HISTORY\_DISCRETE, evaluation for deflection

Item	Discrete beam-ID	Old Label	ISO-CODE
shoulder rib deformation	10060	no label	SHRILE00WSDS0
1. thorax rib deformation	10061	no label	TRRILE01WSDS0
2. thorax rib deformation	10062	no label	TRRILE02WSDS0
3. thorax rib deformation	10063	no label	TRRILE03WSDS0
1. abdomen rib deformation	10064	no label	ABRILE01WSDS0
2. abdomen rib deformation	10065	no label	ABRILE02WSDS0
shoulder rib rotation Z	10050	no label	SHRILE00WSANZ
1. thorax rib rotation Z	10051	no label	TRRILE01WSANZ
2. thorax rib rotation Z	10052	no label	TRRILE02WSANZ
3. thorax rib rotation Z	10053	no label	TRRILE03WSANZ
1. abdomen rib rotation Z	10054	no label	ABRILE01WSANZ
2. abdomen rib rotation Z	10055	no label	ABRILE02WSANZ
knee potentiometer y-rotation left	10040	no label	KNEELE00WSANY
knee potentiometer y-rotation right	10041	no label	KNEERI00WSANY
ankle potentiometer z-rotation left	10042	no label	ANKLLE00WSANZ
ankle potentiometer z-rotation right	10043	no label	ANKLRI00WSANZ

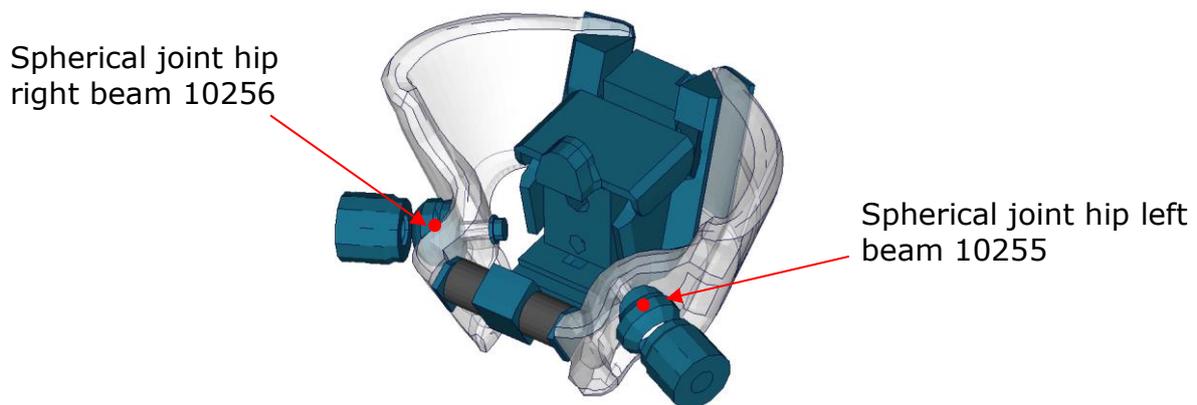
ankle potentiometer y-rotation left	10044	no label	ANKLLE00WSANY
ankle potentiometer y-rotation right	10045	no label	ANKLRI00WSANY
ankle potentiometer x-rotation left	10046	no label	ANKLLE00WSANX
ankle potentiometer x-rotation right	10047	no label	ANKLRI00WSANX

- WorldSID v5.0 provide the global node data of the middle point of marker in output data NODOUT.



Item	Node-ID	Label	Available components
marker sleeve-shoulder left	10048	SLEELEMAWSAC	global node output
marker sleeve-shoulder right	10049	SLEERIMAWSAC	global node output
marker head left	10050	HEADLEMAWSAC	global node output
marker head right	10051	HEADRIMAWSAC	global node output
marker arm-shoulder left	10052	SHLDLEMAWSAC	global node output
marker arm-shoulder right	10053	SHLDRIMAWSAC	global node output
marker arm end left	10054	ARMOLEMAWSAC	global node output
marker arm end right	10055	ARMORIMAWSAC	global node output
marker H-point left	10056	PELVLEMAWSAC	global node output
marker H-point right	10057	PELVRIMAWSAC	global node output
marker outer knee left	10058	KNEELEMOWSAC	global node output
marker outer knee right	10059	KNEERIMOWSAC	global node output
marker inner knee left	10060	KNEELEMIWSAC	global node output
marker inner knee right	10061	KNEERIMIWSAC	global node output
marker outer ankle left	10062	ANKLLEMOWSAC	global node output
marker outer ankle right	10063	ANKLRIMOWSAC	global node output
marker inner ankle left	10064	ANKLLEMIWSAC	global node output
marker inner ankle right	10065	ANKLRIMIWSAC	global node output

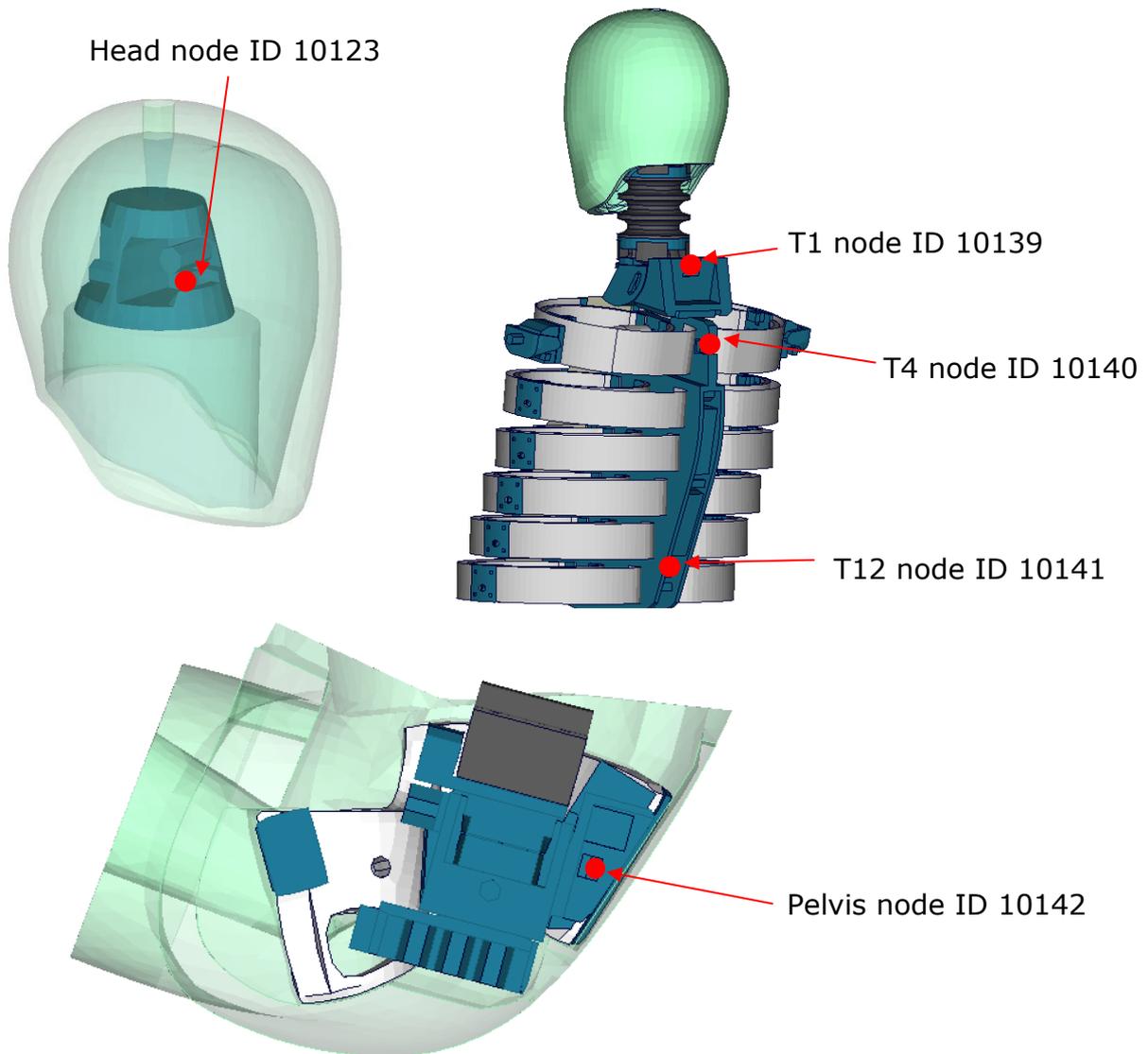
- The global force of the spherical joint hip left and right are new force and moment signals for WorldSID v5.0 in global coordinate system by beam 10255 and 10256.



The Beam are:

Item	Beam-ID	Label	Available components
Spherical joint hip left	10255	HIPJLE00WS	global force and moment
Spherical joint hip right	10256	HIPJRI00WS	global force and moment

- Second nodes of accelerometer for Head, T1, T4, T12 and Pelvis in global output.



The nodes are:

Item	Node-ID	Label	Available components
Head global	10123	HEAD00GBWSAC	global x-,y-,z- acceleration
T1 global	10139	THSP01GBWSAC	global x-,y-,z- acceleration
T4 global	10140	THSP04GBWSAC	global x-,y-,z- acceleration
T12 global	10141	THSP12GBWSAC	global x-,y-,z- acceleration
Pelvis global	10142	PELV00GBWSAC	global x-,y-,z- acceleration

- Length and relative rotation of IR-TRACCs

There is evaluation method for the length and relative rotation of 2D IR-TRACCs from WorldSID 50<sup>th</sup> v5.0 which are measured by key word `CONSTRAINED_JOINTSTIFFNESS_TRANSLATIONAL_TITLE` and `CONSTRAINED_JOINTSTIFFNESS_GENERALIZED_TITLE`.

For evaluating signals of length use the output of the `jntforc` File. Then use type 0 and evaluate y- displacement.

For evaluating signals of relative rotation use the output of the `jntforc` File. Then use type 1 and evaluate z- displacement.

Some post processors show different component output name. In this case evaluate as follows:

For `CONSTRAINED_JOINTSTIFFNESS_TRANSLATIONAL`:  
`theta_degree` = y-displacement, length of 2D IR-TRACCs

For `CONSTRAINED_JOINTSTIFFNESS_GENERALIZED`:  
`psi_degree` = z-displacement, relative rotation degree of 2D IR-TRACCs

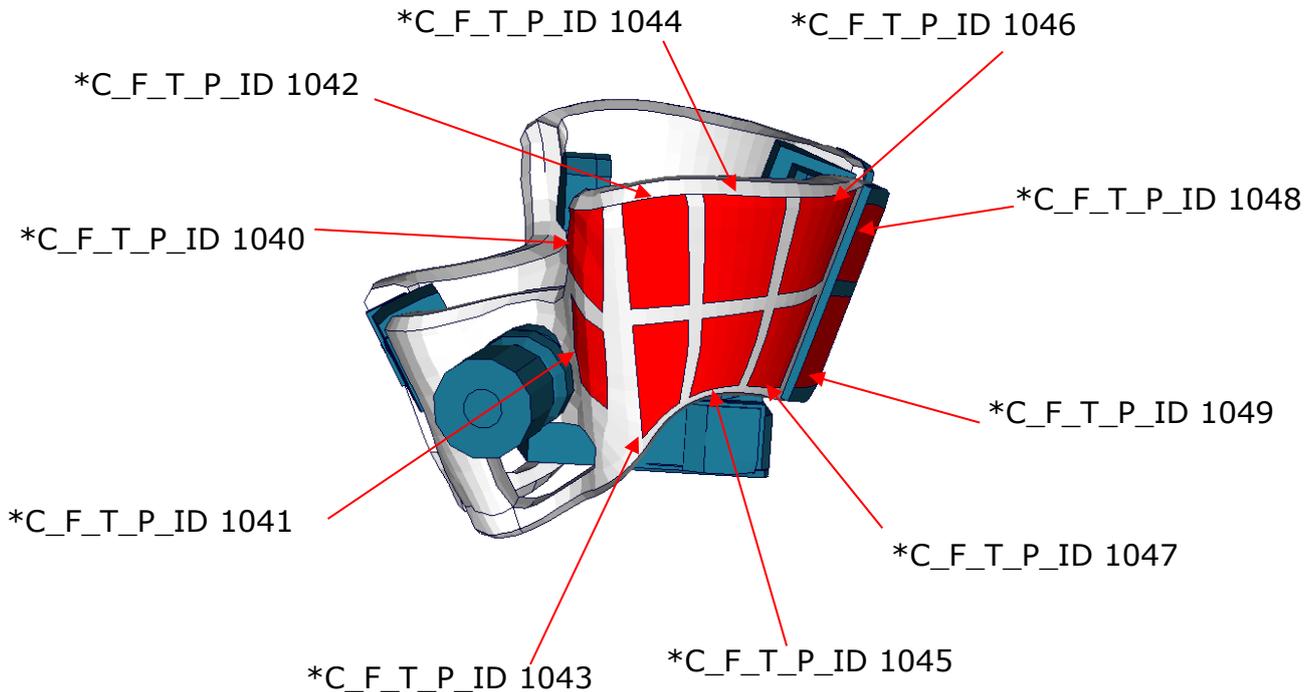
The `CONSTRAINED_JOINT_STIFFNESS_TRANSLATIONAL` cards IDs are as follows:

ID	Title	Local direction	component
1043	IR Tracc Shoulder rib length	y-coordinate	theta_degree
1044	IR Tracc 1st Thorax rib length	y-coordinate	theta_degree
1045	IR Tracc 2nd Thorax rib length	y-coordinate	theta_degree
1046	IR Tracc 3rd Thorax rib length	y-coordinate	theta_degree
1047	IR Tracc 1st Abdomen rib length	y-coordinate	theta_degree
1047	IR Tracc 2nd Abdomen rib length	y-coordinate	theta_degree

The `CONSTRAINED_JOINT_STIFFNESS_GENERALIZED` cards IDs are as follows:

ID	Title	Local rotation's direction	component
1051	IR Tracc Shoulder rib Rotation	z-coordinate	psi_degree
1052	IR Tracc 1st Thorax rib Rotation	z-coordinate	psi_degree
1053	IR Tracc 2nd Thorax rib Rotation	z-coordinate	psi_degree
1054	IR Tracc 3rd Thorax rib Rotation	z-coordinate	psi_degree
1055	IR Tracc 1st Abdomen rib Rotation	z-coordinate	psi_degree
1056	IR Tracc 2nd Abdomen rib Rotation	z-coordinate	psi_degree

- Pelvis bone is separated into small parts for evaluations over  
 \* CONTACT\_FORCE\_TRANSDUCER\_PENALTY\_ID, output data: rcforc

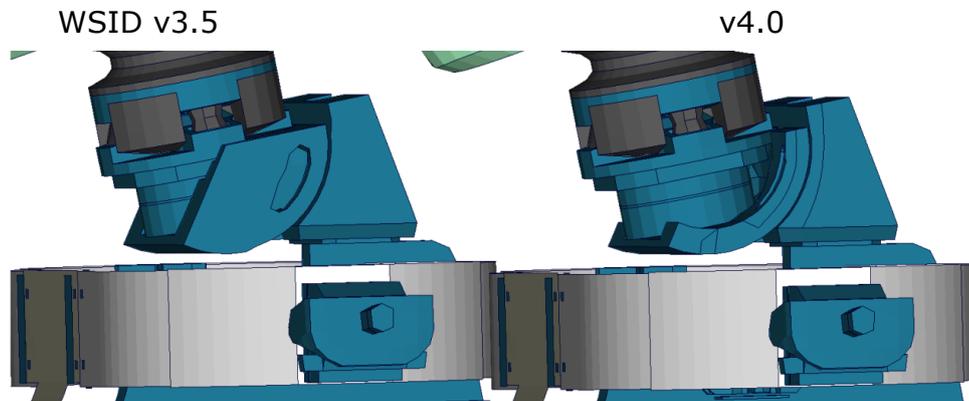


The \* CONTACT\_FORCE\_TRANSDUCER\_PENALTY\_ID list:

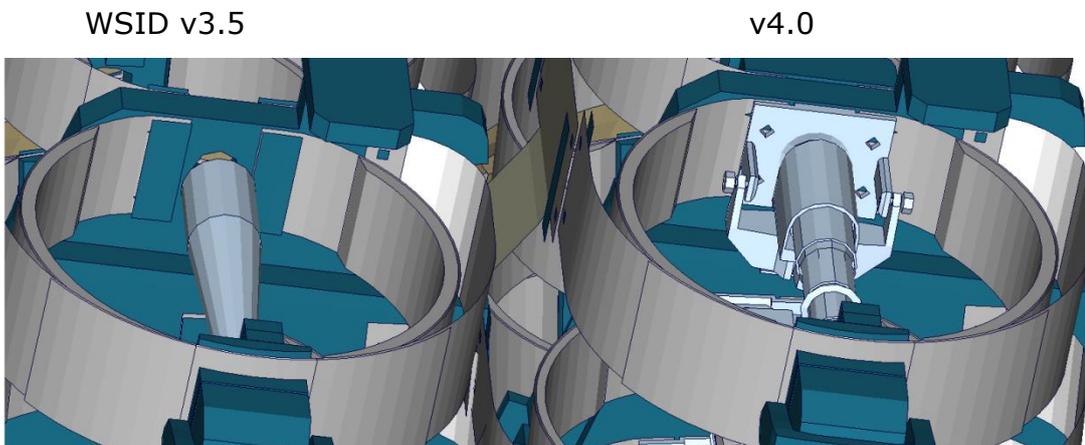
Item	C_F_T_P_ID	Label	Available components
Pelvis Force	1040	pelvis bone force left - upper front	global contact force x-,y-,z-, resultant ;
Pelvis Force	1041	pelvis bone force left - lower front	global contact force x-,y-,z-, resultant ;
Pelvis Force	1042	pelvis bone force left - upper side forward	global contact force x-,y-,z-, resultant ;
Pelvis Force	1043	pelvis bone force left - lower side forward	global contact force x-,y-,z-, resultant ;
Pelvis Force	1044	pelvis bone force left - upper side middle	global contact force x-,y-,z-, resultant ;
Pelvis Force	1045	pelvis bone force left - lower side middle	global contact force x-,y-,z-, resultant ;
Pelvis Force	1046	pelvis bone force left - upper side rear	global contact force x-,y-,z-, resultant ;
Pelvis Force	1047	pelvis bone force left - lower side rear	global contact force x-,y-,z-, resultant ;
Pelvis Force	1048	pelvis bone force left - connection plate - upper	global contact force x-,y-,z-, resultant ;
Pelvis Force	1049	pelvis bone force left - connection plate - lower	global contact force x-,y-,z-, resultant ;

## 5.2 Release notes of WorldSID v4.0

- Geometric modifications to the latest ISO hardware state (SBL-E):
  - Geometric update of neck bracket and can be adjusted also in positioning simulation.



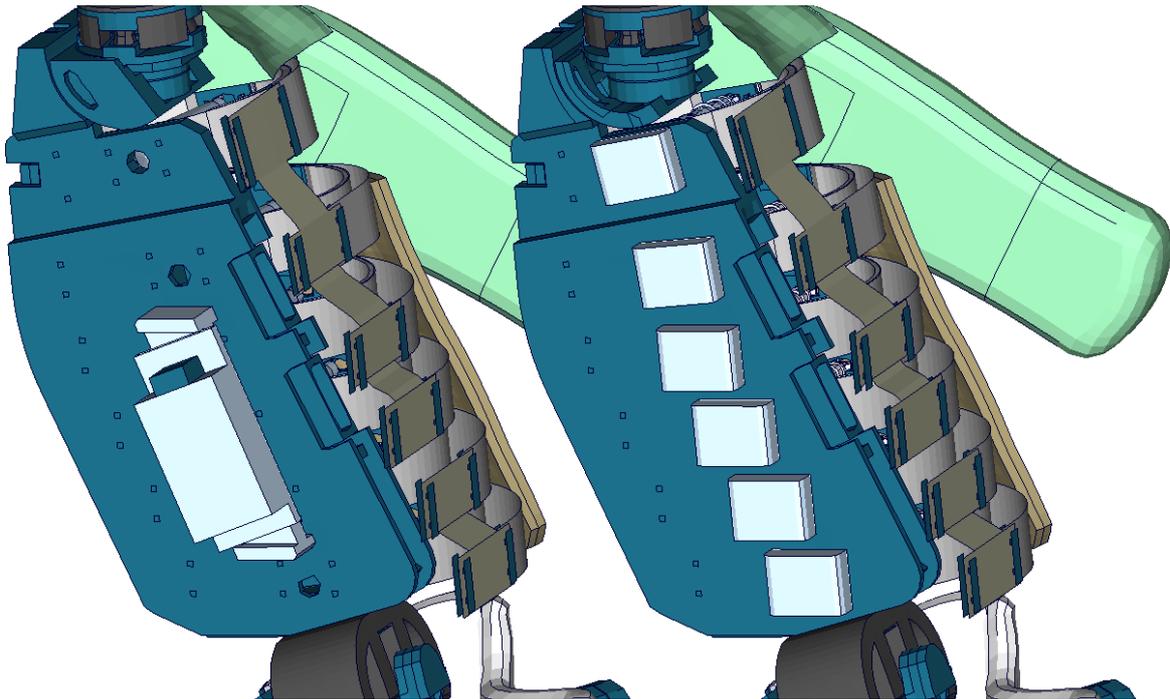
- Update of 2D IR-TRACC geometry. Due to this the physical stop angles are captured much more accurate.



- Battery in thorax has been changed to some smaller mass replacements

WSID v3.5

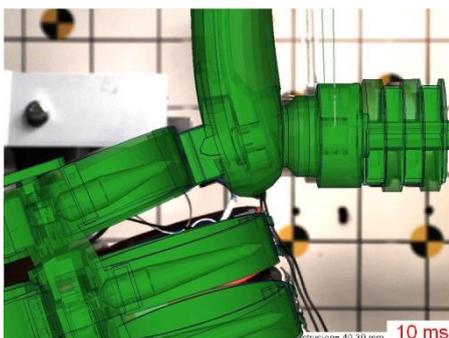
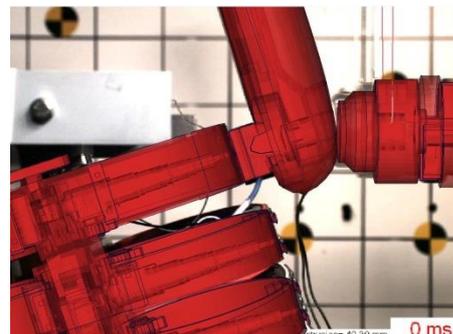
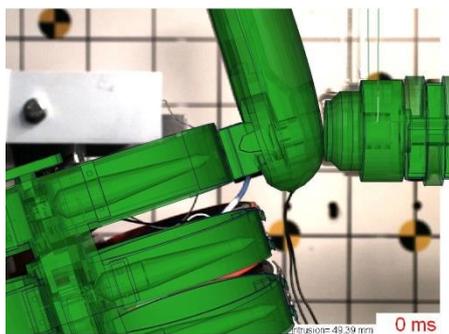
v4.0

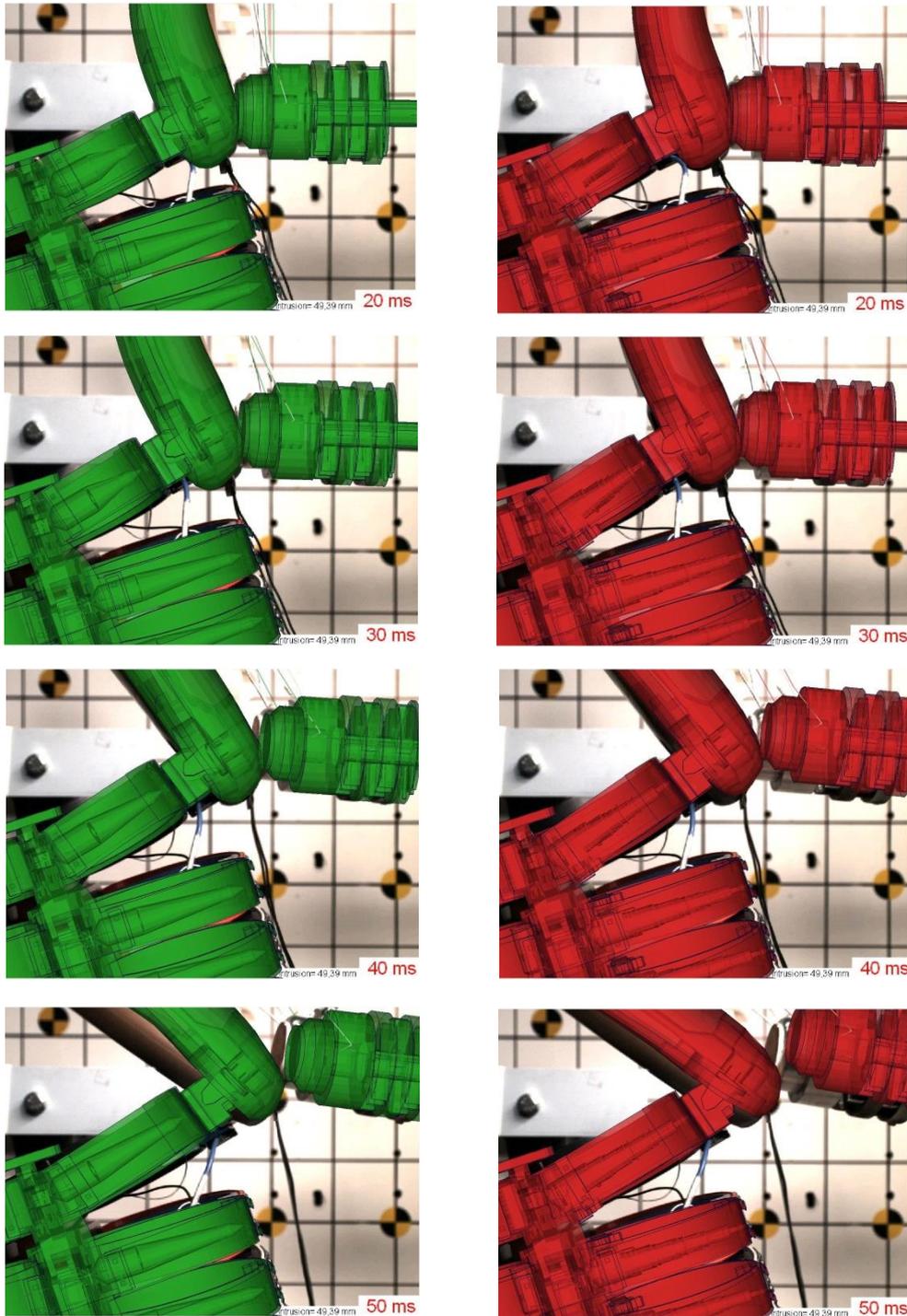


- Other modifications:
  - Arm validation is improved. In some Rib component test it is observer that WSID v3.5 seems to have a very soft arm behavior in bending. Due to this the behavior of the arm is compared to video evaluations and improved. In the following a rib component test with arm is shown for both versions of WorldSID:
  -

WSID v3.5

v4.0





- For output of the EuroNCAP local rib deflections, DATABASE\_HISTORY\_NODE\_LOCALS are defined. These nodes are included as an alternative to the output of the 2D IR-TRACCS. The nodes output the local x-, y- and z-deflection of the ribs. It must not be calculated from the resultant deflection and rotation of the 2D IR-TRACC.

The nodes are:

Item	Node-ID	Label	Available components
shoulder rib	10751	shoulder rib deformation Local X/Y/Z	x-, y-, z-displacement
1. thorax rib	10752	1 thorax rib deformation Local X/Y/Z	x-, y-, z-displacement
2. thorax rib	10753	2 thorax rib deformation Local X/Y/Z	x-, y-, z-displacement
3. thorax rib	10754	3 thorax rib deformation Local X/Y/Z	x-, y-, z-displacement
1. abdomen rib	10755	1 abdomen rib deformation Local X/Y/Z	x-, y-, z-displacement
2. abdomen rib	10756	2 abdomen rib deformation Local X/Y/Z	x-, y-, z-displacement

- For dummy positioning the angles which are shown for Torso and Head are now global angles and no longer in respect to the Pelvis and Torso. So if the pelvis is rotated, they will also change.  
Due to this when the dummy is opened in Primer, two warning messages will occur that a coordinate systems does not belong to assembly 2 and 3.
- Positioning generator psg\_v1.3 is improved. This is used to set up positioning pre simulations. Now it is possible also to rotate the neck backed by pre-simulation. This was missing in v3.5.  
Furthermore we switched the method to pulling the assemblies bye springs and dampers to the right position. This is very similar to the Primer method and very robust.
- The Version 4.0 and higher of the WorldSID provides parameters to scale the friction of the joint off all limbs. As default a 1 g adjustment of the joints is included. The user is now able to increase or decrease the friction values of the joints. The scale factors are used for the left and right hand side assemblies. So it is not possible to scale left and right assembly different.

Parameter name	Joint
Sfarmx	Scale factor arms local x-rotation
sfarmy	Scale factor arms local y-rotation
sffemr	Scale factor upper legs all directions
sfknee	Scale factor knees
sfankl	Scale factor ankle joins all directions

### 5.3 Release notes of WorldSID v3.5

- Geometric modifications:
  - Initial Arm position is set to EuroNCAP position
    - EuroNCAP Oblique Pole Side Impact Testing Protocol (Version 7.0 of June 2014):
      - 5.3.6.1 Place both arms at the first detent downward of the most upward detent that corresponds to a differential angle of  $32^\circ$  between rib angle sensor and the arm angle.
    - Rib angle sensor is  $0^\circ$  if the 2. and 3. thorax ribs are horizontal.
    - Arm must then positioned  $32^\circ$  downwards from the horizontal.
    - Tree File is adjusted to show  $-32^\circ$  for arm position.
    - Outer shape of V3.5 compared to V3.0 has not changed, except the Arm position.
  - One additional Node is generated NID10000. This one has the same coordinate as the node 10501 which is located on the H-Point.
  - This is done due to positioning issues with the psg of the WorldSID50.
- Other modifications:
  - Due to a strange behavior of the Jacket in WSID v3.0 the Jacket is changed:
    - The solid material of the Jacket is improved.
    - The outer shell layer is changed from MAT-NULL to MAT\_FABRIC with physical tension stiffness.

### 5.4 Release notes of WorldSID v3.0

- Geometric modifications:
  - The complete neoprene suit of the WorldSID is now meshed with solids
  - Arm foam and rubber mesh is disconnected from arm bone
  - 2D IR-TRACCs including new stop angles (SBL-E1)
  - New sacrum box data recorder in the pelvis (SBL-E1)
- Component modifications:
  - The arm component was improved
  - Neck model improvement
  - Shoulder rib component test in z-direction
- Other modifications:

- The nitinol material of the rib bands now uses am \*MAT\_SHAPE\_MEMORY. This should increase the overall stability and robustness of the dummy model
- Some load cell orientations were corrected to match the SAE standard: upper and lower neck, shoulder, lumbar spine, pubic, sacro iliac and femur load cells
- Improvement of the pelvis flesh model to avoid high hourglass energies
- Improvement of the hole dummy definitions to reduce time step dependency of the model
- Parameter tpref to switch on/off the foam reference geometry of the thorax pad
- More robustness against variation of time step size
- New positioning procedure

## **5.5 Release notes of WorldSID v2.0**

- The new sled tests are now validated in a first loop. So the interaction of different parts is adjusted and validated.
- First observations show very hard movement of the ribs in local z-direction. To investigate in this behavior there are planned new pendulum tests on the shoulder of the WorldSID.
- The validation of the single component tests of Version 1.0 is not changed. All single components of the WorldSID v2.0 are still the same.
- The WorldSID v2.0 fulfils still all available calibration tests.

## **5.6 Release notes of WorldSID v1.0**

- The WorldSID model v1.0 is the first commercial available PDB WorldSID.
- The geometry and mass of the model are based on the data of ISO 15830 part 1 to 4.
- All important materials have been tested and used to generate corresponding material models.
- All available component tests are validated for the WorldSID v1.0
- The WorldSID v1.0 fulfills all available calibration tests.

## 6. Limitations and Further Work

The current release of the WorldSID has been validated by using material, component, dummy certification and sled tests. First experiences of full car simulations are included to the model.

The model is validated in use of the depicted tests in this Manual. The validation is done every time under physical aspects and in use of all know how which was available to this point in time.

The WorldSID 50<sup>th</sup> v5.0 provide optional for thickness of damping material of thorax-rib. But this feature restrain user to renumber the nodes of this model, why this feature is defined by parameter. More possibility will be tried to improve the feature and to make the processor of numbering simply in future.

To carry on improving the model response and the usability we appreciate all users' feedback.

## 7. Material Tests

Material tests on all major foams, rubber like materials and plastics have been performed. The specimens were taken from components of the WorldSID or from blocks provided by FTSS. The material test samples are depicted below.



**Figure 25:** Material test samples of WorldSID

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
- plastics iliac wings
- arm bone
- head bone

The emphasis was on static and dynamic tension and compression tests. For the rubber like materials, the compression tests were also performed with a lateral obstructed expansion.

The strain rates used for the foam and rubber materials were:

Test	Type	Strain rate	Lateral expansion
1	Tension	0.001 1/s (static)	free
2	Tension	0.1 1/s	free
3	Tension	20 1/s	free
4	Tension	100 1/s	free
5	Tension	400 1/s	free
6	Compression	0.001 1/s (static)	obstructed
7	Compression	0.001 1/s (static)	free
8	Compression	0.1 1/s	free
9	Compression	20 1/s	free
10	Compression	100 1/s	free
11	Compression	400 1/s	free

**Table 35:** Strain rates used for material tests

## 8. Performance

### 8.1 Component tests

Selected components of the WorldSID are tested in special defined component tests. The target of these tests is to have a fine validated component in a load range which can also be observed in a full car crash like the oblique pole of the FMVSS 214 new.

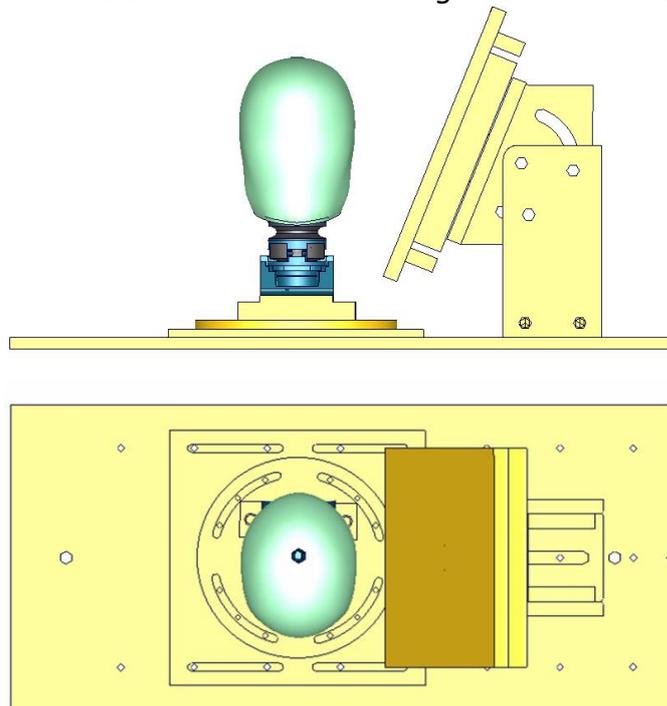
The tested components are:

- Head-neck unit
- Neck Torsion
- Half arm
- Arm Bending
- Arm Joint test
- Different ribs of the thorax and abdomen
- Lumbar spine
- Iliac wing

The description of the single component tests and the performance is given in the following chapters.

#### 8.1.1 Head-neck test

This test is built to validate the neck unit in use of the mounted head assembly. The test setup is depicted in the figure below. The loads on the sled are defined to get signals which are similar to the neck signals in a full car crash.



**Figure 26:** Head-neck test setup - 90 degree, side and top view

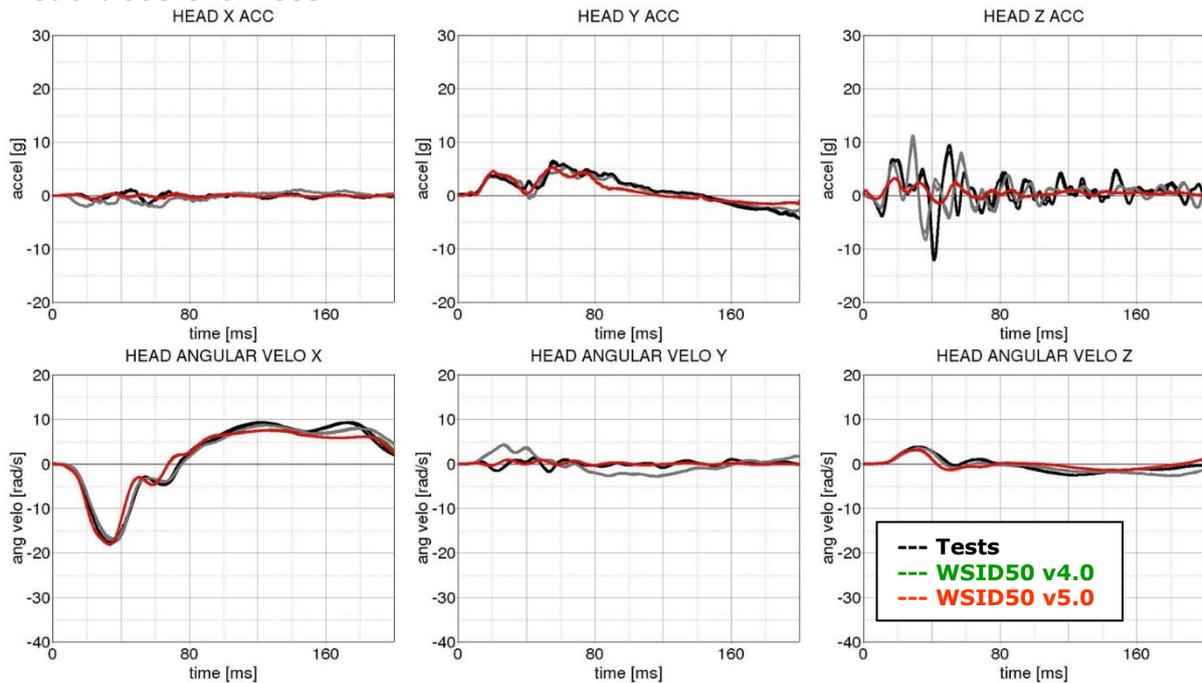
The oblique plate is adapted only as a guide for the neck in the higher pulses. Two different pulses are tested for a 90 degree configuration as depicted in the previous figure and the same two pulses for a 75 degree configuration of the component. The configurations are listed in the table below.

Test	Load angle	Pulse
1	90 degree	20 g triangular pulse
2	90 degree	35 g triangular pulse
3	75 degree	20 g triangular pulse
4	75 degree	35 g triangular pulse

**Table 36:** Test configurations of head-neck test

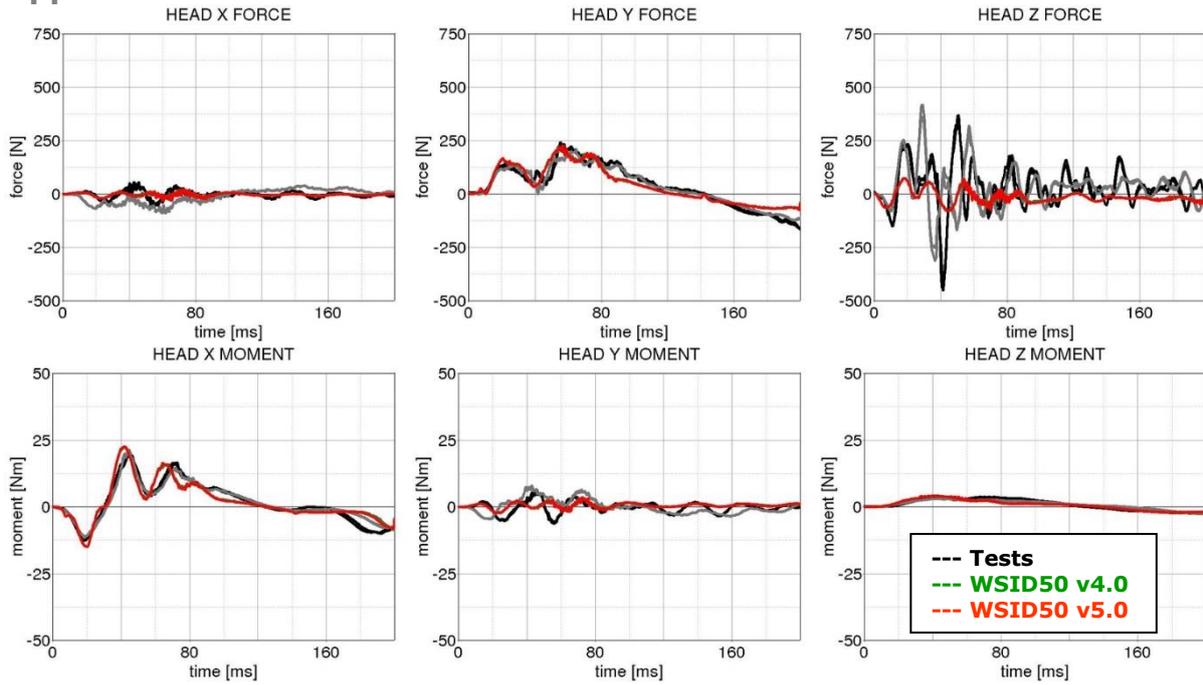
**Results of 90 degree, 20g configuration:**

**Head accelerometer**



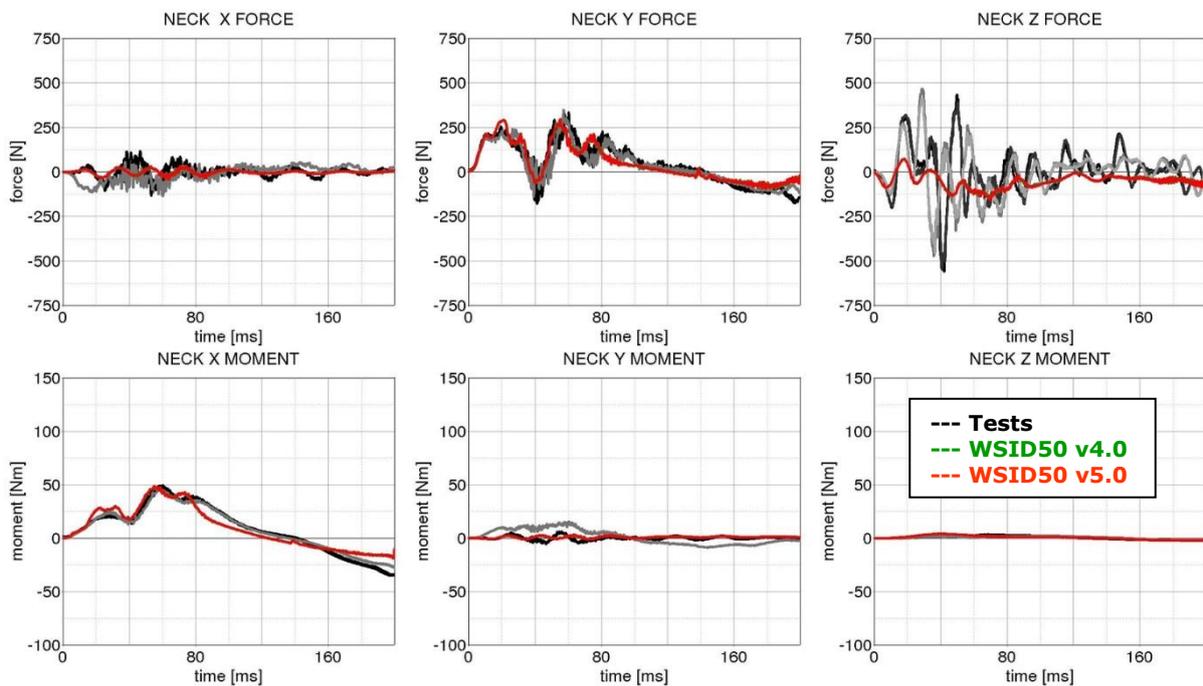
**Figure 27:** Result of head-neck test -- 20g, 90 degree (Head acceleration)

**Upper neck load cell**



**Figure 28:** Result of head-neck test -- 20g, 90 degree (Upper neck forces and moments)

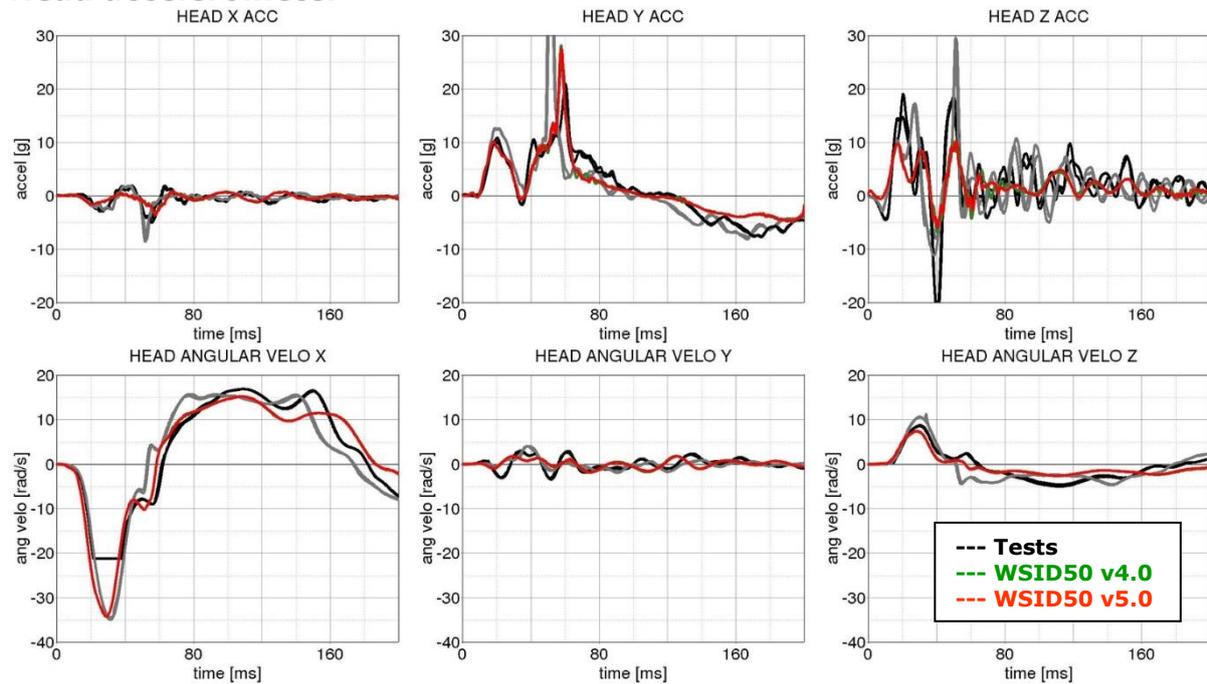
**Lower neck load cell**



**Figure 29:** Result of head-neck test -- 20g, 90 degree (Lower neck forces and moments)

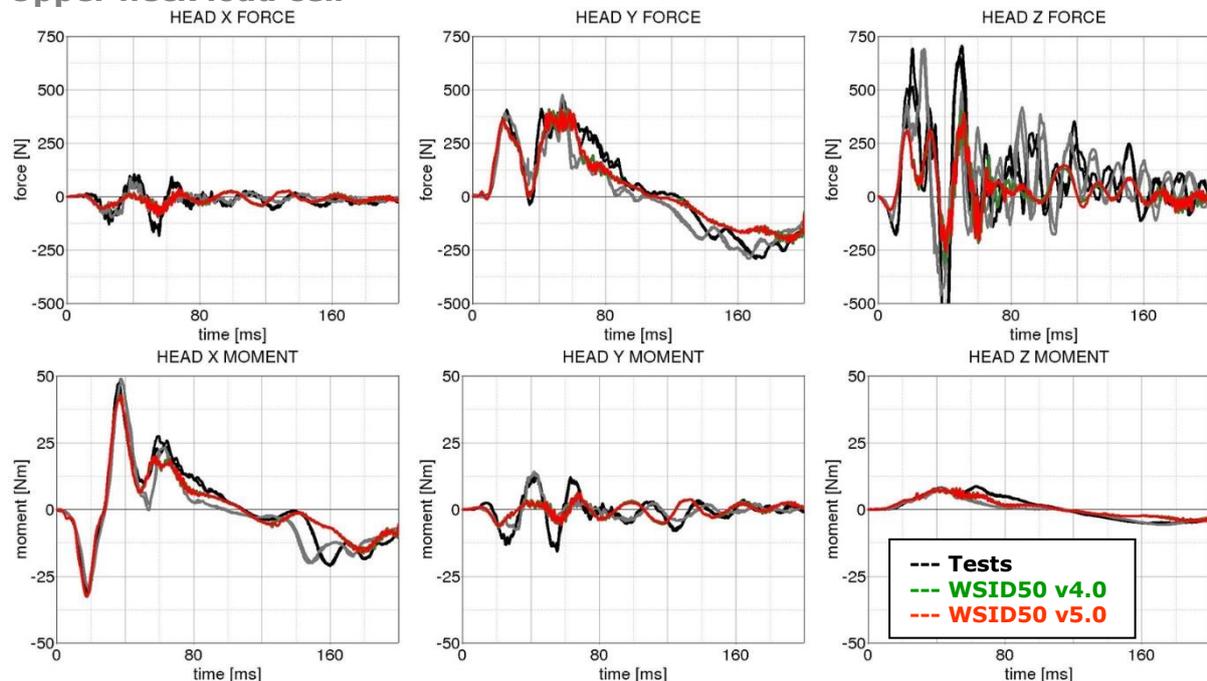
**Results of 90 degree, 35g configuration:**

**Head accelerometer**



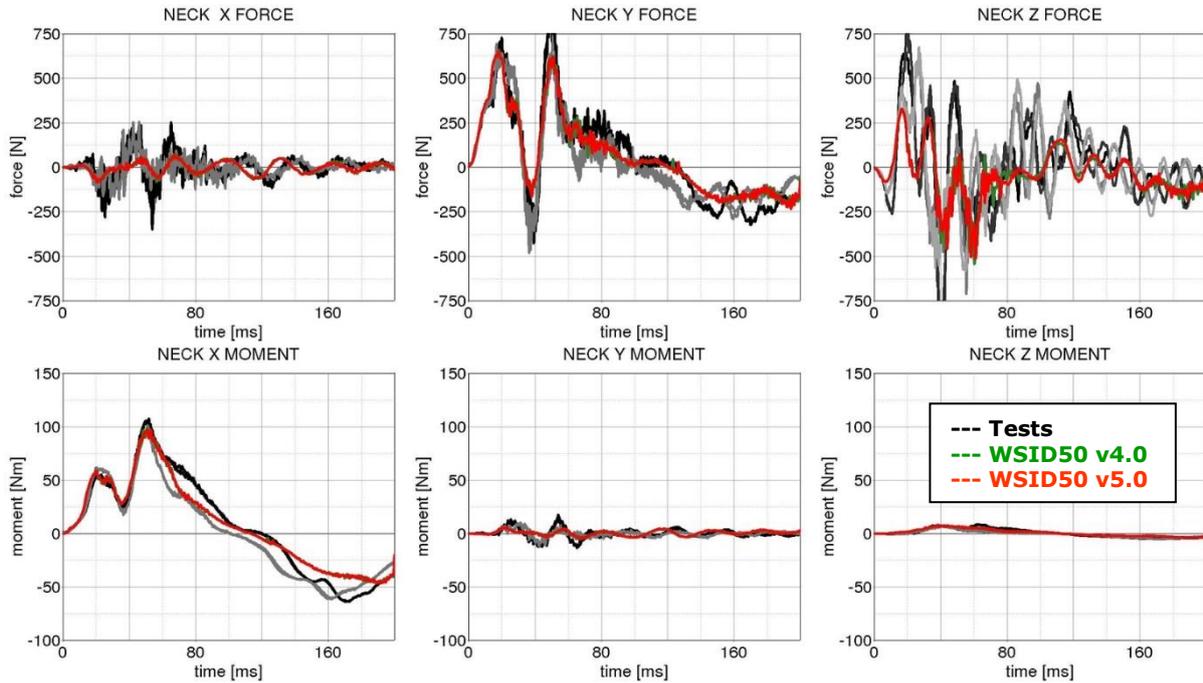
**Figure 30:** Result of head-neck test -- 35g, 90 degree (Head acceleration)

**Upper neck load cell**



**Figure 31:** Result of head-neck test -- 35g, 90 degree (Upper neck forces and moments)

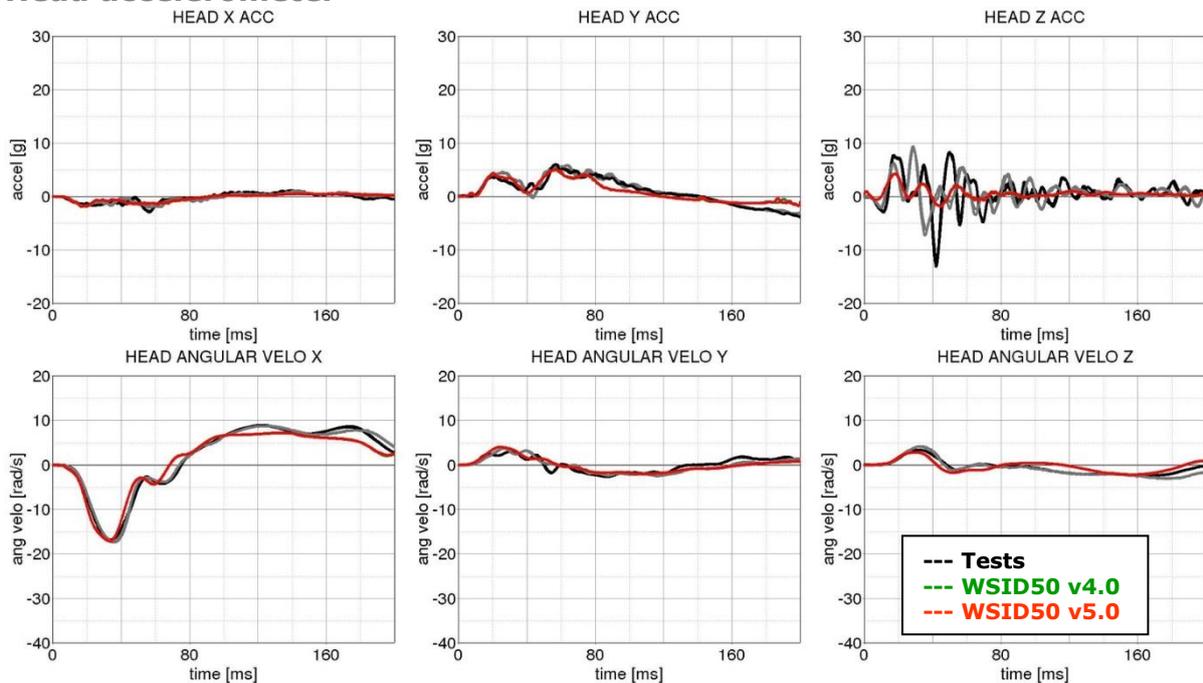
**Lower neck load cell**



**Figure 32:** Result of head-neck test -- 35g, 90 degree (Lower neck forces and moments)

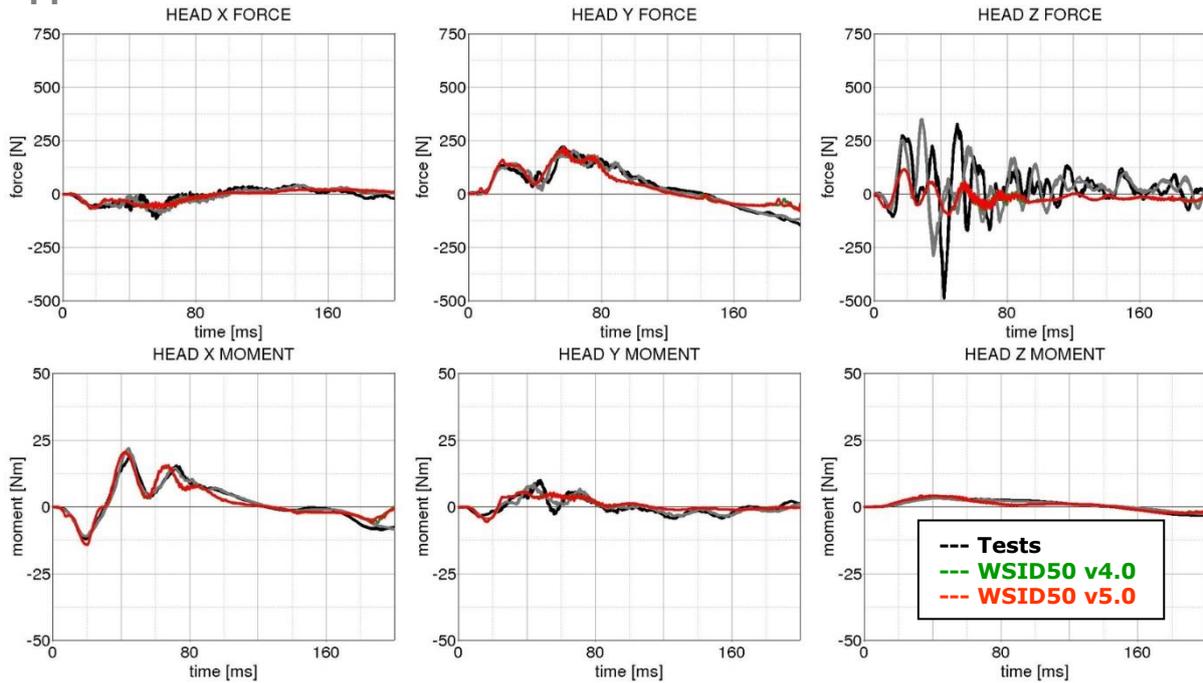
**Results of 75 degree, 20g configuration:**

**Head accelerometer**



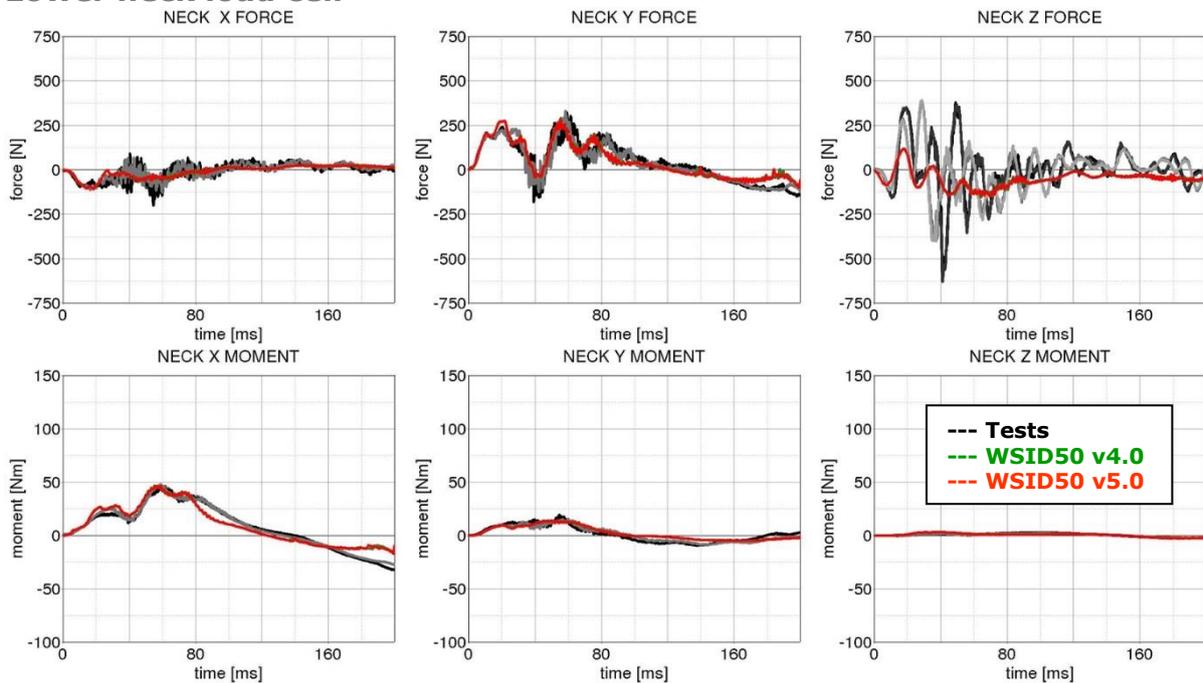
**Figure 33:** Result of head-neck test -- 20g, 75 degree (Head acceleration)

**Upper neck load cell**



**Figure 34:** Result of head-neck test -- 20g, 75 degree (Upper neck forces and moments)

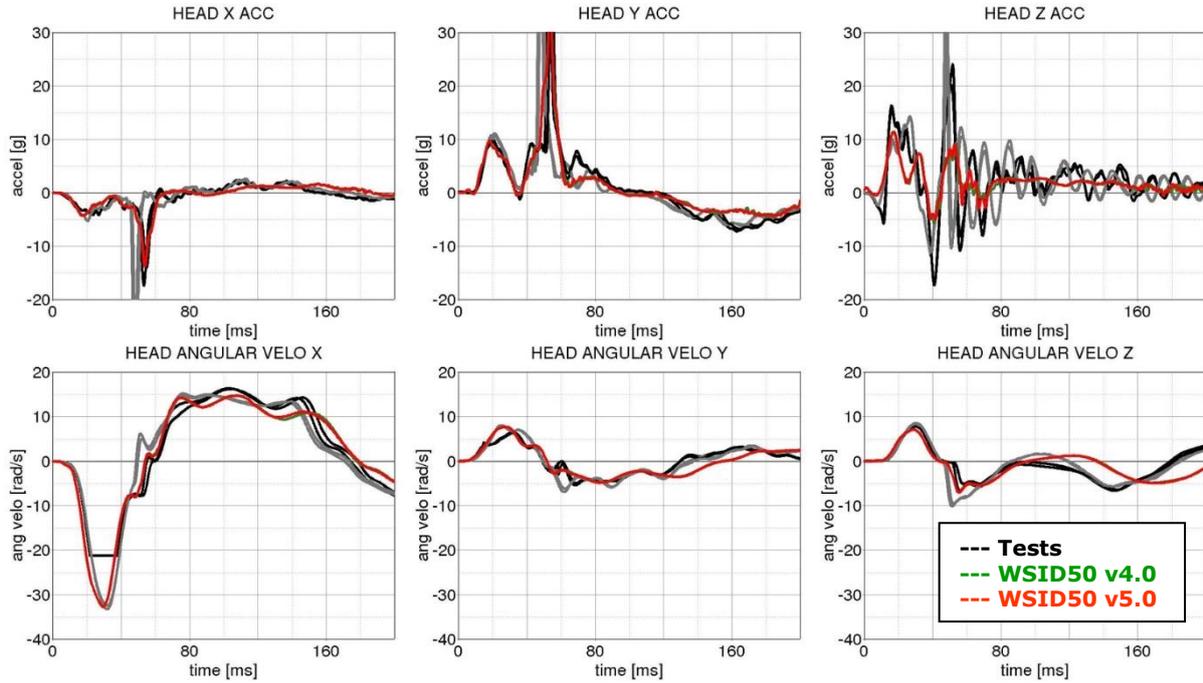
**Lower neck load cell**



**Figure 35:** Result of head-neck test -- 20g, 75 degree (Lower neck forces and moments)

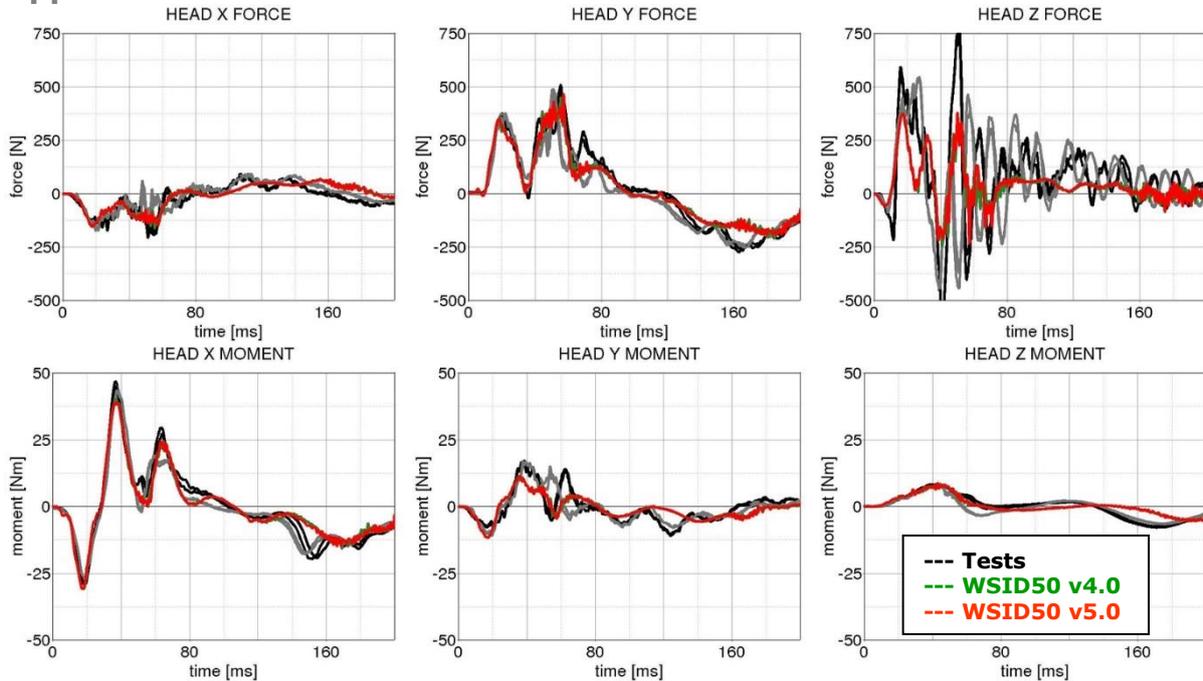
**Results of 75 degree, 35g configuration:**

**Head accelerometer**



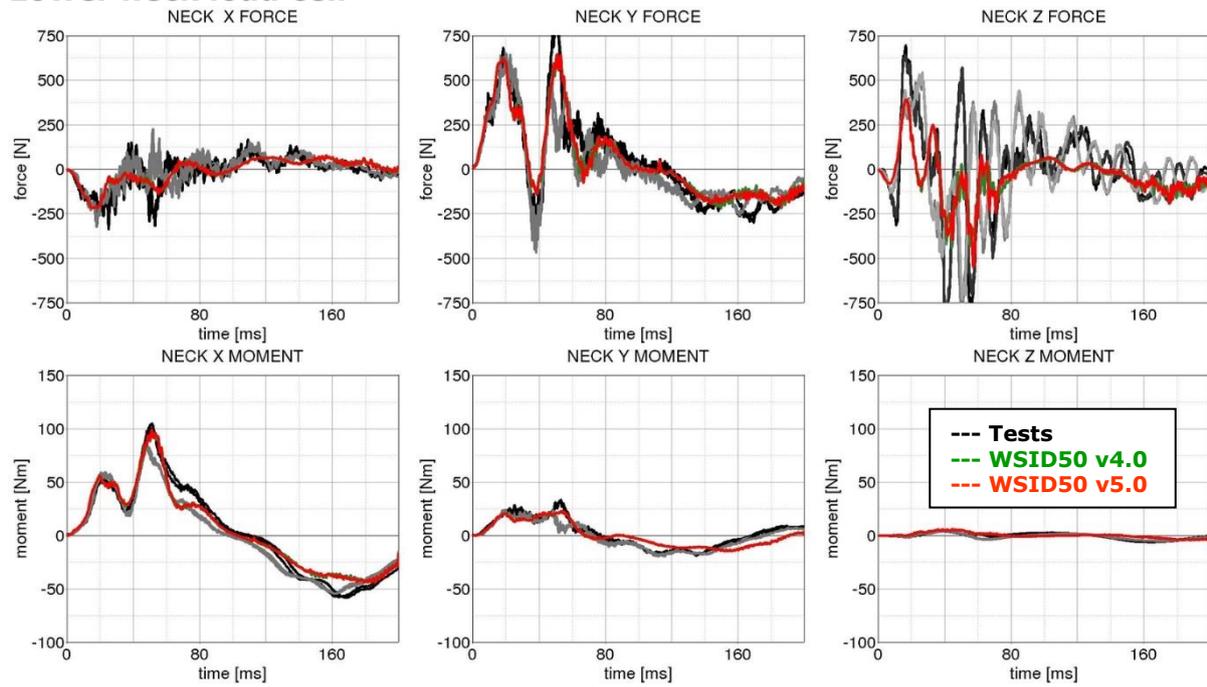
**Figure 36:** Result of head-neck test -- 35g, 75 degree (Head acceleration)

**Upper neck load cell**



**Figure 37:** Result of head-neck test -- 35g, 75 degree (Upper neck forces and moments)

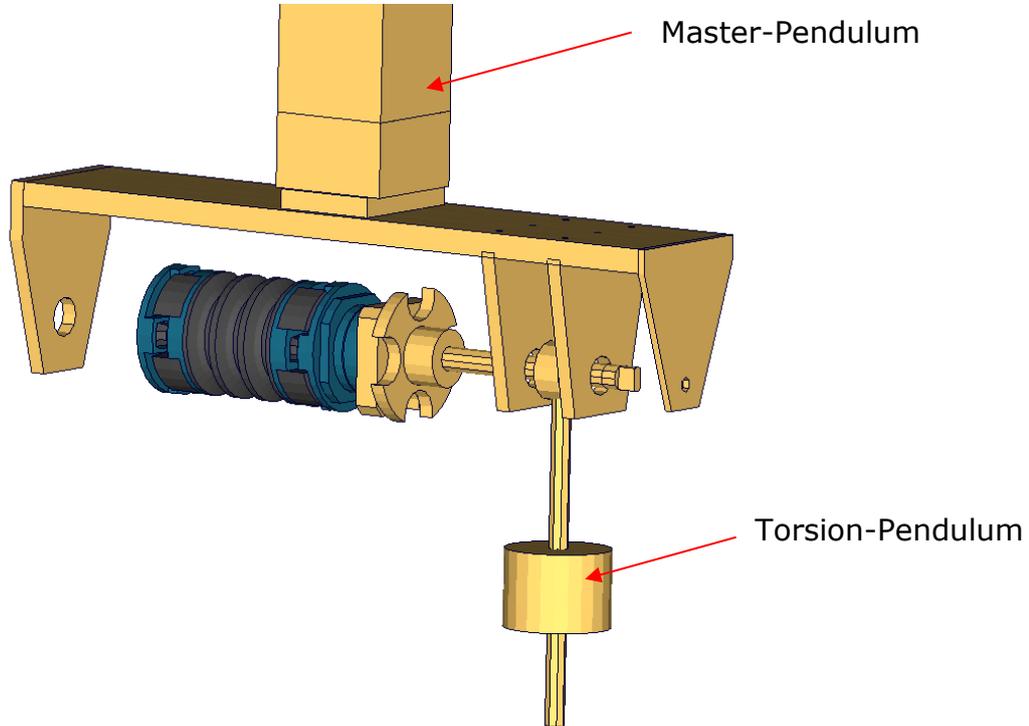
**Lower neck load cell**



**Figure 38:** Result of head-neck test -- 35g, 75 degree (Lower neck forces and moments)

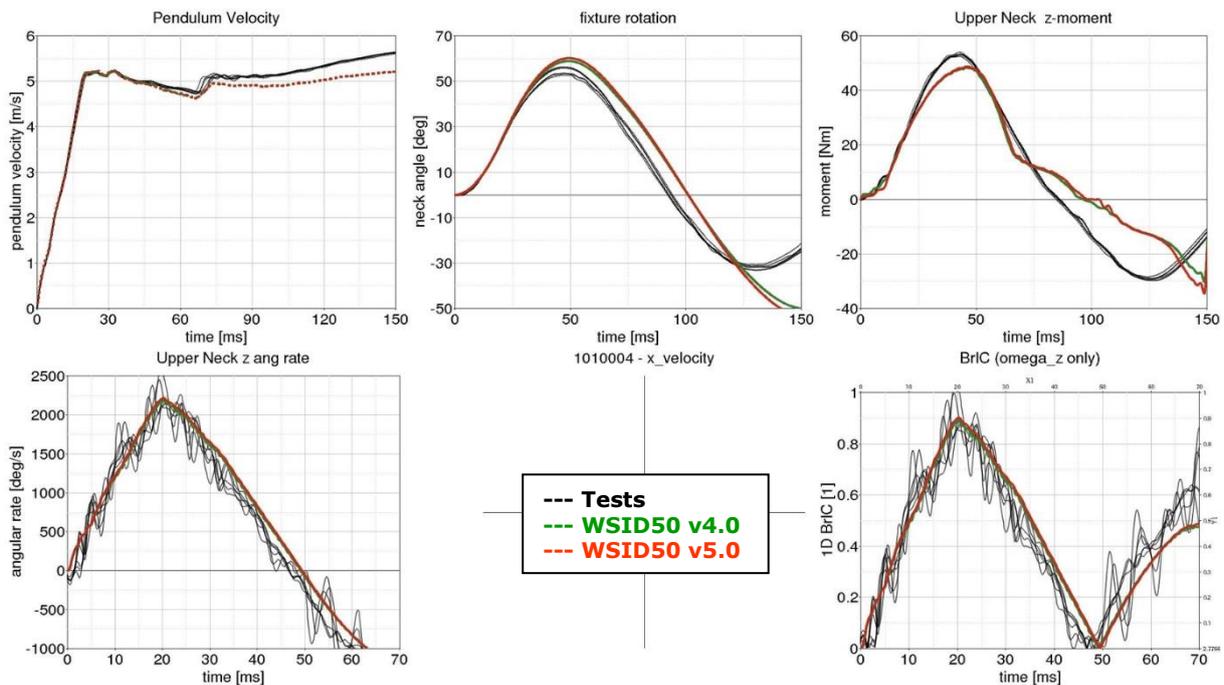
### 8.1.2 Neck Torsion test

The neck is mounted on the test master-pendulum. The whole system get the velocity from master pendulum. There is a torsion pendulum which add an additional torsion to the neck.



**Figure 39:** Neck Torsion test setup with pendulum

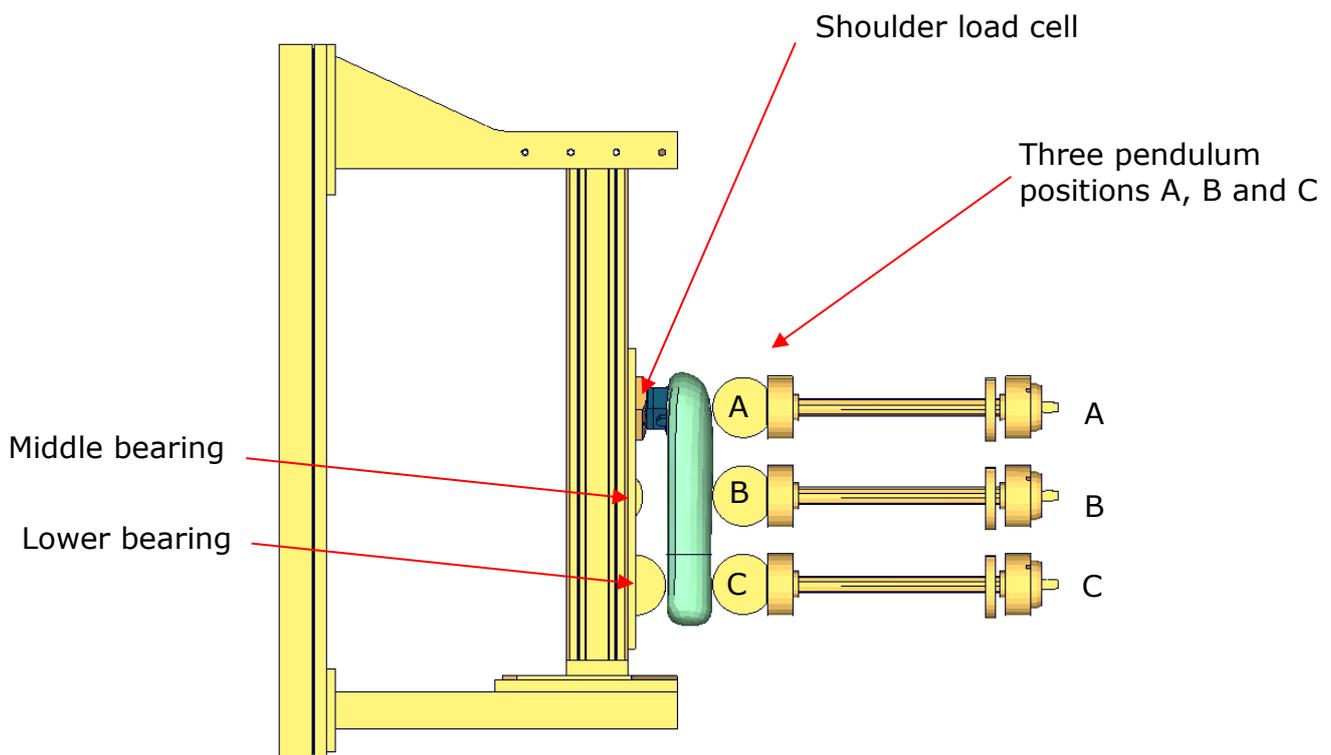
The results of the test are shown in the following figure:



**Figure 40:** Results – Neck Torsion test

### 8.1.3 Half arm test

The arm is mounted on the test box using the original shoulder load cell. In most of the tests, the notch of the arm is in the 40 degree position. The load cell is then rotated so that the arm in each test is in a vertical position. For a different notch of the arm adjustment, only the shoulder load cell is rotated. The figure below shows the three pendulum positions used for the arm tests. In Table 37 all test setup configurations are listed.



**Figure 41:** Half arm test setup with all pendulum positions

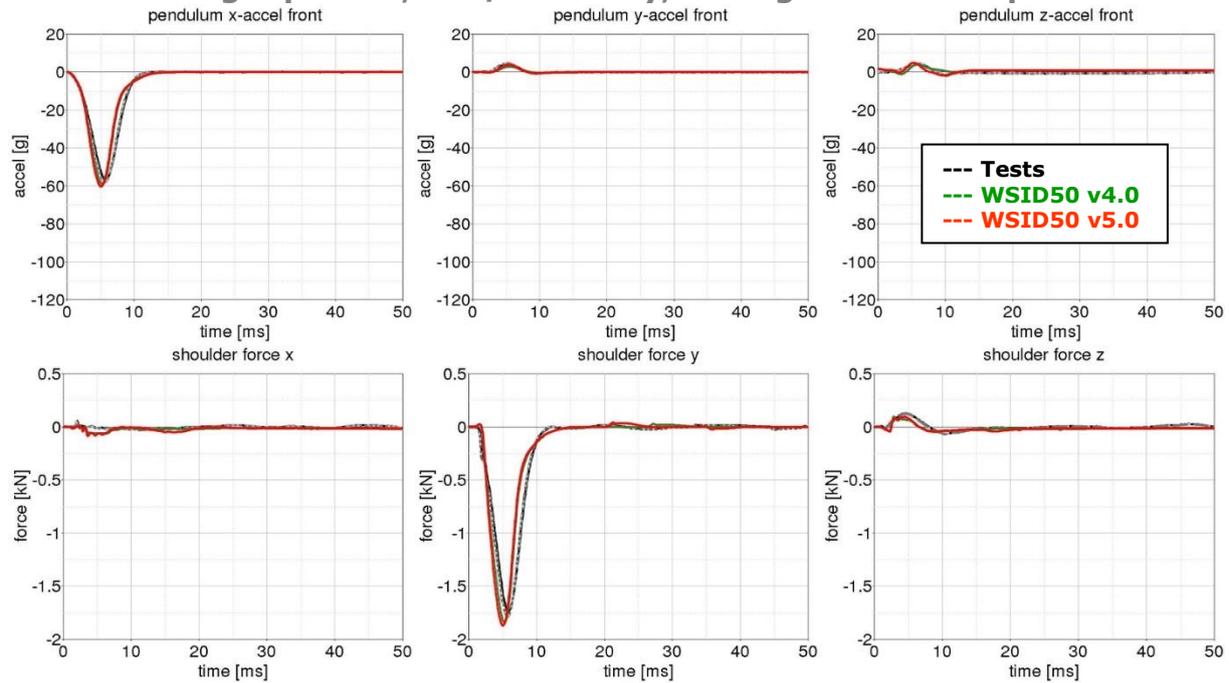
Test	Shoulder load cell angle	Target point	Velocities
1	48 degree	A	2 m/s and 4 m/s
2	48 degree	B	2 m/s and 4 m/s
3	48 degree	C	2 m/s and 4 m/s
4	8 degree	B	2 m/s and 4 m/s
5	8 degree / middle bearing modified	B	4 m/s and 6 m/s

**Table 37:** Test configurations for half arm test

Test number 5 is done by using a reduced distance between the middle bearing and the arm. Target is that the arm hits the middle bearing after bending.

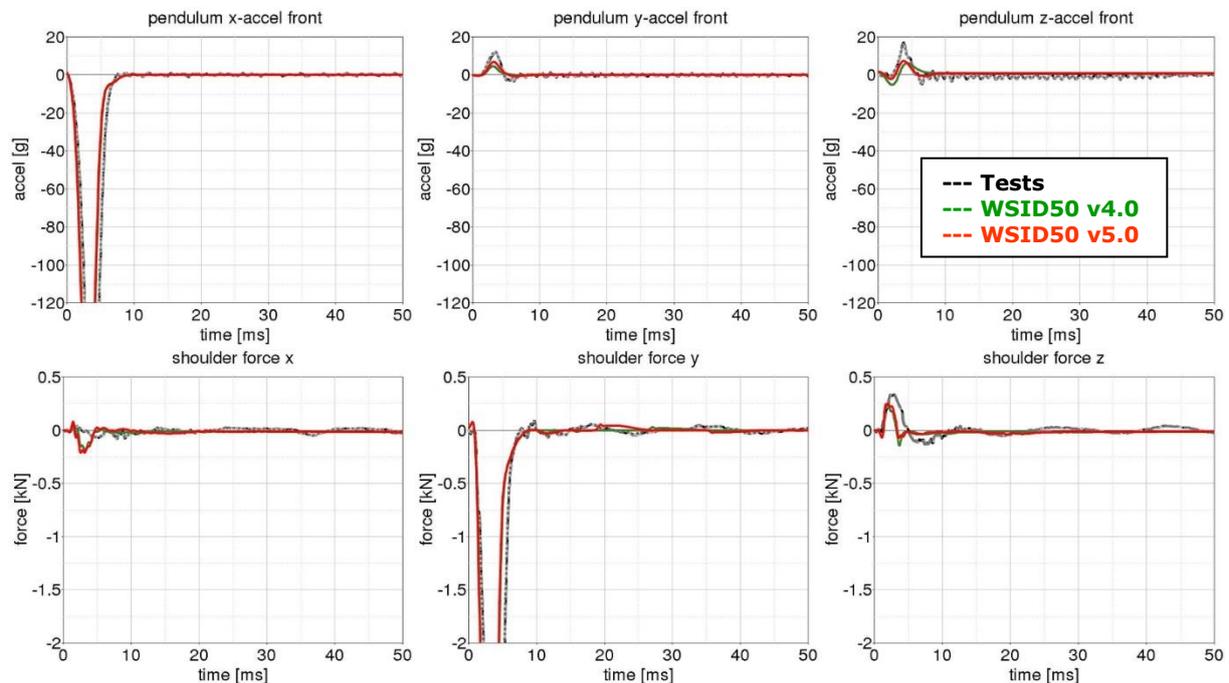
The results of all tests are shown in the following figures:

**Results - Target point A, 2 m/s velocity, 48 degree load cell position**



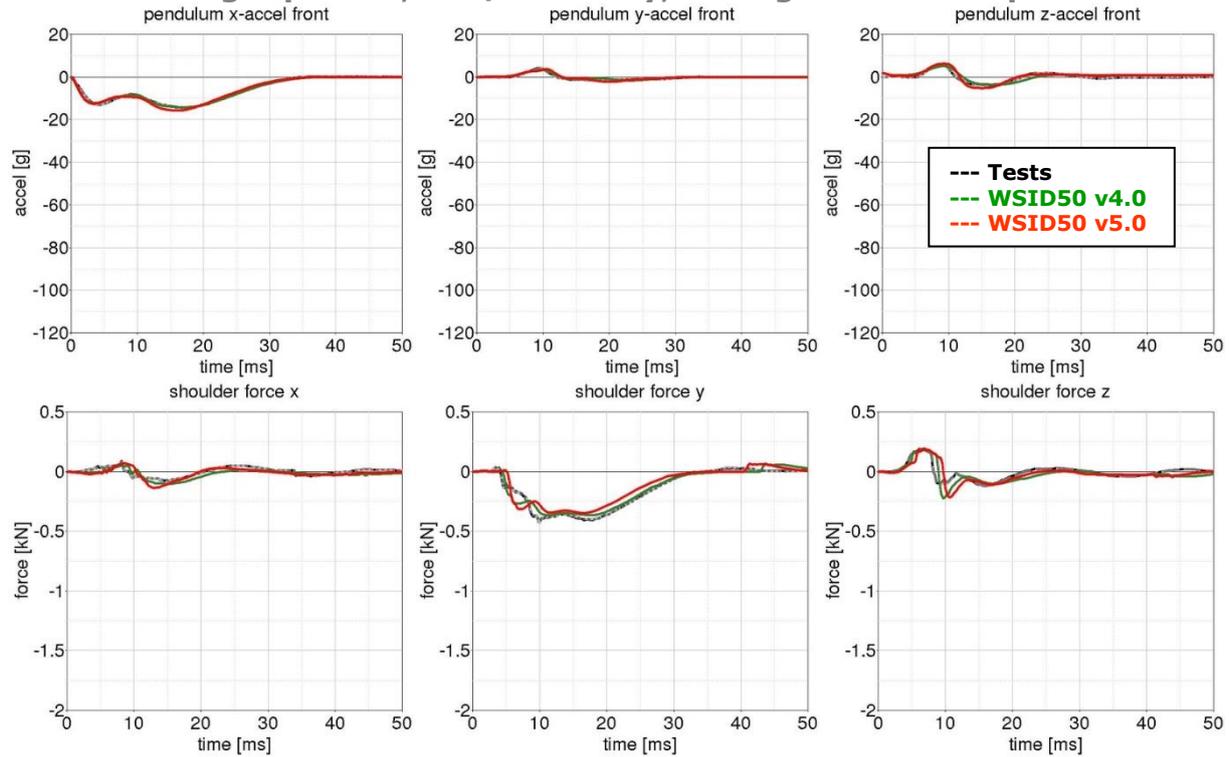
**Figure 42:** Results - target point A, 2 m/s velocity, 48 degree load cell position

**Results - Target point A, 4 m/s velocity, 48 degree load cell position**



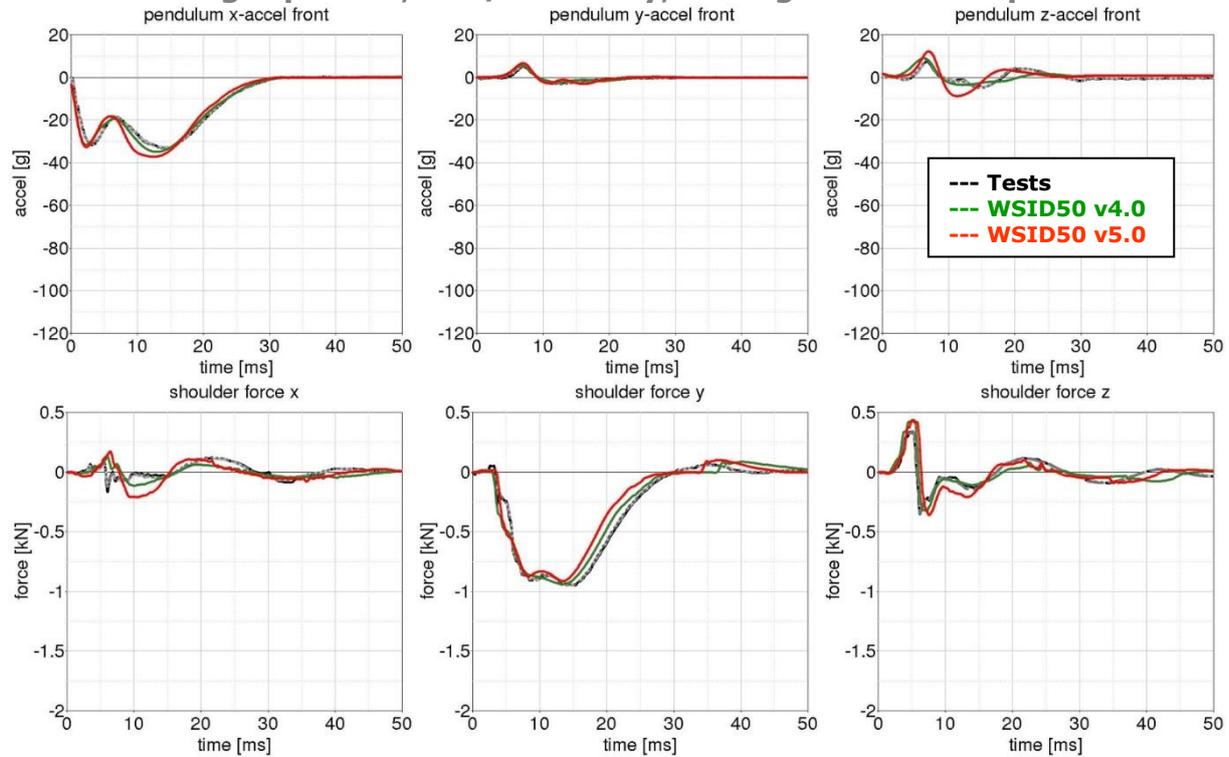
**Figure 43:** Results - Target point A, 4 m/s velocity, 48 degree load cell position

**Results - Target point B, 2 m/s velocity, 48 degree load cell position**



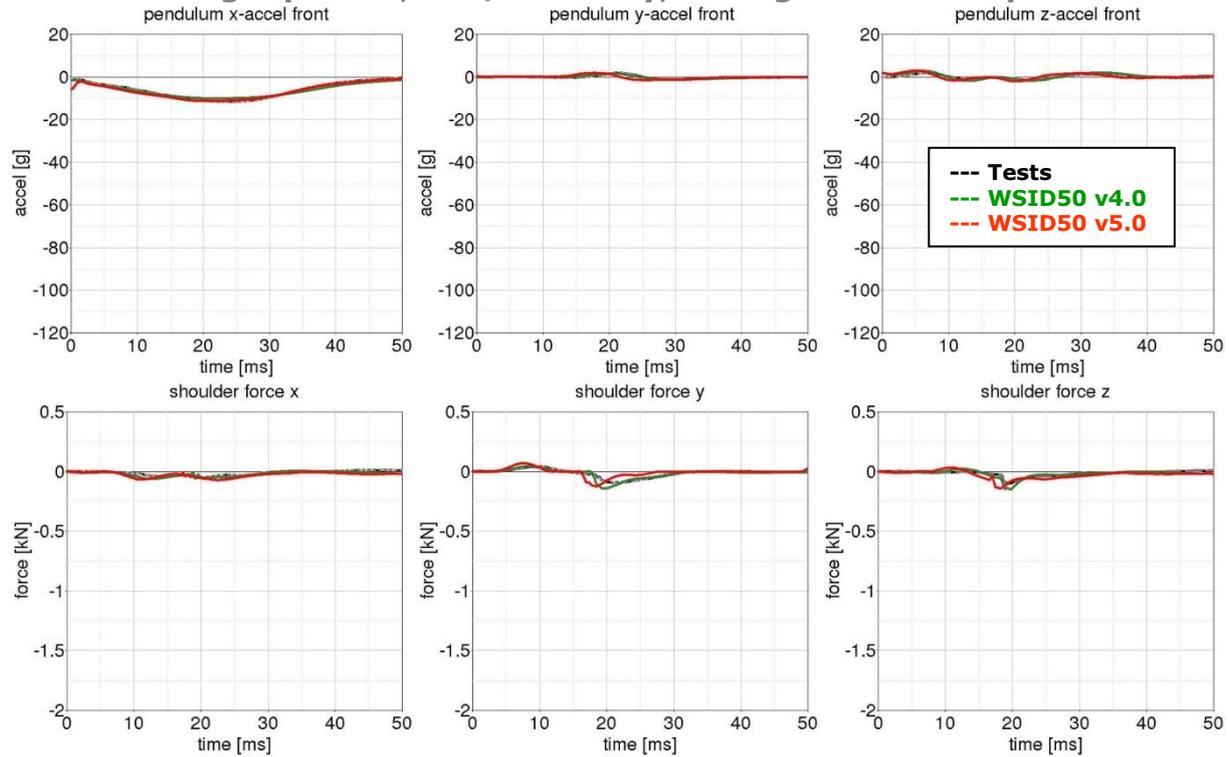
**Figure 44:** Results - Target point B, 2 m/s velocity, 48 degree load cell position

**Results - Target point B, 4 m/s velocity, 48 degree load cell position**



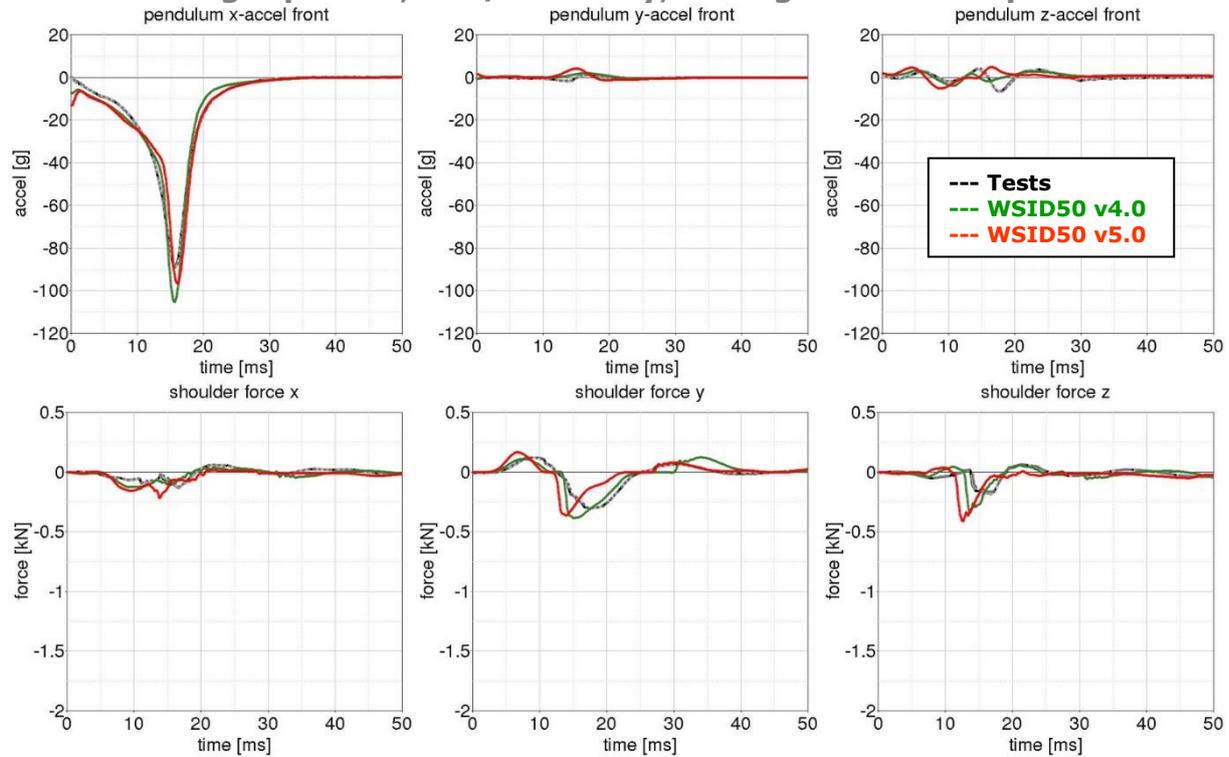
**Figure 45:** Results - Target point B, 4 m/s velocity, 48 degree load cell position

**Results - Target point C, 2 m/s velocity, 48 degree load cell position**



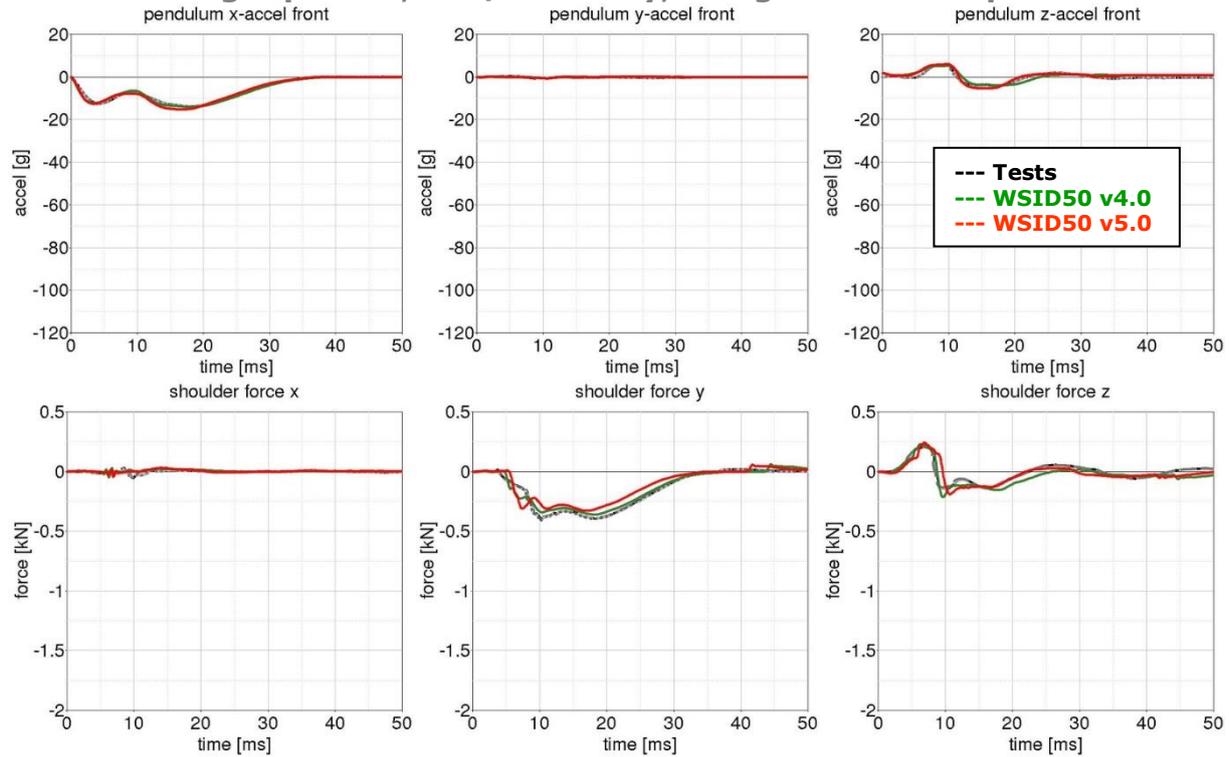
**Figure 46:** Results - Target point C, 2 m/s velocity, 48 degree load cell position

**Results - Target point C, 4 m/s velocity, 48 degree load cell position**



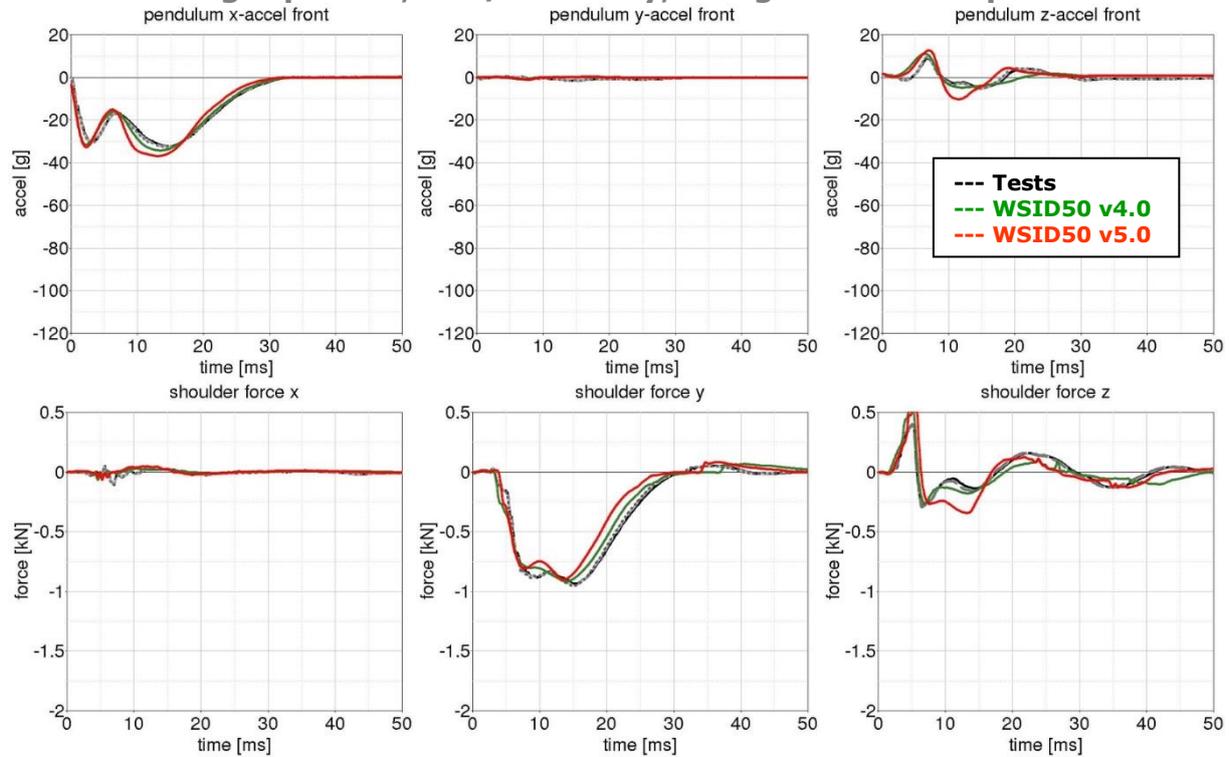
**Figure 47:** Results - Target point C, 4 m/s velocity, 48 degree load cell position

**Results - Target point B, 2 m/s velocity, 8 degree load cell position**



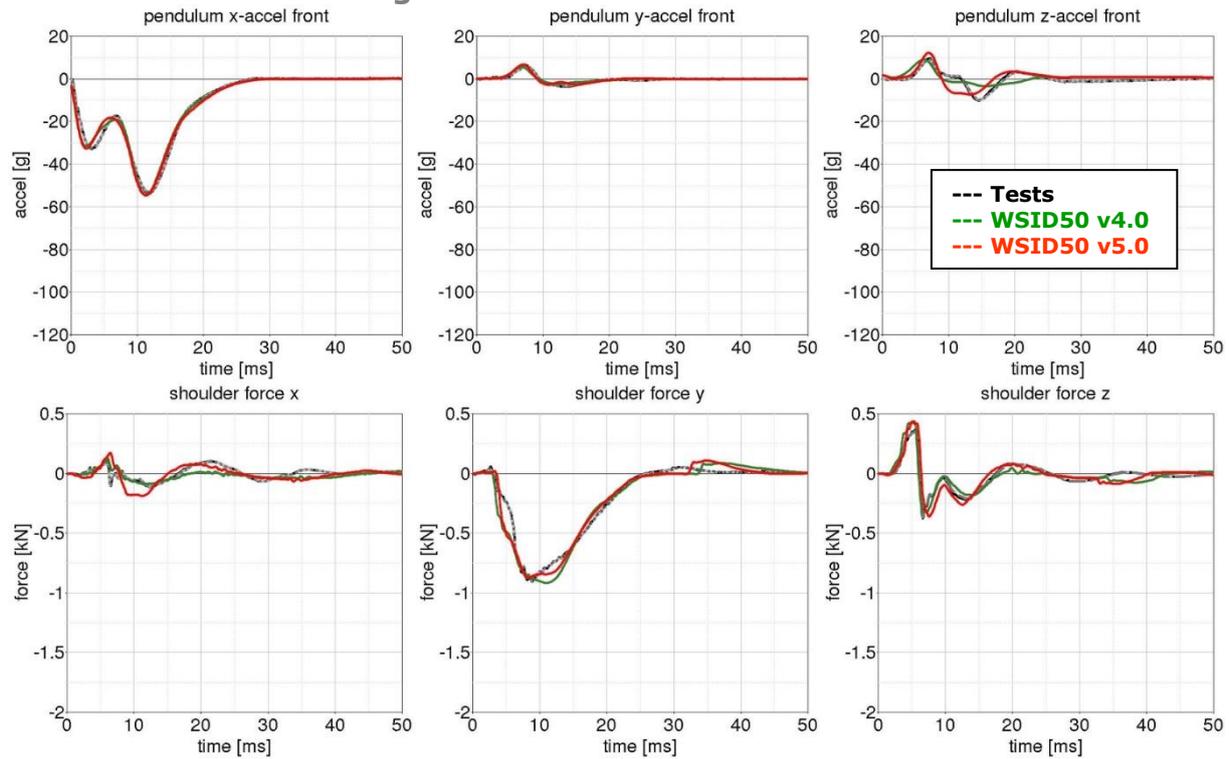
**Figure 48:** Results - Target point B, 2 m/s velocity, 8 degree load cell position

**Results - Target point B, 4 m/s velocity, 8 degree load cell position**



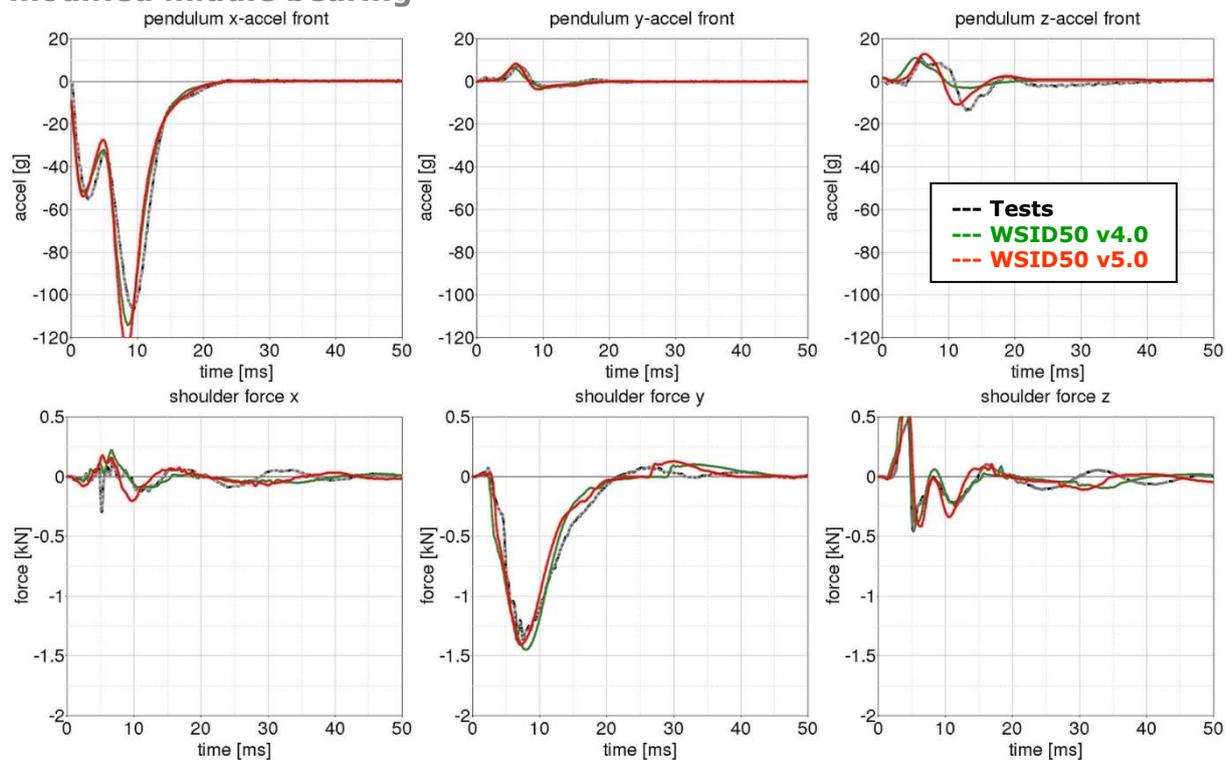
**Figure 49:** Results - Target point B, 4 m/s velocity, 8 degree load cell position

**Results - Target point B, 4 m/s velocity, 48 degree load cell position and modified middle bearing**



**Figure 50:** Results - Target point B, 4 m/s velocity, 8 degree load cell position, modified middle bearing

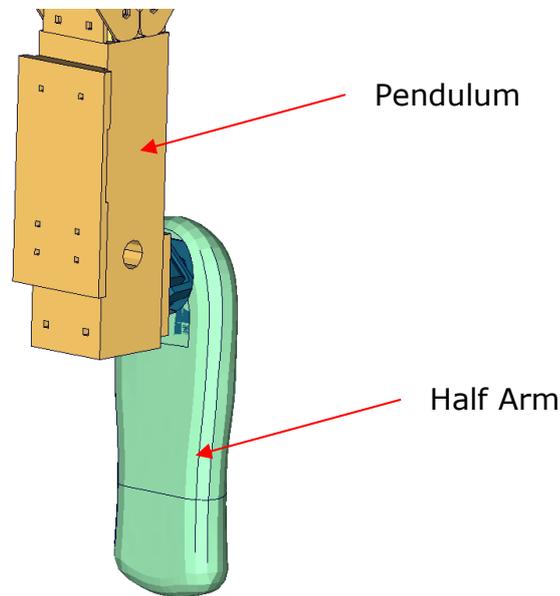
**Results - Target point B, 6 m/s velocity, 48 degree load cell position and modified middle bearing**



**Figure 51:** Results - Target point B, 6 m/s velocity, 8 degree load cell position, modified middle bearing

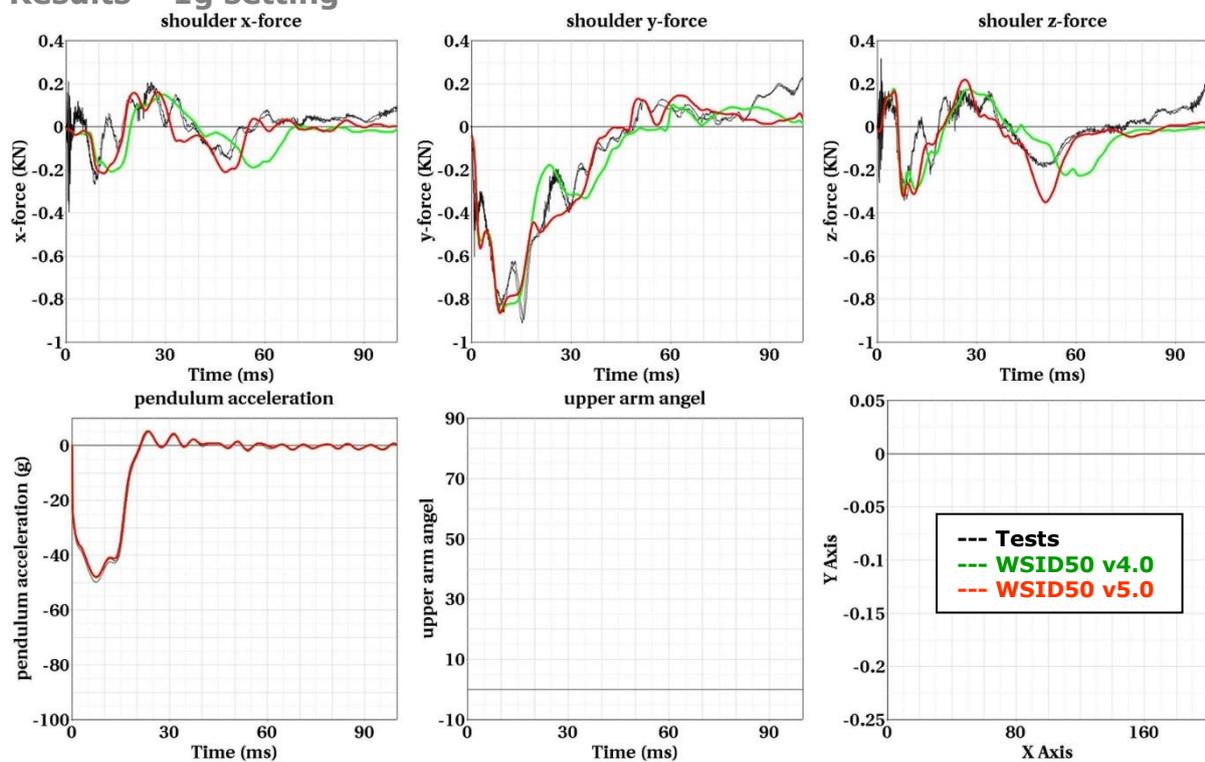
### 8.1.4 Arm Bending test

In order to validate the bending behavior of the half arm of WorldSID 50th, there are arm bending tests. Half arm with arm joint is mounted on a pendulum. There are two type of test: Arm joint in Y-direction is under 1g setting and fixed setting.



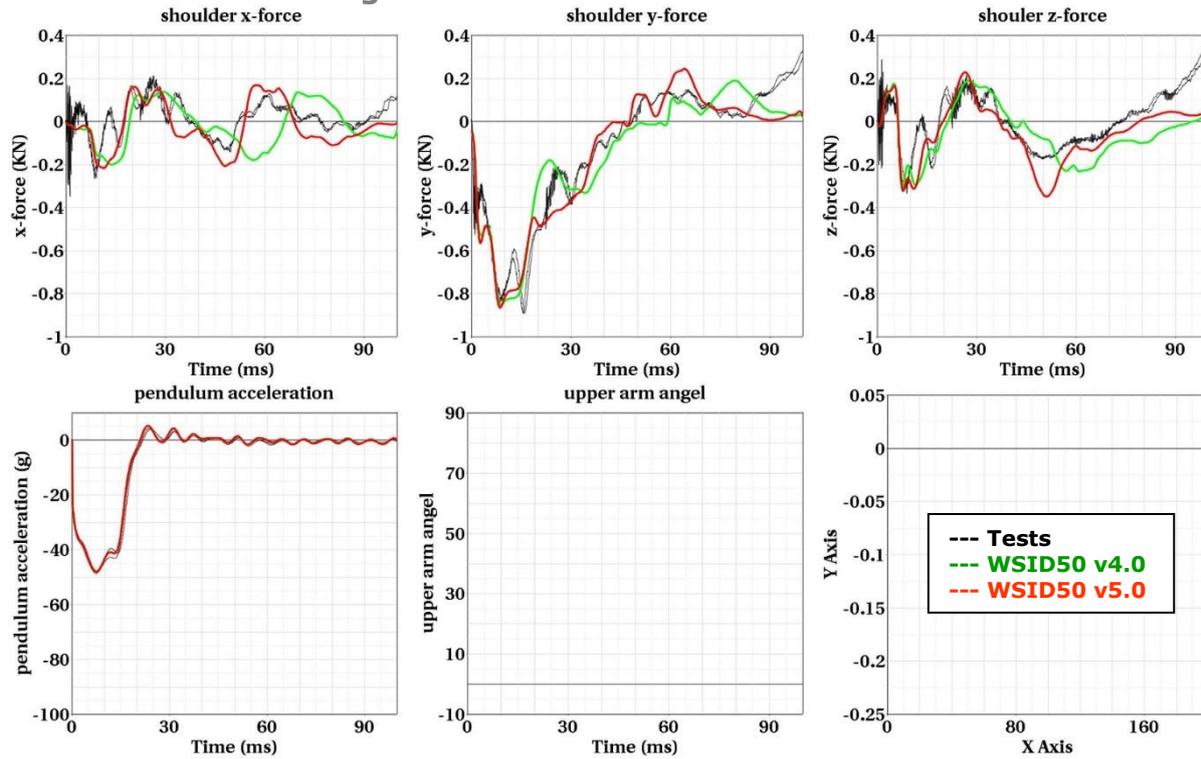
**Figure 52:** Arm bending test of WorldSID 50th

#### Results – 1g setting



**Figure 53:** Results – 1g setting

**Results – fixed setting**

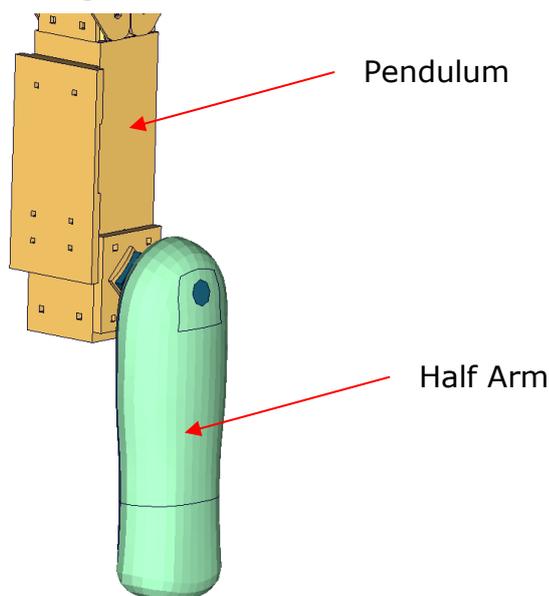


**Figure 54:** Results – fixed setting

**8.1.5 Arm Joint test**

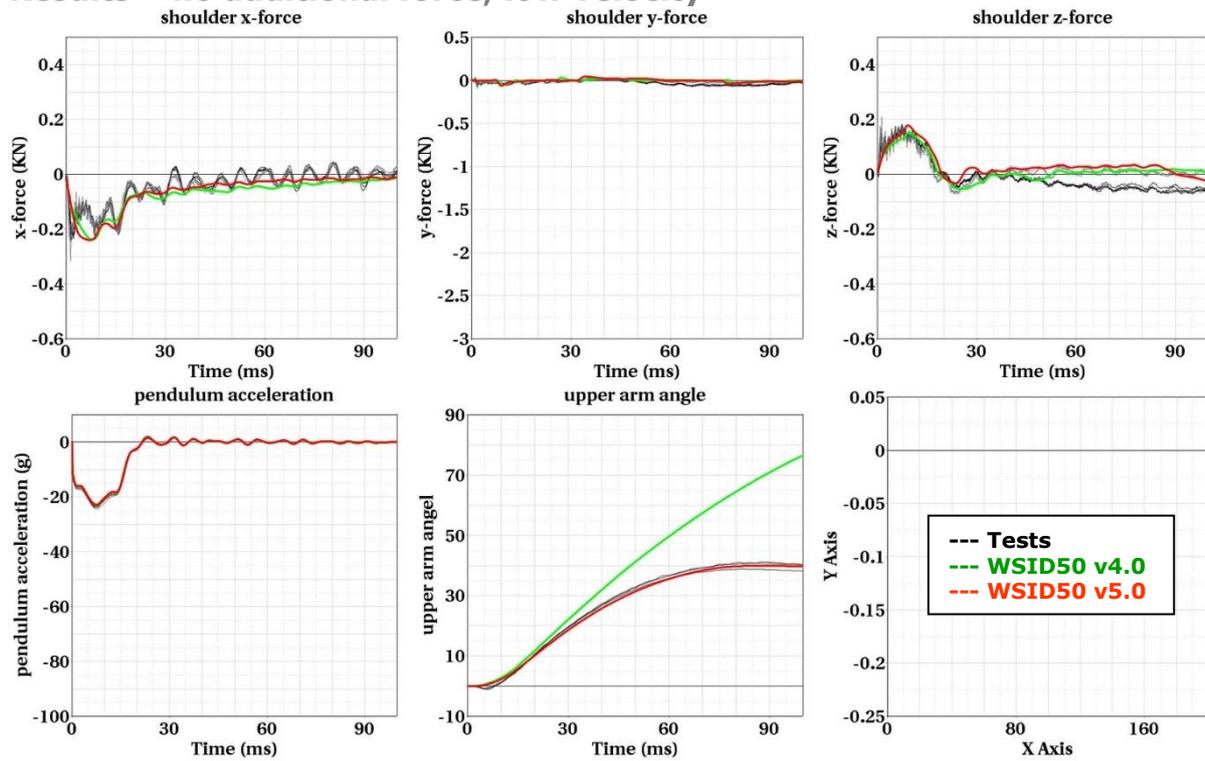
In order to validate the rotation behavior of the arm joint of WorldSID 50th, there are type of half arm pendulum tests: no additional force on arm joint, different additional force on arm joint.

**No additional force on arm joint:**



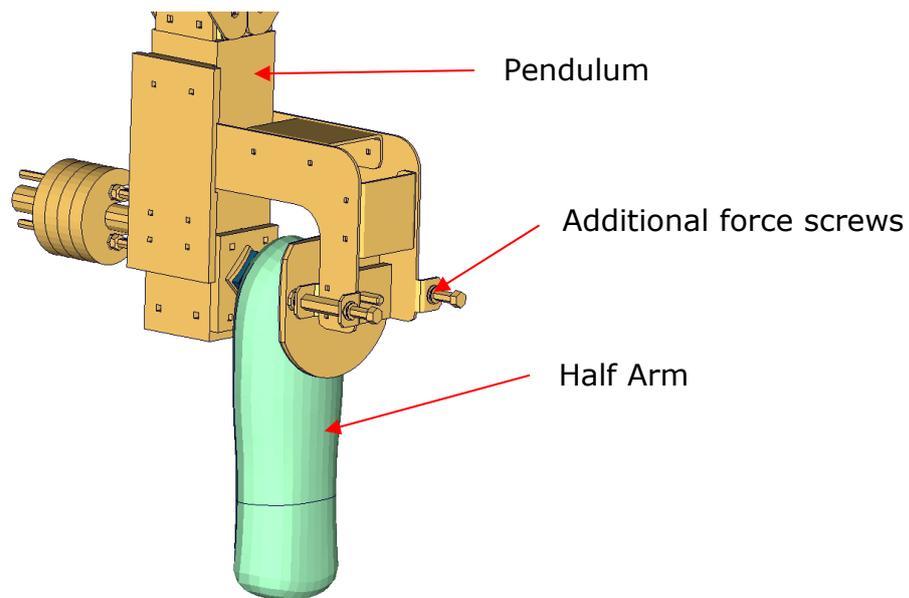
**Figure 55:** Arm joint test of WorldSID 50th, no additional force

**Results – no additional force, low velocity**



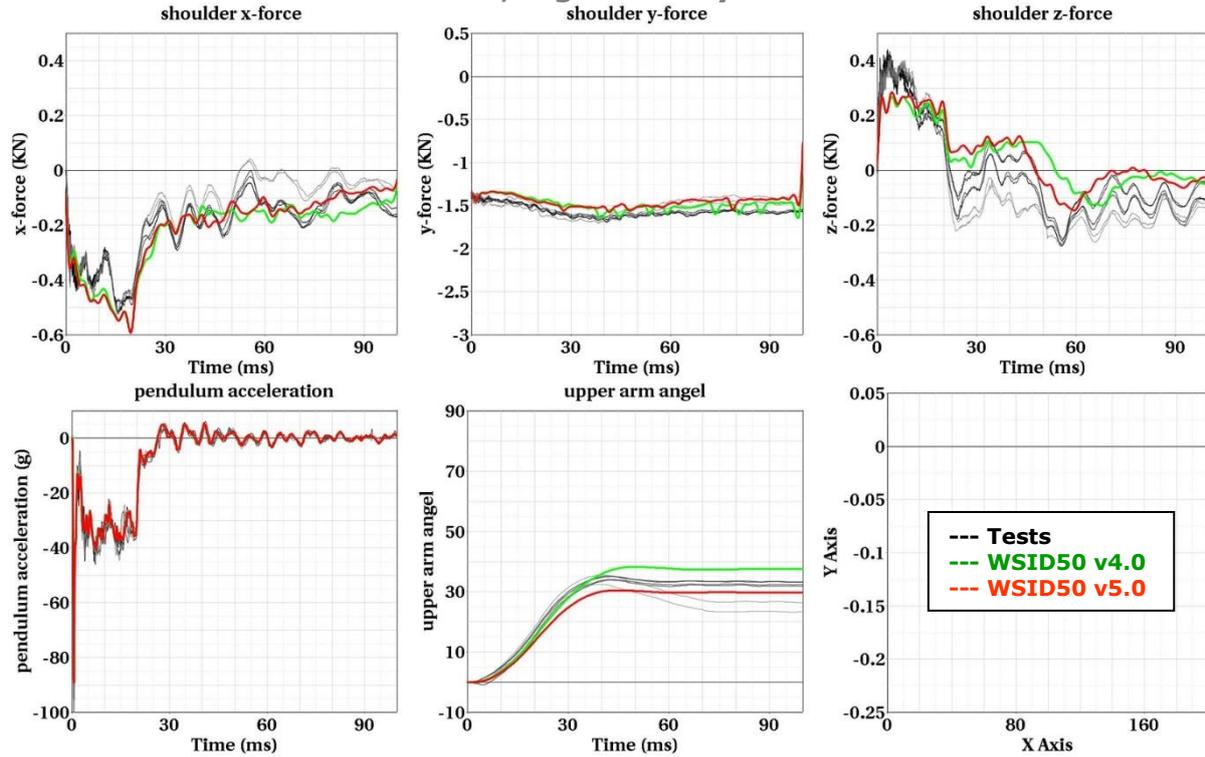
**Figure 56:** Results – no additional force on arm joint, low velocity

**Additional force on arm joint:**



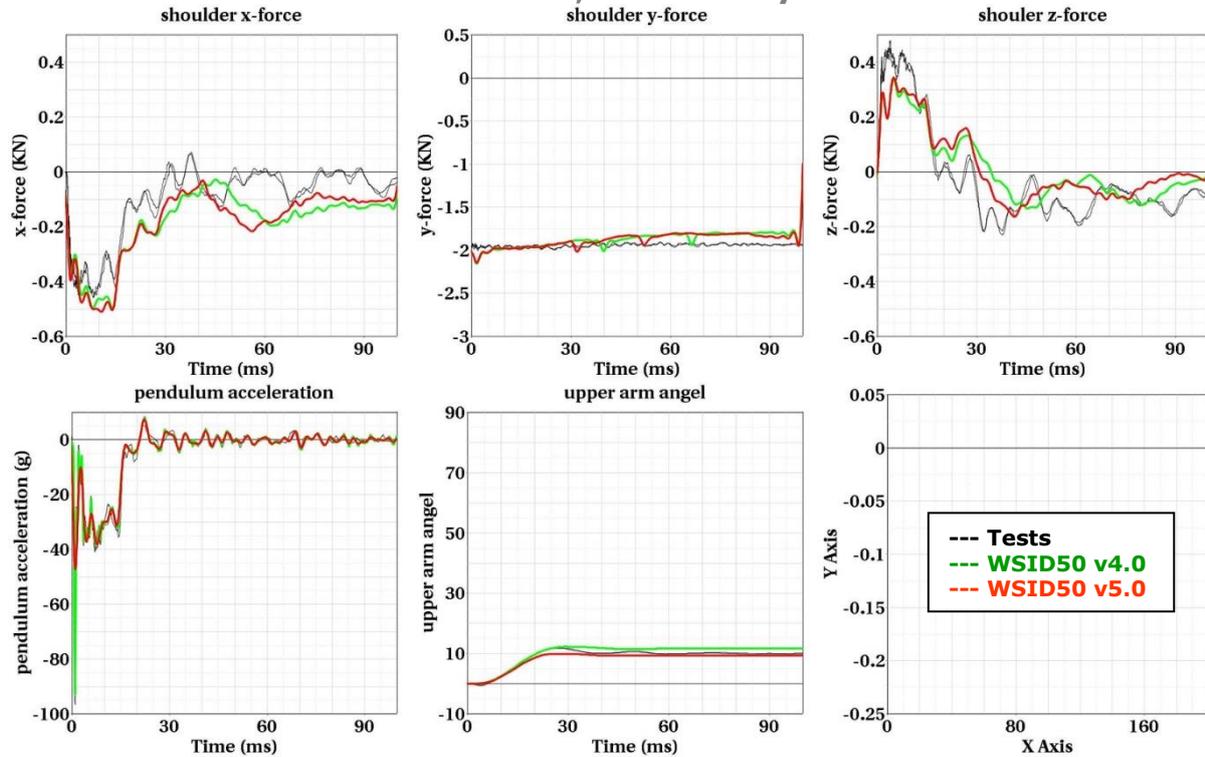
**Figure 57:** Arm joint test of WorldSID 50th, no additional force

**Results – low additional force, high velocity**



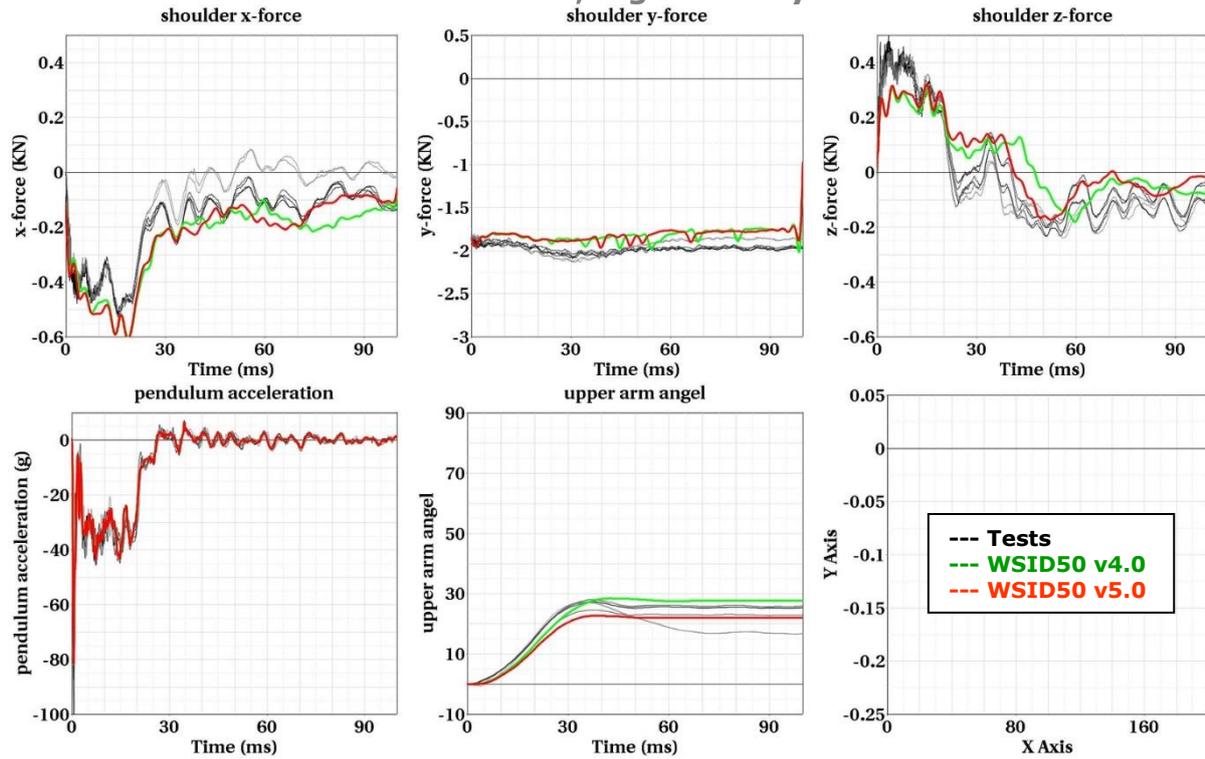
**Figure 58:** Results – low additional force on arm joint, high velocity

**Results – medium additional force, low velocity**



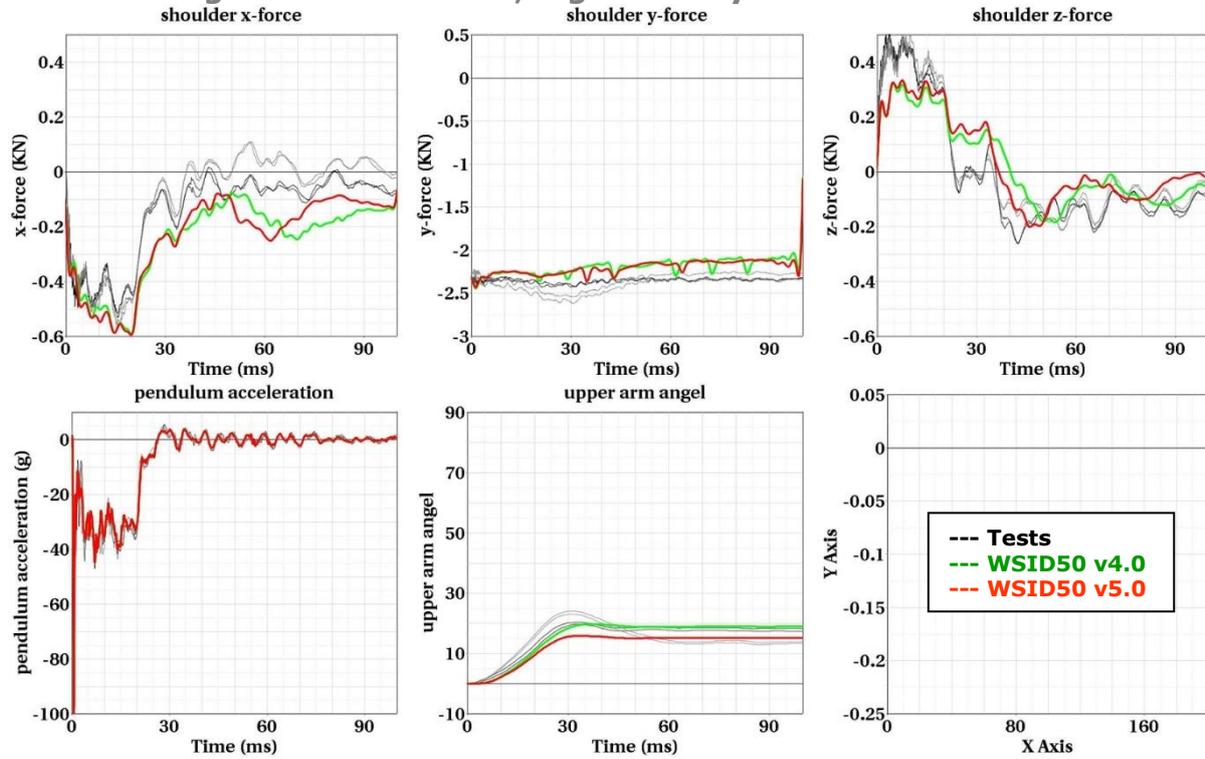
**Figure 59:** Results – medium additional force on arm joint, low velocity

**Results – medium additional force, high velocity**



**Figure 60:** Results – medium additional force on arm joint, high velocity

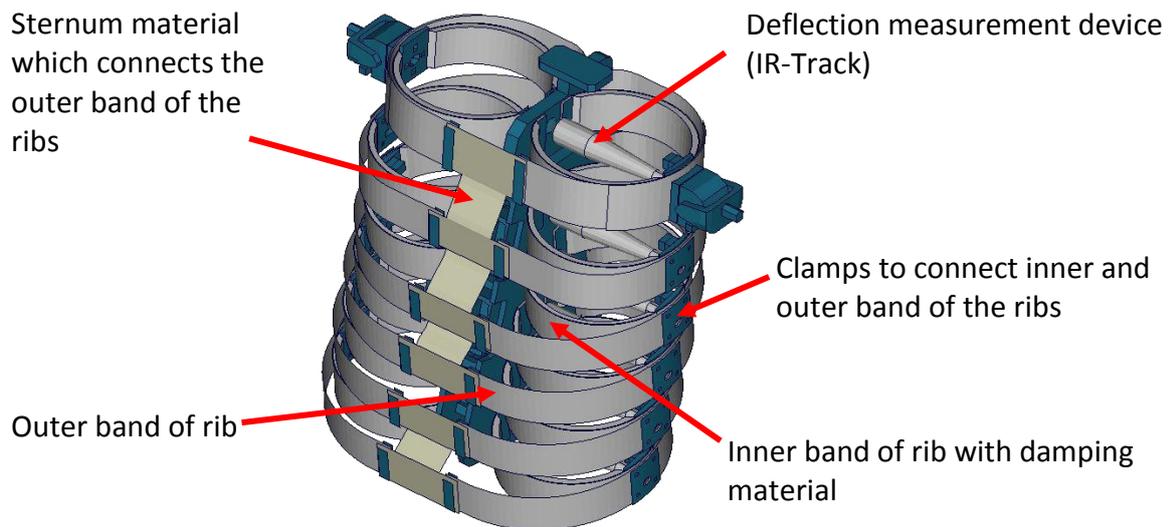
**Results – high additional force, high velocity**



**Figure 61:** Results – high additional force on arm joint, high velocity

### 8.1.6 Rib test

For the validation of the rib module of the WorldSID, many different tests have been performed. One single rib consists of two rib bands - an inner and an outer band. On the inner side of the inner band a blue damping material is tied. All ribs are built in a similar way. The difference in the shoulder, thorax and abdomen ribs are in the geometry and in the thickness of the damping material. The rib module is shown in the figure below:

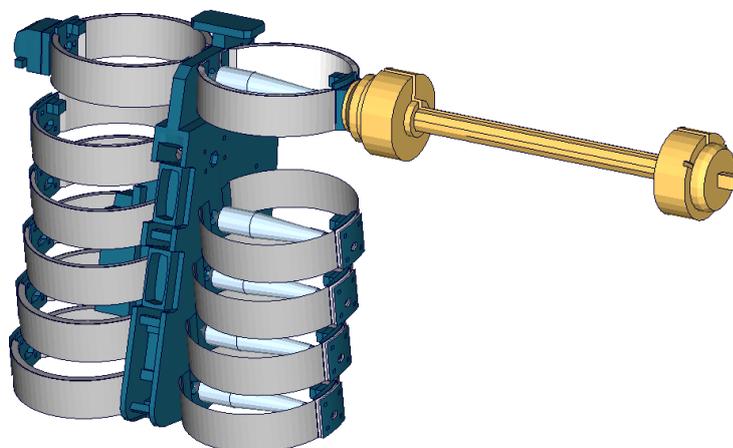


**Figure 62:** Thorax construction of WorldSID

#### 8.1.6.1 Inner rib band

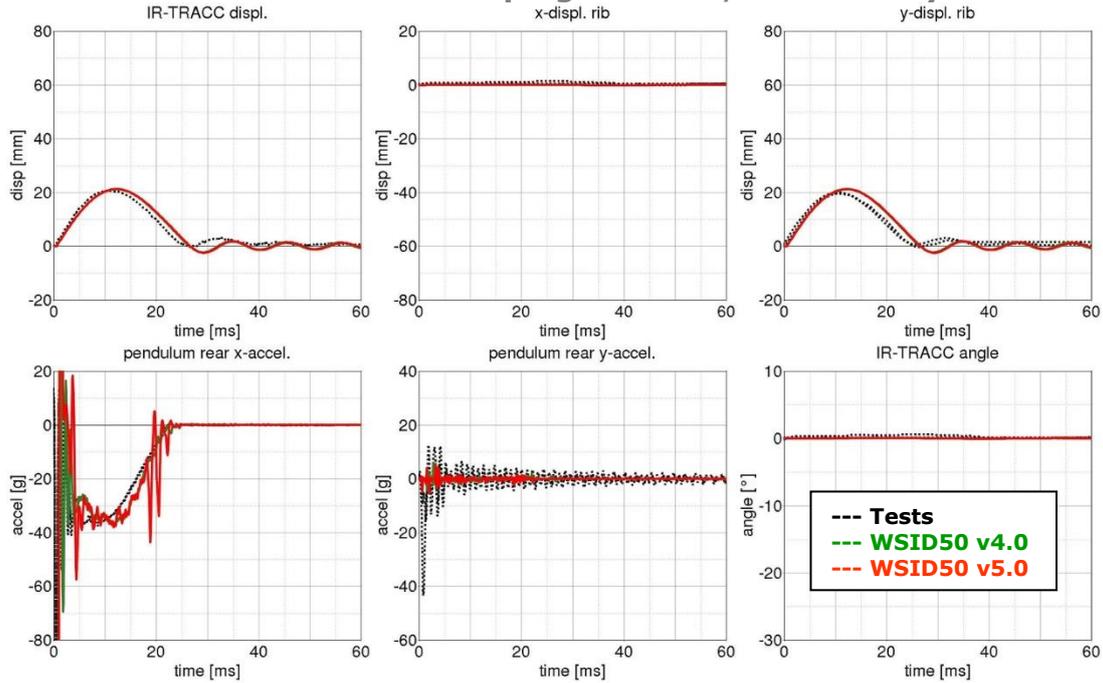
The inner rib bands with damping material of the shoulder, the third thorax and second abdomen rib are tested. A pendulum test is performed with two different velocities on the single rib band as depicted below.

#### Shoulder rib:



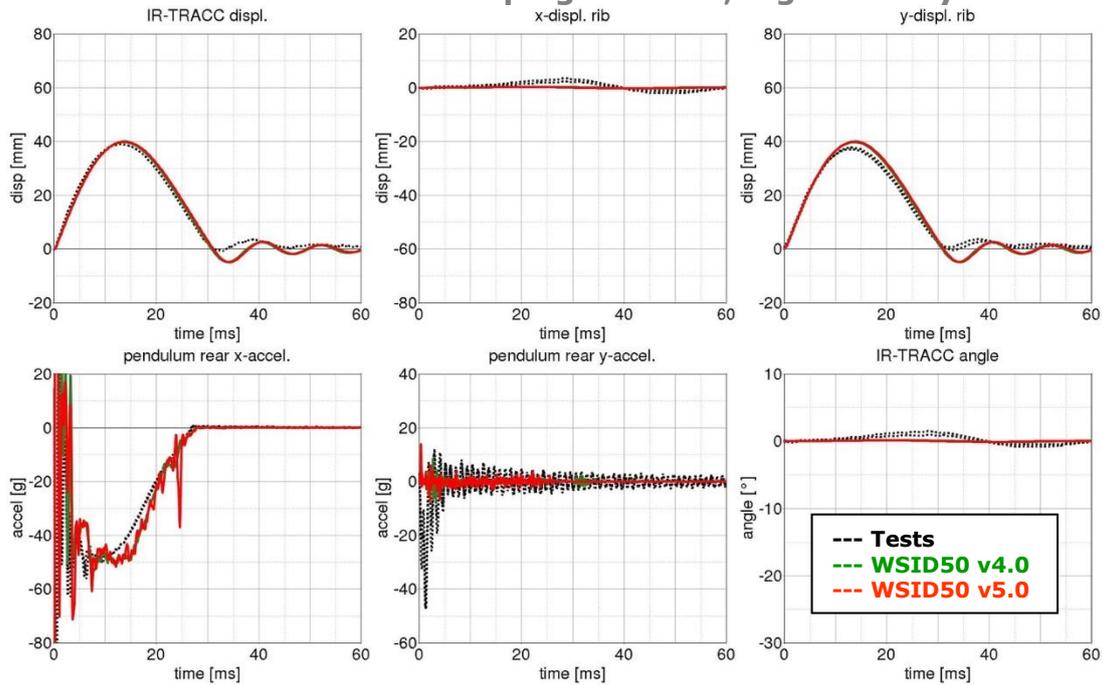
**Figure 63:** Shoulder rib test on inner band with damping material

### Shoulder rib inner band with damping material, low velocity



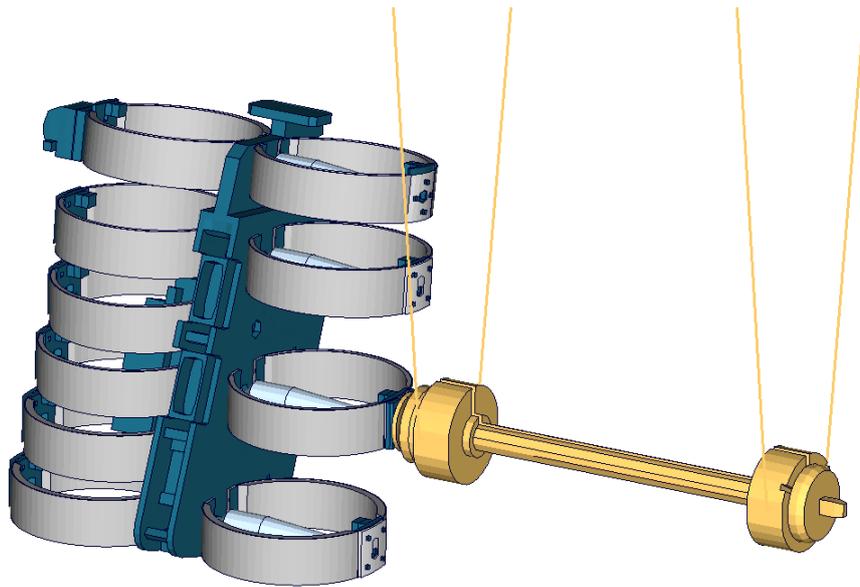
**Figure 64:** Shoulder rib test on inner band with damping material, low velocity

### Shoulder rib inner band with damping material, high velocity



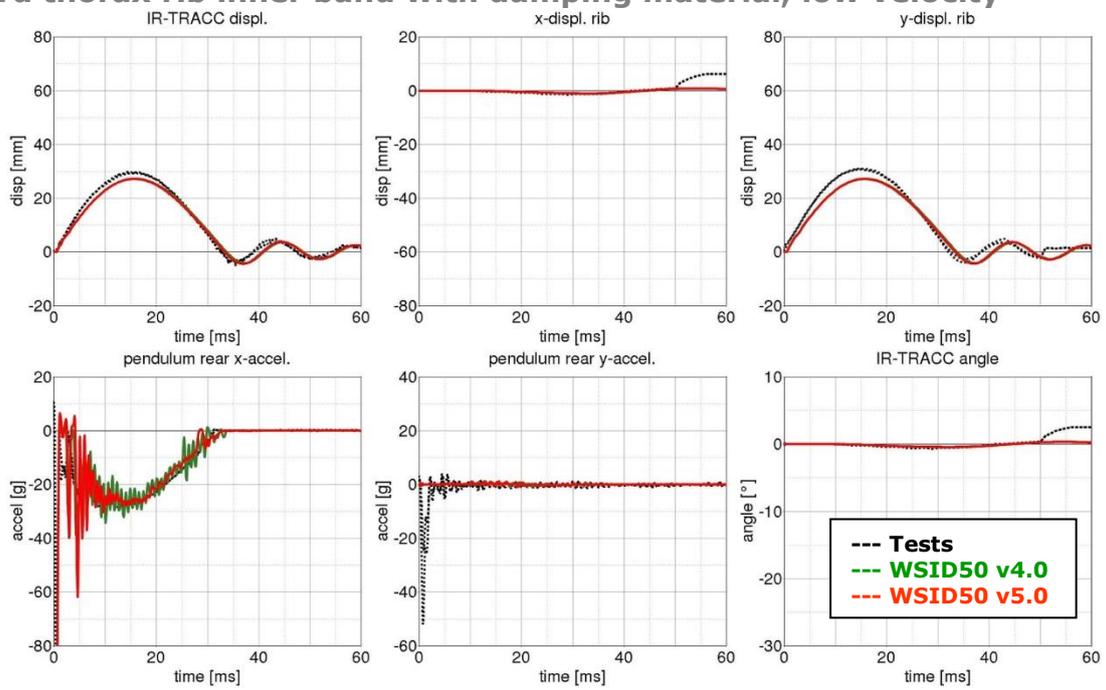
**Figure 65:** Shoulder rib test on inner band with damping material, high velocity

Third thorax rib:



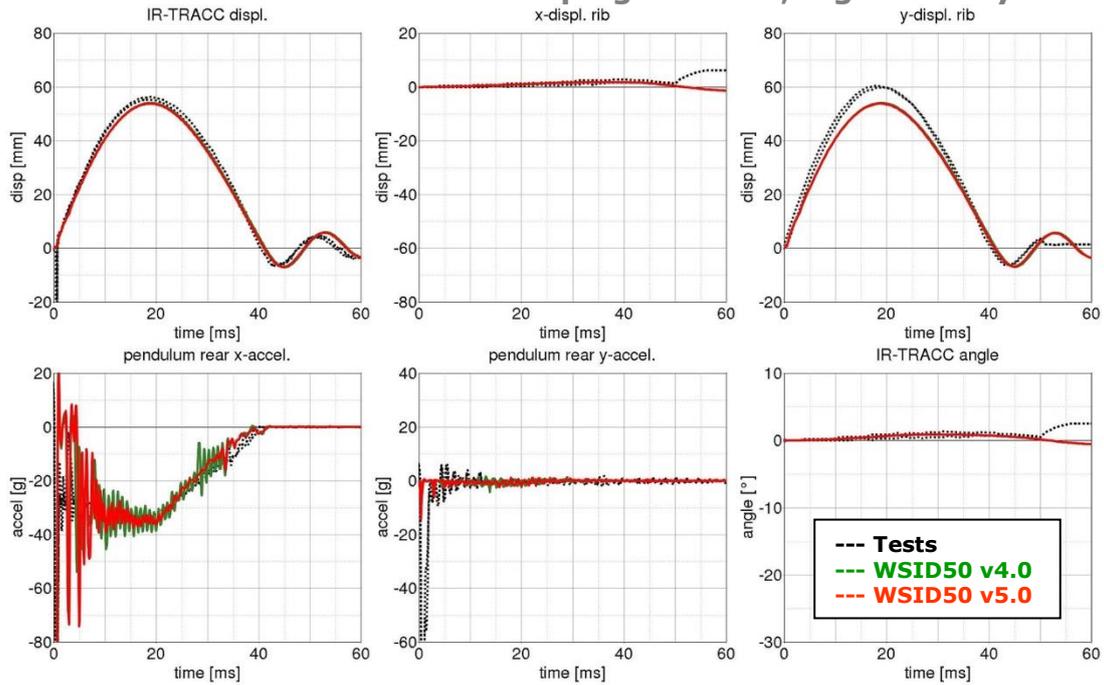
**Figure 66:** Third thorax rib test on inner band with damping material

Third thorax rib inner band with damping material, low velocity



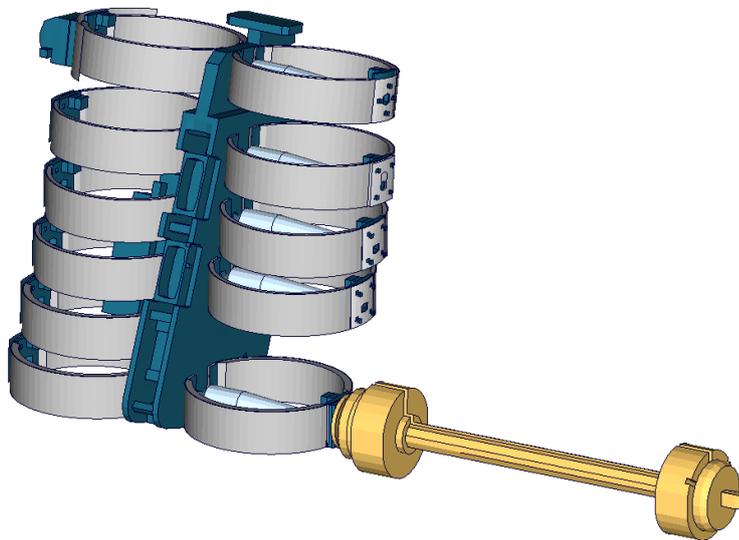
**Figure 67:** Shoulder rib test on inner band with damping material, low velocity

### Third thorax rib inner band with damping material, high velocity



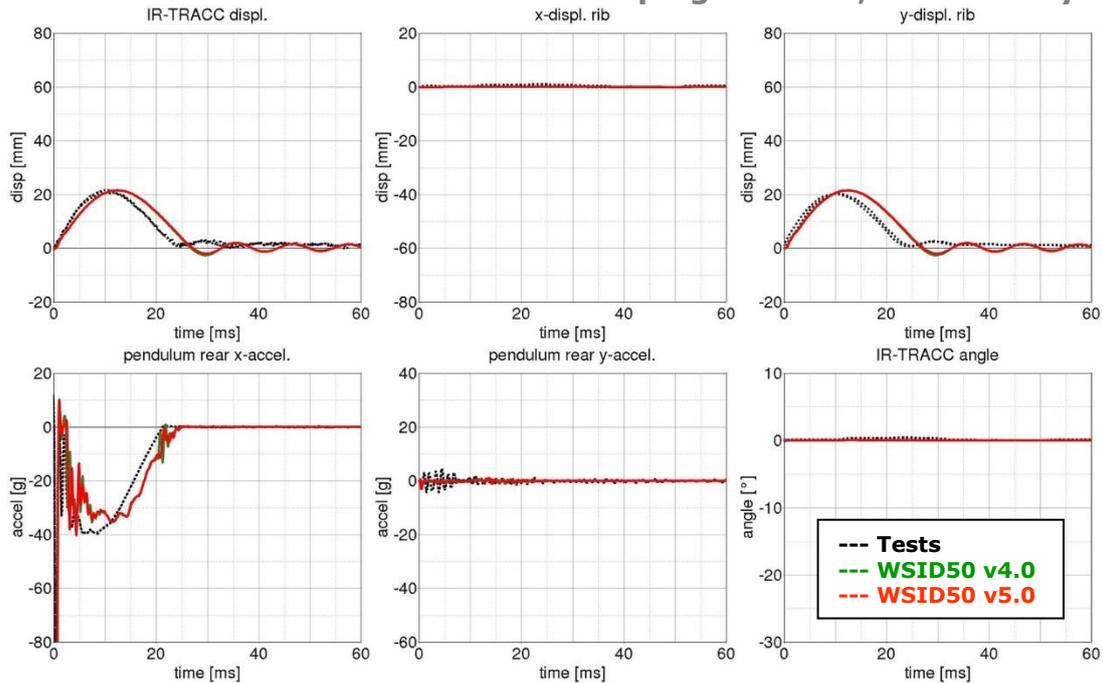
**Figure 68:** Shoulder rib test on inner band with damping material, high velocity

### Second abdomen rib:



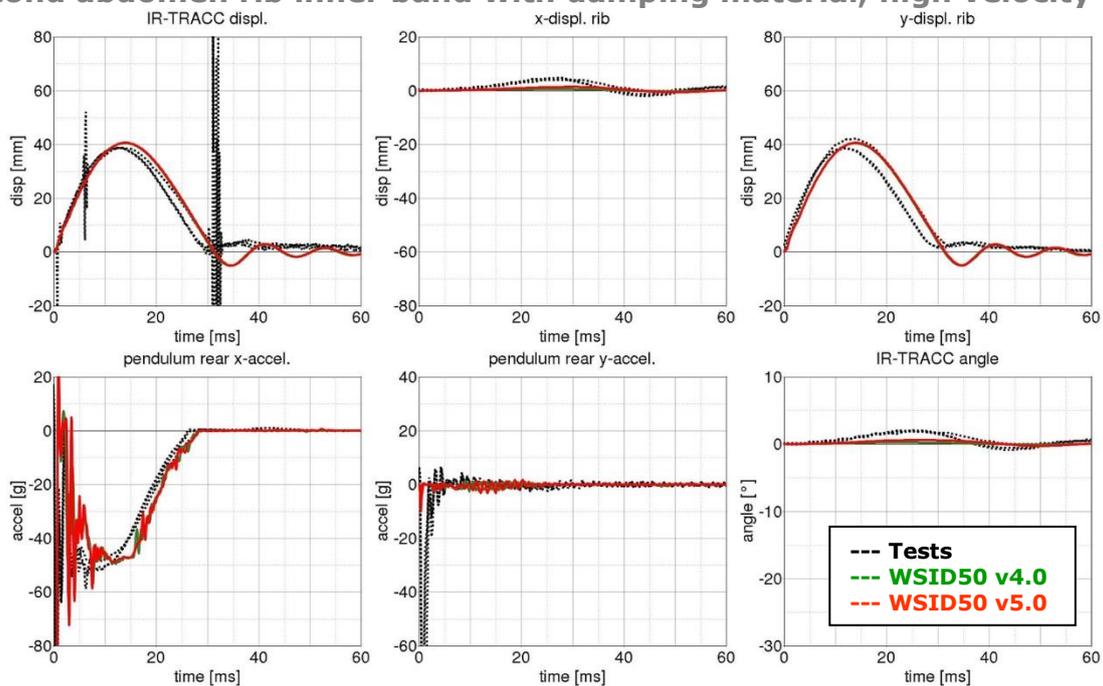
**Figure 69:** Second abdomen rib test on inner band with damping material.

### Second abdomen rib inner band with damping material, low velocity



**Figure 70:** Second abdomen rib test on inner band with damping material, low velocity

### Second abdomen rib inner band with damping material, high velocity



**Figure 71:** Second abdomen rib test on inner band with damping material, high velocity

### 8.1.6.2 Outer rib band

The outer rib band is tested in a similar way. A fully assembled thorax assembly is used and only the ribs above and below the tested rib are disassembled. The tested ribs are:

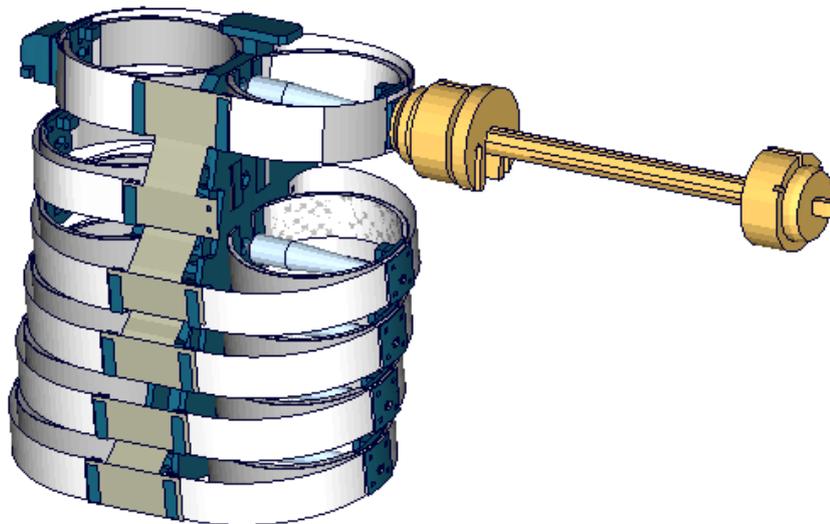
- Shoulder rib
- First thorax rib
- Third thorax rib
- Second abdomen rib

Each rib is tested with two velocities except the first thorax rib, where three different pendulum speeds are used.

The test is used to validate the behavior of the complete rib modules including the sternum materials.

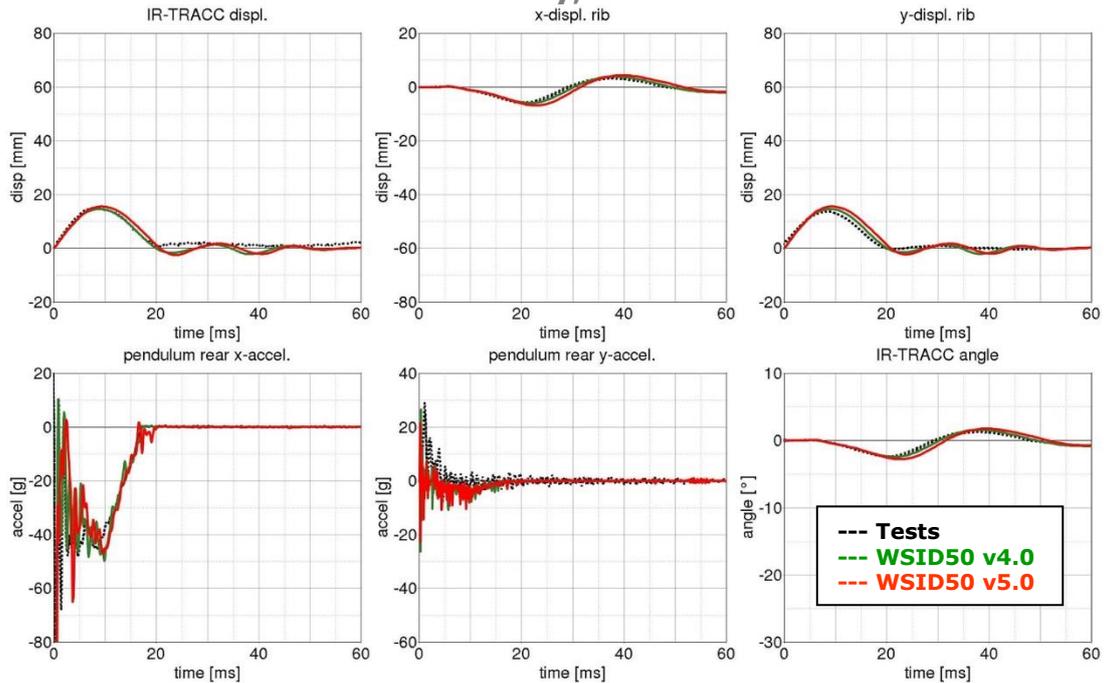
Furthermore two different masses are used for the pendulum; hence there are four different test configurations for each single rib.

#### Shoulder rib:



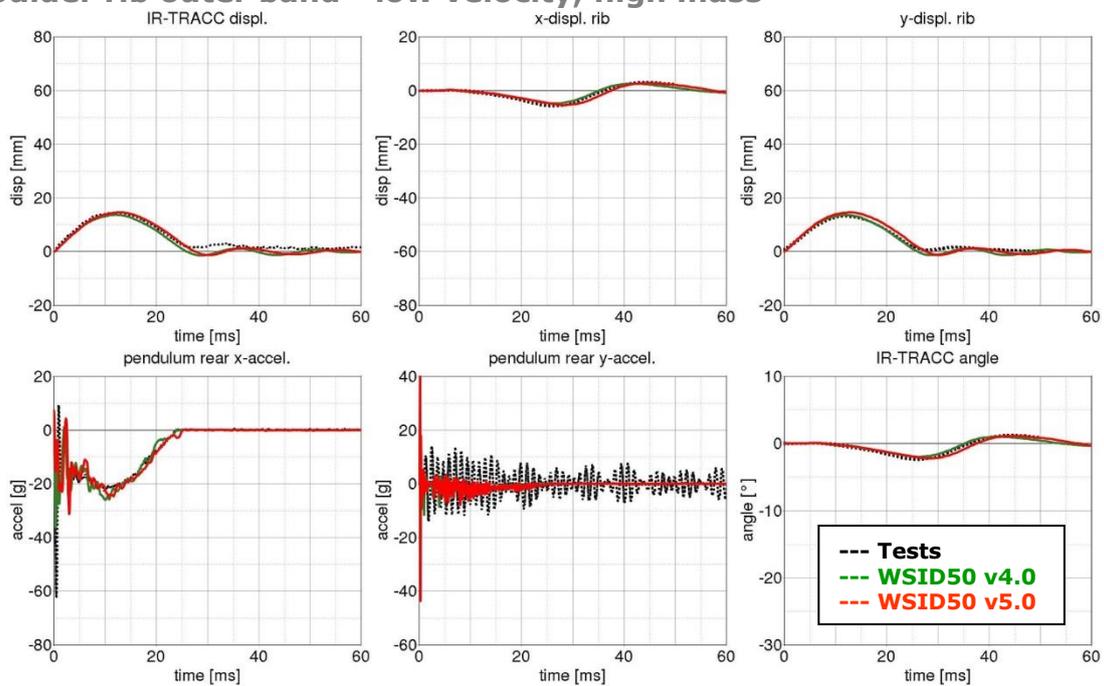
**Figure 72:** Shoulder rib outer band test

### Shoulder rib outer band - low velocity, low mass



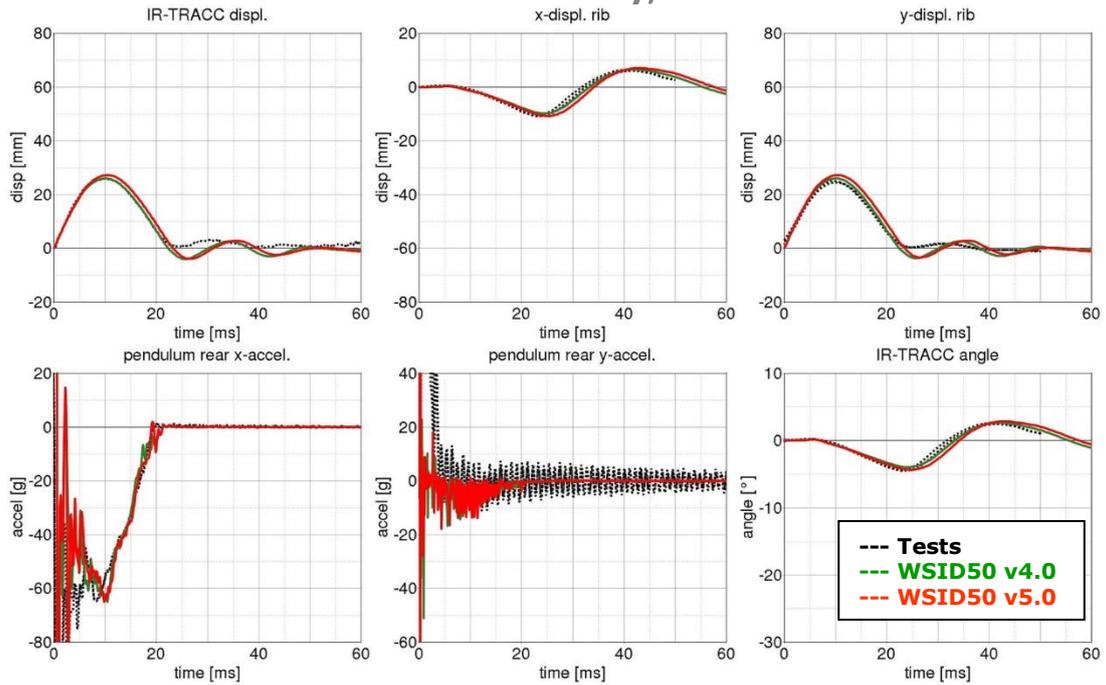
**Figure 73:** Shoulder rib test on outer band - low velocity and low mass

### Shoulder rib outer band - low velocity, high mass



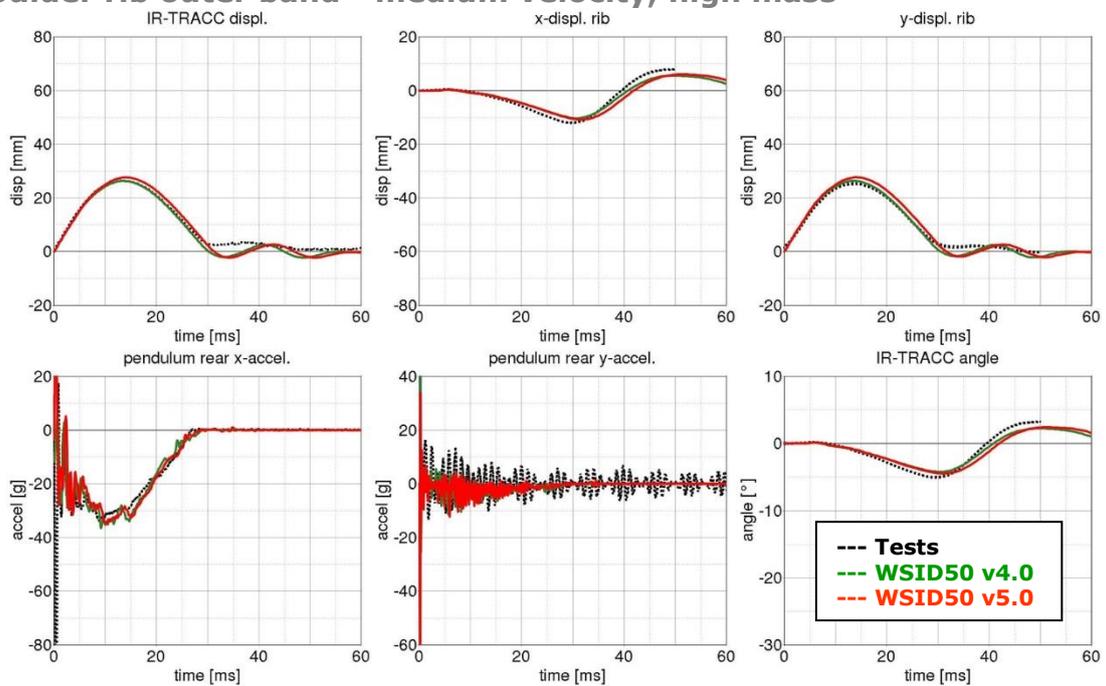
**Figure 74:** Shoulder rib test on outer band - low velocity and high mass

### Shoulder rib outer band - medium velocity, low mass



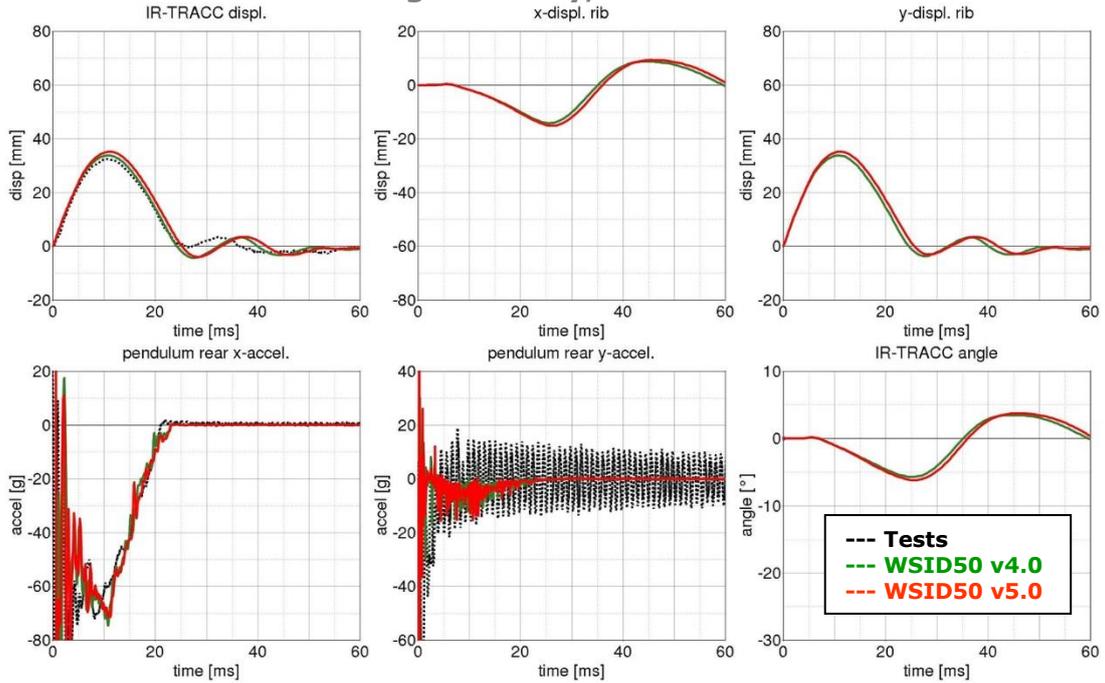
**Figure 75:** Shoulder rib test on outer band - middle velocity and low mass

### Shoulder rib outer band - medium velocity, high mass



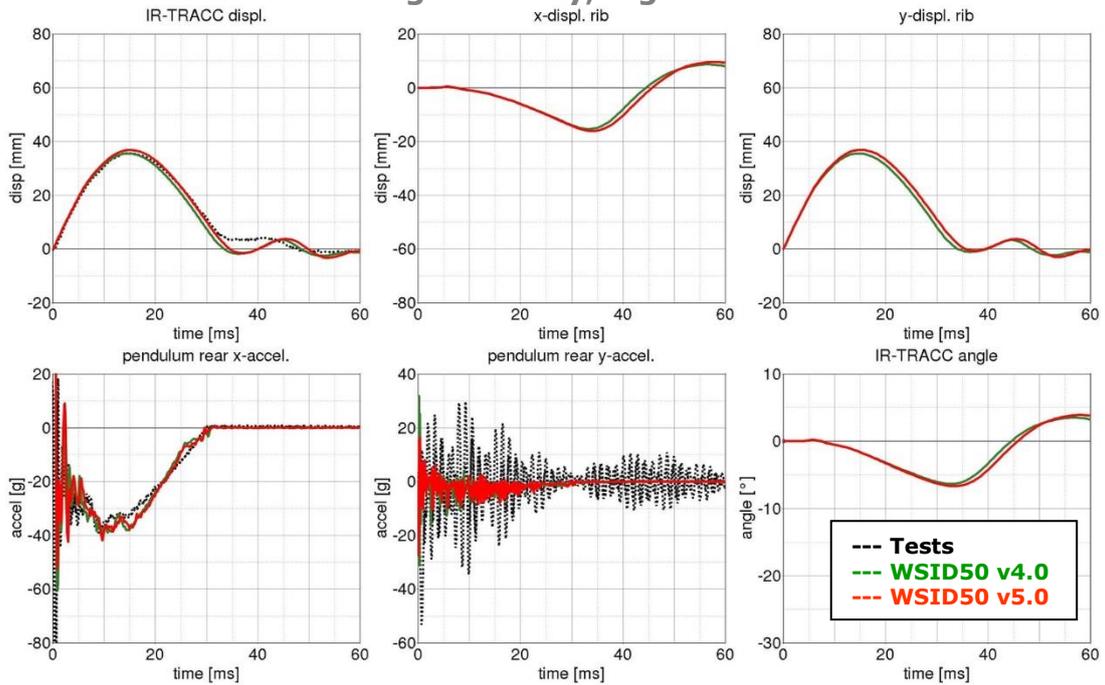
**Figure 76:** Shoulder rib test on outer band - middle velocity and high mass

### Shoulder rib outer band - high velocity, low mass



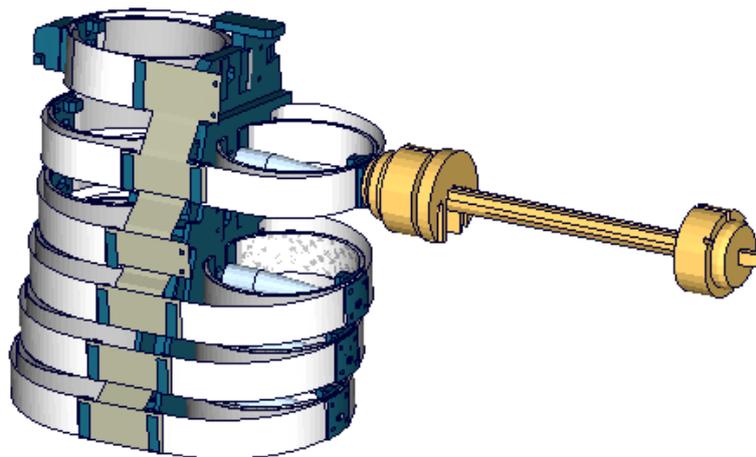
**Figure 77:** Shoulder rib test on outer band - high velocity and low mass

### Shoulder rib outer band - high velocity, high mass



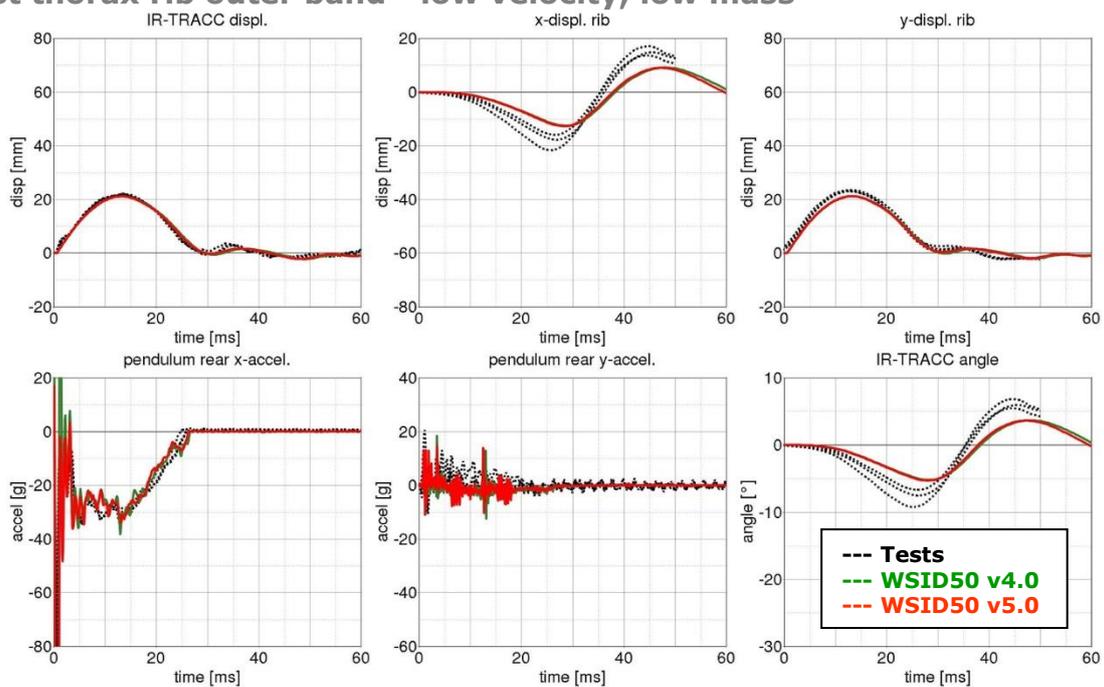
**Figure 78:** Shoulder rib test on outer band - high velocity and high mass

First thorax rib:



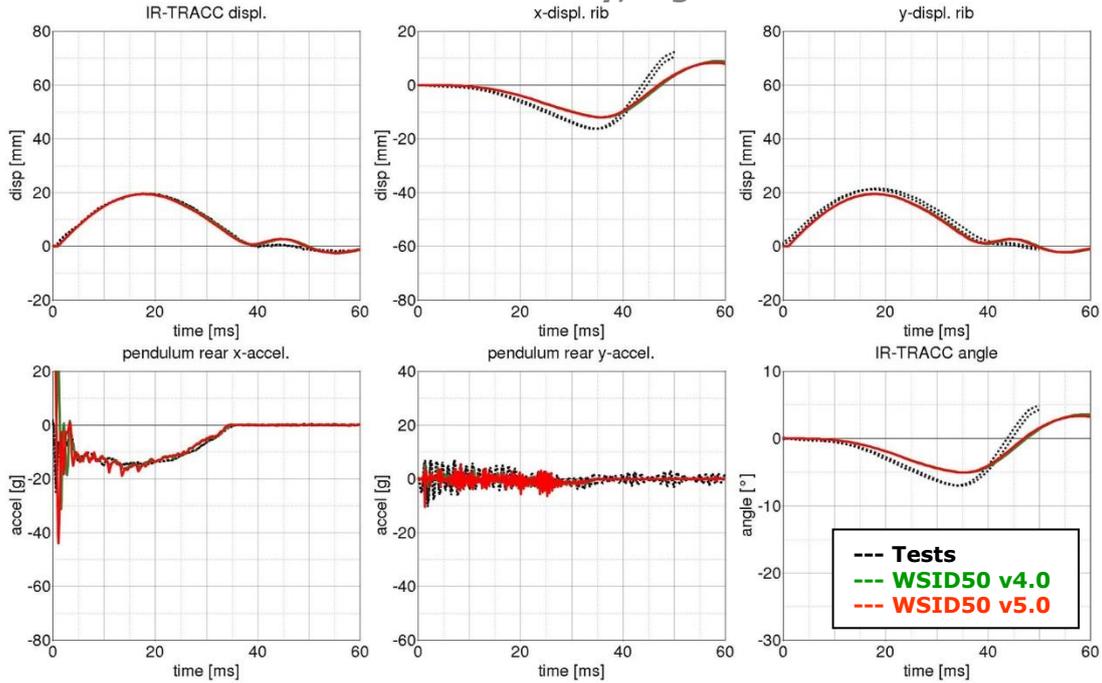
**Figure 79:** First thorax rib outer band test

First thorax rib outer band - low velocity, low mass



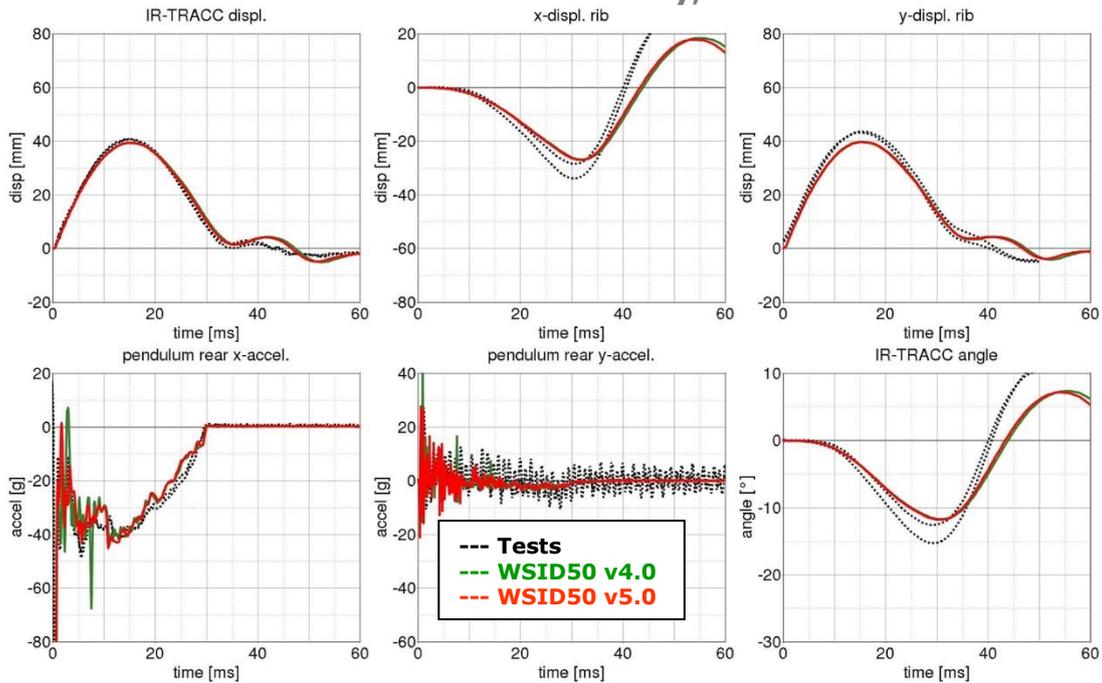
**Figure 80:** First thorax rib test on outer band - low velocity and low mass

**First thorax rib outer band - low velocity, high mass**



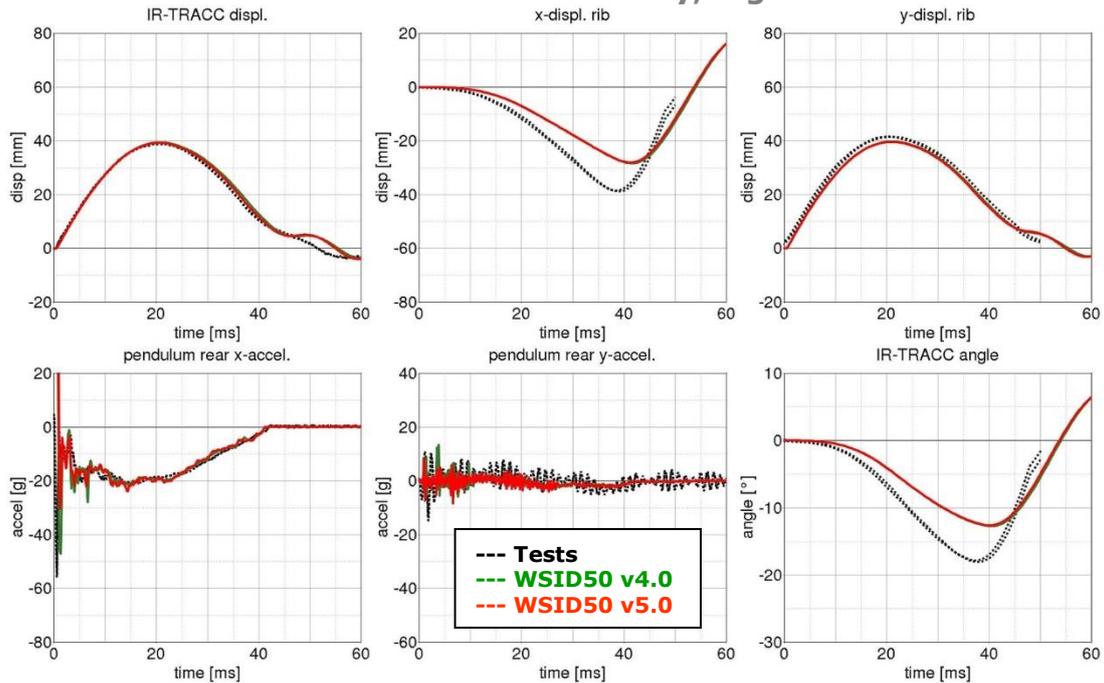
**Figure 81:** First thorax rib test on outer band - low velocity and high mass

**First thorax rib outer band - medium velocity, low mass**



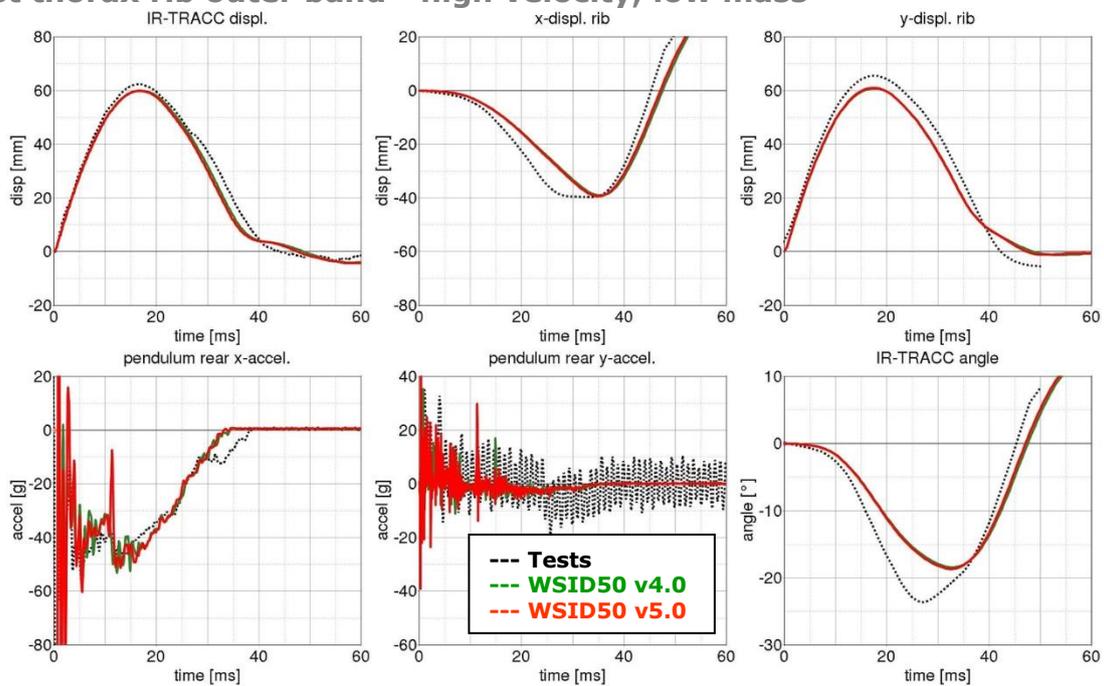
**Figure 82:** First thorax rib test on outer band - middle velocity and low mass

### First thorax rib outer band - medium velocity, high mass



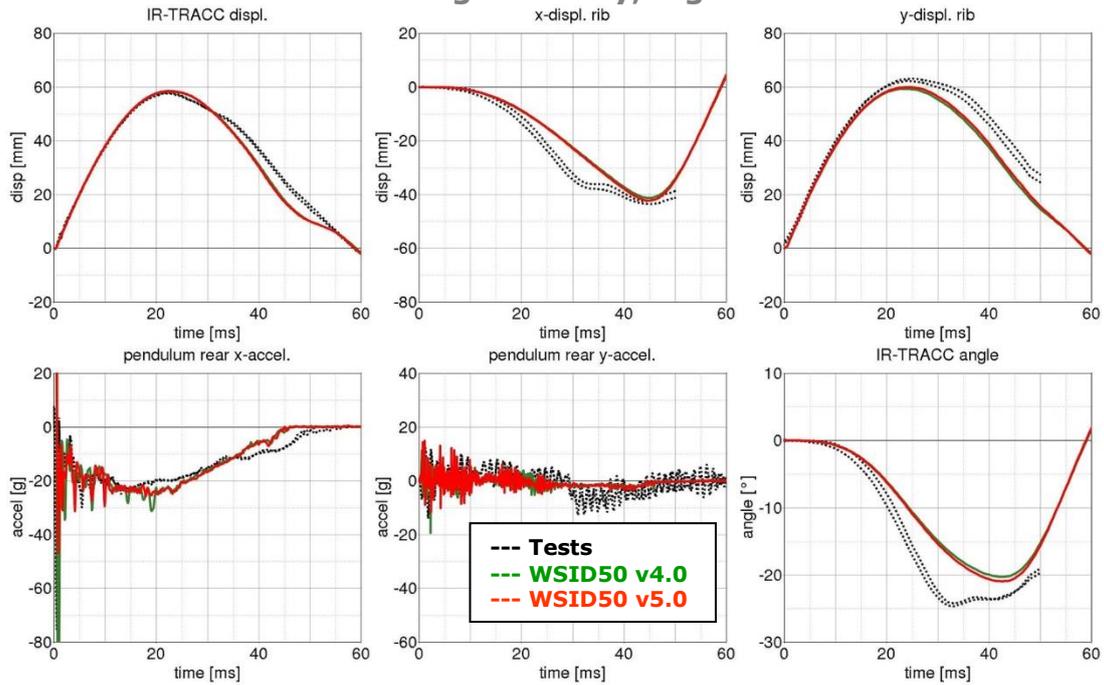
**Figure 83:** First thorax rib test on outer band - middle velocity and high mass

### First thorax rib outer band - high velocity, low mass



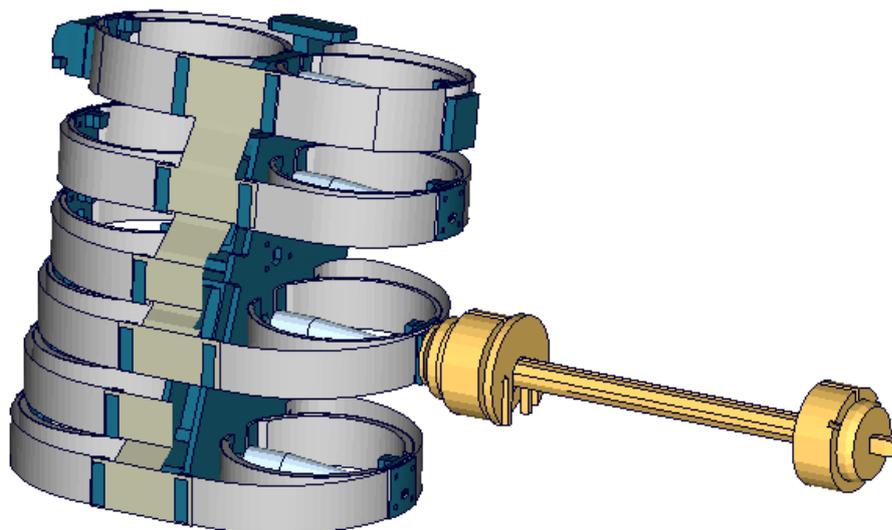
**Figure 84:** First thorax rib test on outer band - high velocity and low mass

### First thorax rib outer band - high velocity, high mass



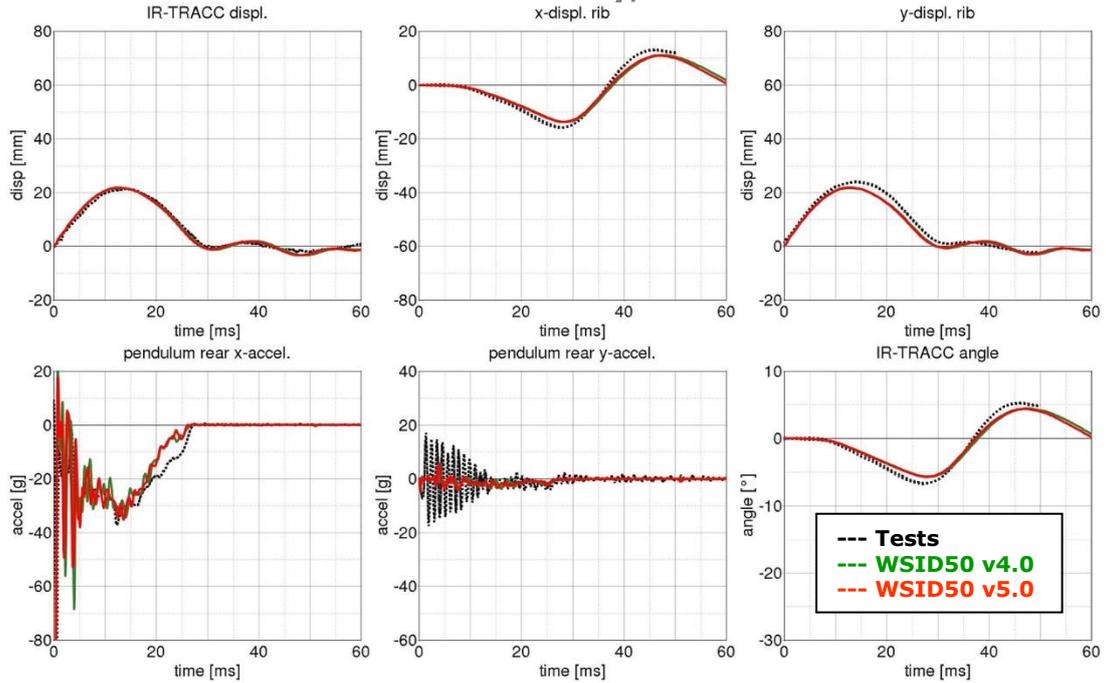
**Figure 85:** First thorax rib test on outer band - high velocity and high mass

### Third thorax rib:



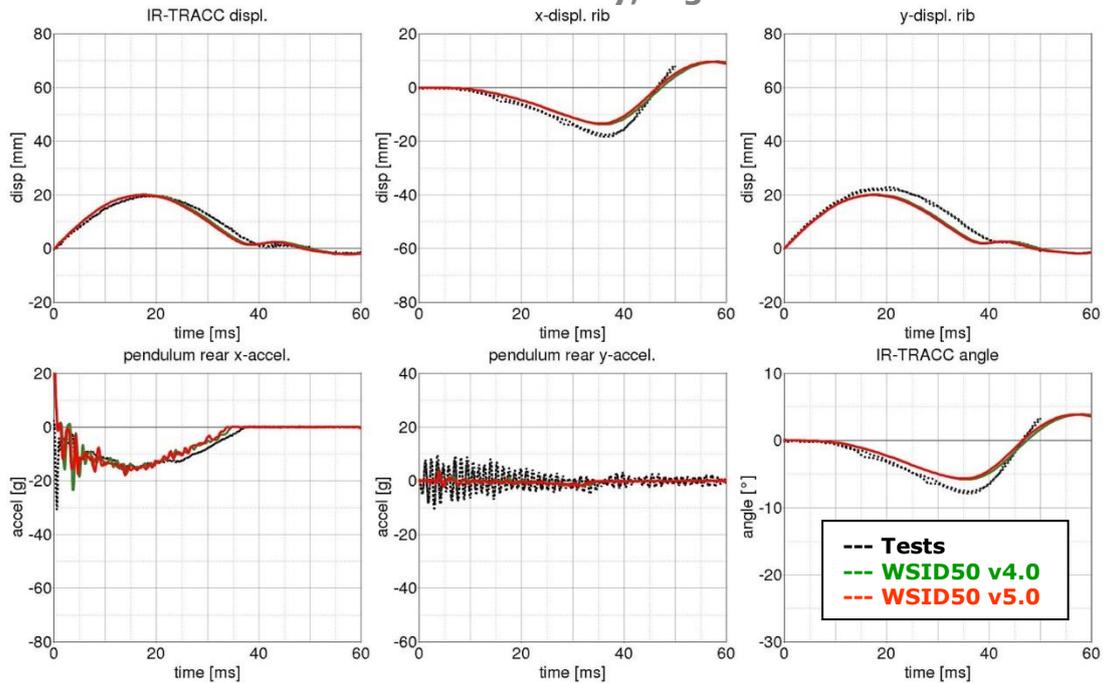
**Figure 86:** Third thorax rib outer band test

### Third thorax rib outer band - low velocity, low mass



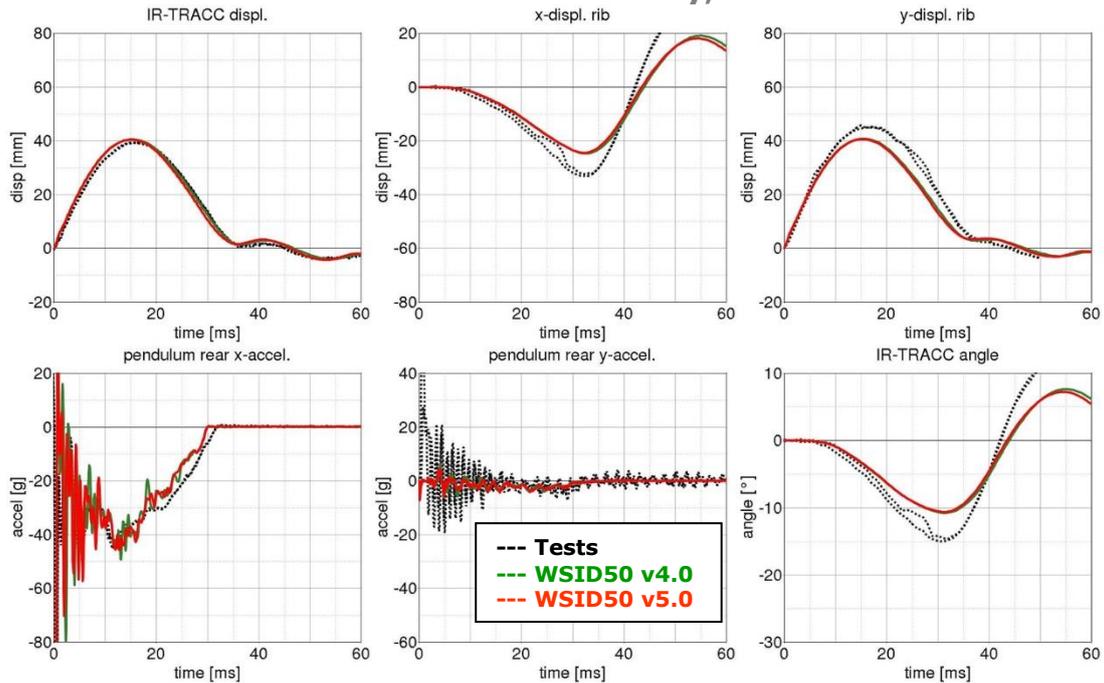
**Figure 87:** Third thorax rib test on outer band - low velocity and low mass

### Third thorax rib outer band - low velocity, high mass



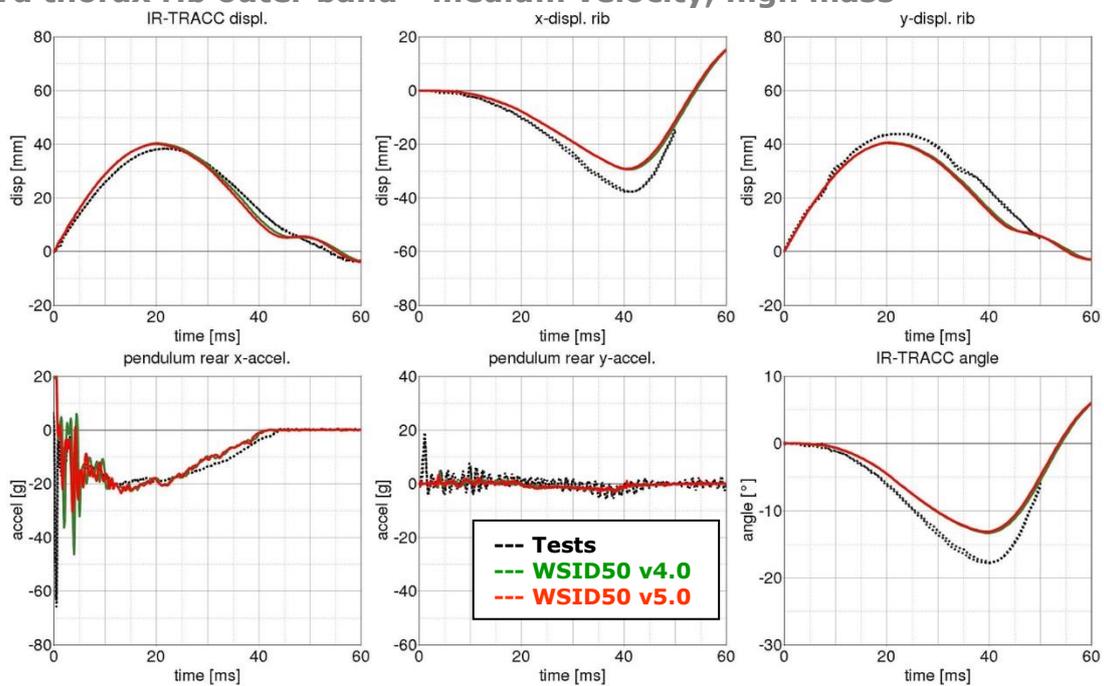
**Figure 88:** Third thorax rib test on outer band - low velocity and high mass

### Third thorax rib outer band - medium velocity, low mass



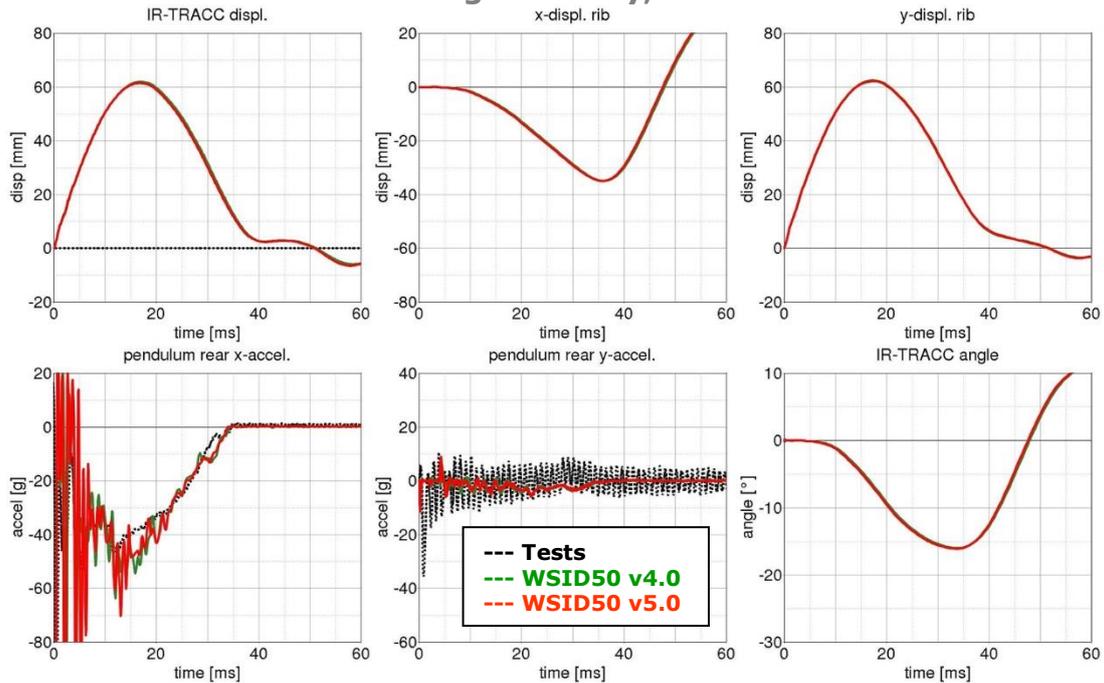
**Figure 89:** Third thorax rib test on outer band - medium velocity and low mass

### Third thorax rib outer band - medium velocity, high mass



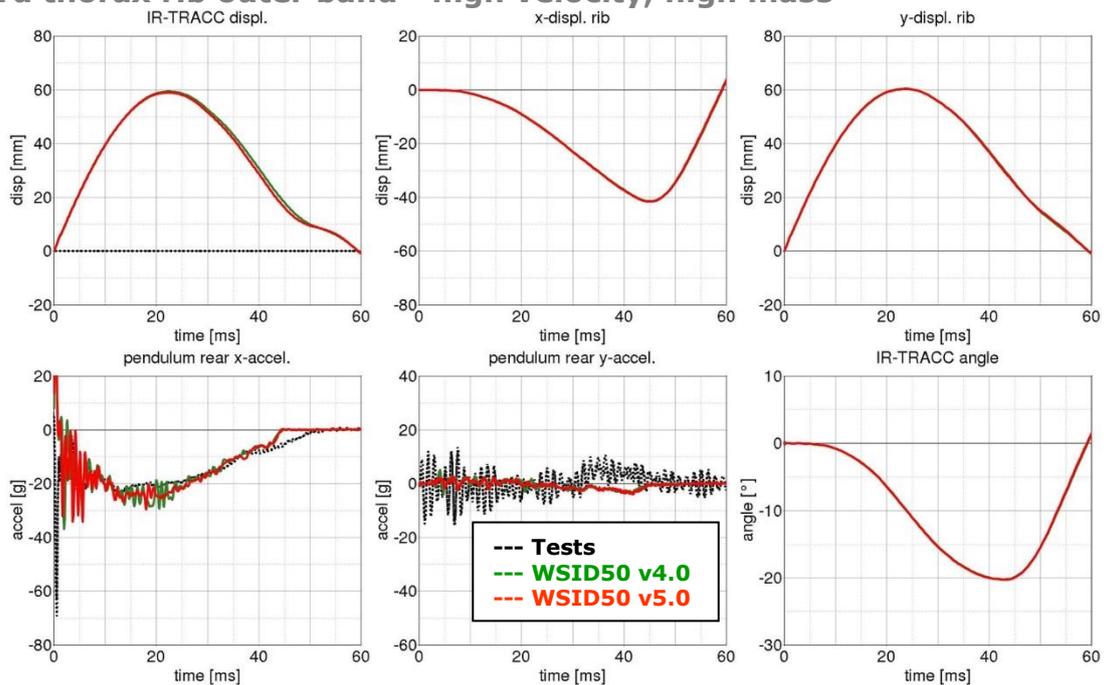
**Figure 90:** third thorax rib test on outer band - medium velocity and high mass

### Third thorax rib outer band - high velocity, low mass



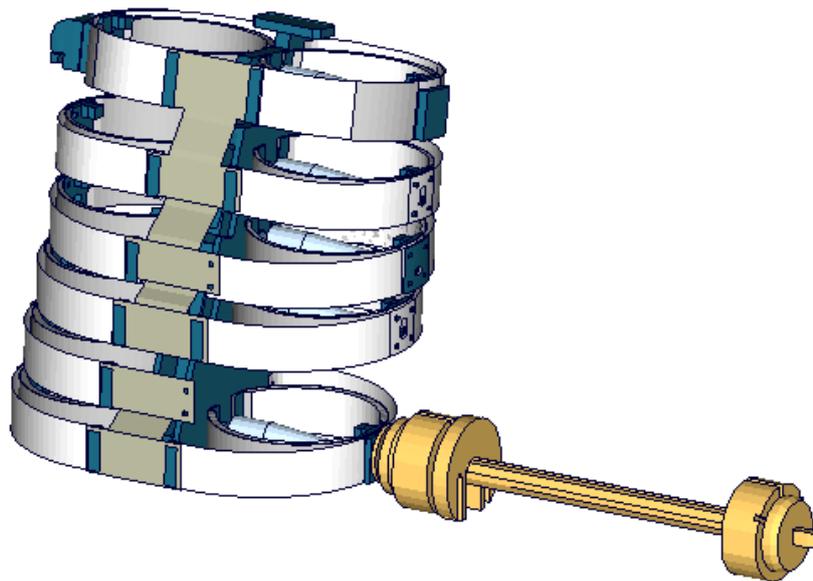
**Figure 91:** Third thorax rib test on outer band - high velocity and low mass

### Third thorax rib outer band - high velocity, high mass



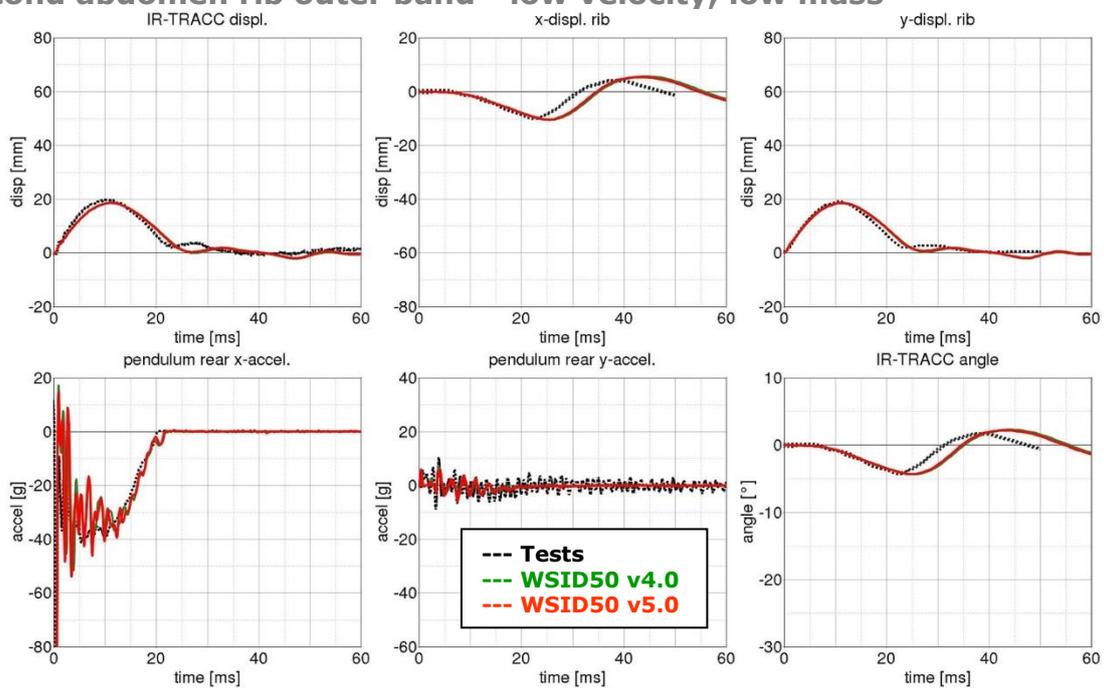
**Figure 92:** third thorax rib test on outer band - high velocity and high mass

Second abdomen rib:



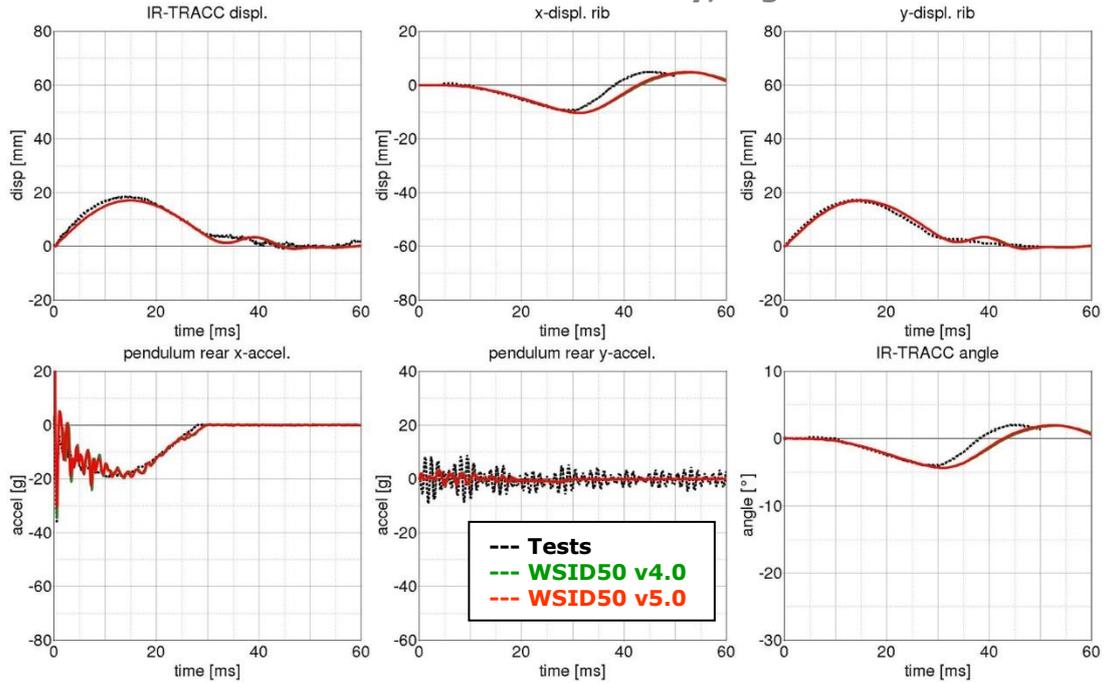
**Figure 93:** Second abdomen rib outer band test

Second abdomen rib outer band - low velocity, low mass



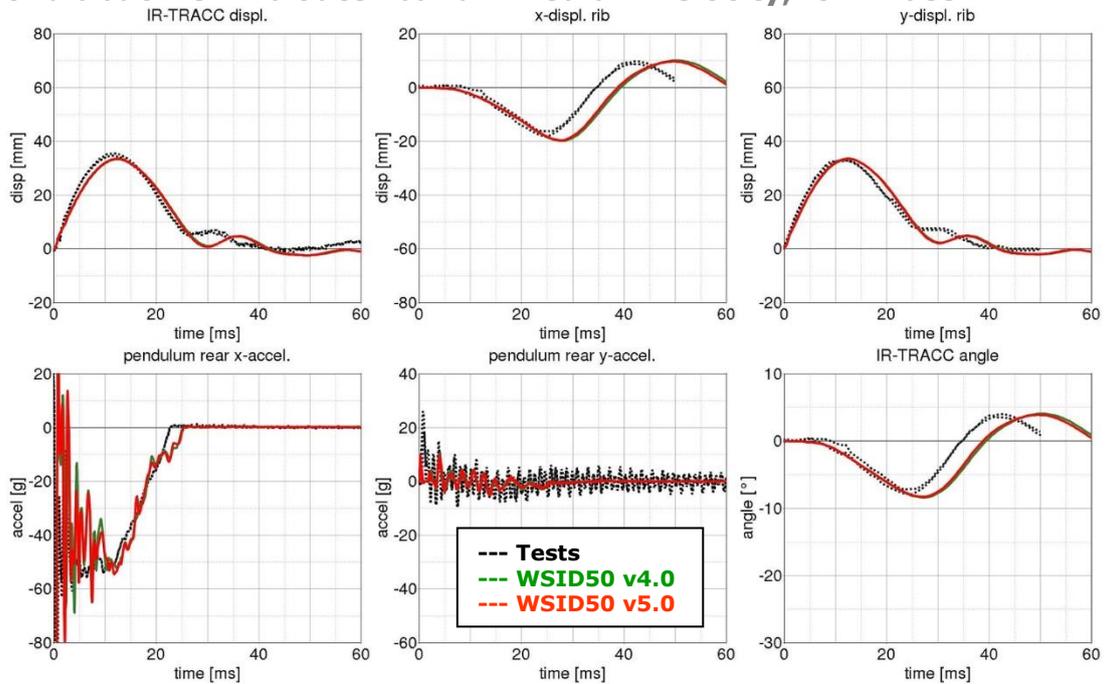
**Figure 94:** Second abdomen rib test on outer band - low velocity and low mass

**Second abdomen rib outer band - low velocity, high mass**



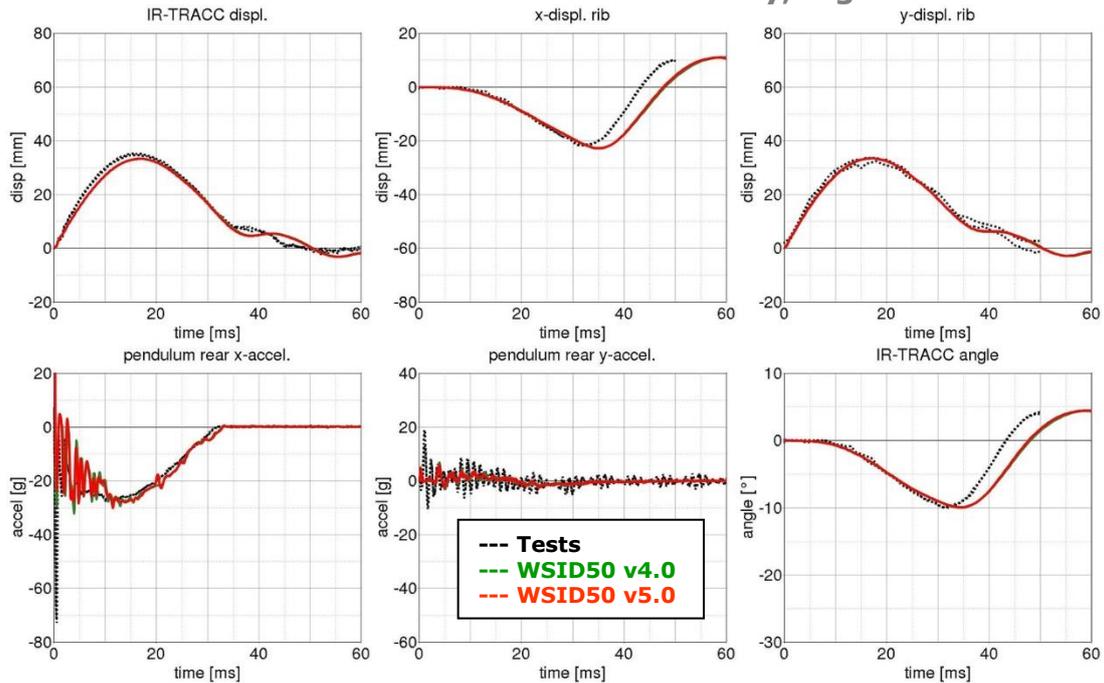
**Figure 95:** Second abdomen rib test on outer band - low velocity and high mass

**Second abdomen rib outer band - medium velocity, low mass**



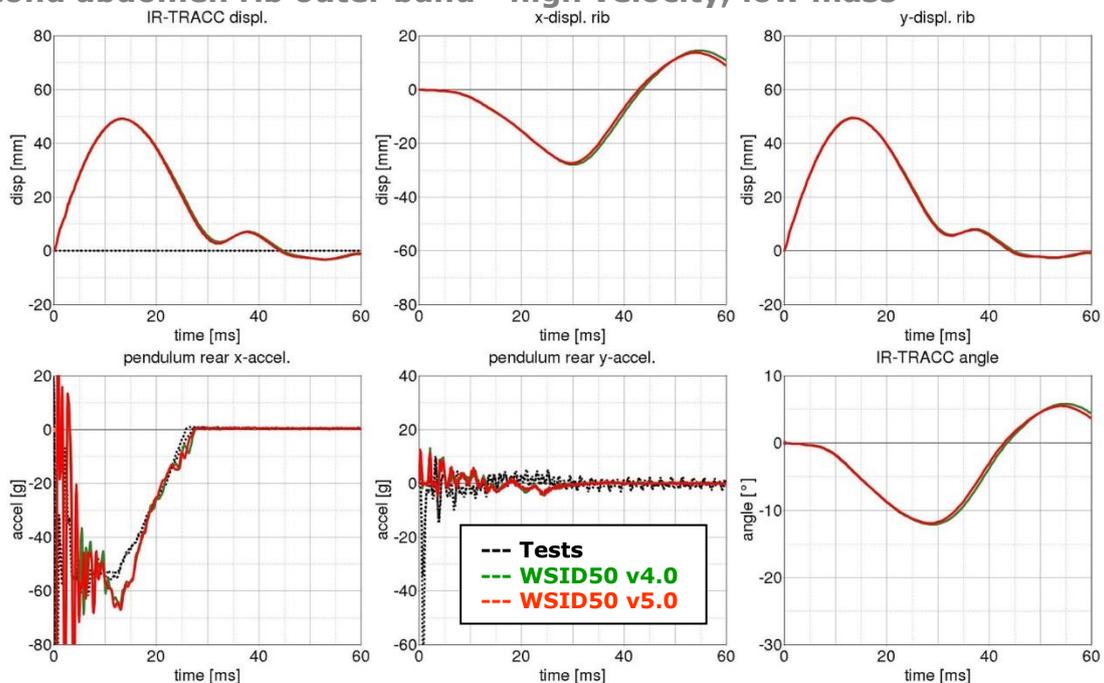
**Figure 96:** Second abdomen rib test on outer band - middle velocity and low mass

### Second abdomen rib outer band - medium velocity, high mass



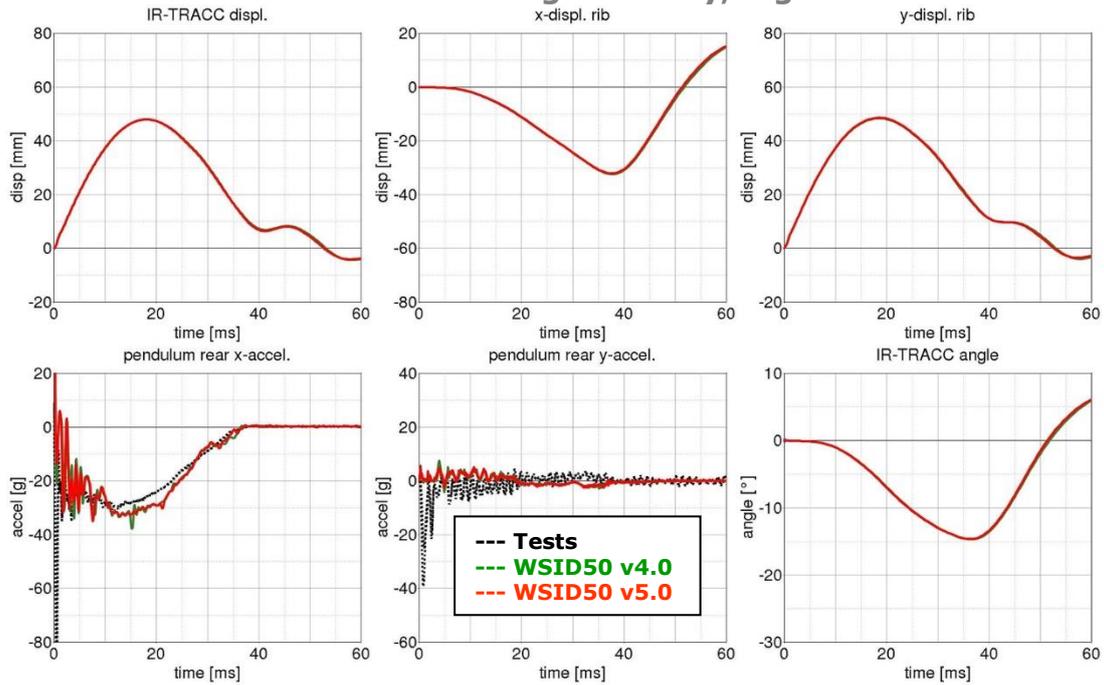
**Figure 97:** Second abdomen rib test on outer band - middle velocity and high mass

### Second abdomen rib outer band - high velocity, low mass



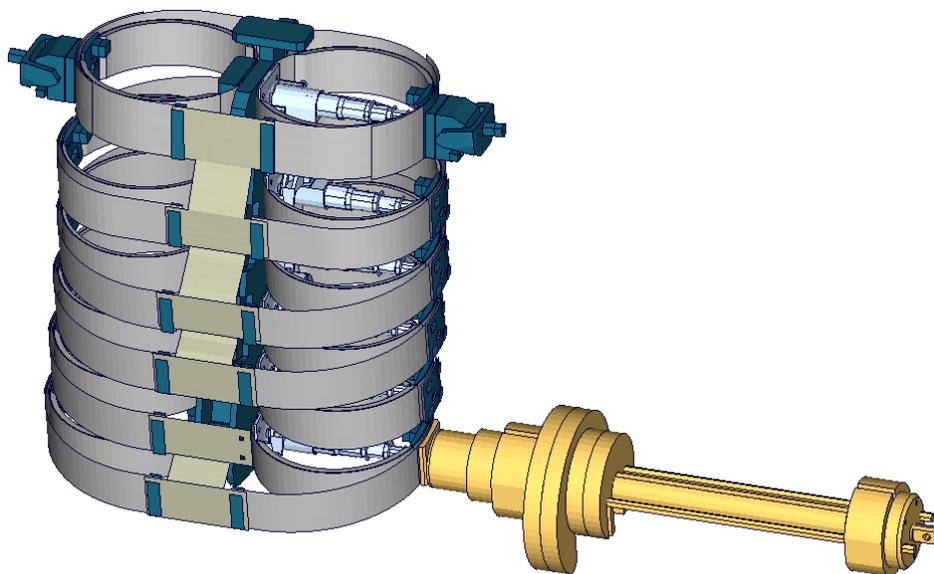
**Figure 98:** Second abdomen rib test on outer band - high velocity and low mass

**Second abdomen rib outer band - high velocity, high mass**



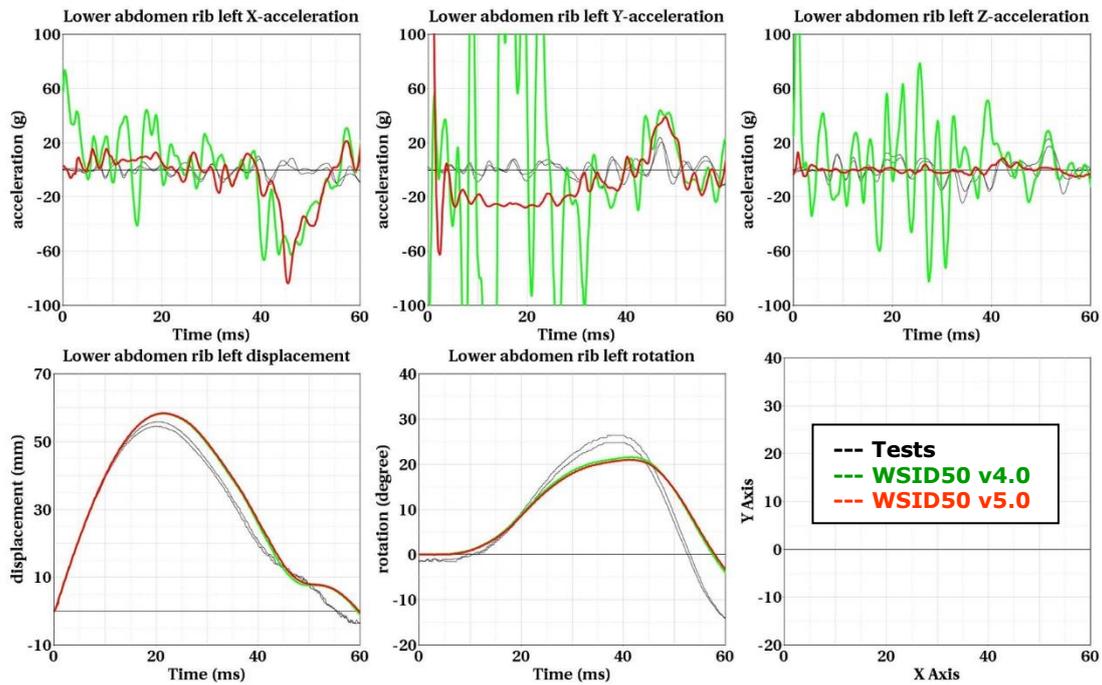
**Figure 99:** Second abdomen rib test on outer band - high velocity and high mass

**Additional second abdomen rib test:**

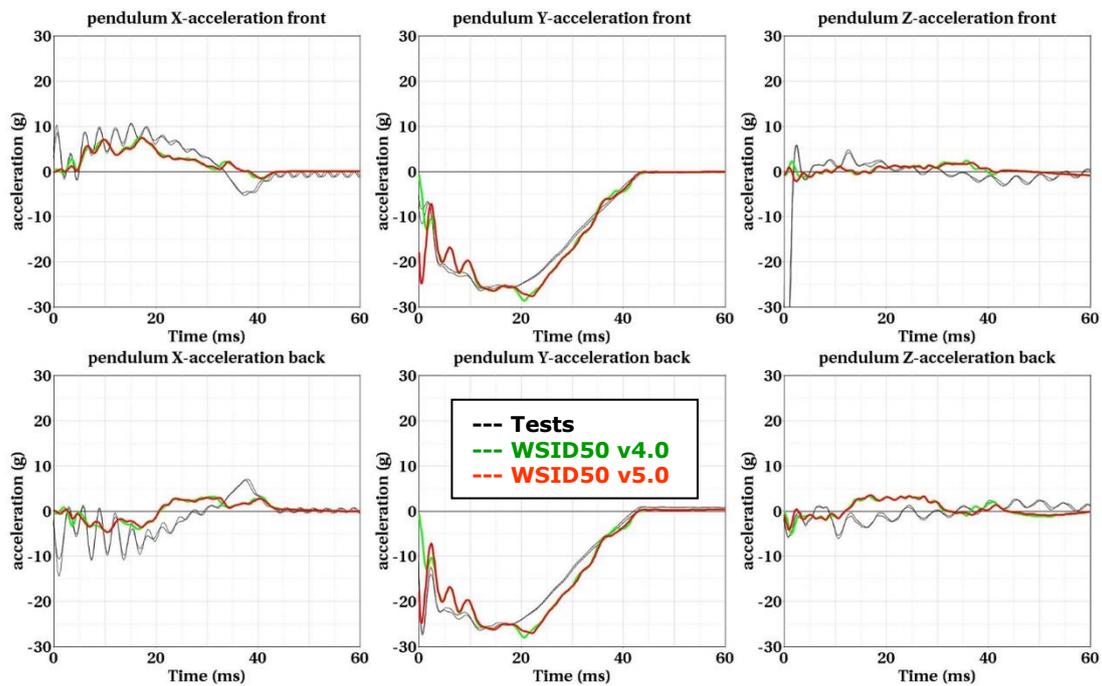


**Figure 100:** Second abdomen rib additional test

### Second abdomen rib additional - high velocity



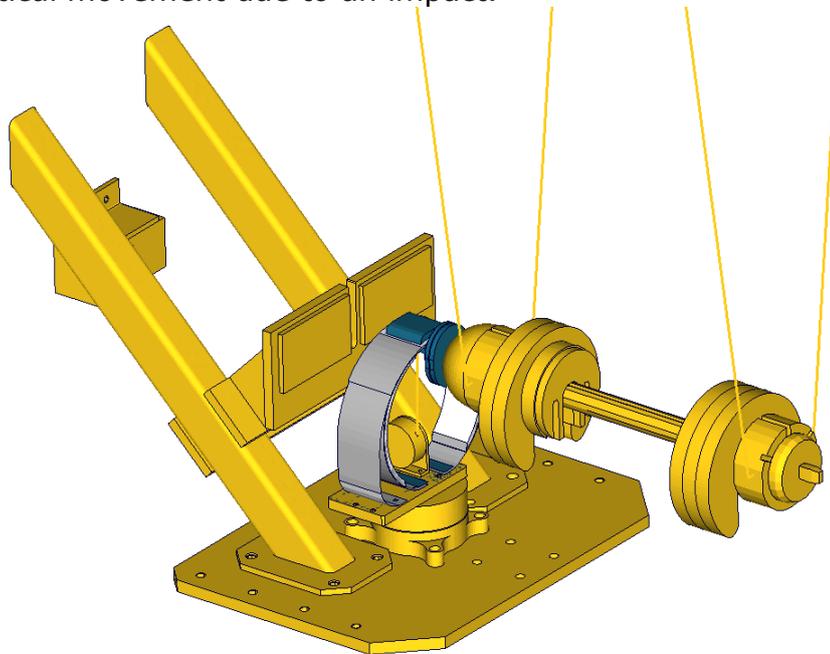
**Figure 101:** Second abdomen rib test on outer band - high velocity and high mass



**Figure 102:** Second abdomen rib test on outer band - high velocity and high mass

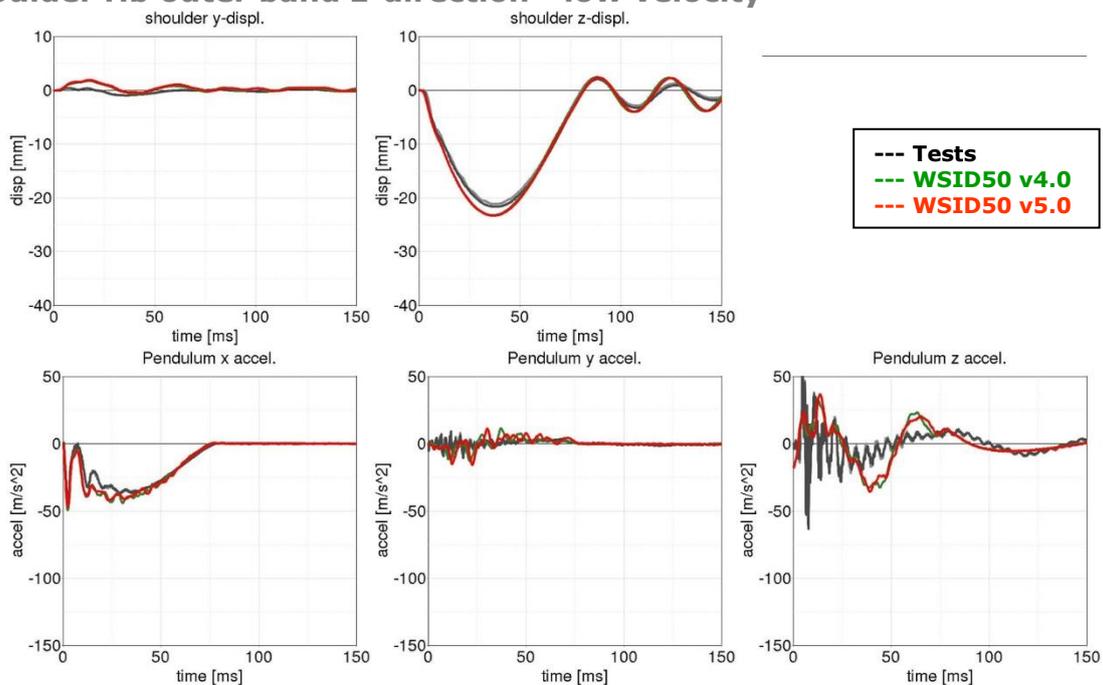
### 8.1.6.3 Outer rib band vertical pendulum test

Since the release v3.5 there are additional test for the shoulder rib in vertical direction. With these tests the WorldSID model can be fine-tuned to capture the ribs vertical movement due to an impact.

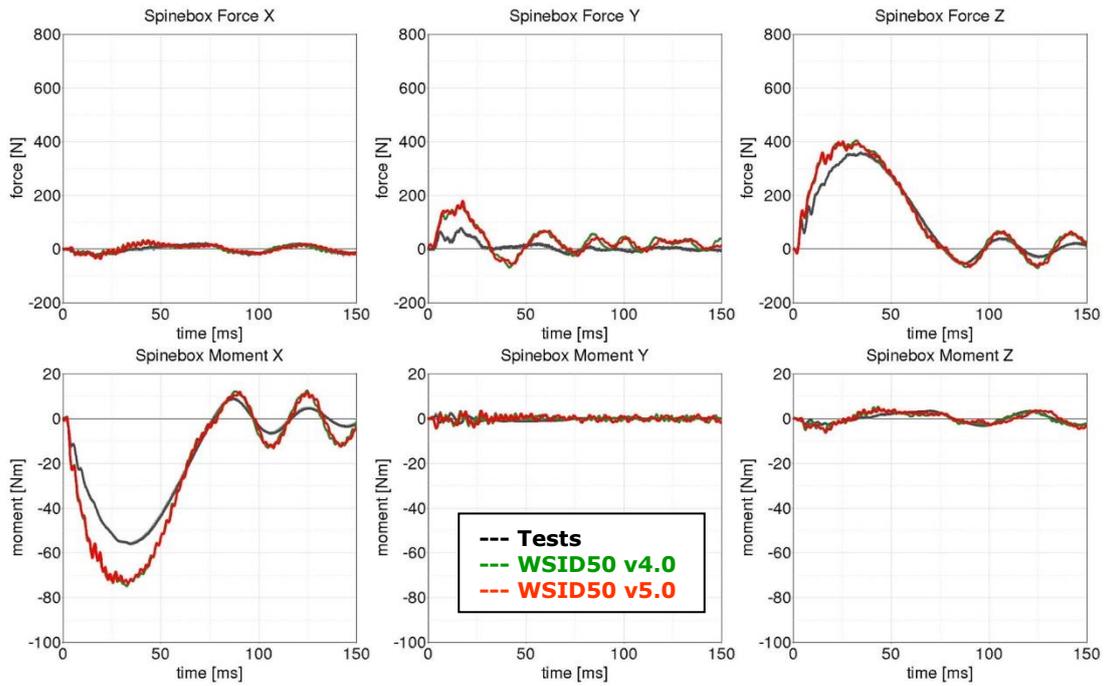


**Figure 103:** shoulder rib tests in z-direction

#### Shoulder rib outer band z-direction - low velocity

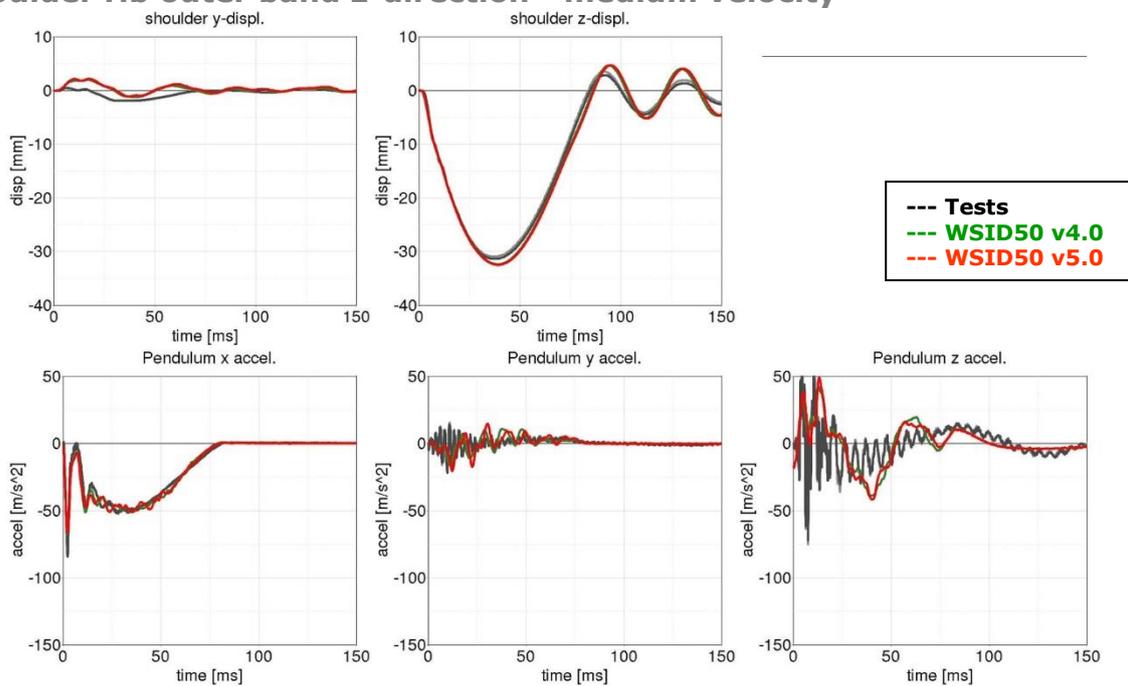


**Figure 104:** shoulder rib test on outer band z-direction – low velocity

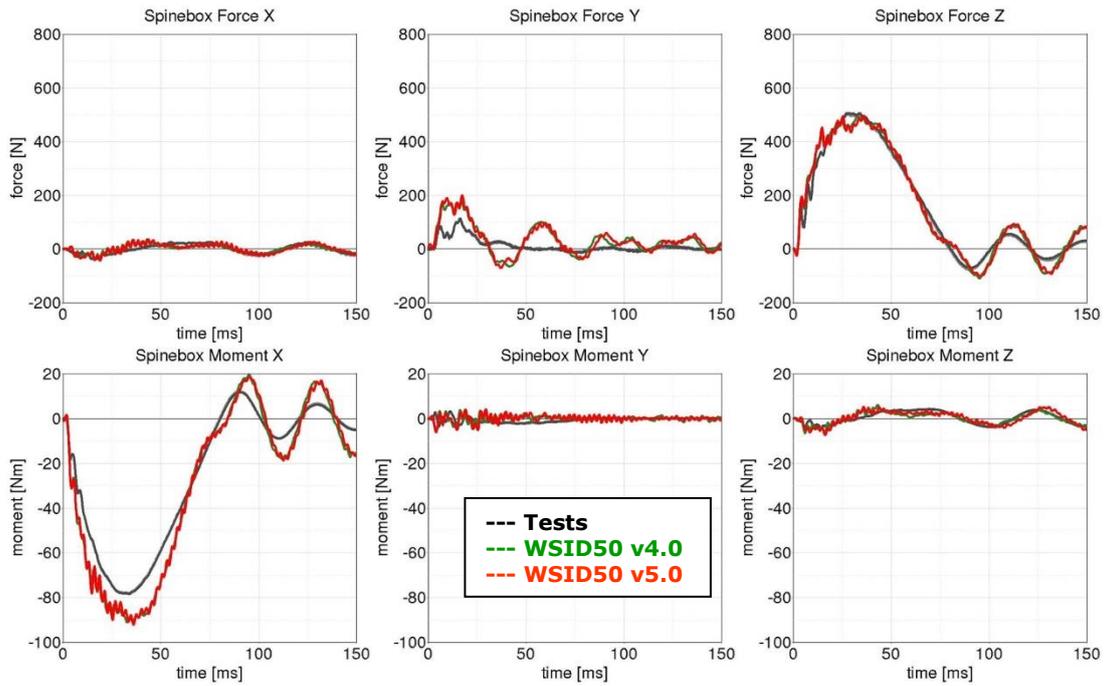


**Figure 105:** shoulder rib test on outer band z-direction – low velocity

**Shoulder rib outer band z-direction - medium velocity**

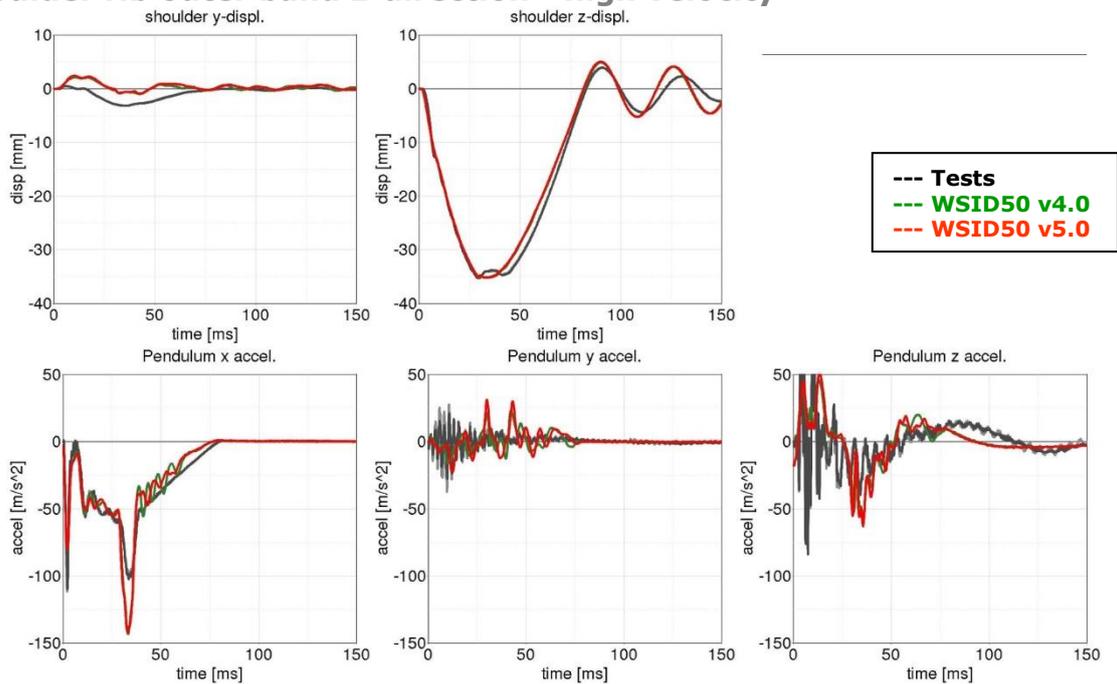


**Figure 106:** shoulder rib test on outer band z-direction – medium velocity

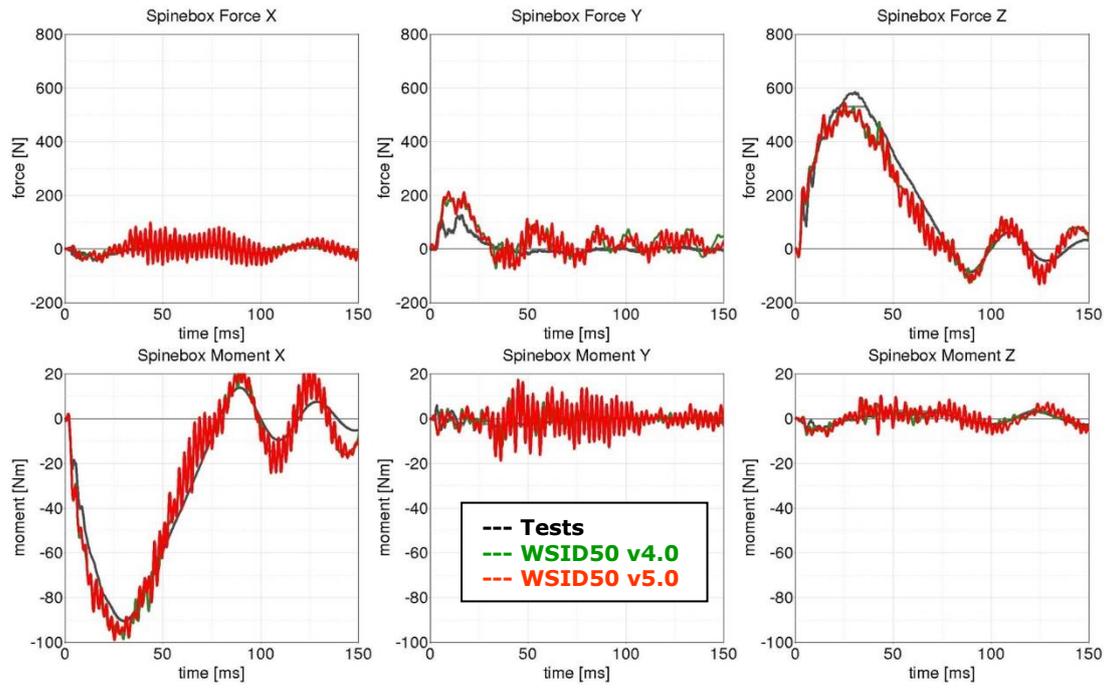


**Figure 107:** shoulder rib test on outer band z-direction – medium velocity

**Shoulder rib outer band z-direction - high velocity**



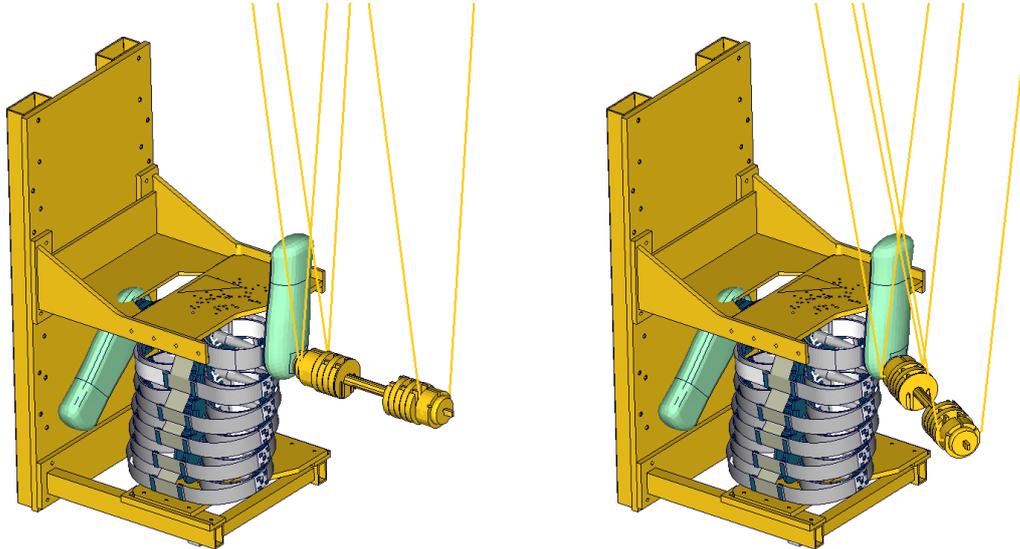
**Figure 108:** shoulder rib test on outer band z-direction – high velocity



**Figure 109:** shoulder rib test on outer band z-direction – high velocity

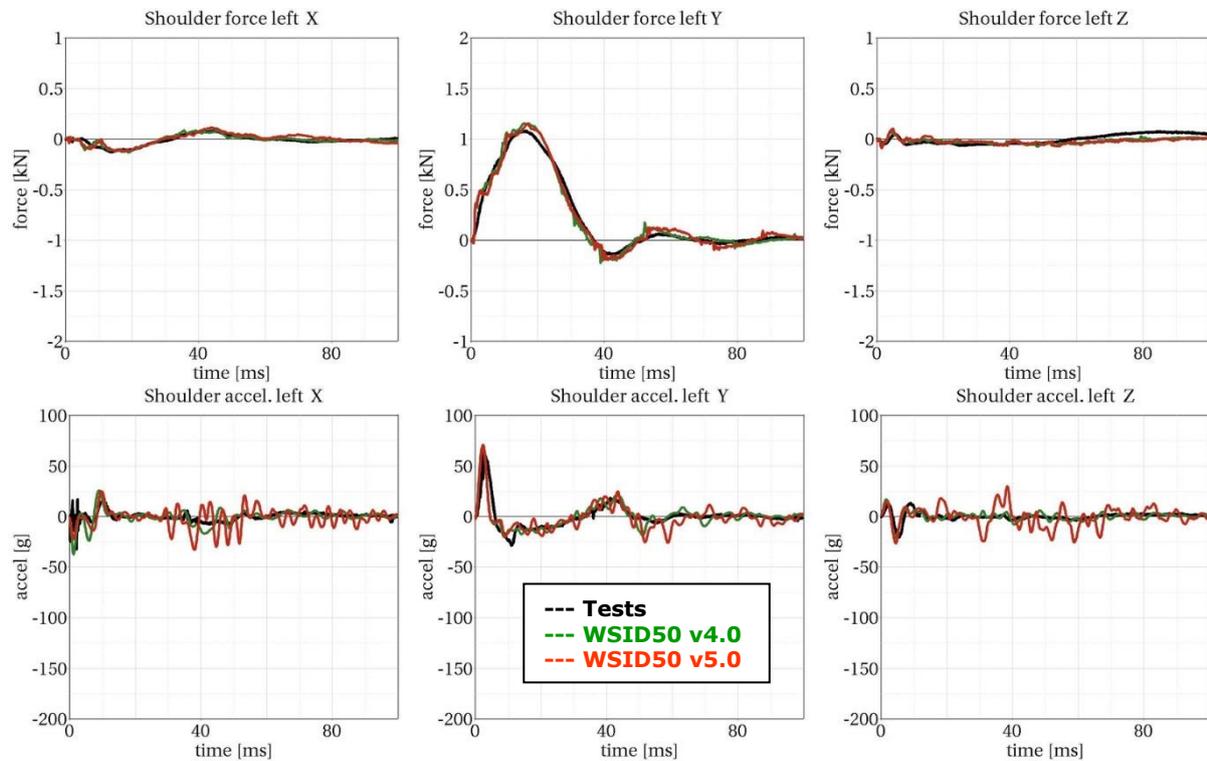
8.1.6.4 Outer rib band with arm

Since the release v3.5 there are additional test for the shoulder rib with the assembled arm. These tests were performed with different pendulum velocities and two different impact angles.

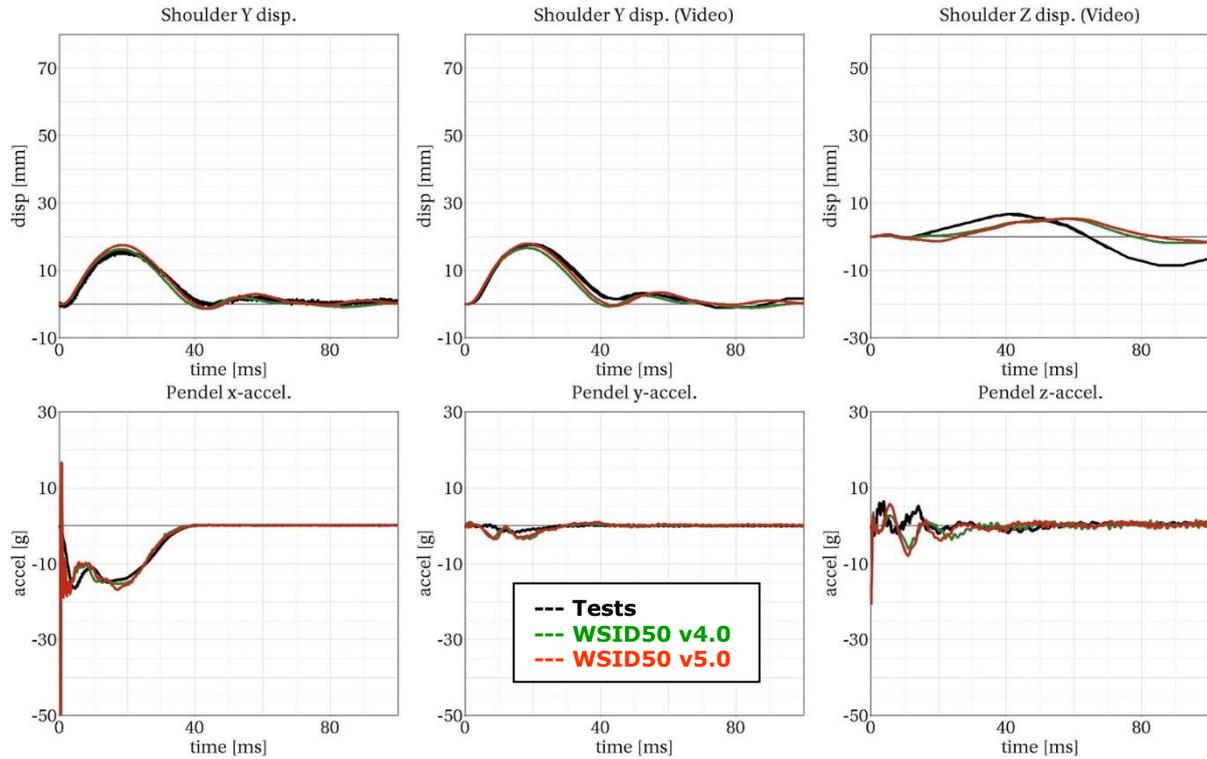


**Figure 110:** shoulder rib tests with arm (90° on the right and 60° on the left)

**Shoulder rib outer band with arm - low velocity, 90°**

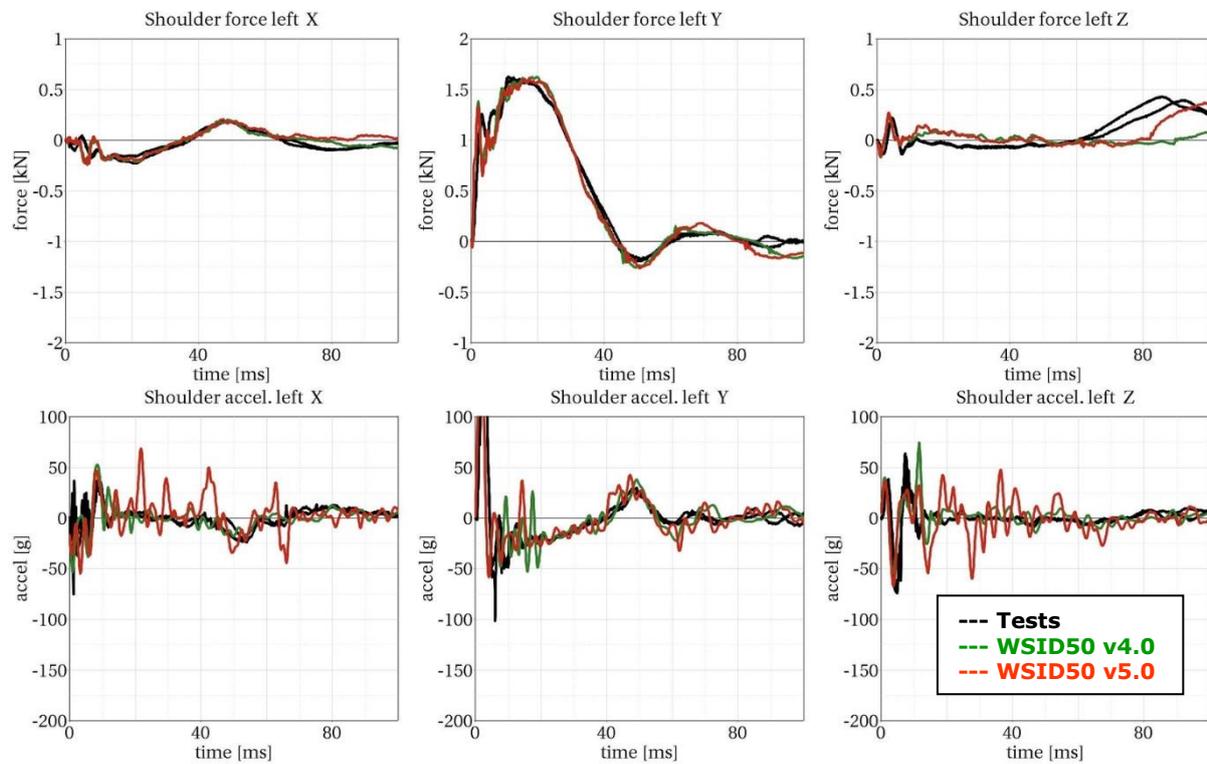


**Figure 111:** shoulder rib test on outer band with arm – low velocity, 90°

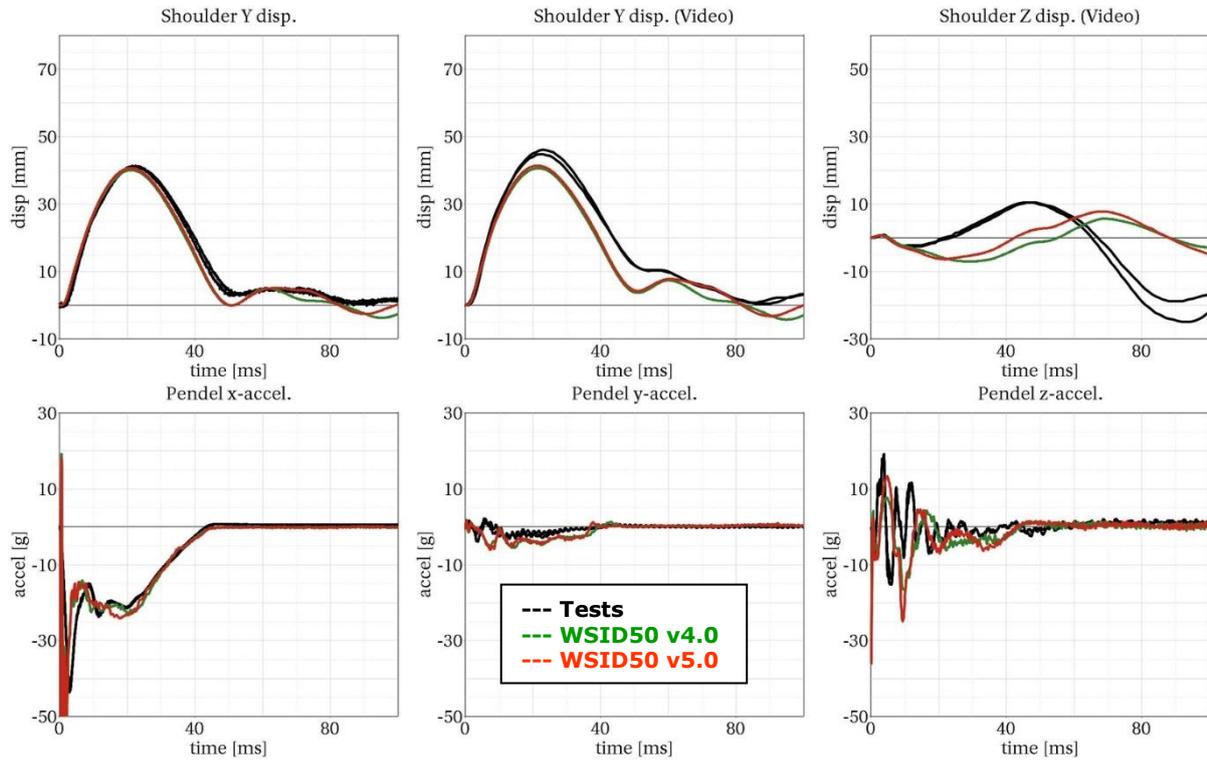


**Figure 112:** shoulder rib test on outer band with arm – low velocity, 90°

**Shoulder rib outer band with arm - high velocity, 90°**

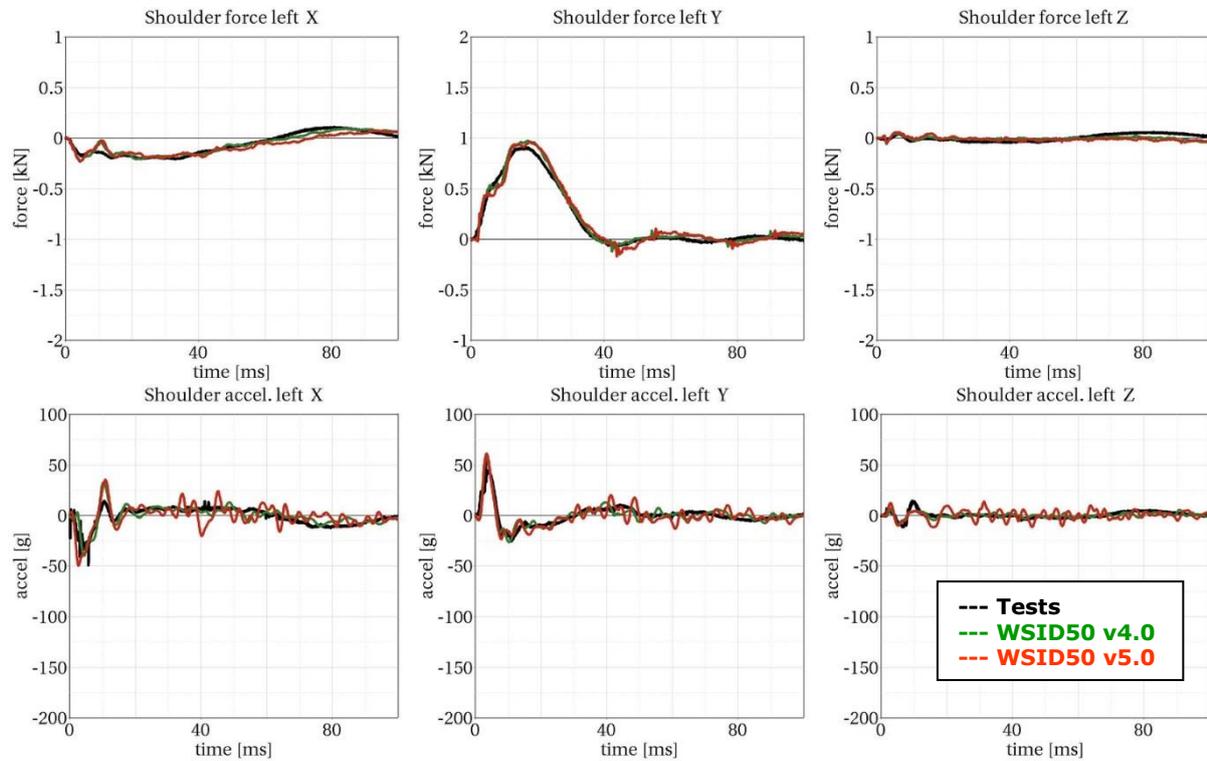


**Figure 113:** shoulder rib test on outer band with arm - high velocity, 90°

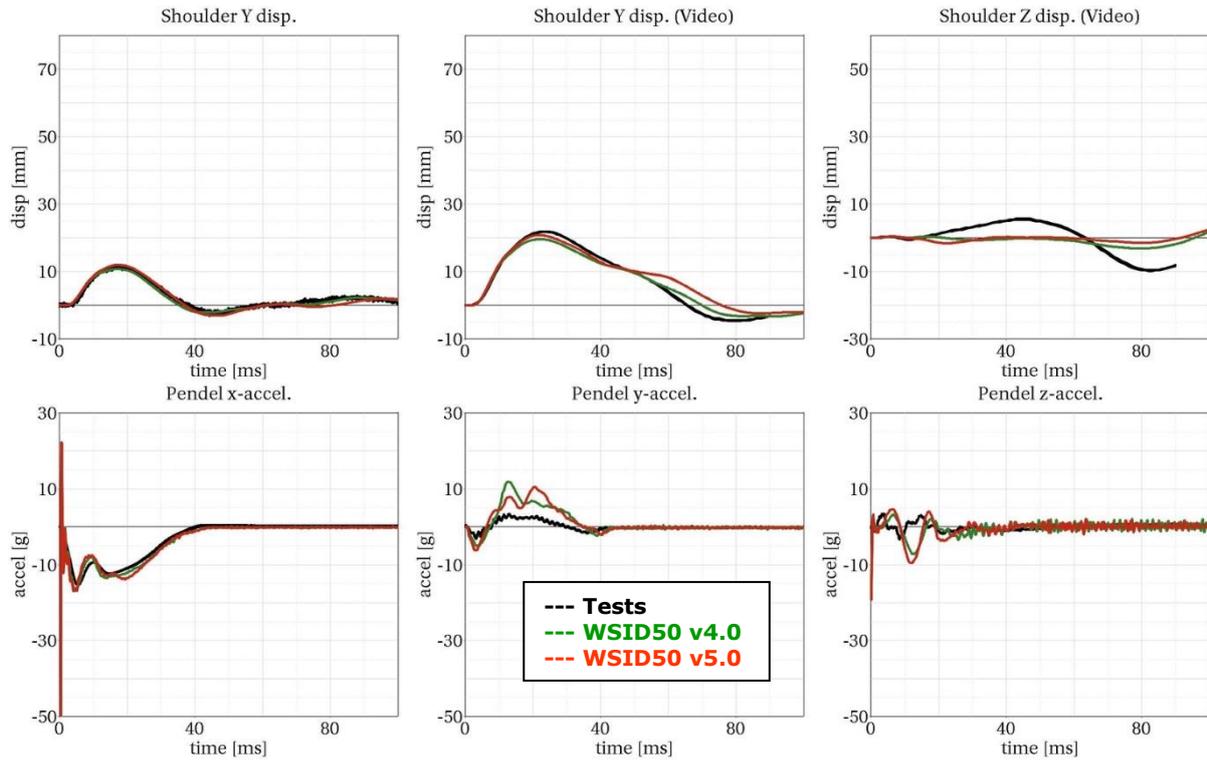


**Figure 114:** shoulder rib test on outer band with arm - high velocity, 90°

**Shoulder rib outer band with arm - low velocity, 60°**

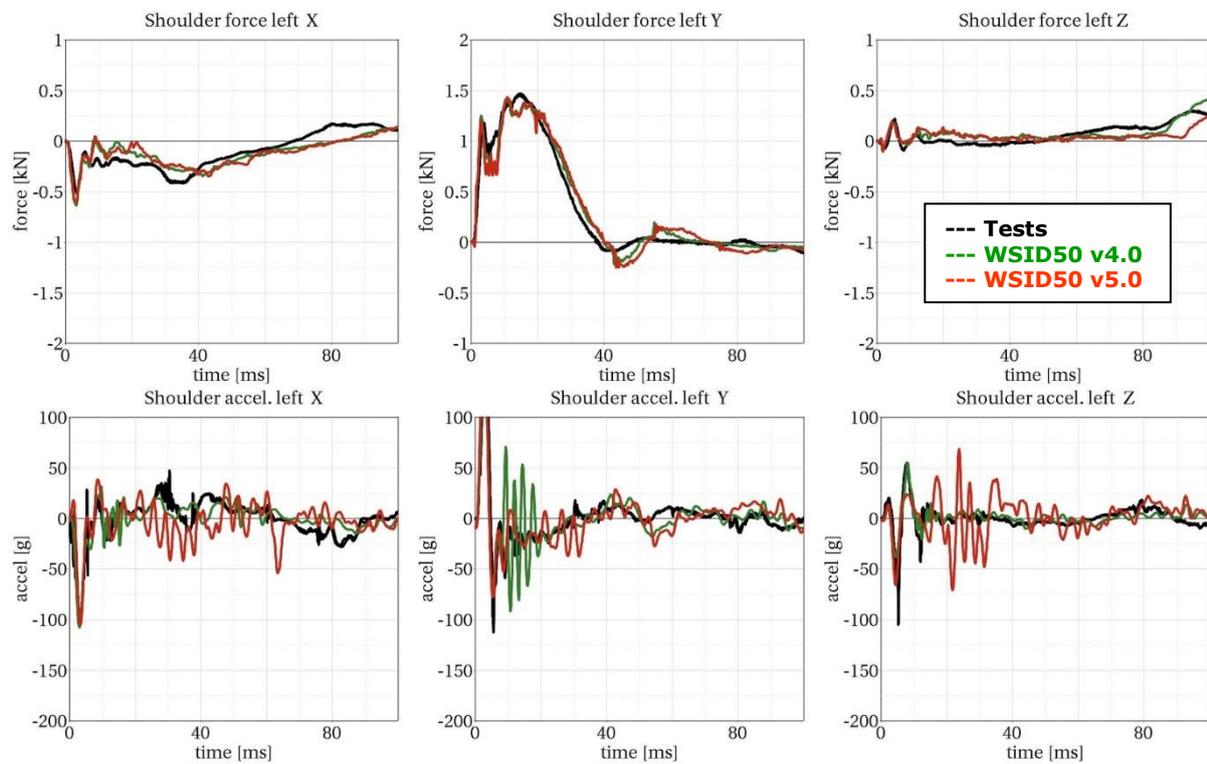


**Figure 115:** shoulder rib test on outer band with arm – low velocity, 60°

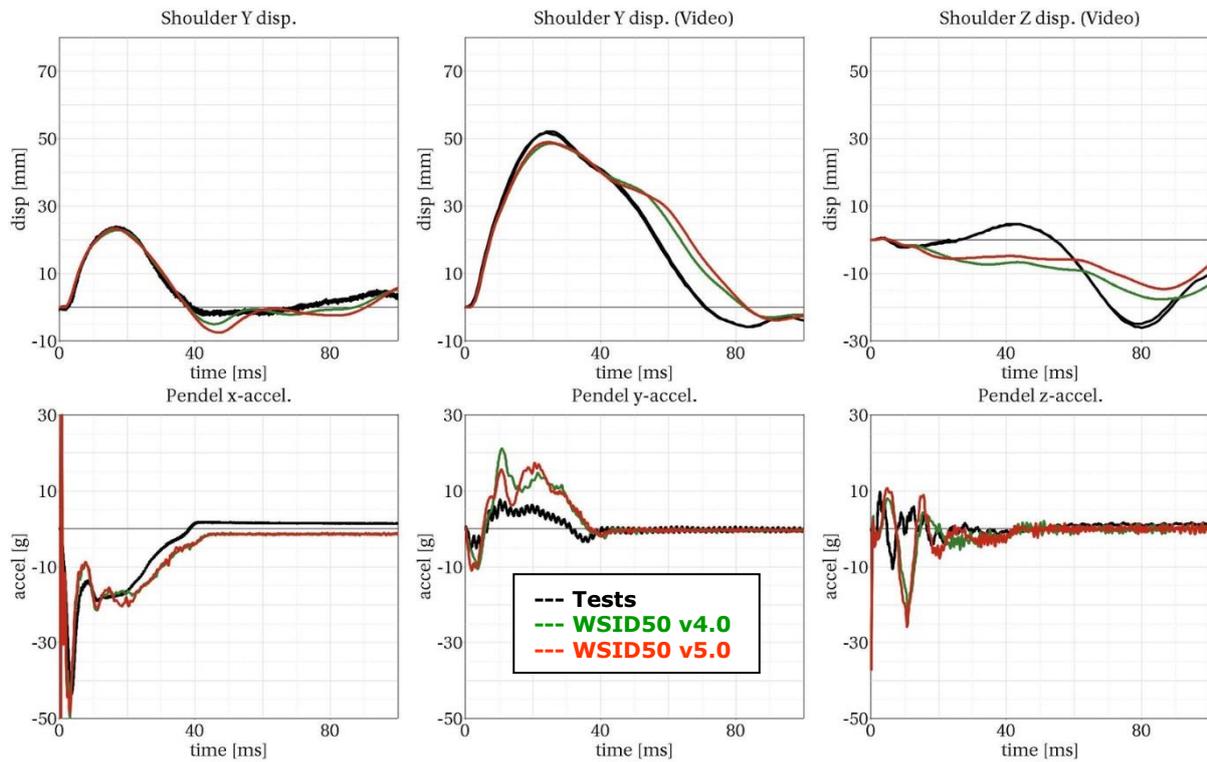


**Figure 116:** shoulder rib test on outer band with arm – low velocity, 60°

**Shoulder rib outer band with arm - high velocity, 60°**



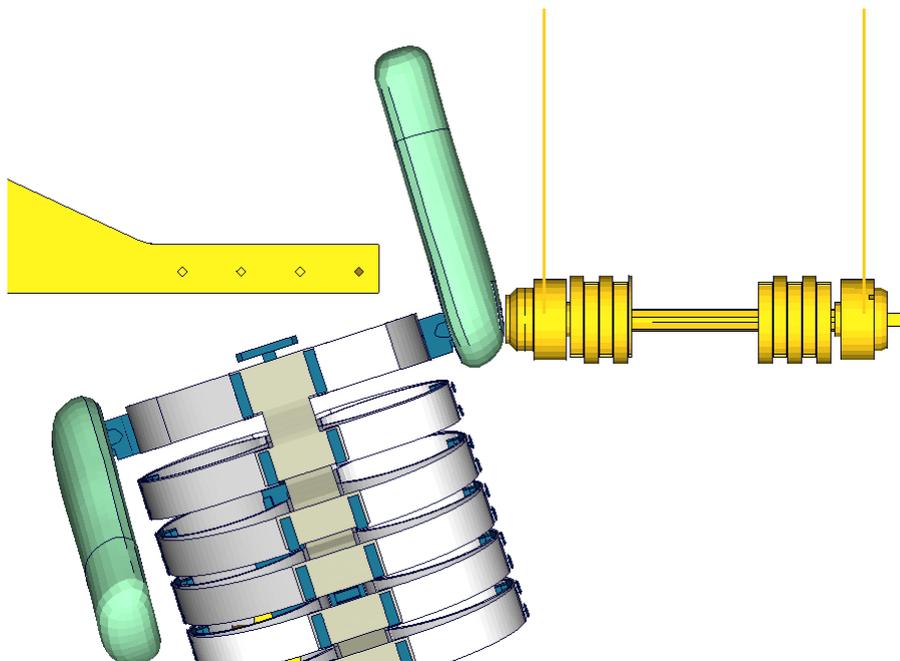
**Figure 117:** shoulder rib test on outer band with arm - high velocity, 60°



**Figure 118:** shoulder rib test on outer band with arm - high velocity, 60°

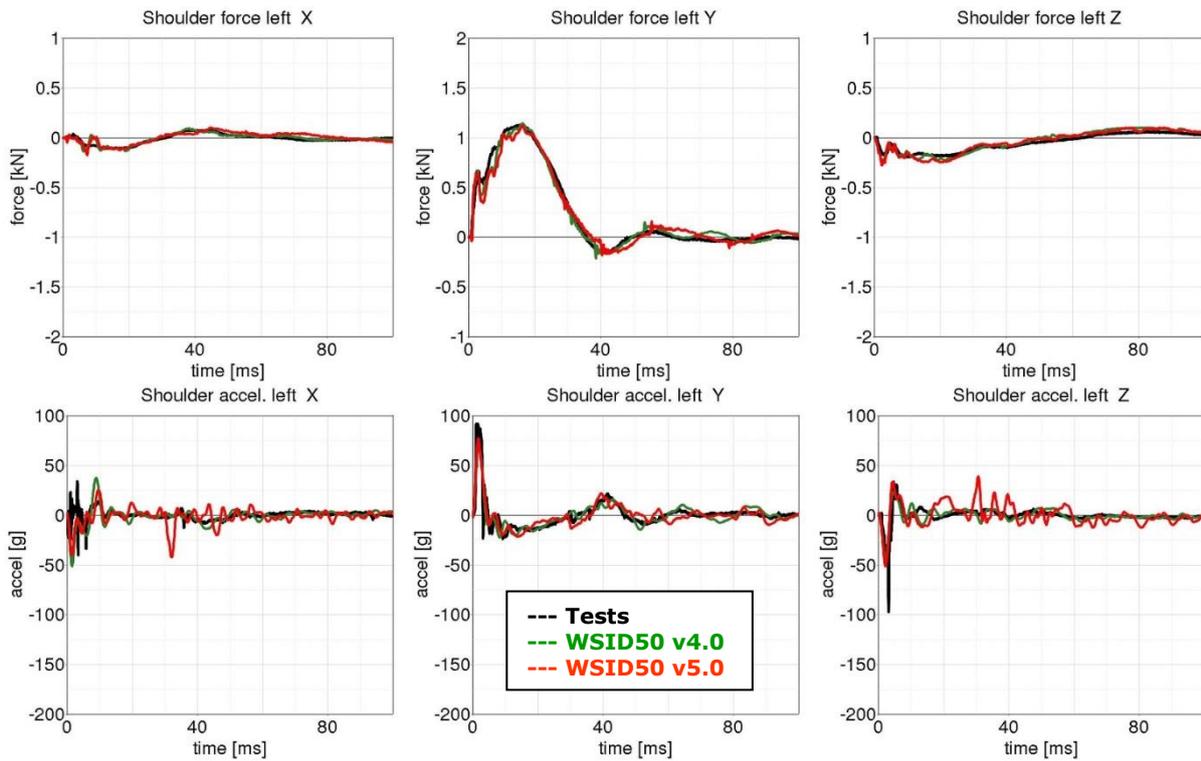
#### 8.1.6.5 Outer rib ban vertical pendulum test with arm

Since the release v3.5 there are additional test for the shoulder rib in oblique z-direction with assembled arm.

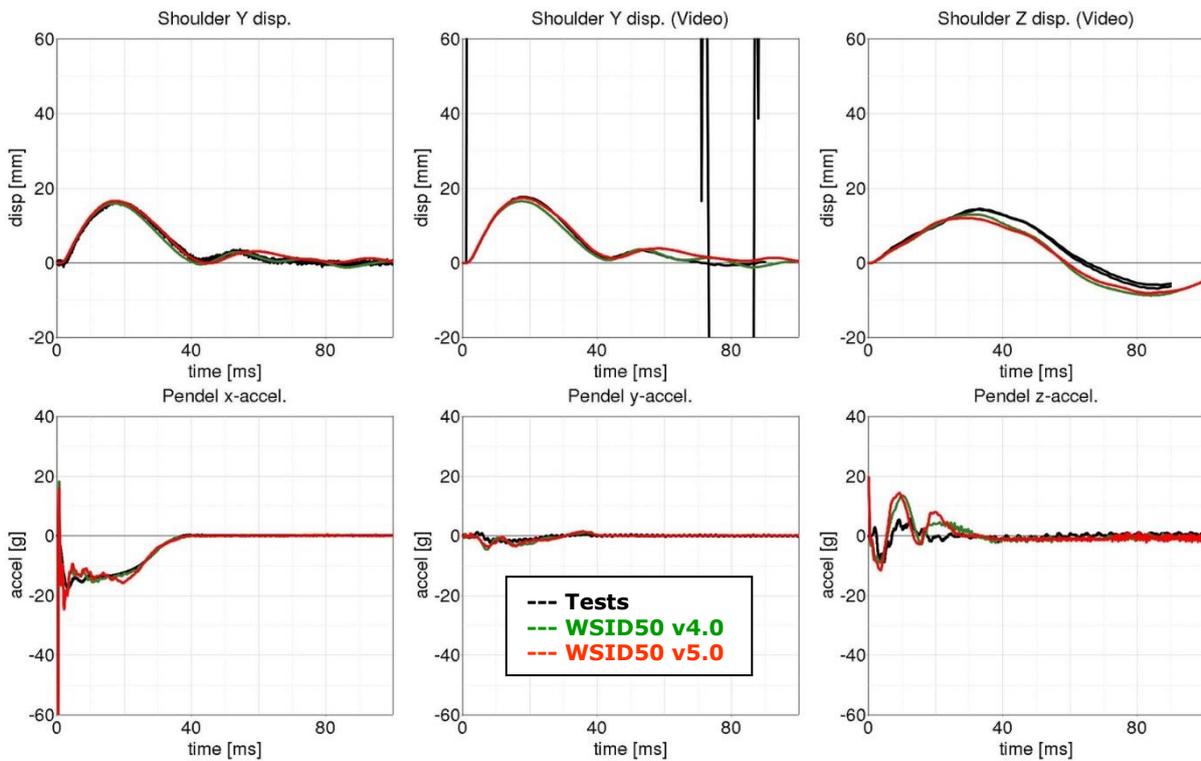


**Figure 119:** shoulder rib tests in oblique z-direction with arm

### Shoulder rib test oblique z-direction with arm - low velocity

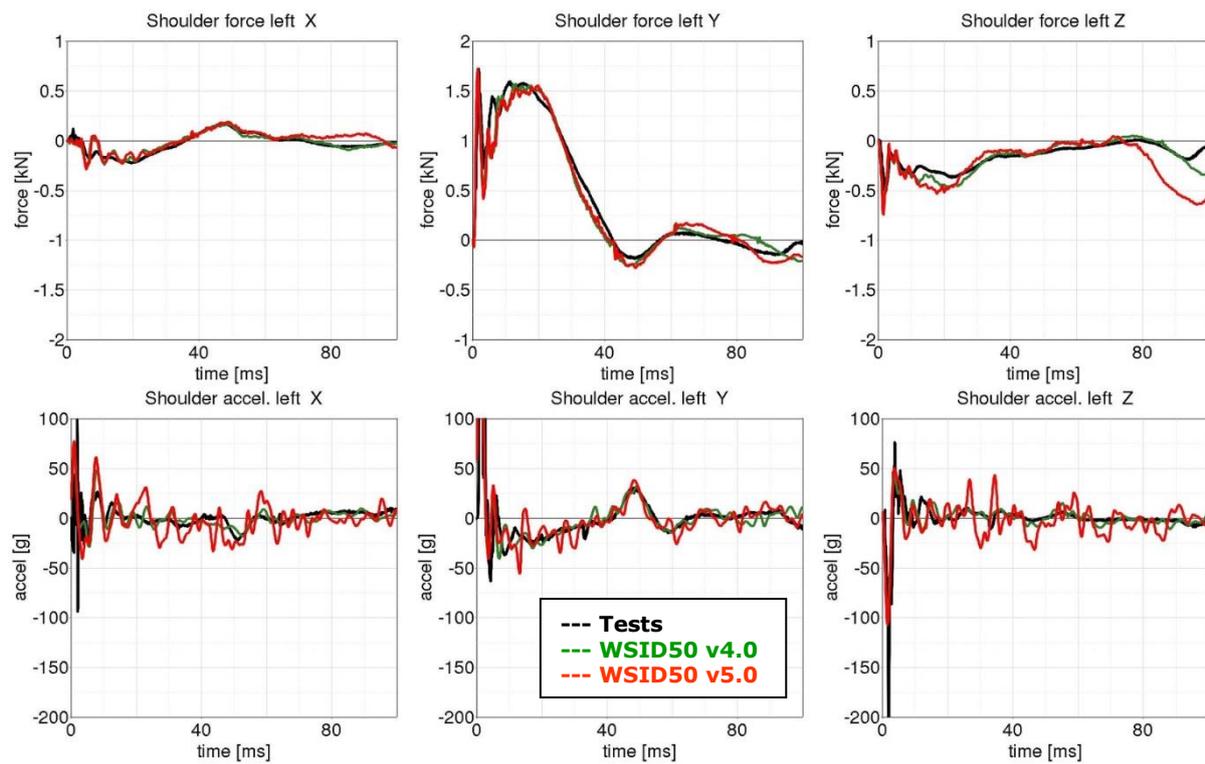


**Figure 120:** shoulder rib test oblique z-direction with arm – low velocity

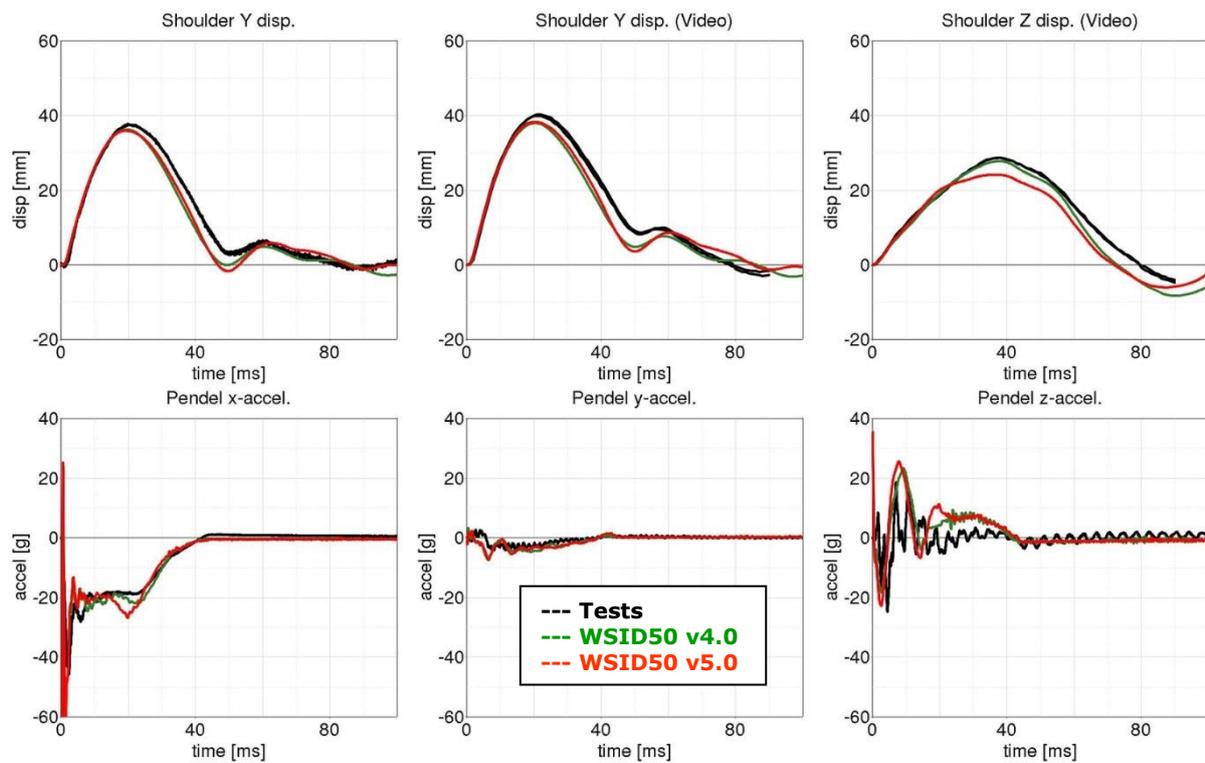


**Figure 121:** shoulder rib test oblique z-direction – low velocity

### Shoulder rib test oblique z-direction with arm - medium velocity

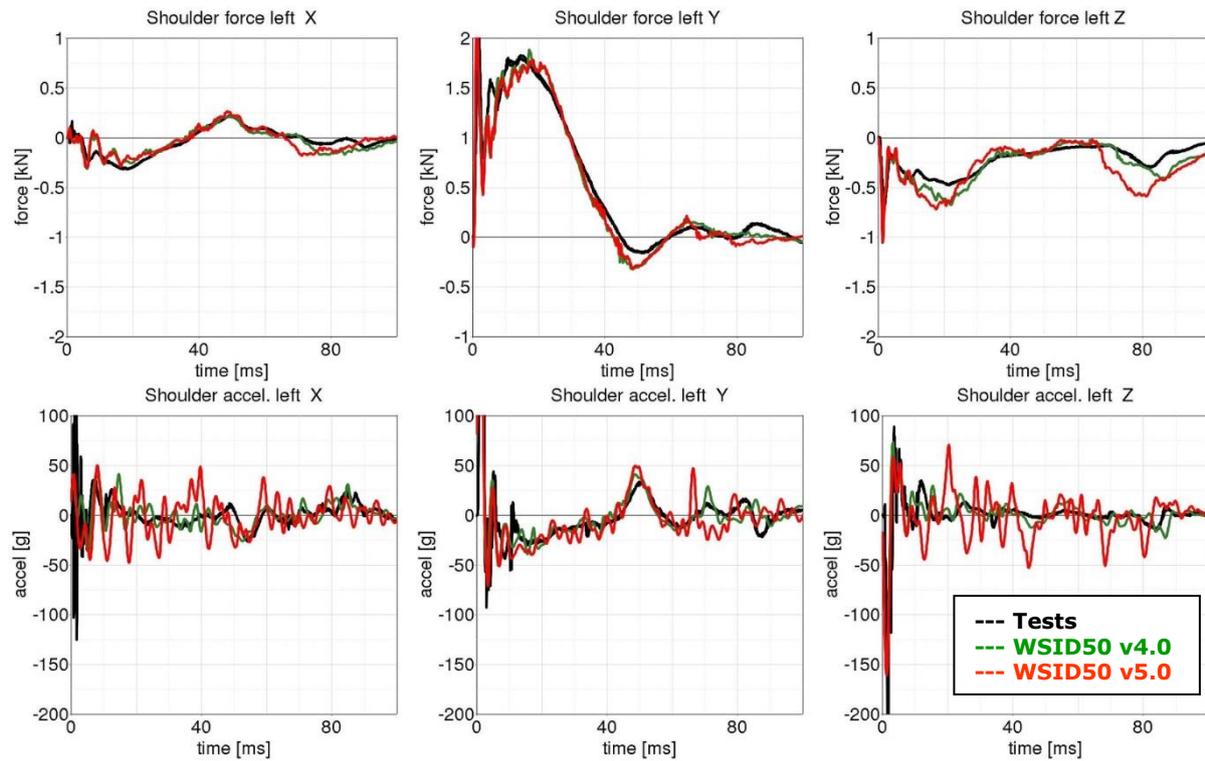


**Figure 122:** shoulder rib test oblique z-direction with arm – medium velocity

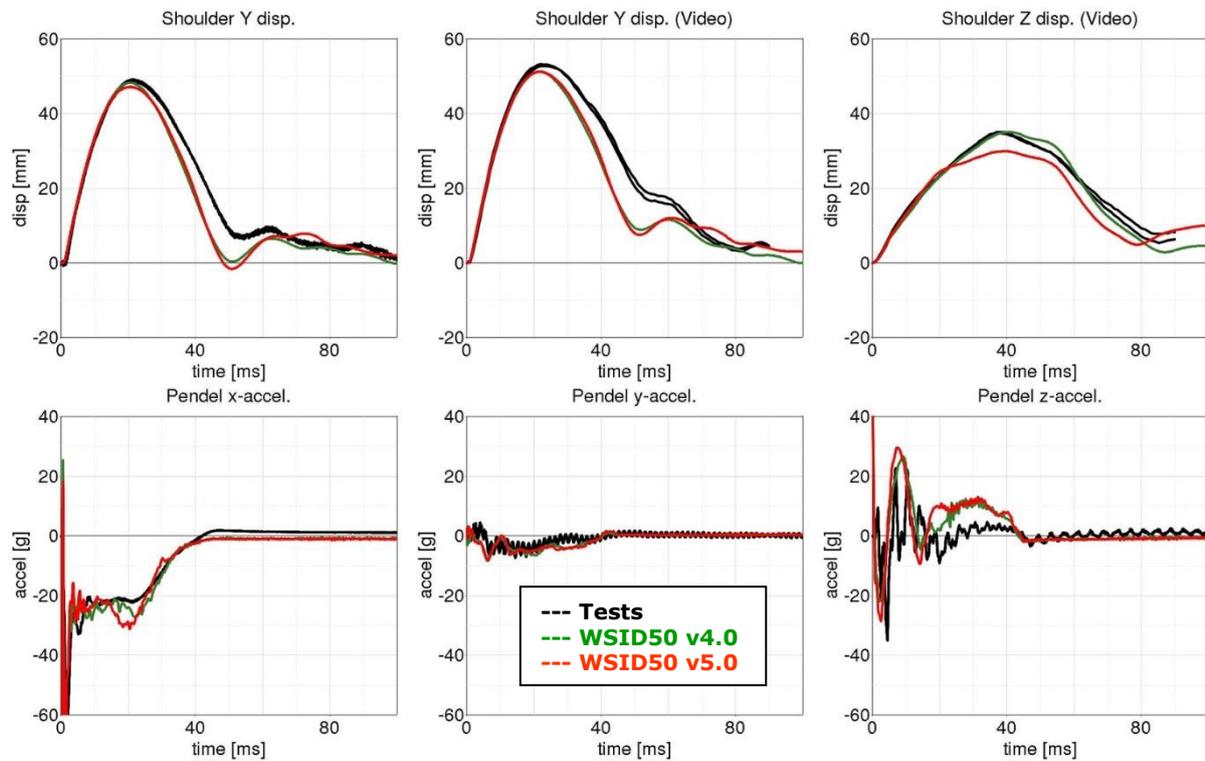


**Figure 123:** shoulder rib test oblique z-direction – medium velocity

### Shoulder rib test oblique z-direction with arm - high velocity



**Figure 124:** shoulder rib test oblique z-direction with arm – high velocity

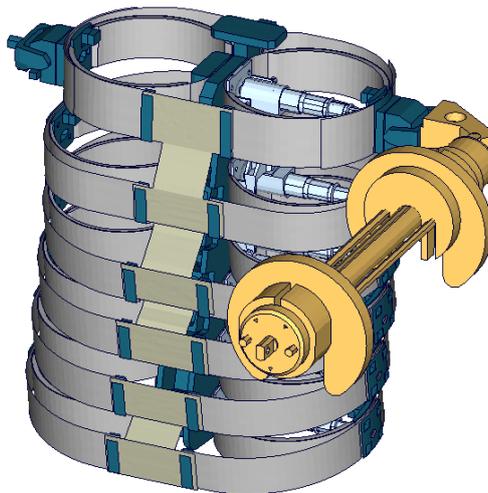


**Figure 125:** shoulder rib test oblique z-direction – high velocity

8.1.6.6 Additional Shoulder Rib test

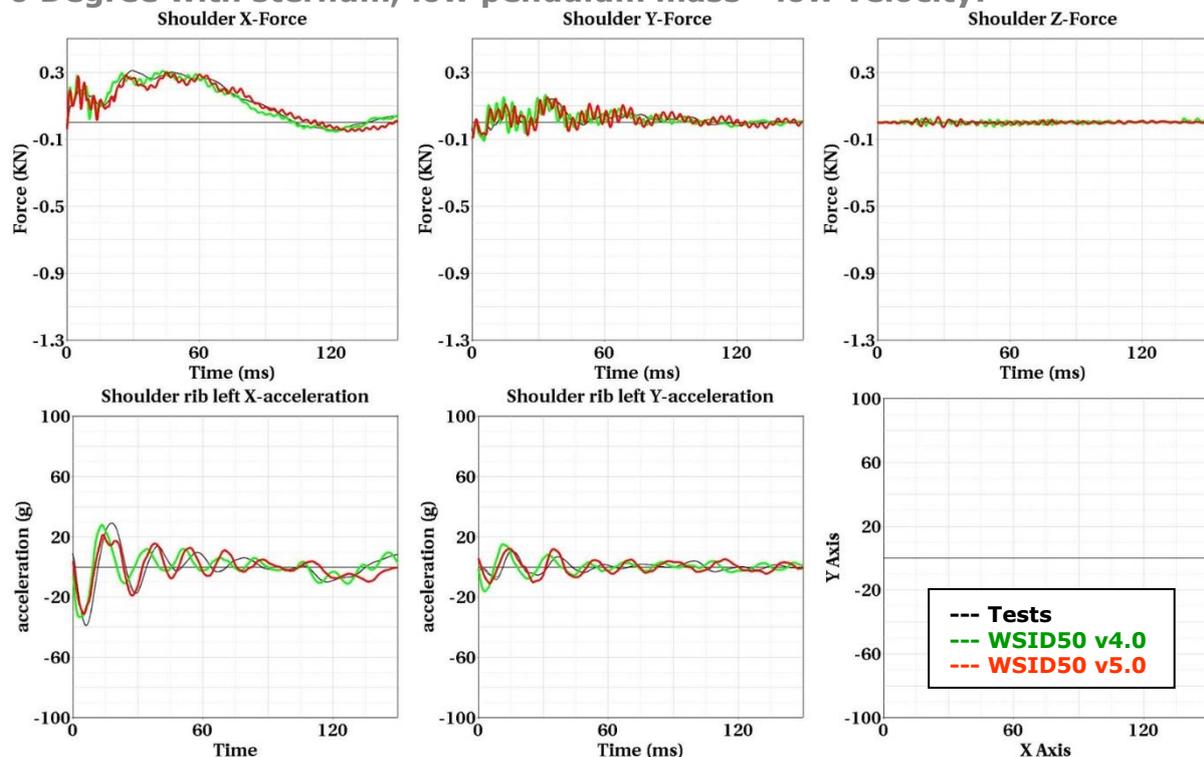
Since the release v5.0 there are additional tests for the shoulder rib in different impact angle, Pendulum mass and impact Pendulum-velocity. Impact angle include 0, 90 and 180 degree. There is an impact box as half arm which is fixed on the arm joint. The test include two type, with sternum and without sternum. This is in order to identify the influence of the sternum. With these tests the WorldSID model can be fine-tuned to capture the rotation of shoulder rib by vertical axis.

**0 Degree with sternum**

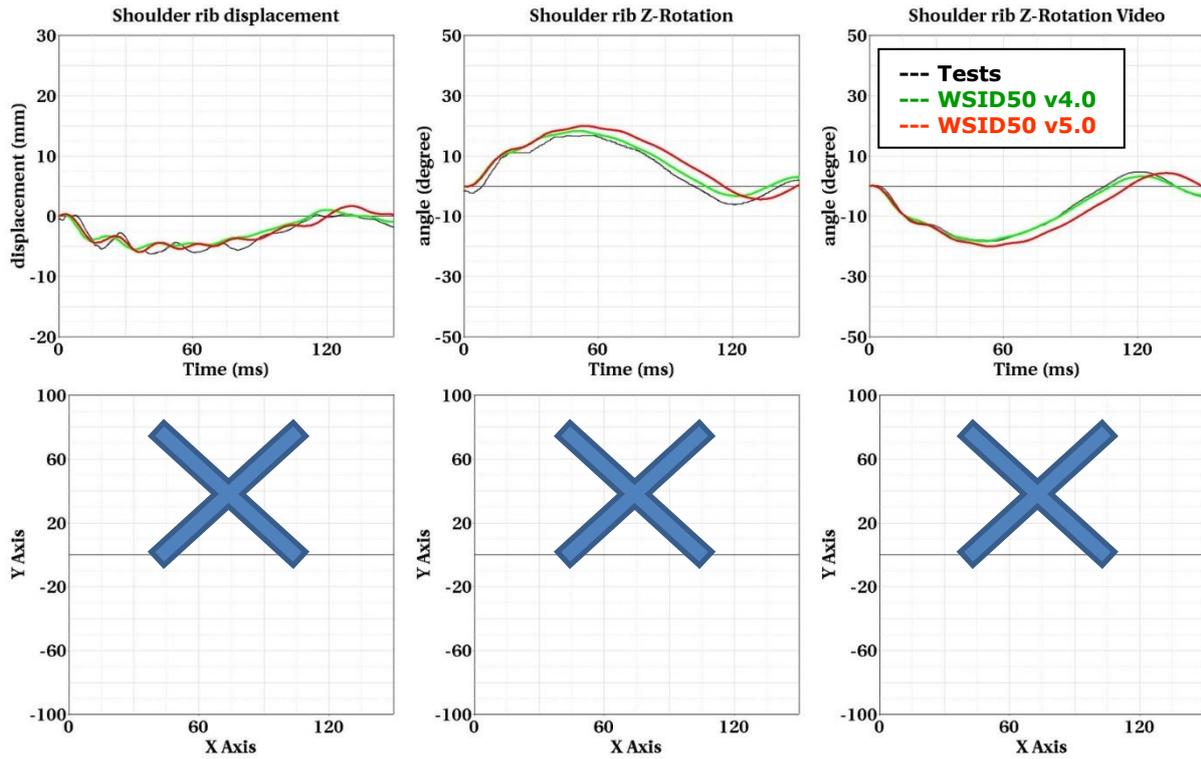


**Figure 126:** Additional shoulder rib test, 0 degree with sternum

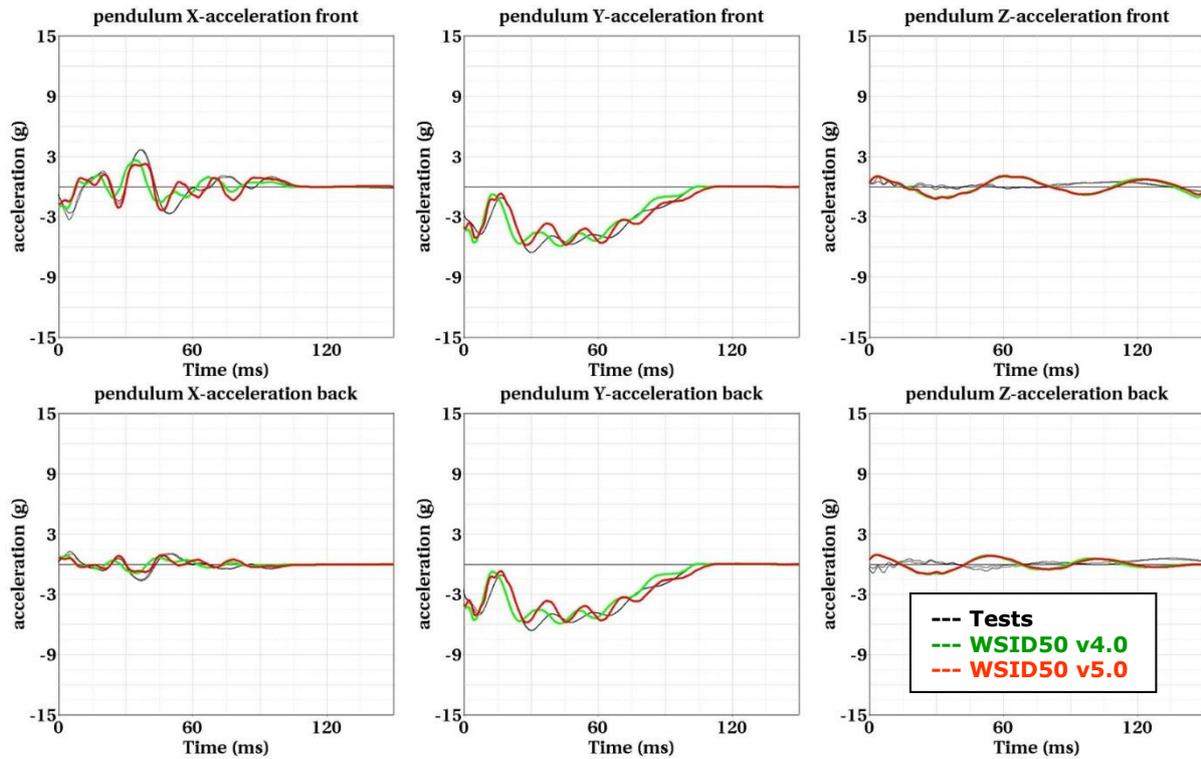
**0 Degree with sternum, low pendulum mass - low velocity:**



**Figure 127:** 0 Degree with sternum – low velocity

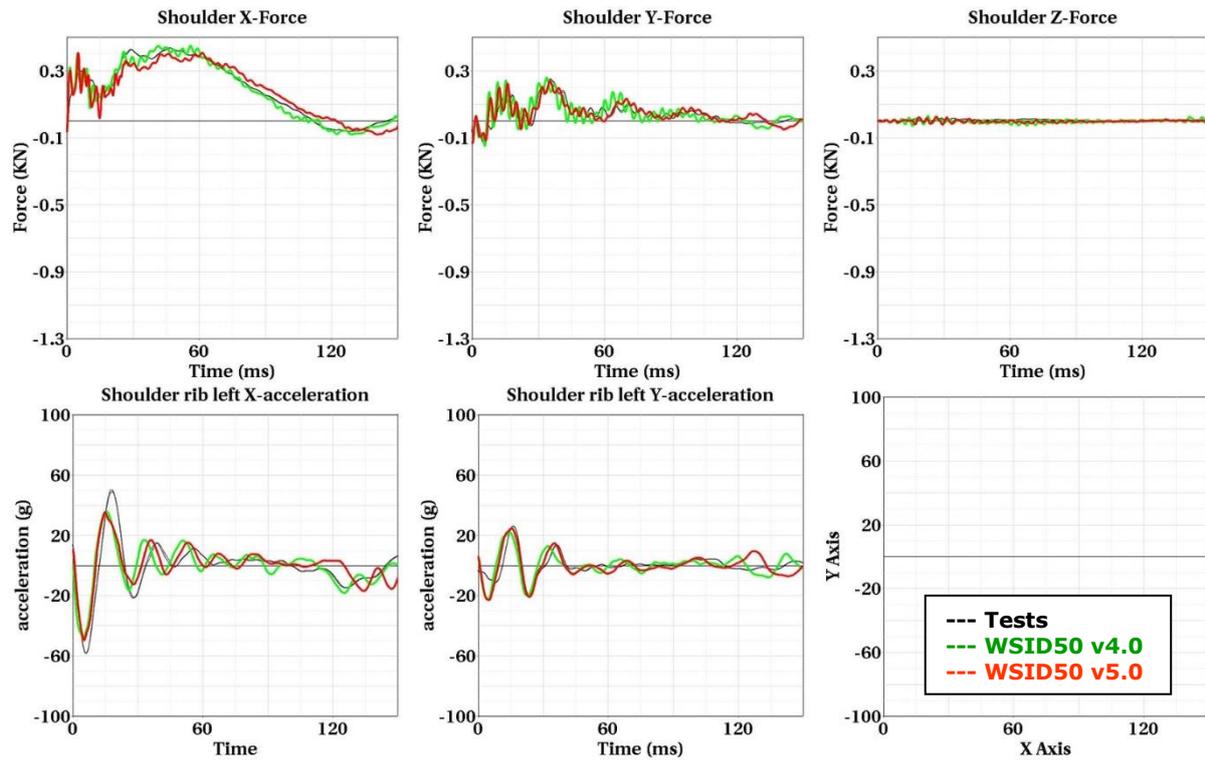


**Figure 128:** 0 Degree with sternum – low velocity

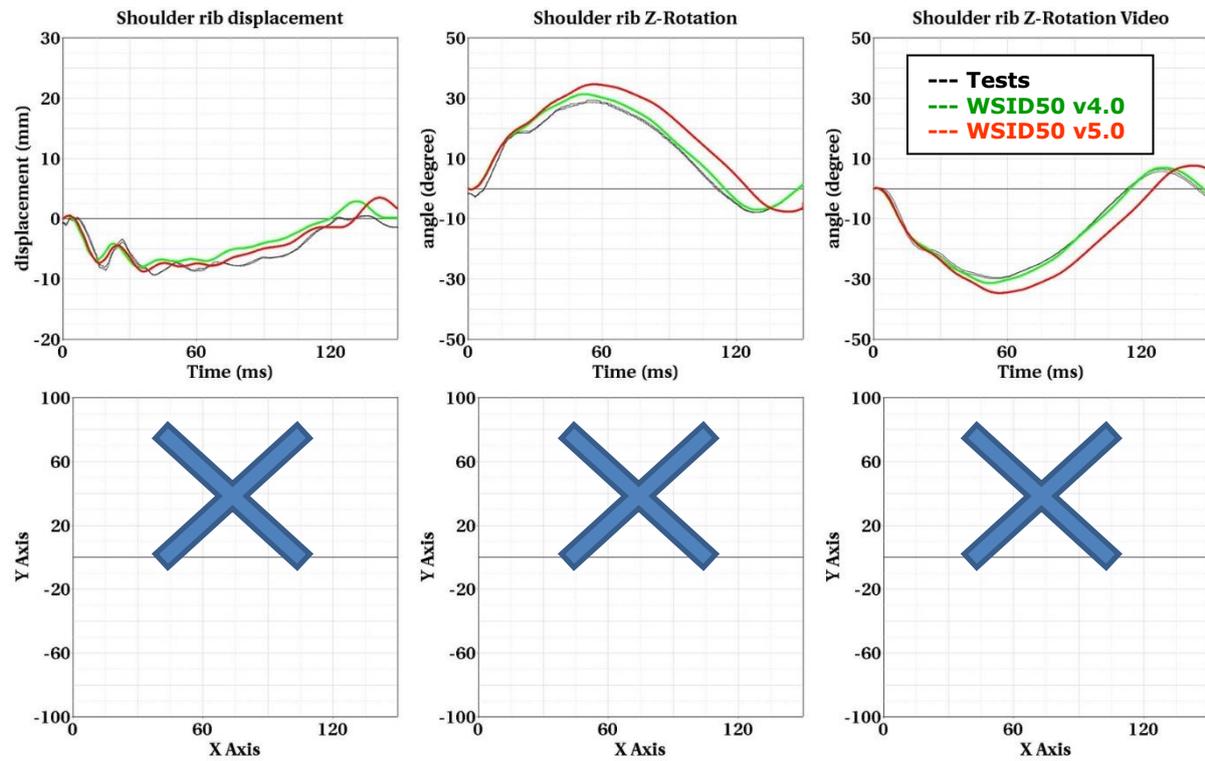


**Figure 129:** 0 Degree with sternum – low velocity

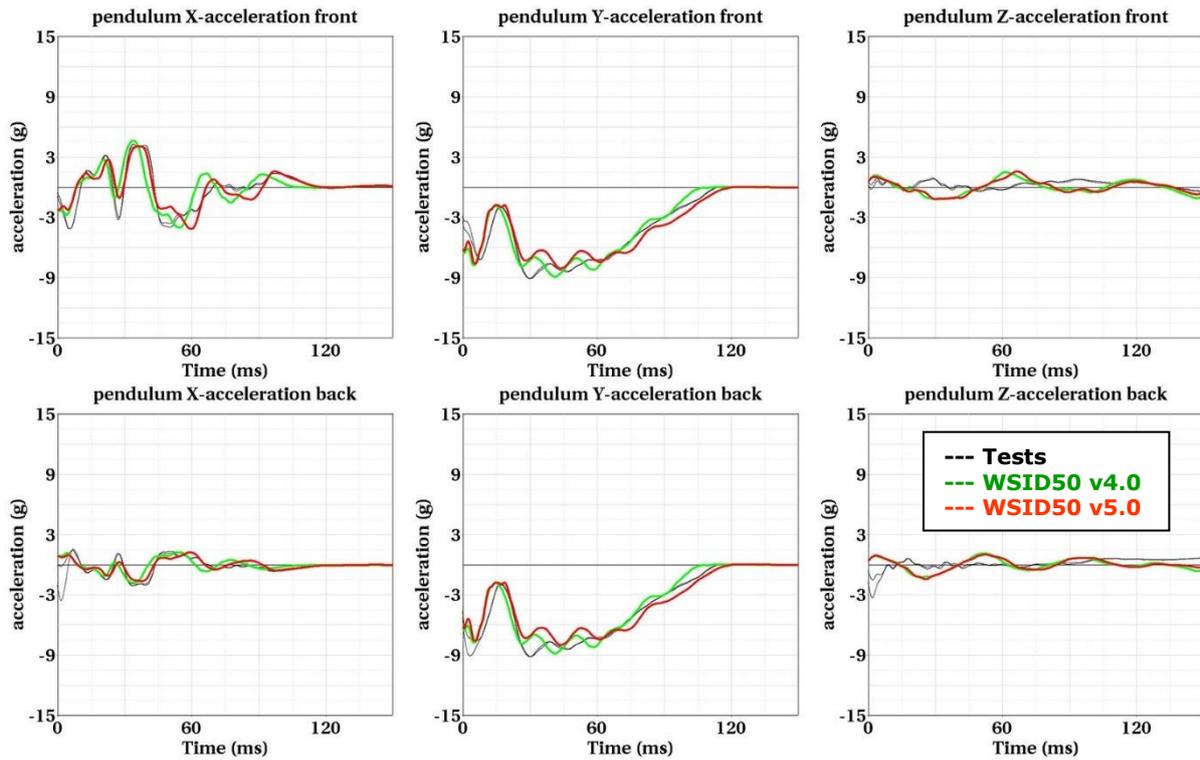
**0 Degree with sternum, low pendulum mass - high velocity:**



**Figure 130:** 0 Degree with sternum – high velocity

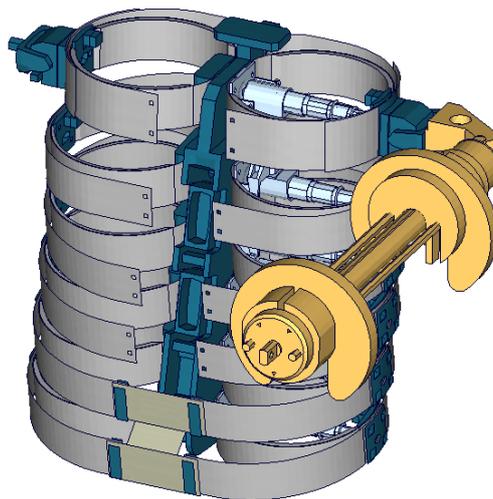


**Figure 131:** 0 Degree with sternum – high velocity



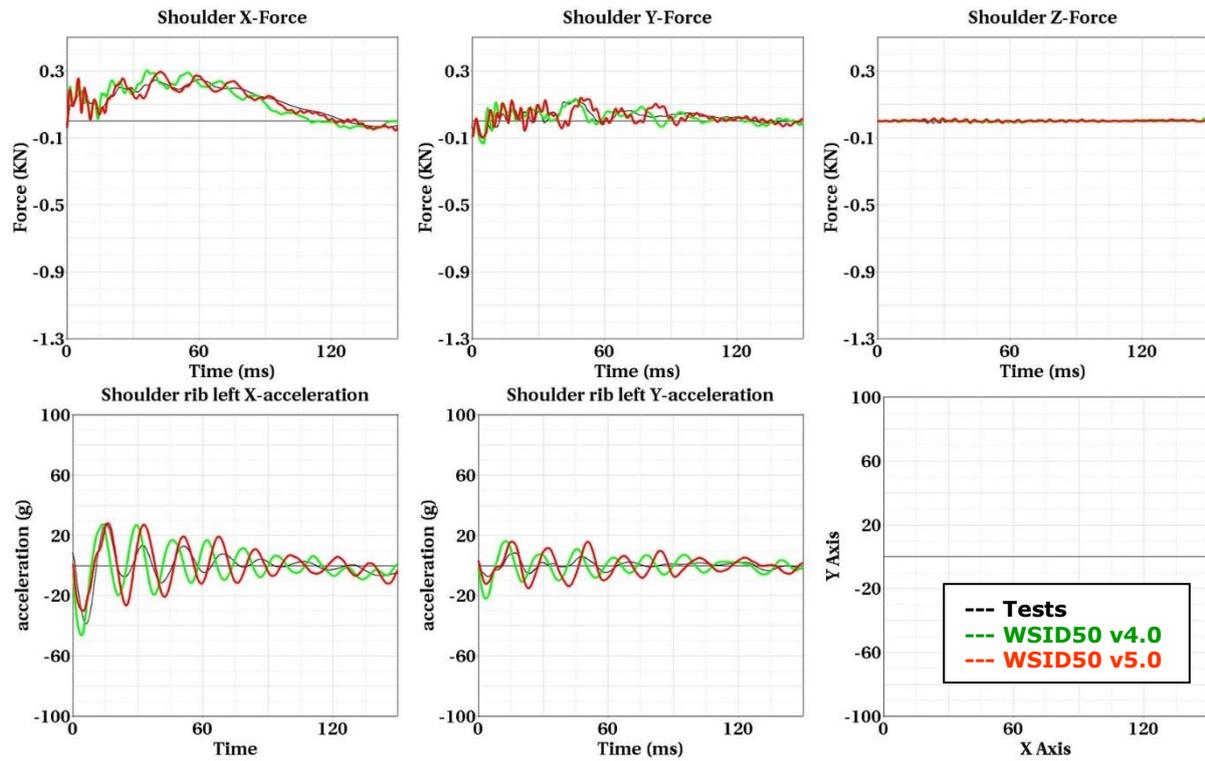
**Figure 132:** 0 Degree with sternum – high velocity

**0 Degree without sternum**

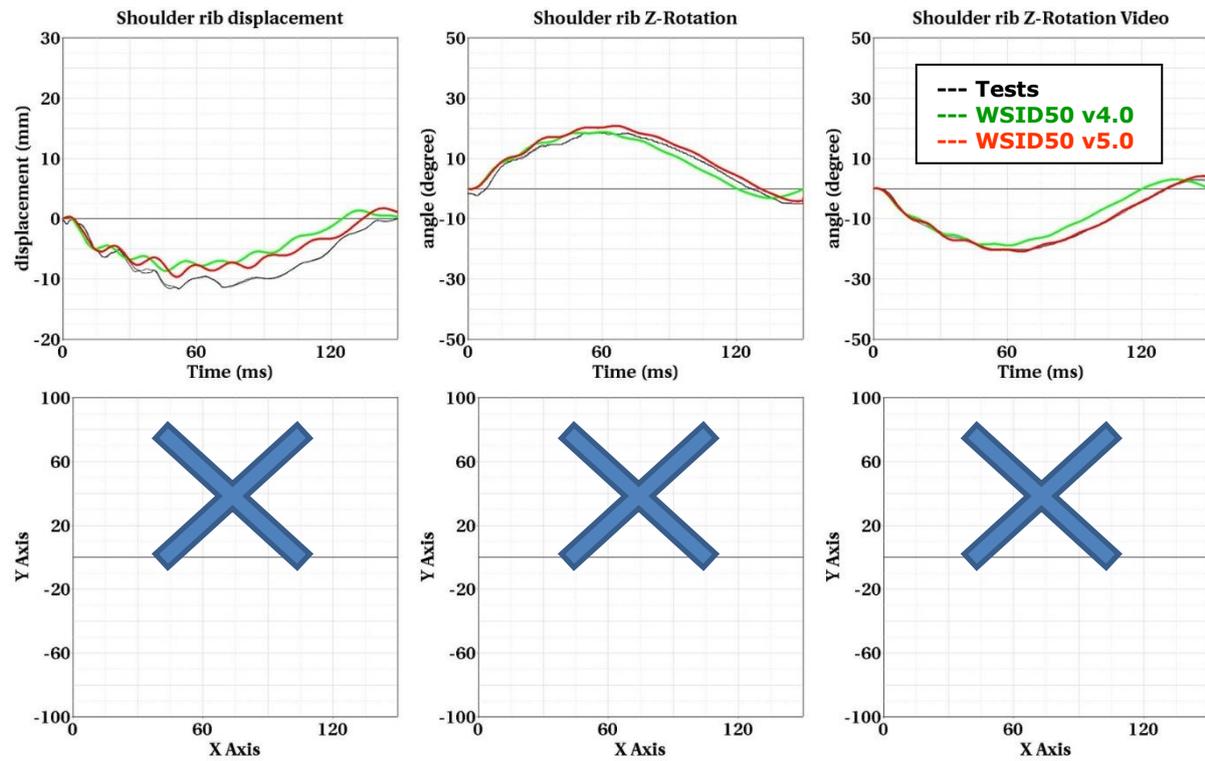


**Figure 133:** Additional shoulder rib test, 0 degree without sternum

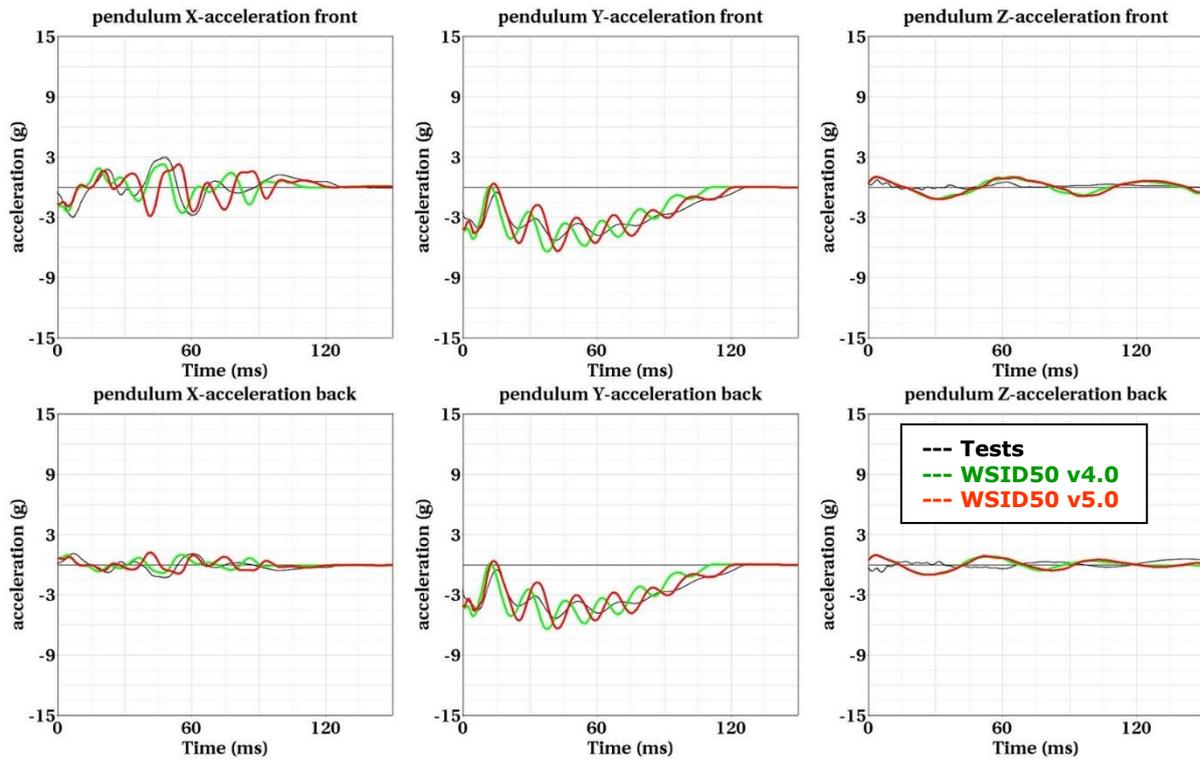
**0 Degree without sternum, low pendulum mass - low velocity:**



**Figure 134:** 0 Degree without sternum – low velocity

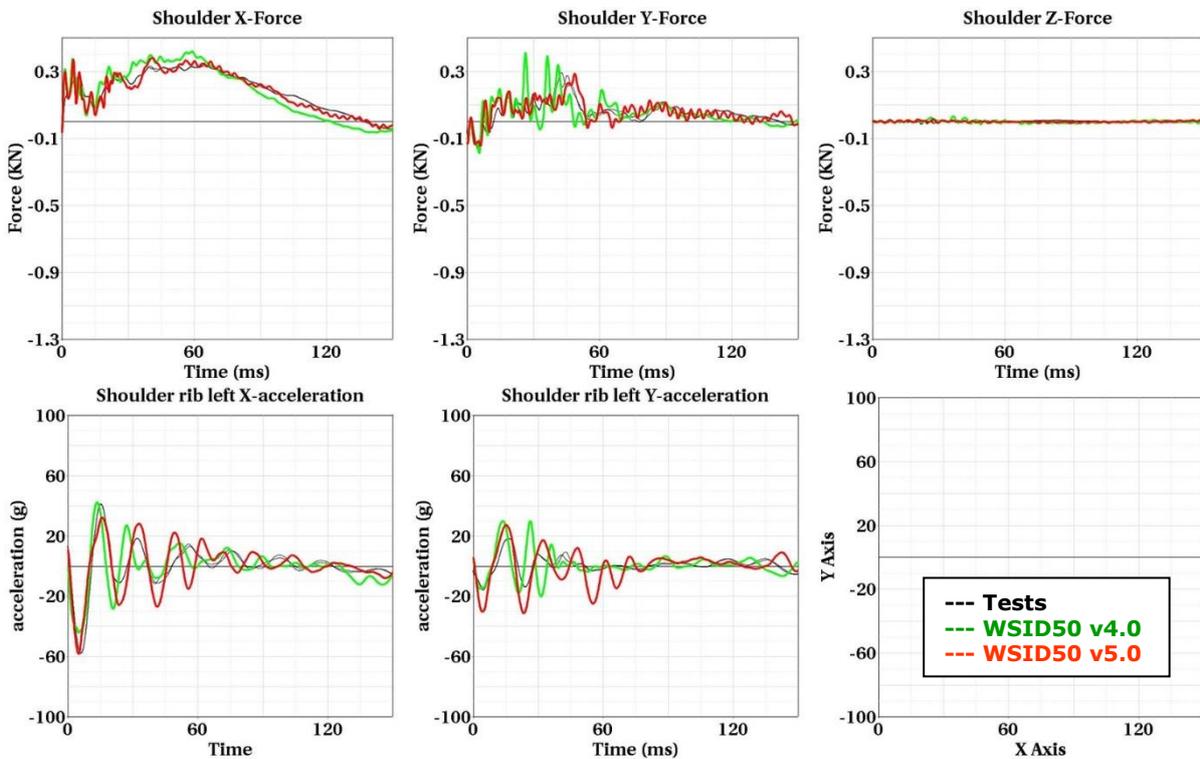


**Figure 135:** 0 Degree without sternum – low velocity

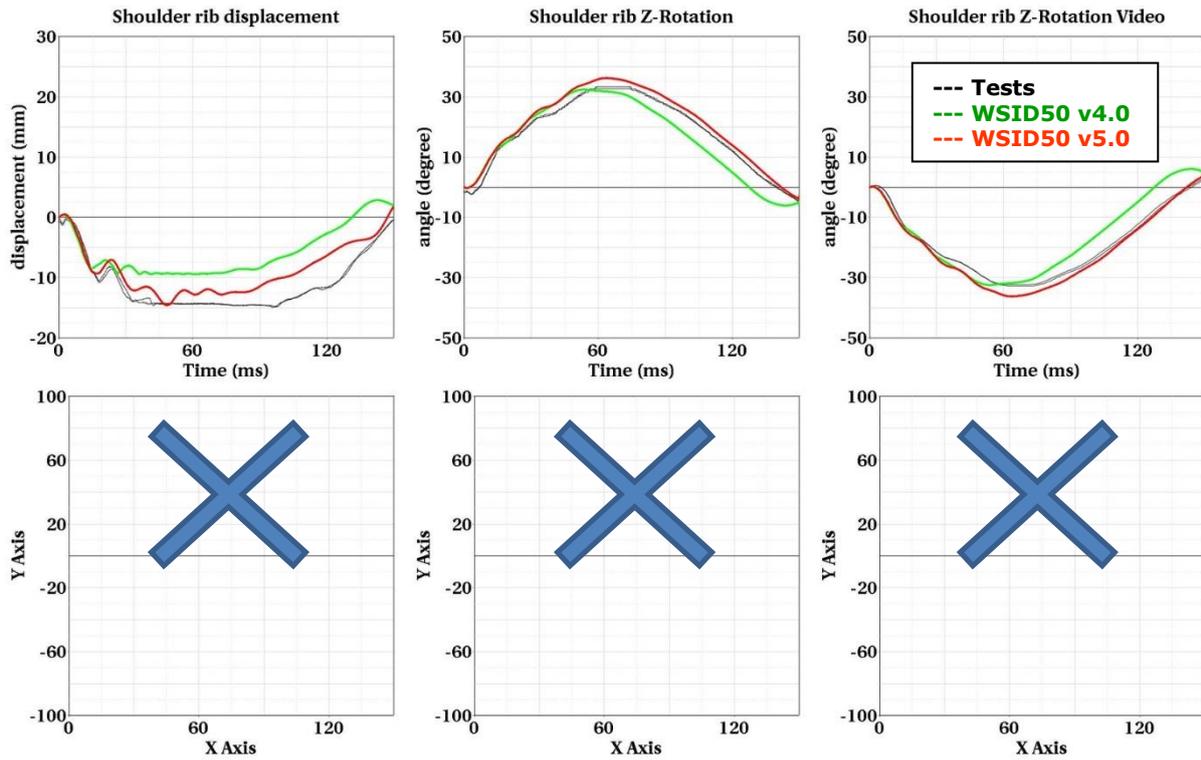


**Figure 136:** 0 Degree without sternum – low velocity

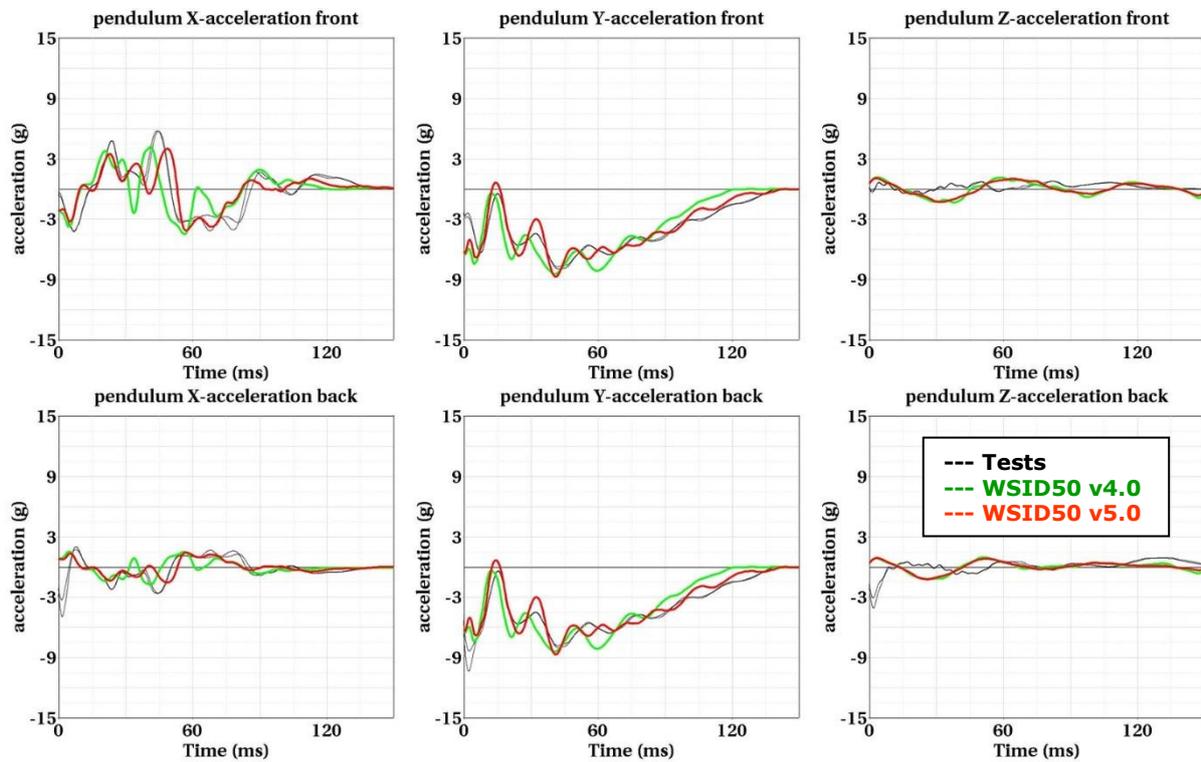
**0 Degree without sternum, low pendulum mass - high velocity:**



**Figure 137:** 0 Degree without sternum – high velocity

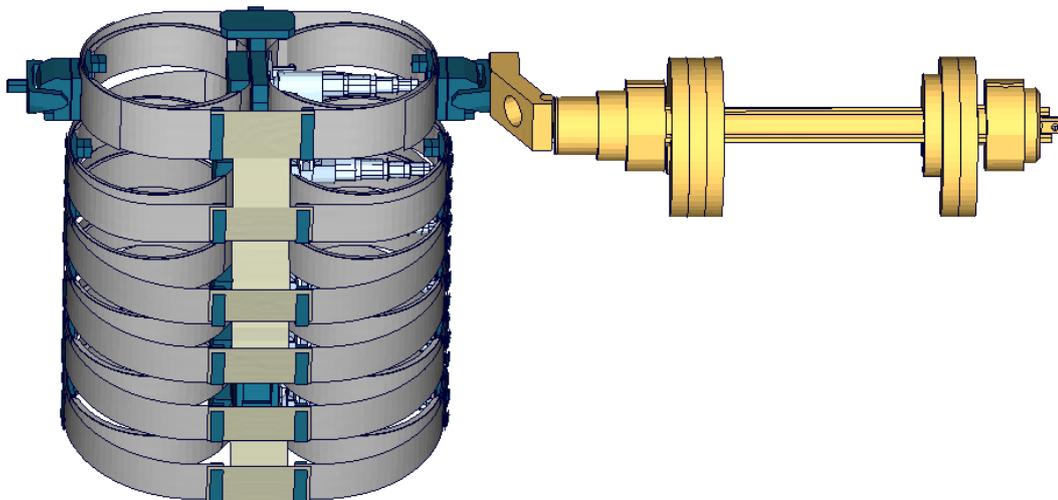


**Figure 138:** 0 Degree without sternum – high velocity



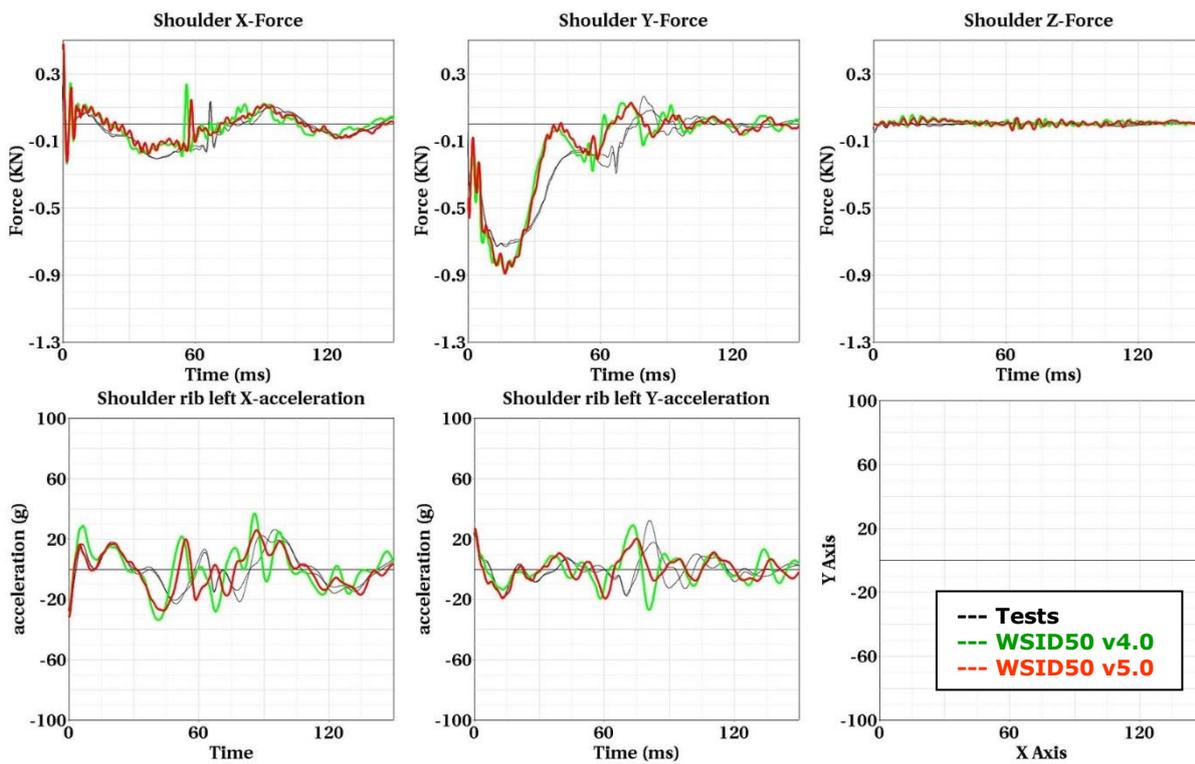
**Figure 139:** 0 Degree without sternum – high velocity

90 Degree with sternum

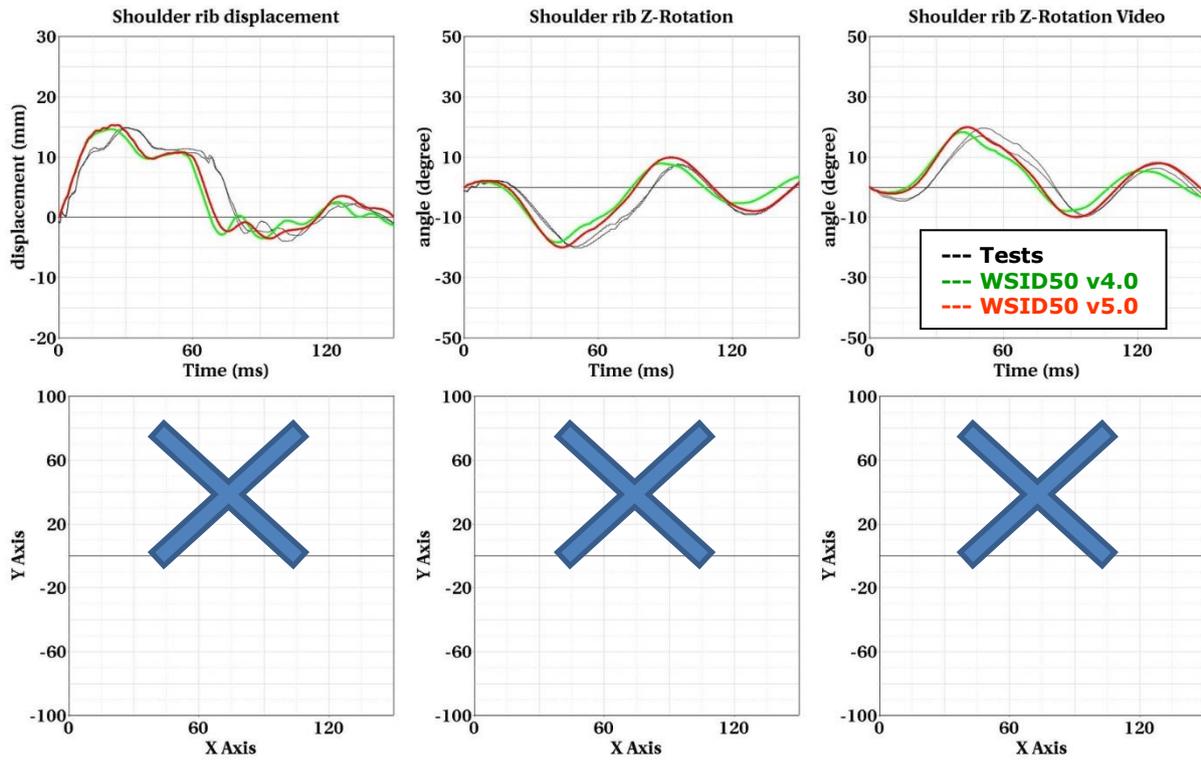


**Figure 140:** Additional shoulder rib test, 90 degree with sternum

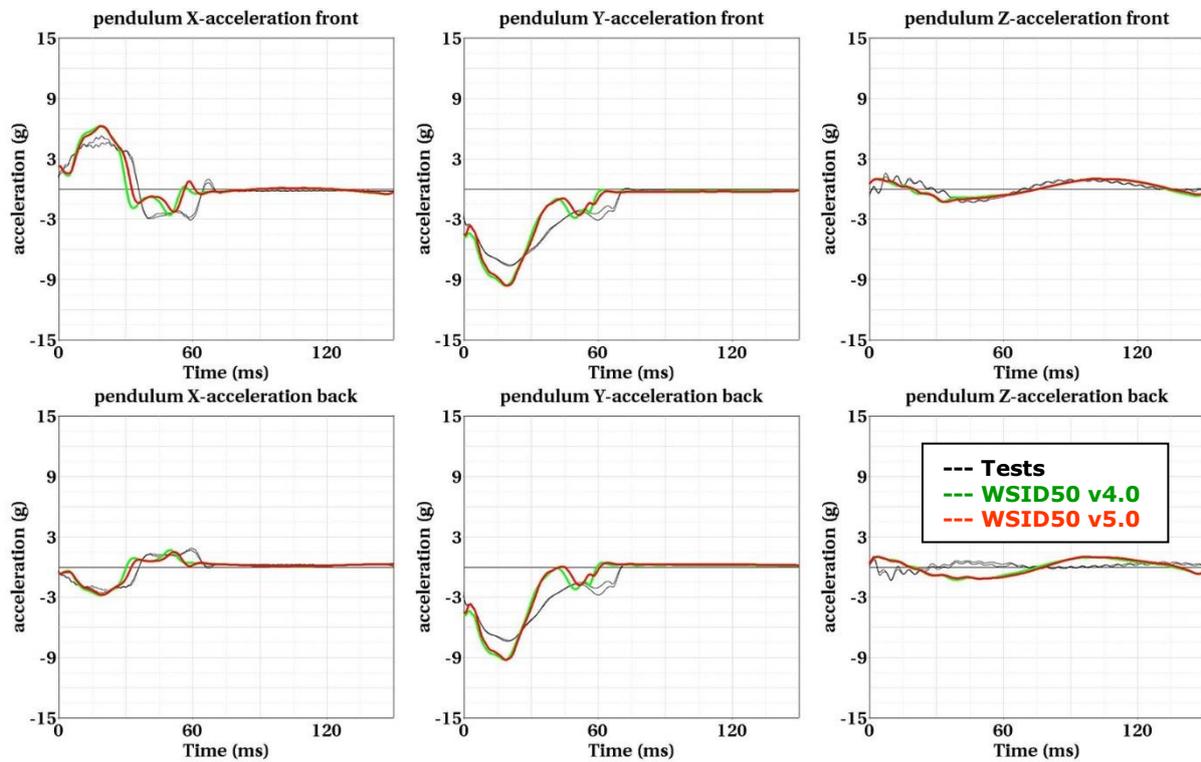
90 Degree with sternum, high pendulum mass - low velocity:



**Figure 141:** 90 Degree with sternum – low velocity



**Figure 142: 90 Degree with sternum – low velocity**



**Figure 143: 90 Degree with sternum – low velocity**

90 Degree with sternum, high pendulum mass - high velocity:

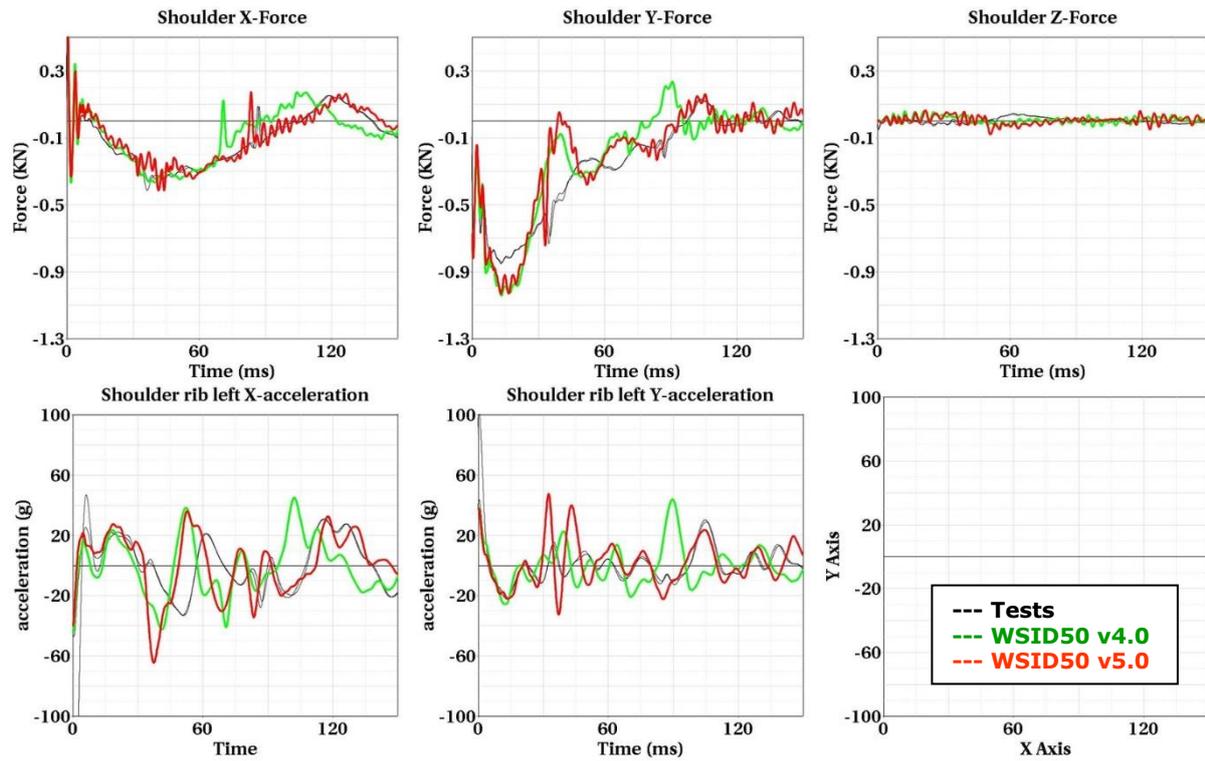


Figure 144: 90 Degree with sternum – high velocity

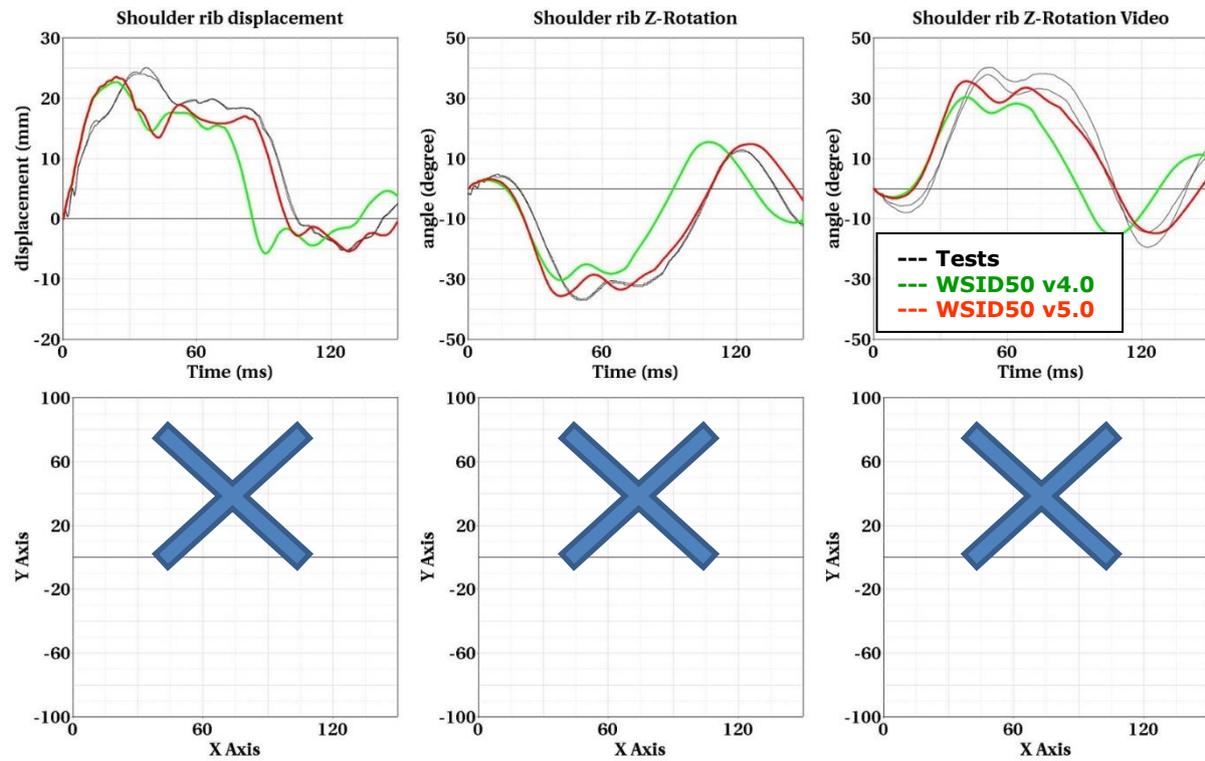
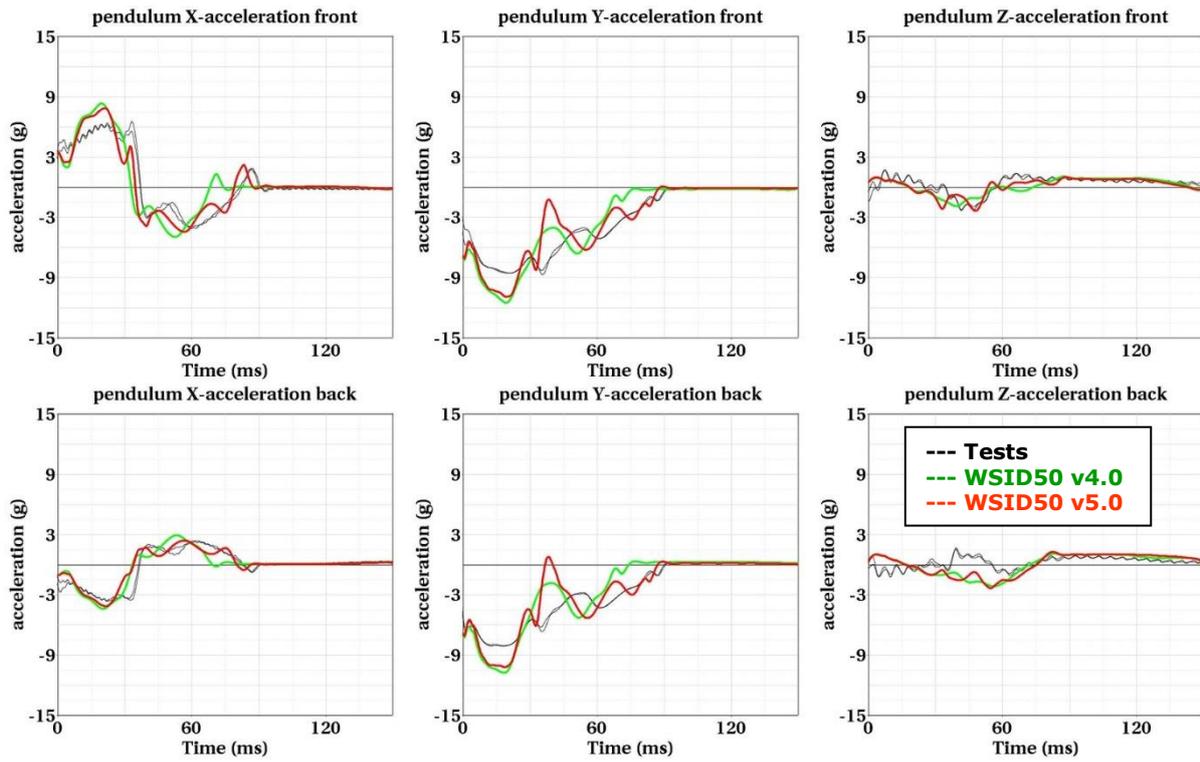
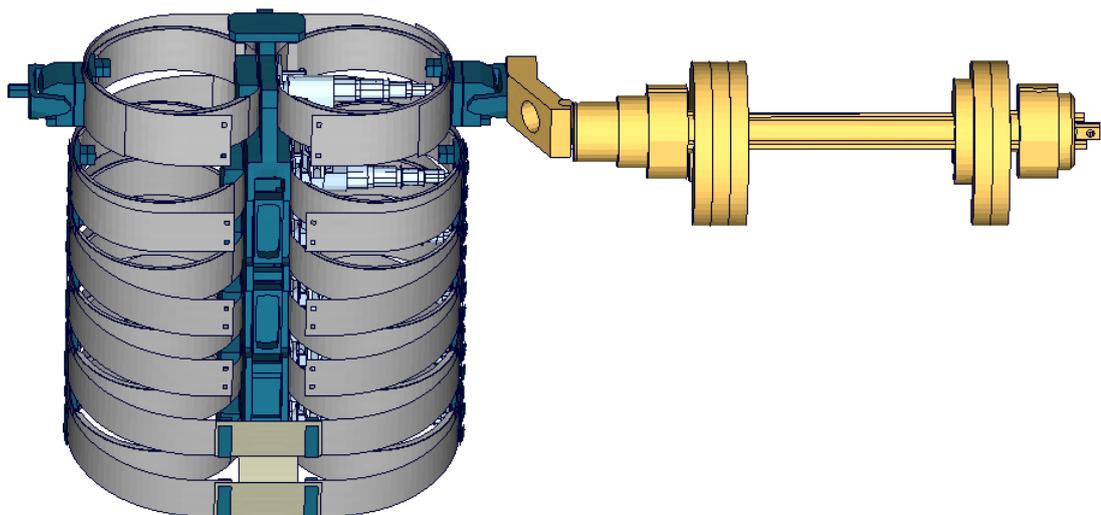


Figure 145: 90 Degree with sternum – high velocity



**Figure 146: 90 Degree with sternum – high velocity**

**90 Degree without sternum**



**Figure 147: Additional shoulder rib test, 90 degree without sternum**

90 Degree without sternum, high pendulum mass - low velocity:

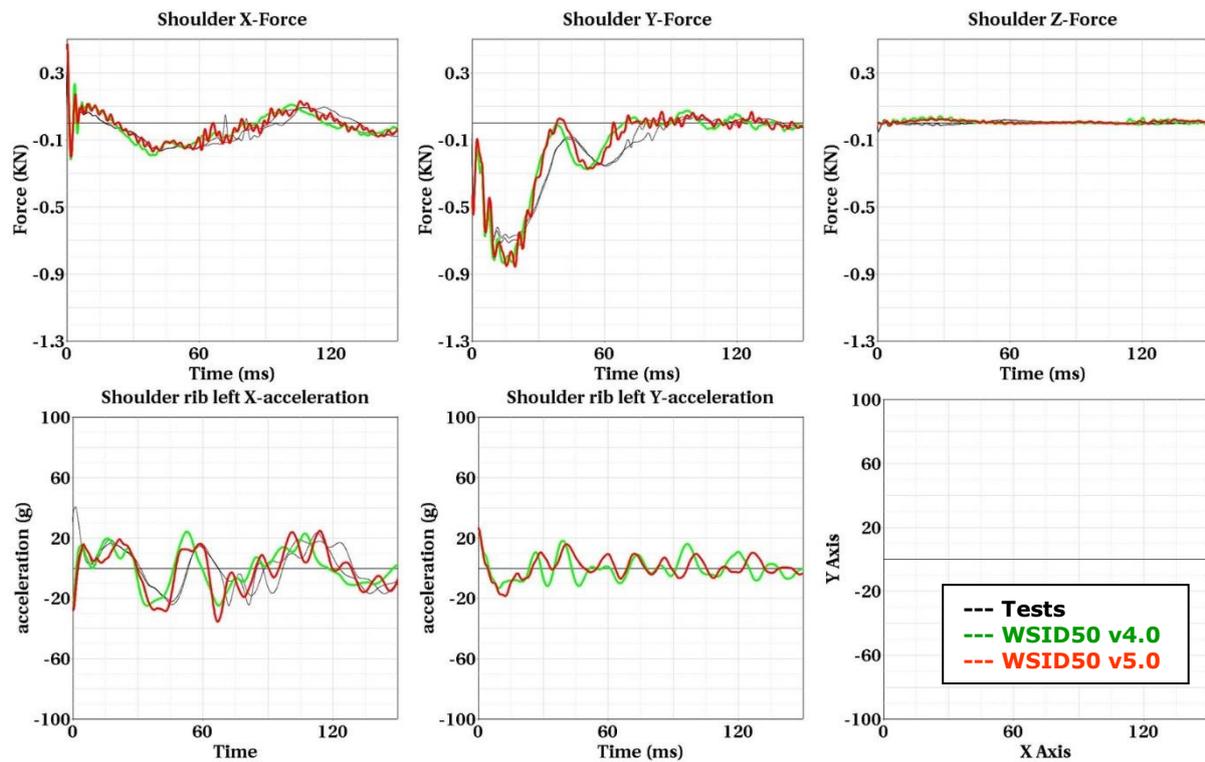


Figure 148: 90 Degree without sternum – low velocity

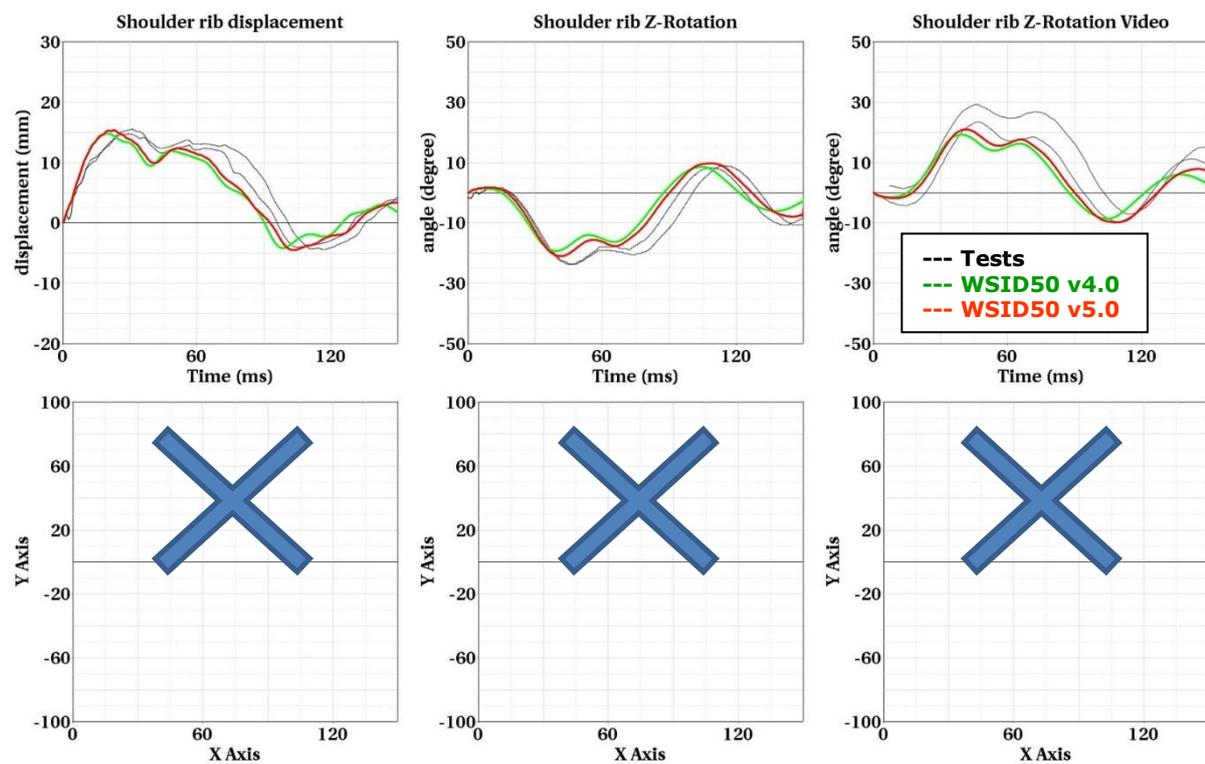
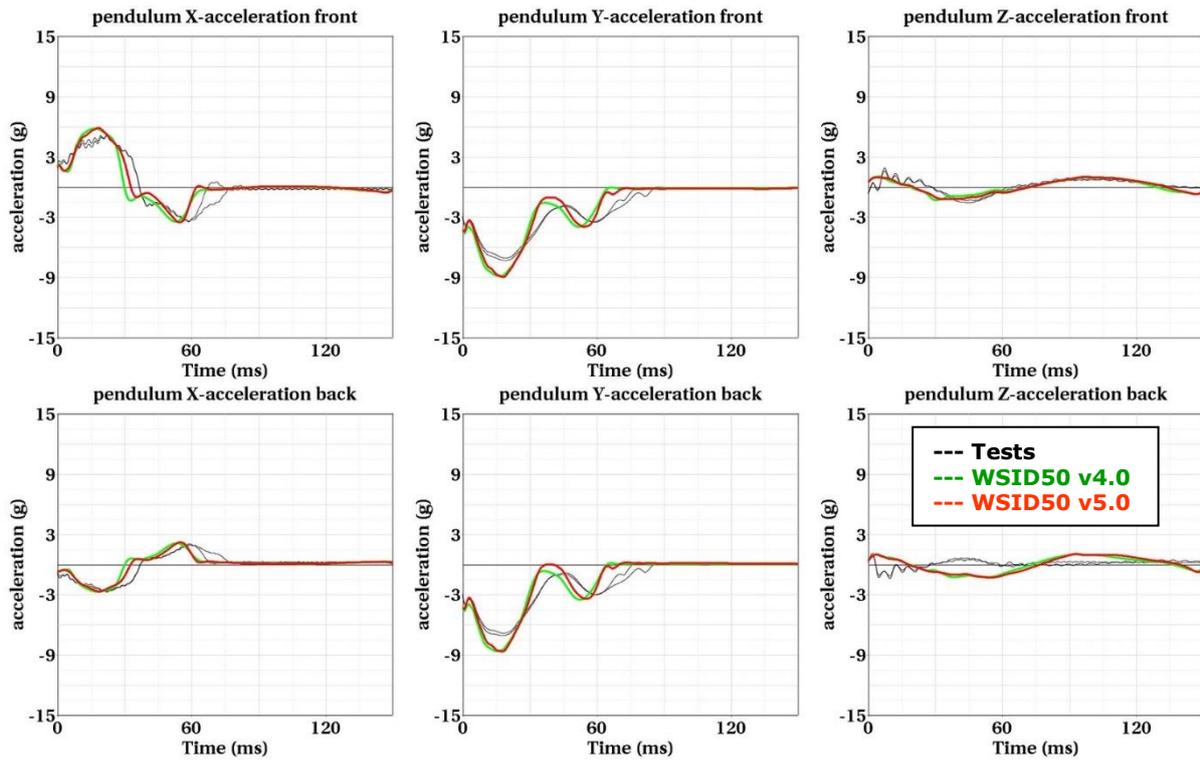
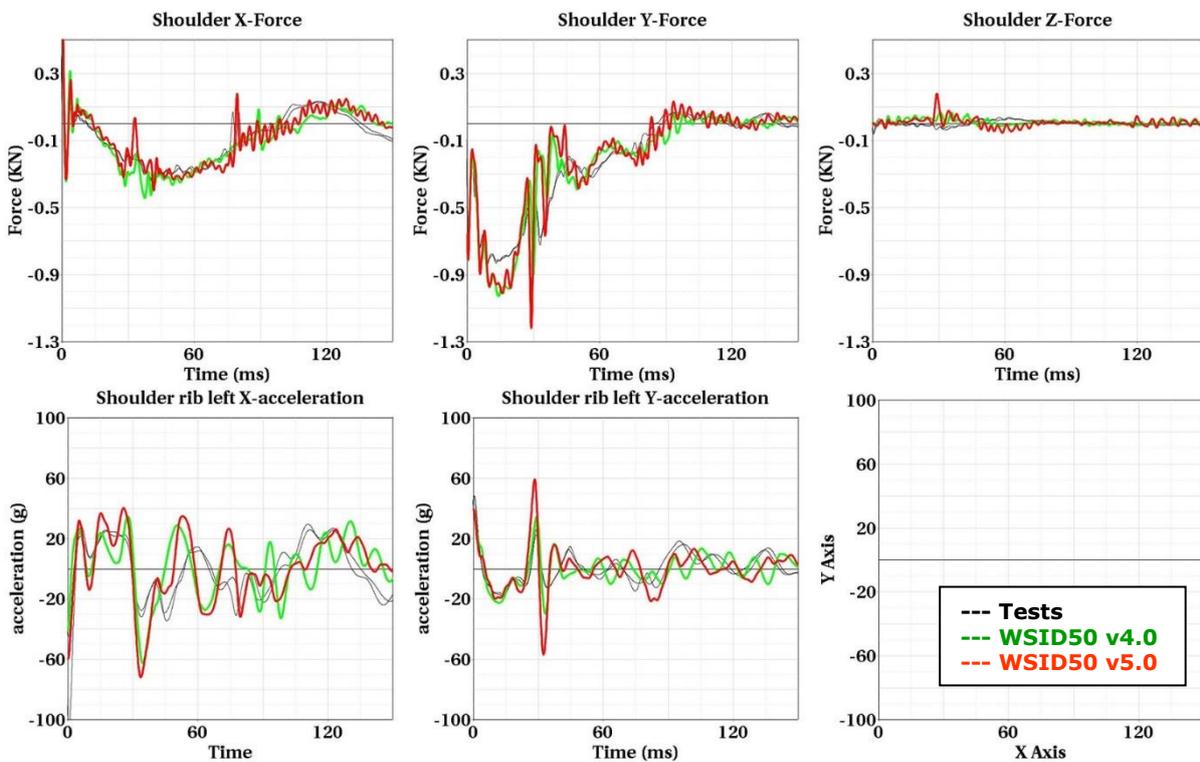


Figure 149: 90 Degree without sternum – low velocity

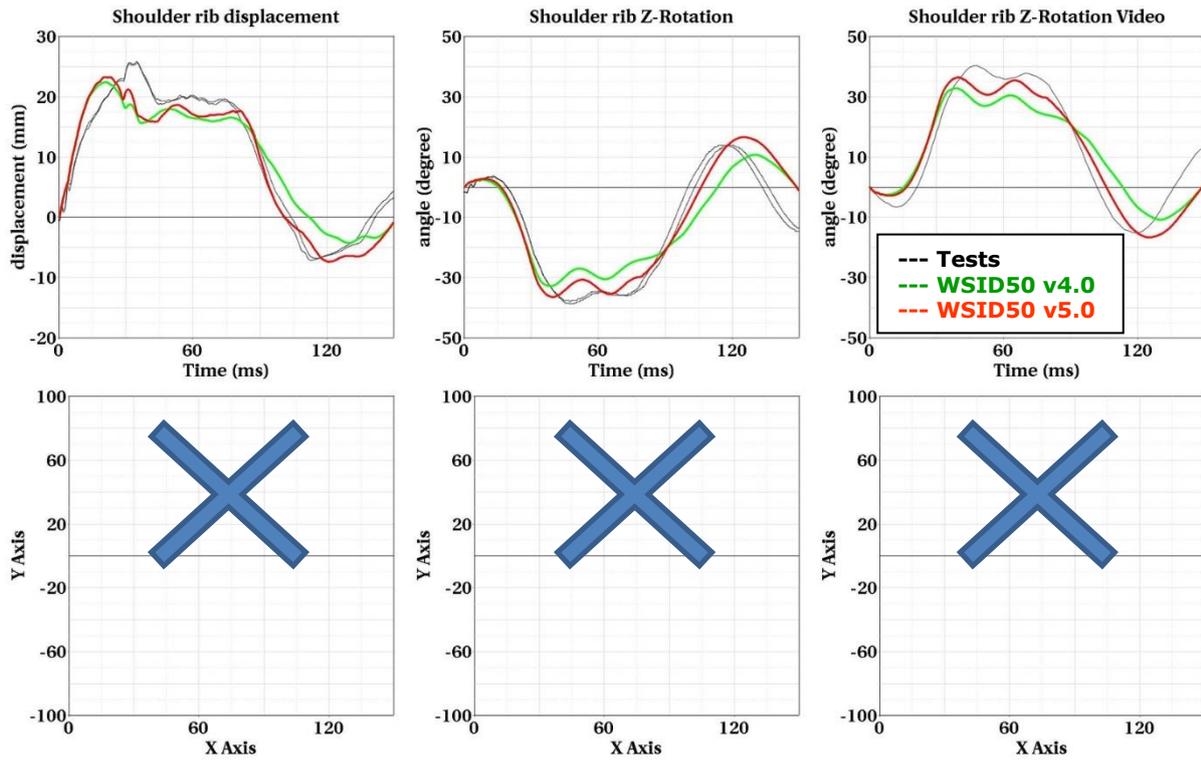


**Figure 150: 90 Degree without sternum – low velocity**

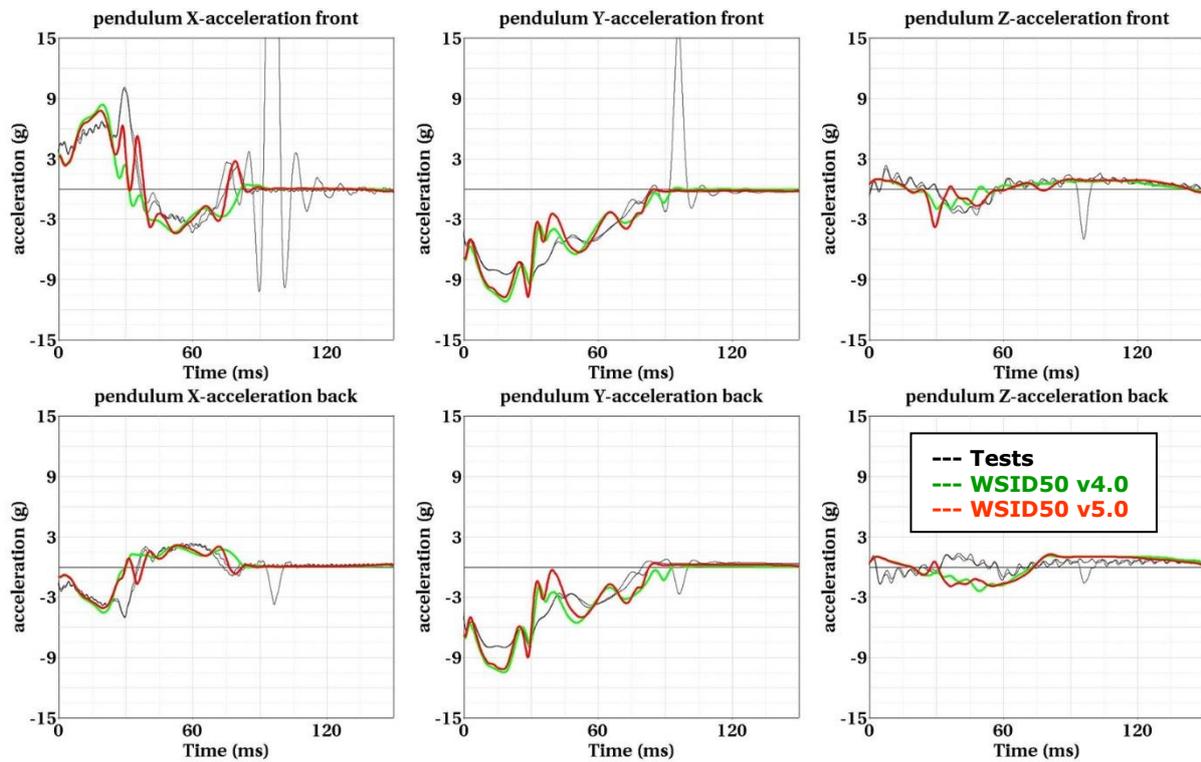
**90 Degree without sternum, high pendulum mass - high velocity:**



**Figure 151: 90 Degree without sternum – high velocity**

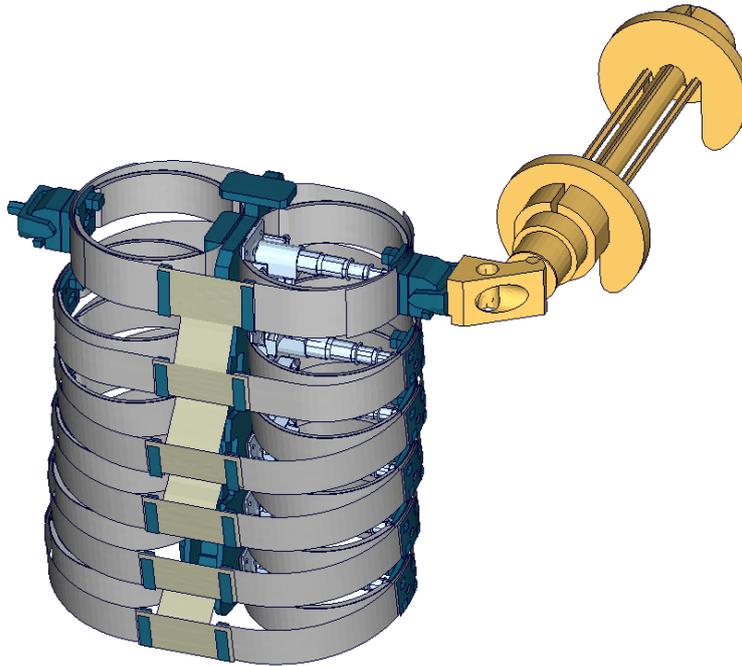


**Figure 152: 90 Degree without sternum – high velocity**



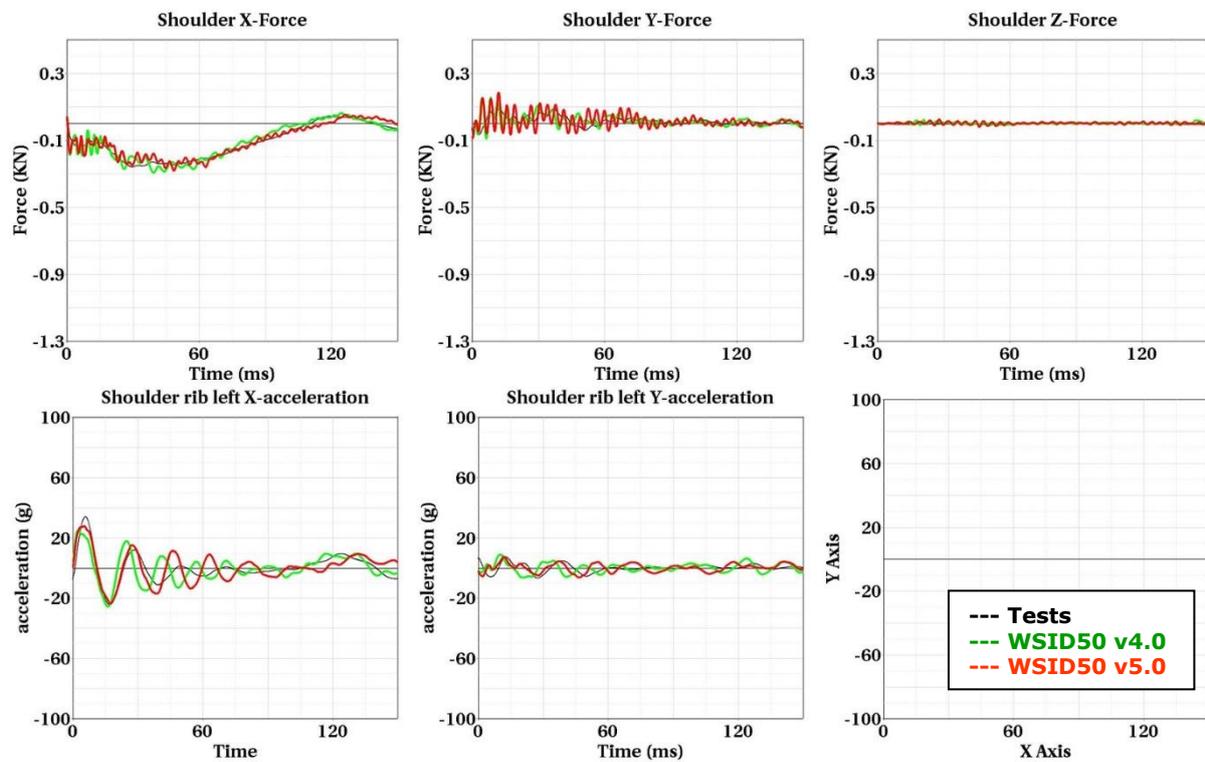
**Figure 153: 90 Degree without sternum – high velocity**

**180 Degree with sternum**

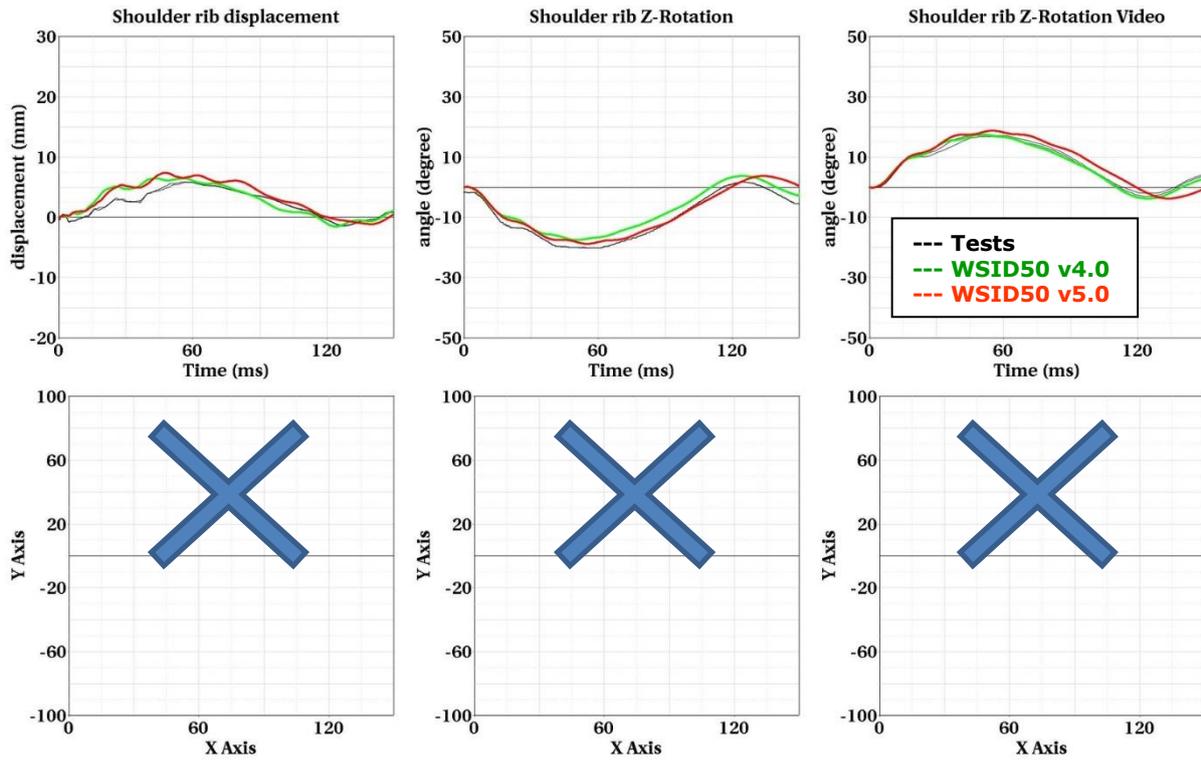


**Figure 154:** Additional shoulder rib test, 180 degree with sternum

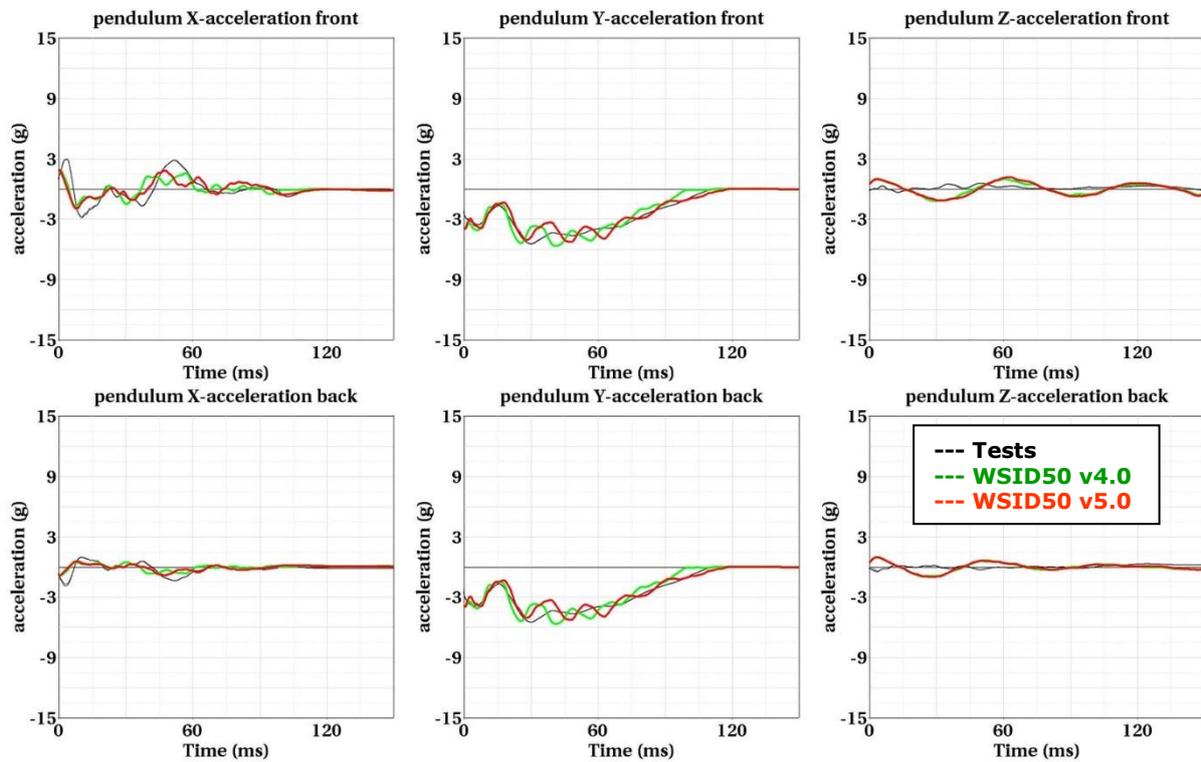
**180 Degree with sternum, low pendulum mass - low velocity:**



**Figure 155:** 180 Degree with sternum – low velocity

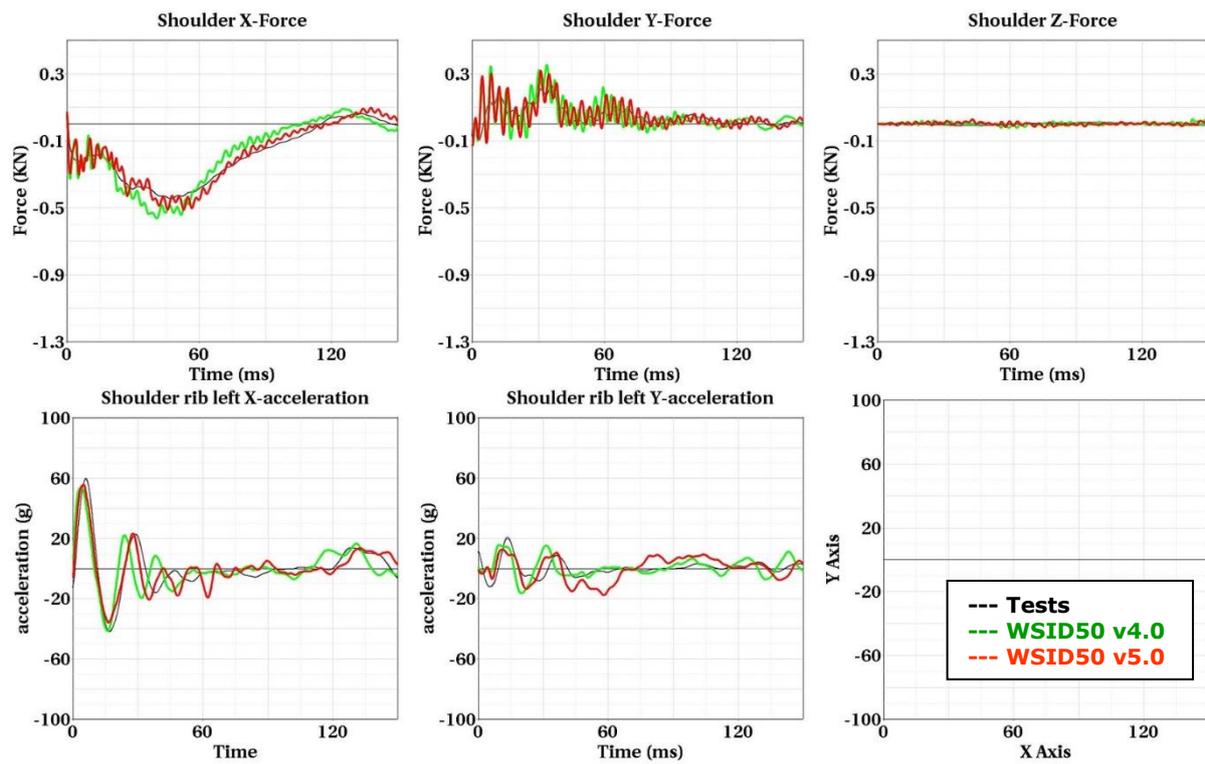


**Figure 156: 180 Degree with sternum – low velocity**

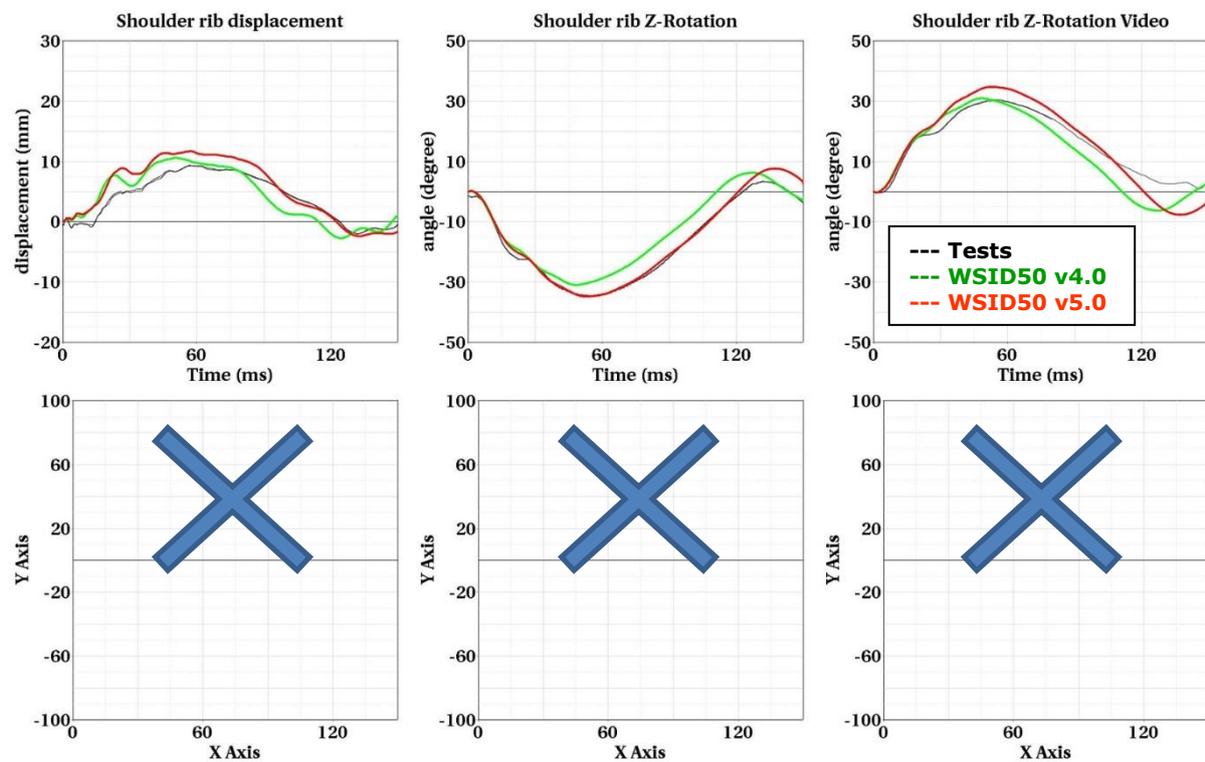


**Figure 157: 180 Degree with sternum – low velocity**

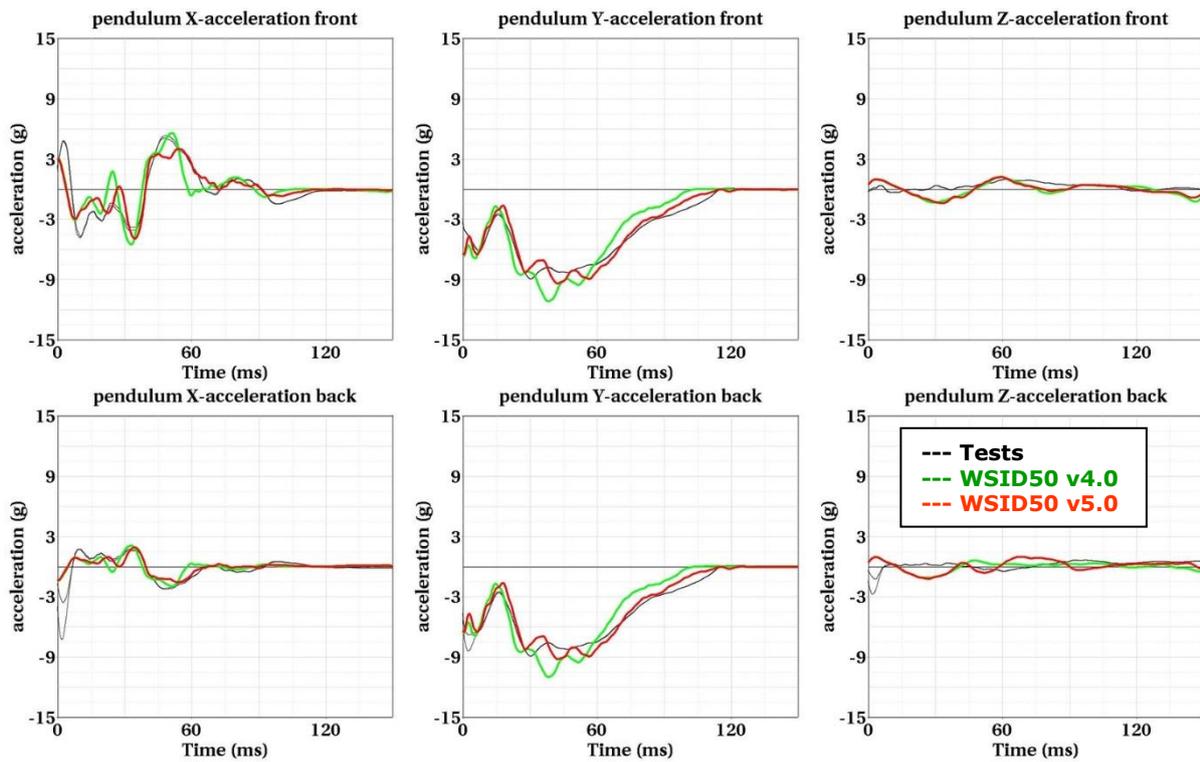
**180 Degree with sternum, low pendulum mass - high velocity:**



**Figure 158: 180 Degree with sternum – high velocity**

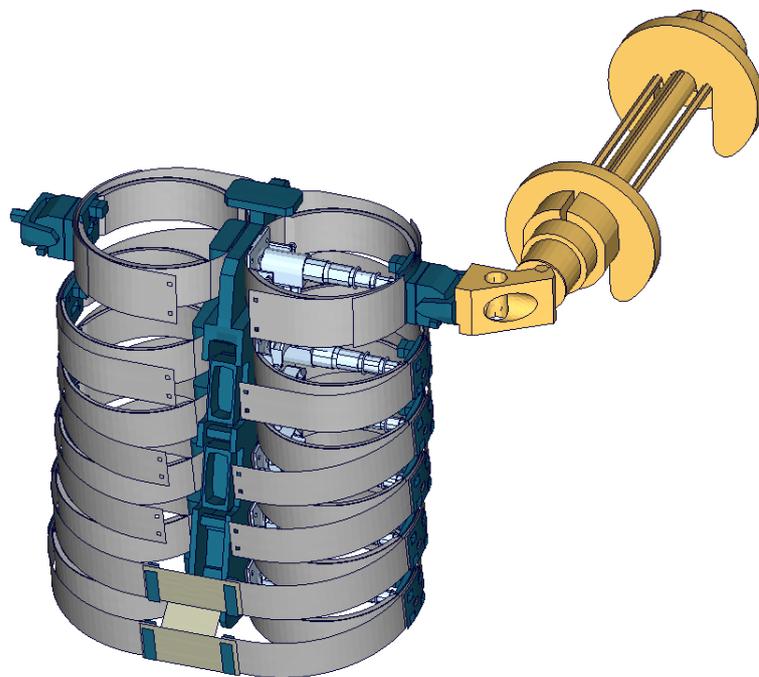


**Figure 159: 180 Degree with sternum – high velocity**



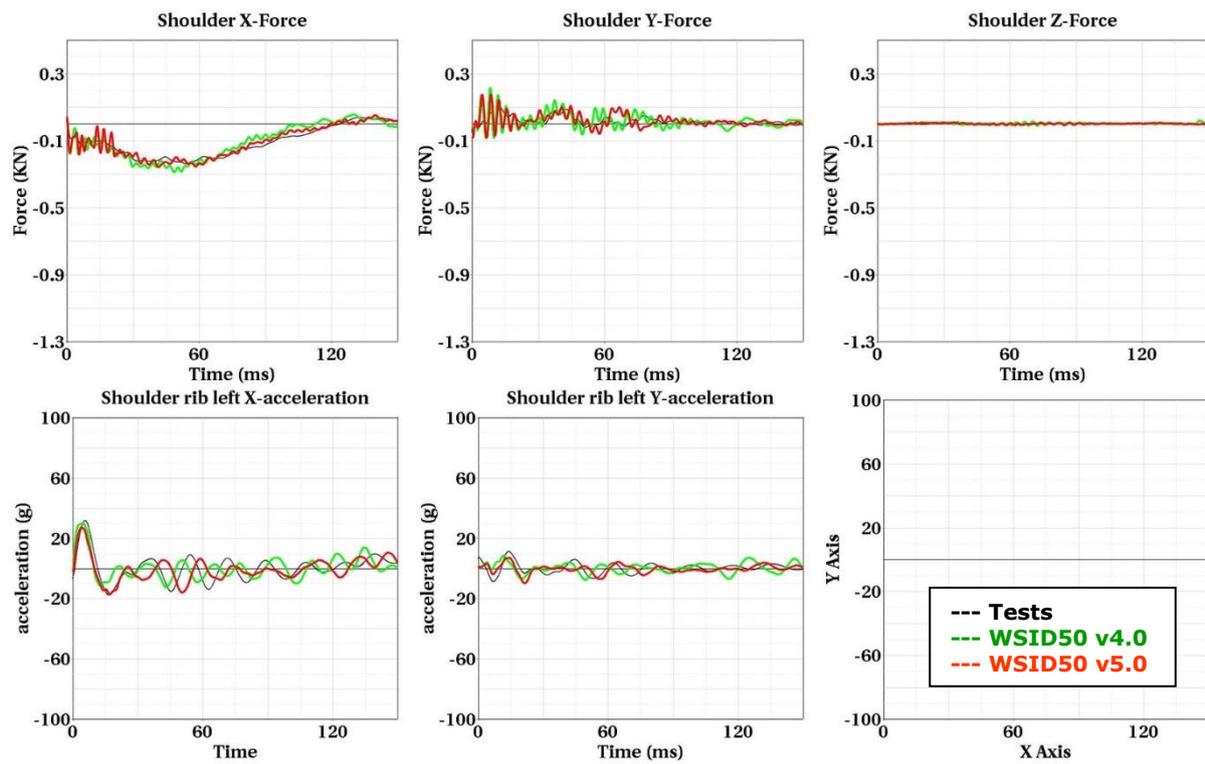
**Figure 160:** 180 Degree with sternum – high velocity

**180 Degree without sternum**

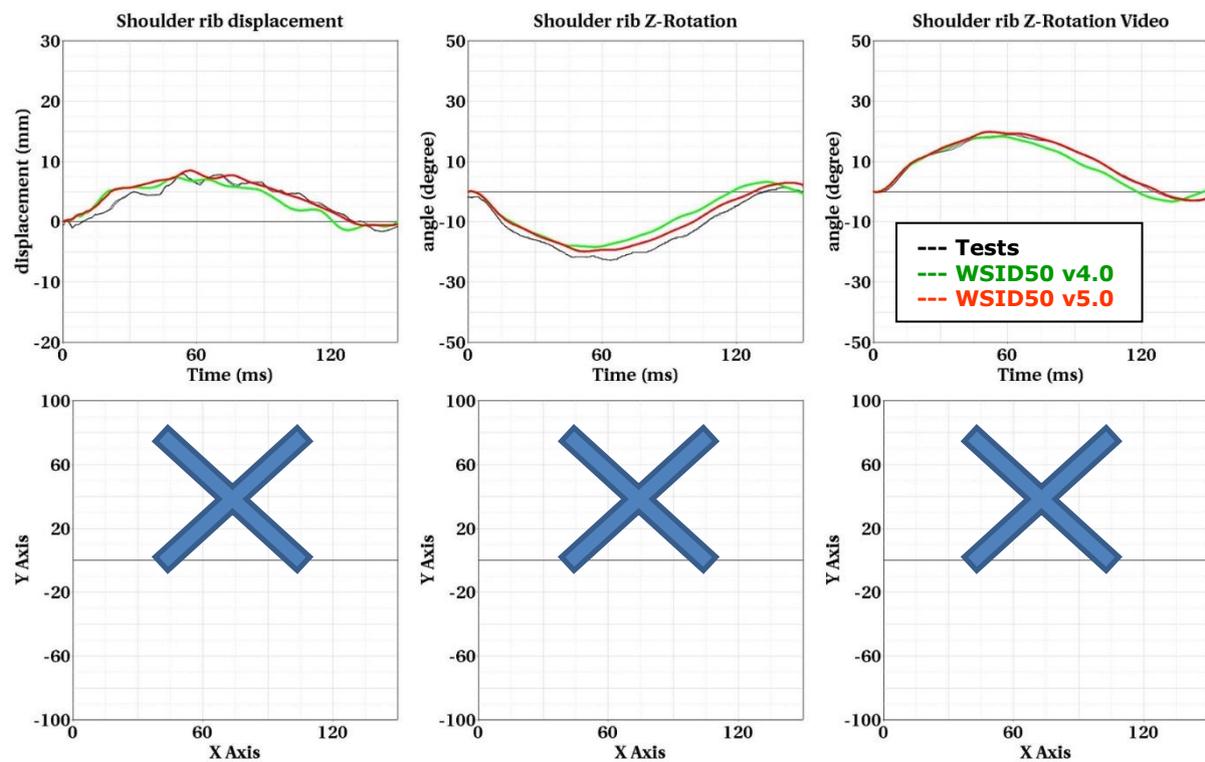


**Figure 161:** Additional shoulder rib test, 180 degree without sternum

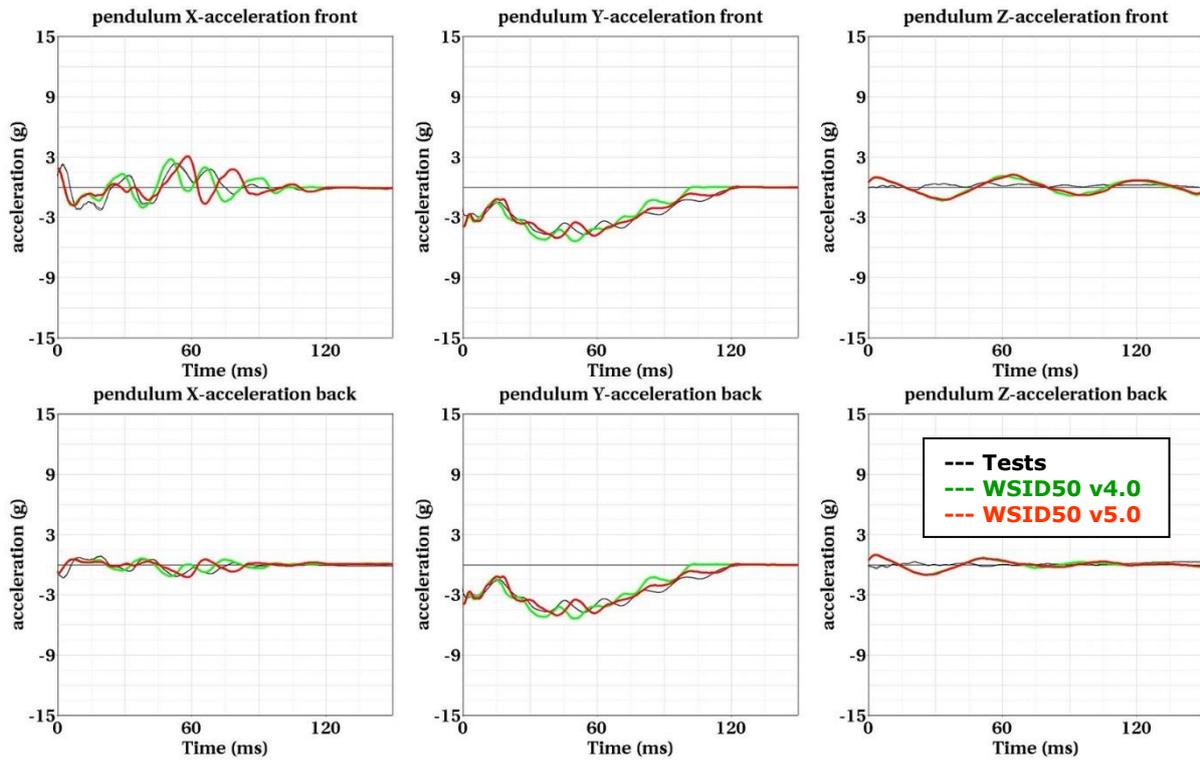
**180 Degree without sternum, low pendulum mass - low velocity:**



**Figure 162: 180 Degree without sternum – low velocity**

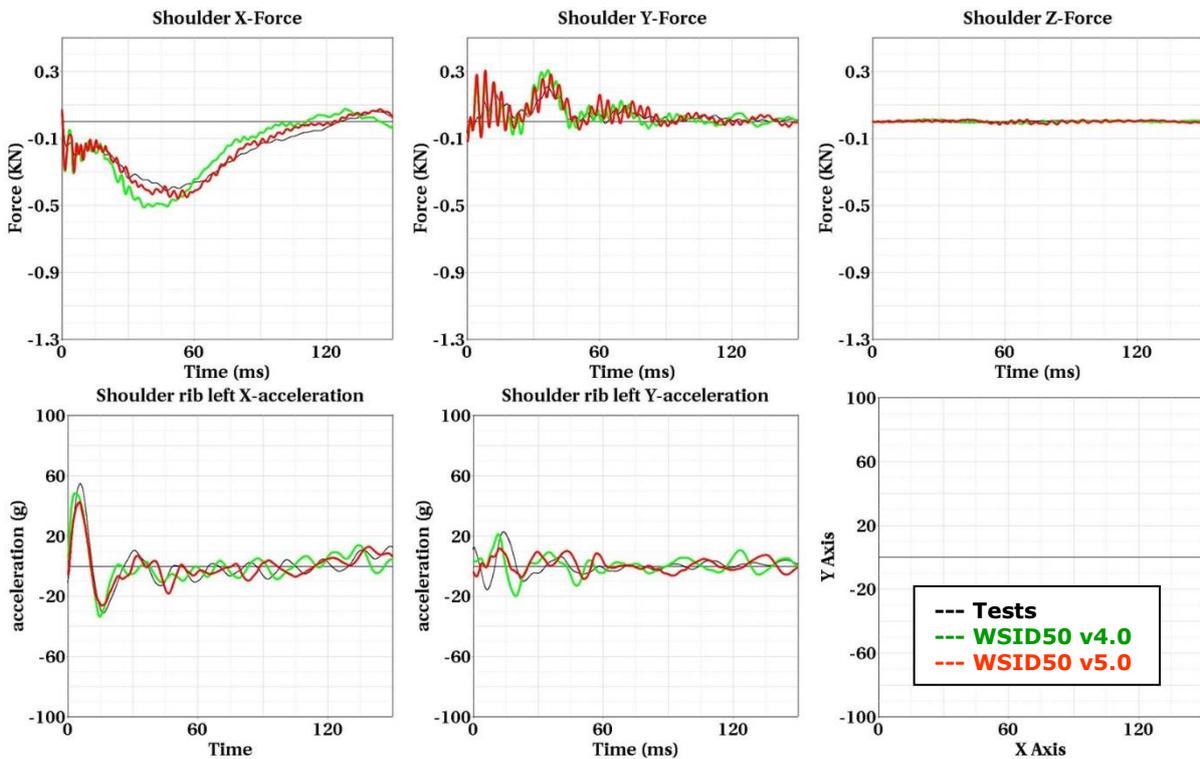


**Figure 163: 180 Degree without sternum – low velocity**

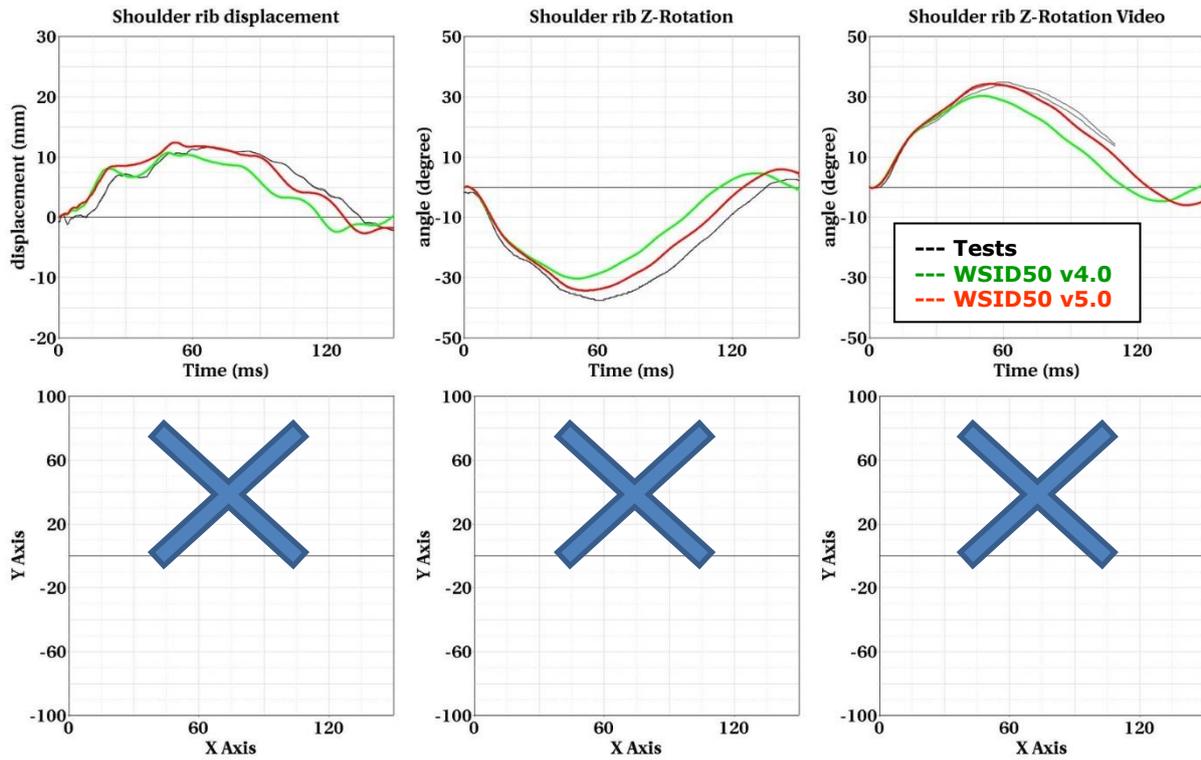


**Figure 164: 180 Degree without sternum – low velocity**

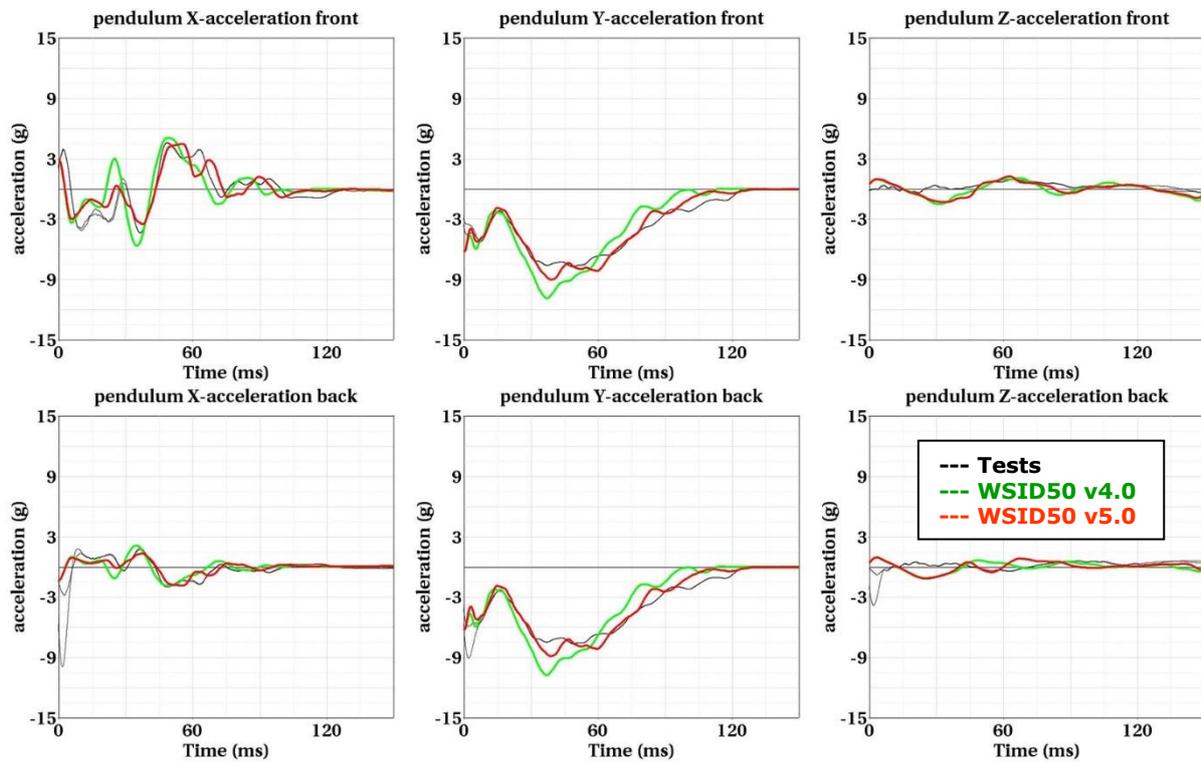
**180 Degree without sternum, low pendulum mass - high velocity:**



**Figure 165: 180 Degree without sternum – high velocity**



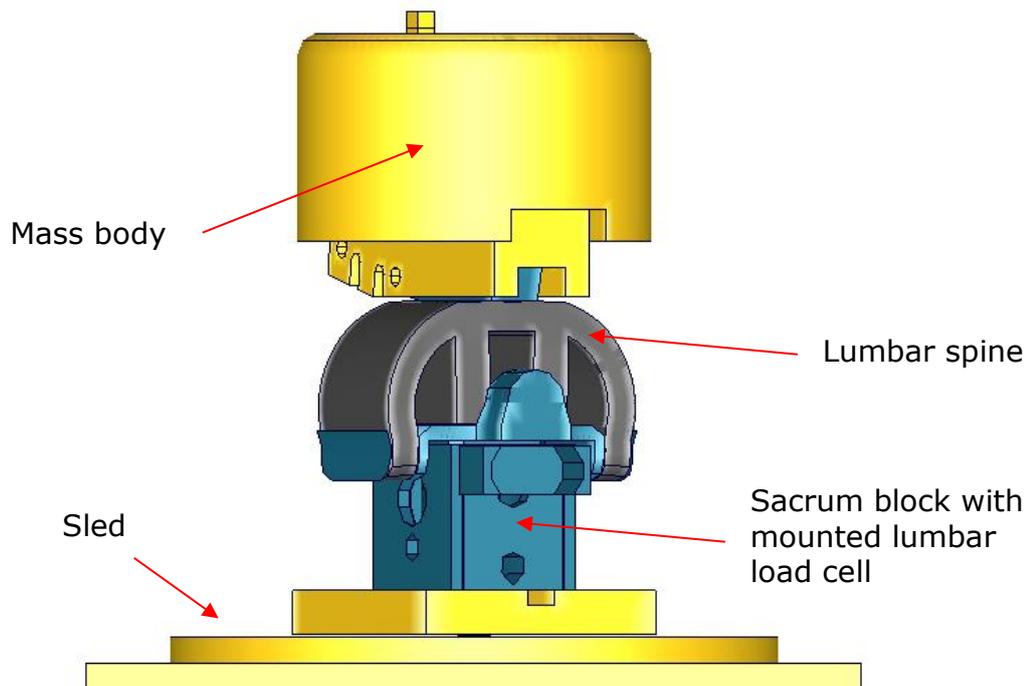
**Figure 166: 180 Degree without sternum – high velocity**



**Figure 167: 180 Degree without sternum – high velocity**

### 8.1.7 Lumbar spine test

The lumbar spine component has also been validated by the use of a component test. Here, the sacrum block with adapted lumbar load cell and the lumbar spine itself is mounted on a sled. On the lumbar spine, a mass body is mounted, which should represent the load on the lumbar spine from the torso of the WorldSID. The test setup is depicted in the following picture.



**Figure 168:** Lumbar spine component test setup

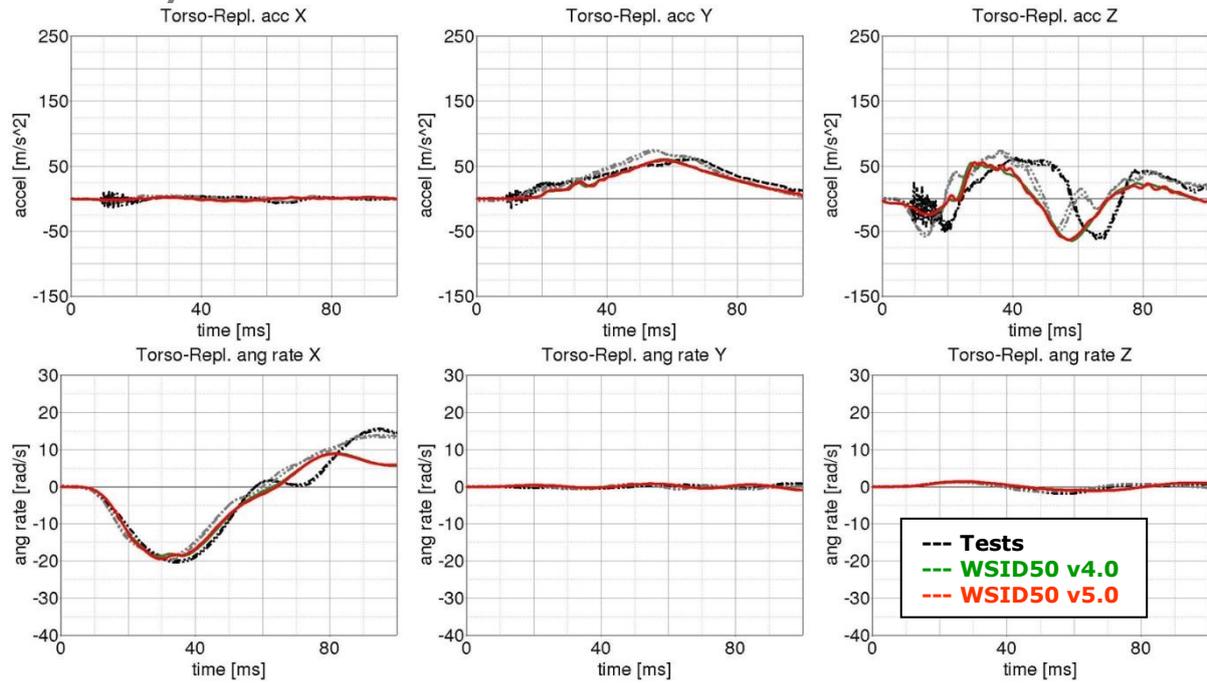
The sled is loaded by the use of two different pulses (20g triangular and 35g triangular) and the orientation of the lumbar spine is made for each pulse -- 90 and 60 degree. The test configurations are listed in the Table 38.

Test	Load angle	Pulse
1	90 degree	20 g triangular pulse
2	90 degree	35 g triangular pulse
3	60 degree	20 g triangular pulse
4	60 degree	35 g triangular pulse

**Table 38:** Test configurations for lumbar spine test

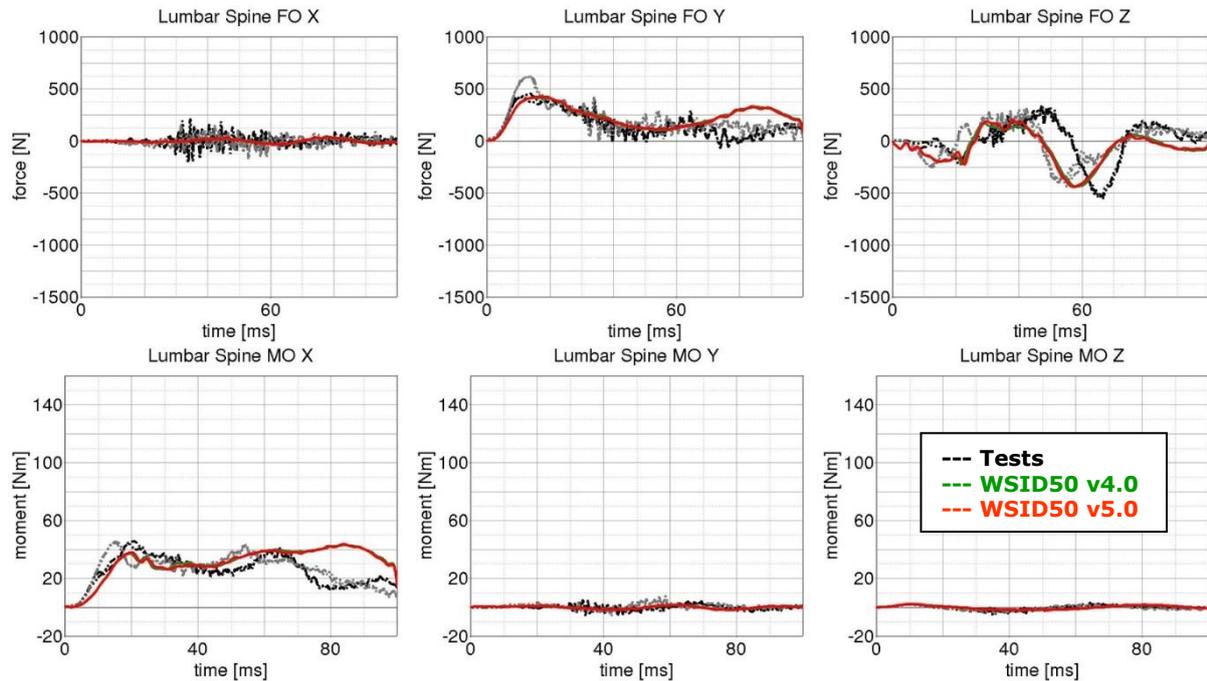
**Results of 90 degree, 20g configuration:**

**Mass body accelerations**



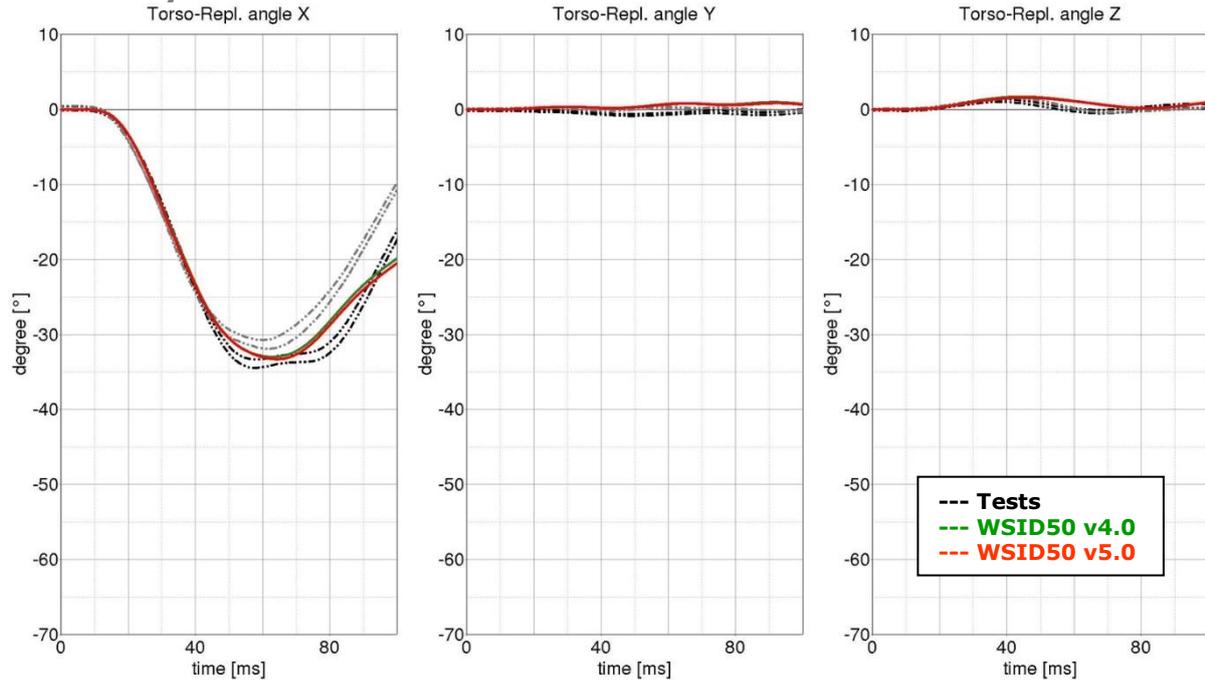
**Figure 169:** Result of lumbar spine test -- 20g, 90 degree (Mass body accelerations)

**Lumbar load cell forces and moments**



**Figure 170:** Result of lumbar spine test -- 20g, 90 degree (Lumbar load cell forces and moments)

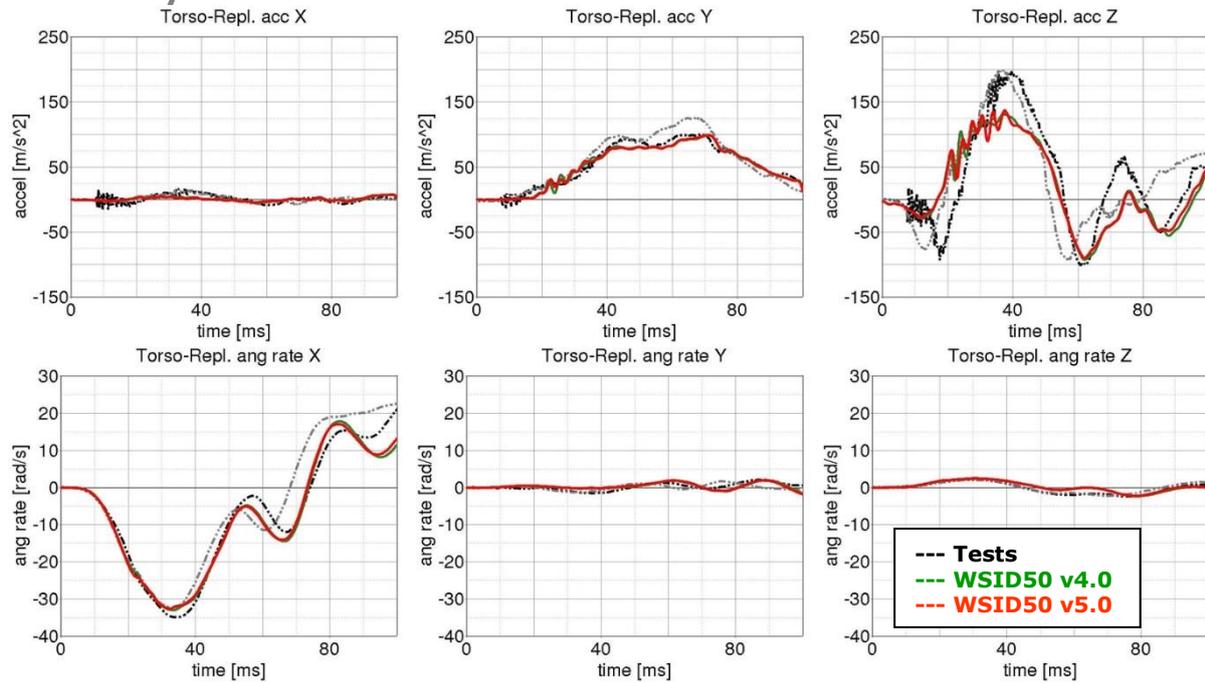
**Mass body rotations**



**Figure 171:** Result of lumbar spine test -- 20g, 90 degree (Mass body rotations)

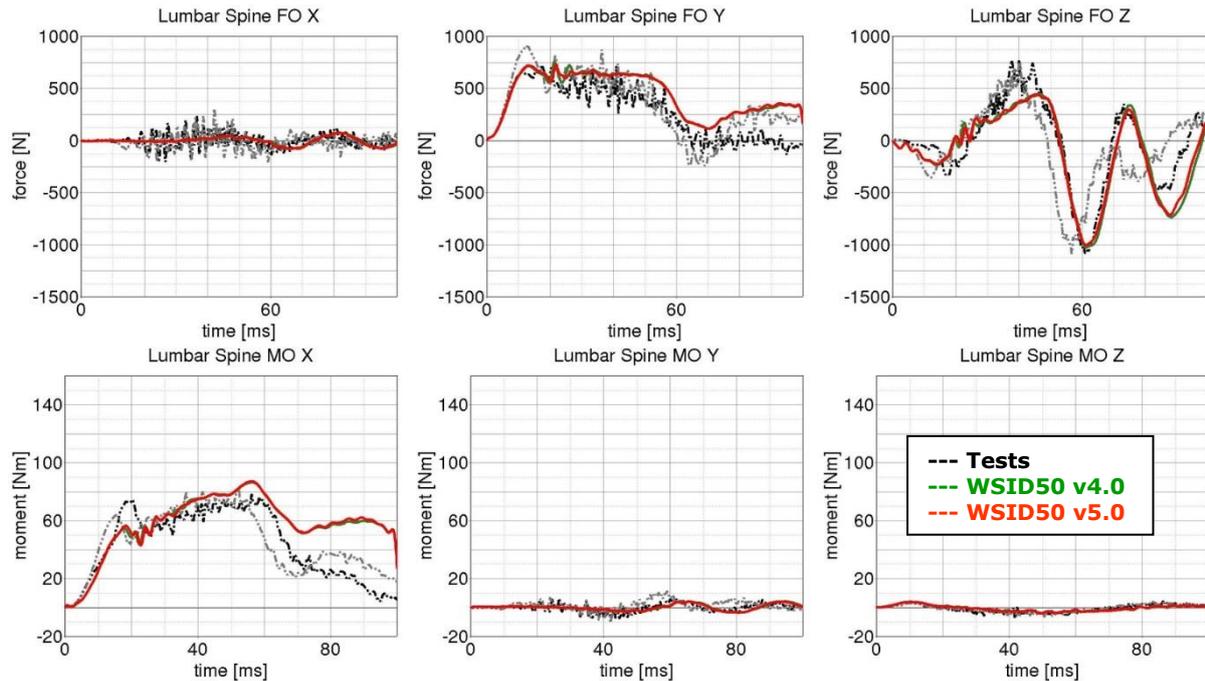
**Results of 90 degree, 35g configuration:**

**Mass body accelerations**



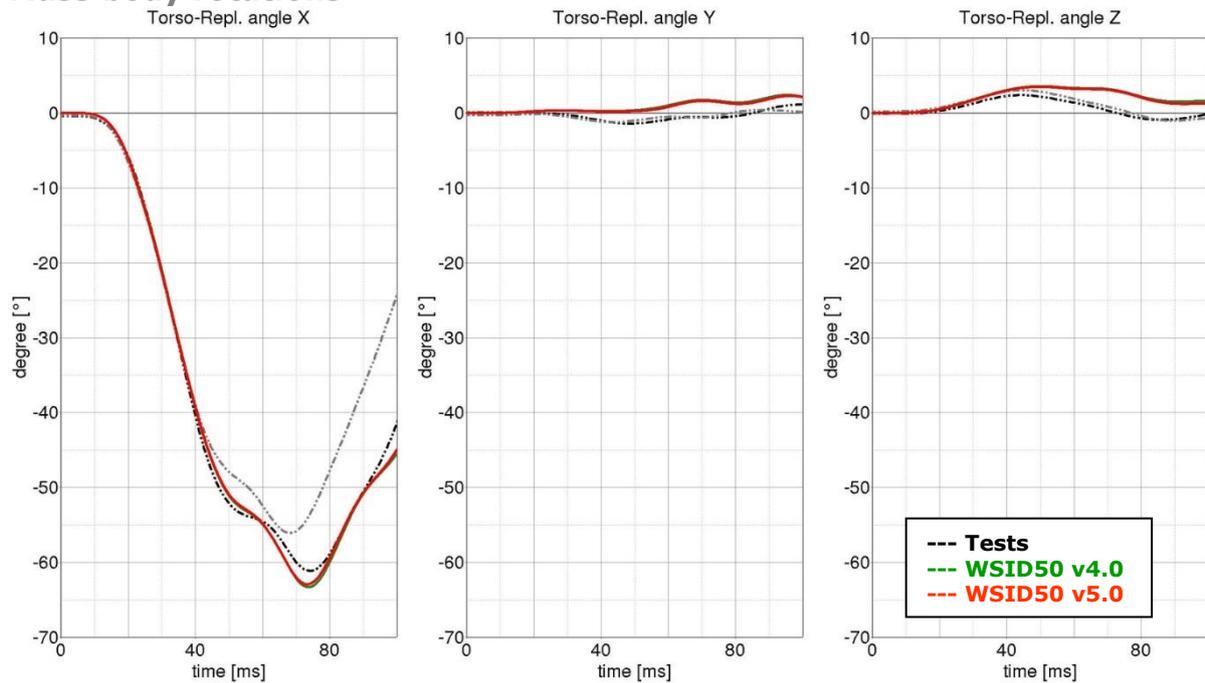
**Figure 172:** Result of lumbar spine test -- 35g, 90 degree (Mass body accelerations)

### Lumbar load cell forces and moments



**Figure 173:** Result of lumbar spine test -- 35g, 90 degree (Lumbar load cell forces and moments)

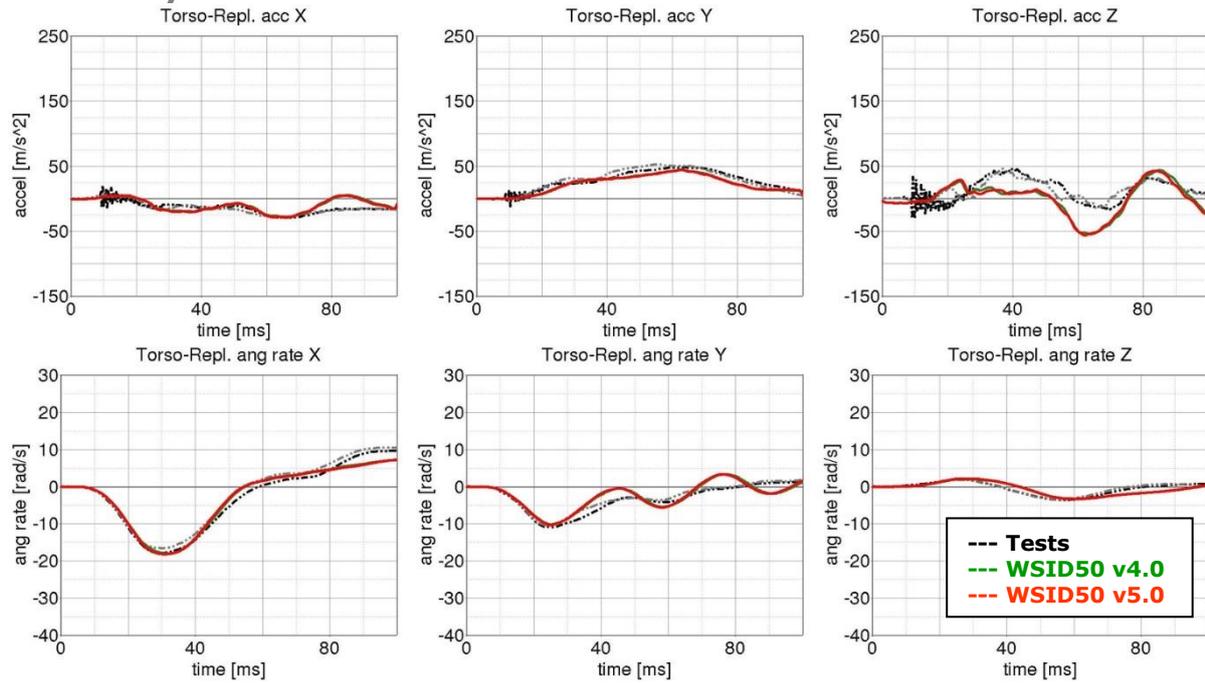
### Mass body rotations



**Figure 174:** Result of lumbar spine test -- 35g, 90 degree (Mass body rotations)

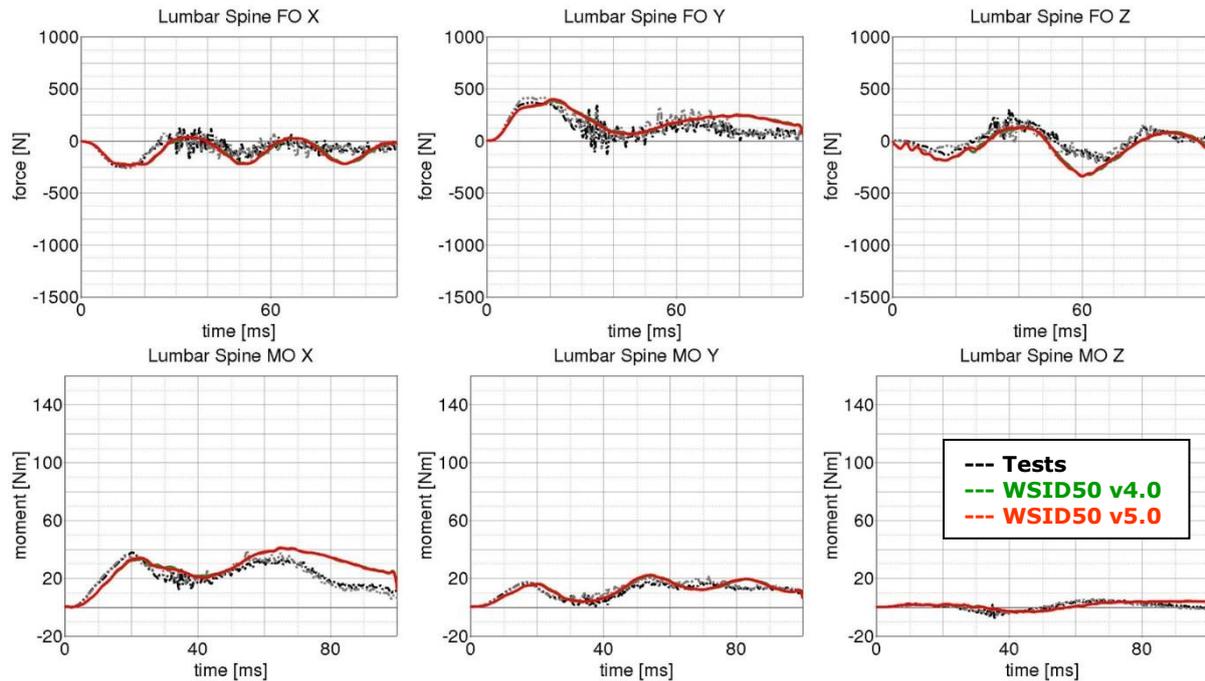
**Results of 60 degree, 20g configuration:**

**Mass body accelerations**



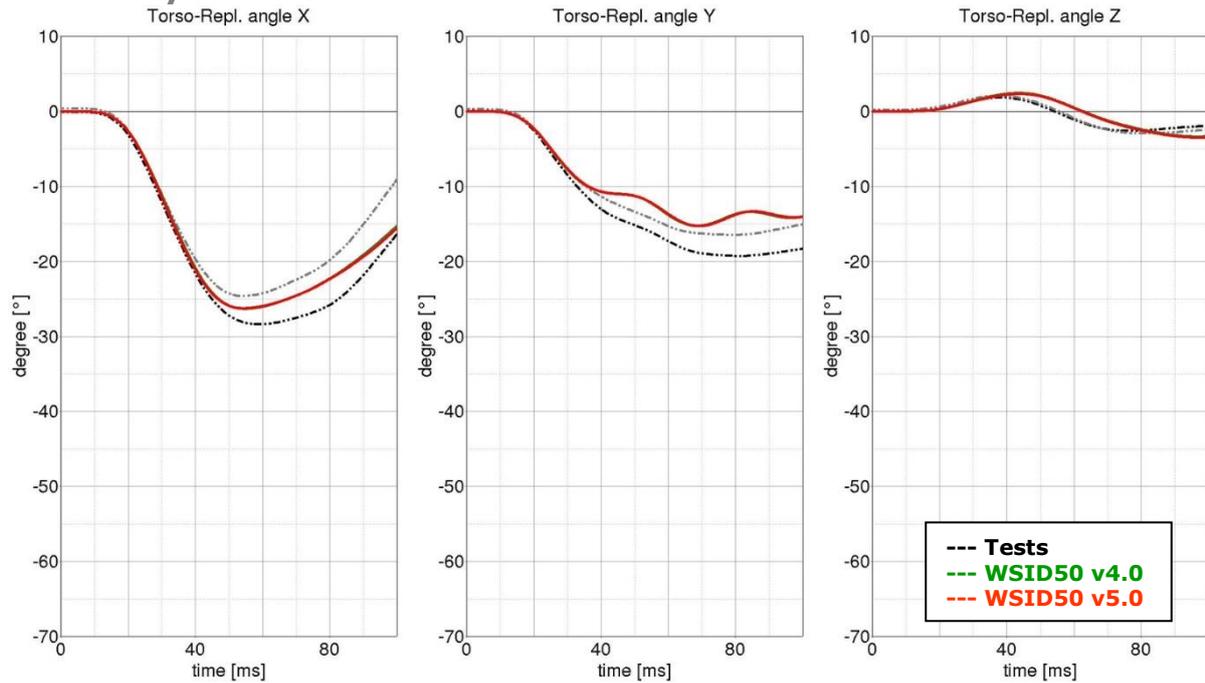
**Figure 175:** Result of lumbar spine test -- 20g, 60 degree (Mass body accelerations)

**Lumbar load cell forces and moments**



**Figure 176:** Result of lumbar spine test -- 20g, 60 degree (Lumbar load cell forces and moments)

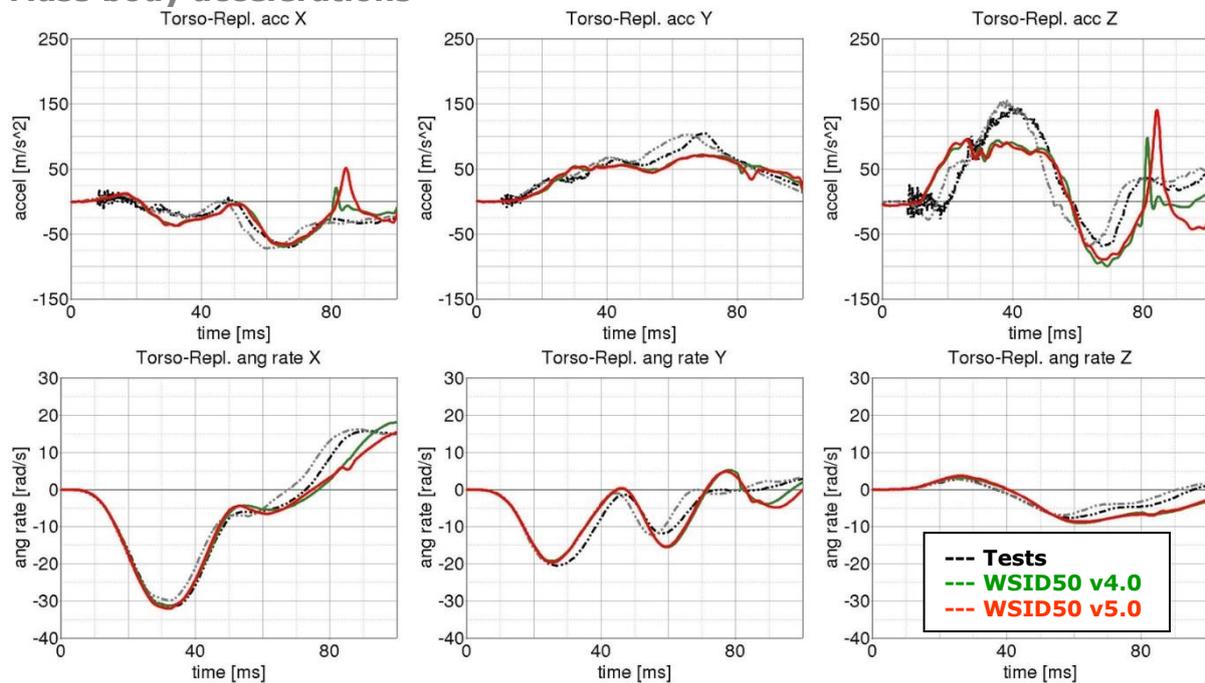
**Mass body rotations**



**Figure 177:** Result of lumbar spine test -- 20g, 60 degree (Mass body rotations)

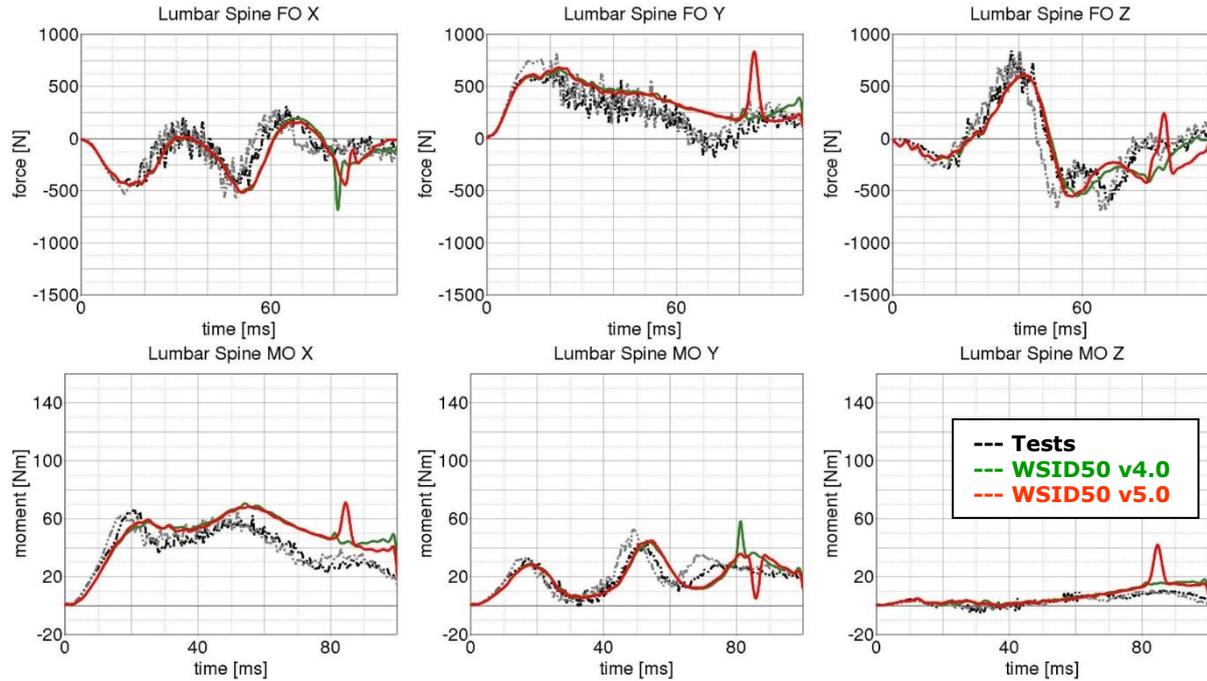
**Results of 60 degree, 35g configuration:**

**Mass body accelerations**



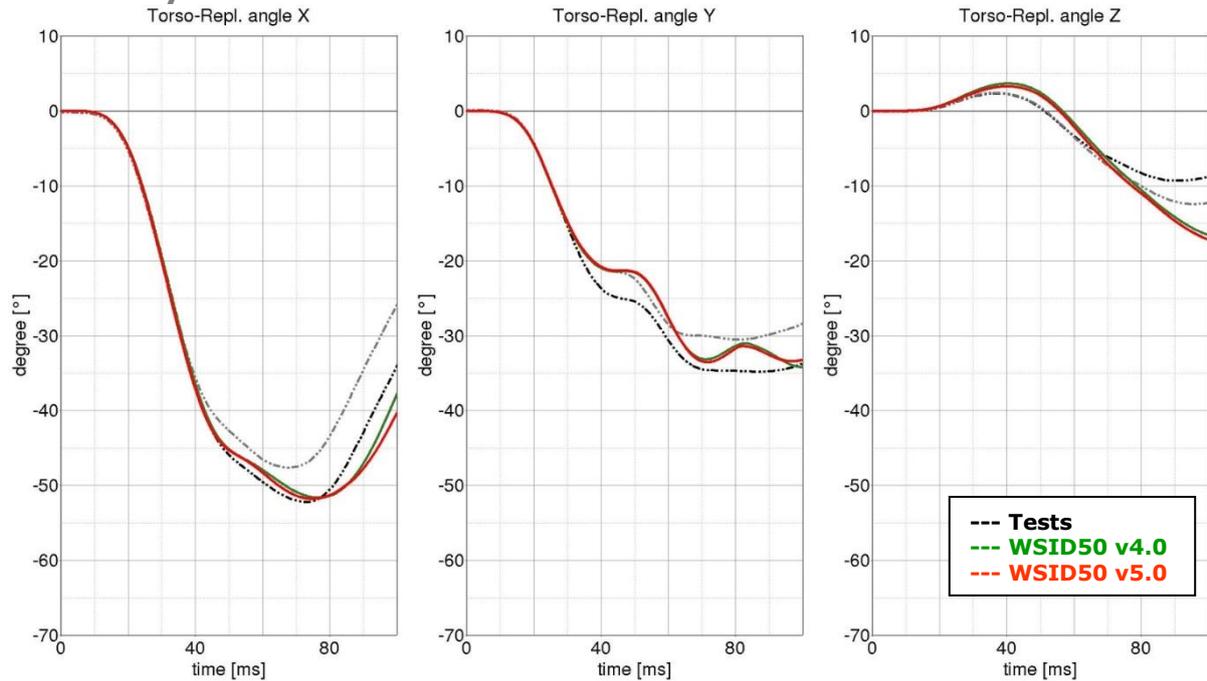
**Figure 178:** Result of lumbar spine test -- 35g, 60 degree (Mass body accelerations)

**Lumbar load cell forces and moments**



**Figure 179:** Result of lumbar spine test -- 35g, 60 degree (Lumbar load cell forces and moments)

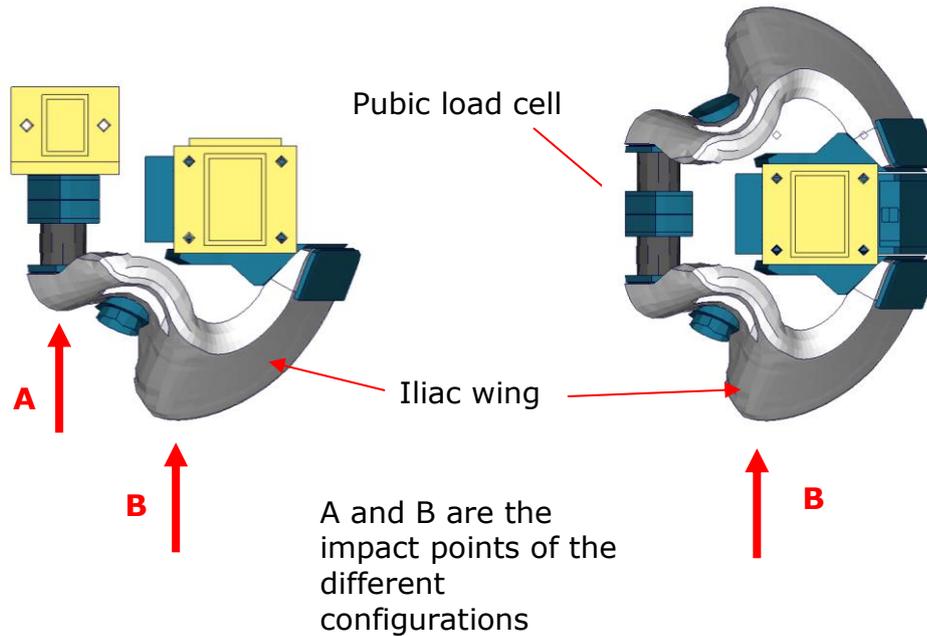
**Mass body rotations**



**Figure 180:** Result of lumbar spine test -- 35g, 60 degree (Mass body rotations)

### 8.1.8 Iliac wing test

The iliac wings are tested in three different configurations with the use of two different velocities. Here, the sacrum block with mounted iliac wings and pubic load cell is fixed on a table. The first two configurations use only one iliac wing and the half pubic construction. The third configuration is a load on the complete assembled pelvis area without the pelvis foam. The different configurations are depicted in the following figures.



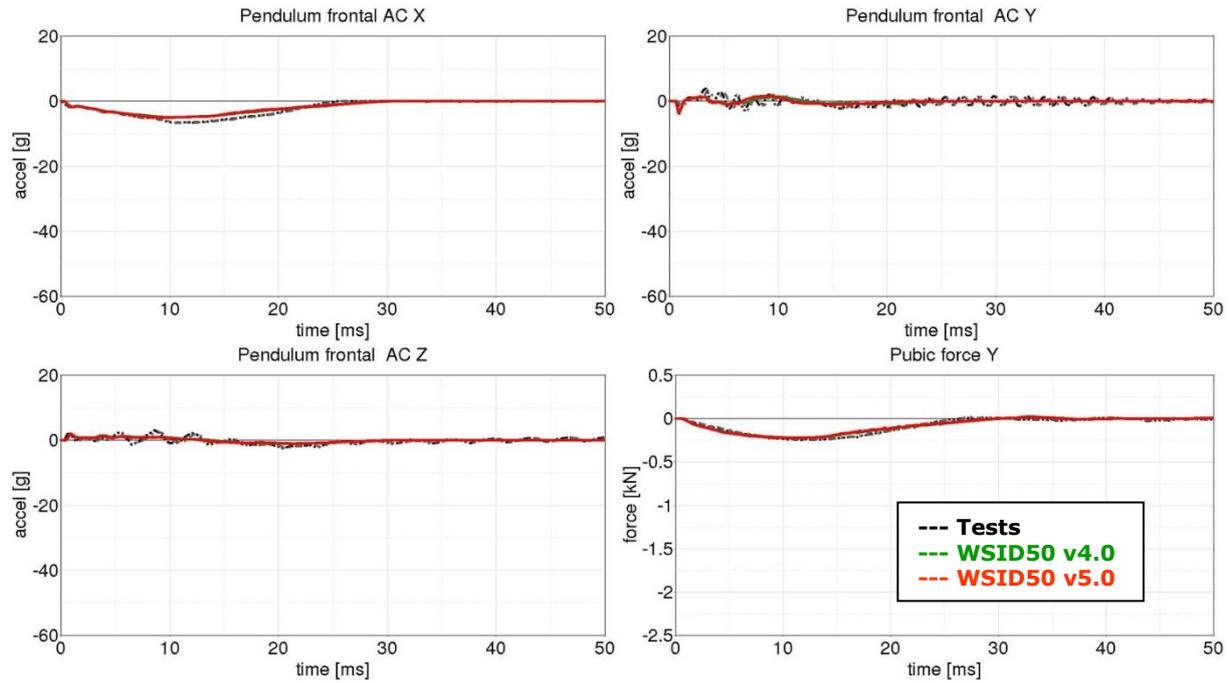
**Figure 181:** Iliac wing component test configurations

Test	Target point	Test setup	Velocities
1	A	half pelvis	low and high velocity
2	B	half pelvis	low and high velocity
3	B	full pelvis	low and high velocity

**Table 39:** Test configurations for iliac wing test

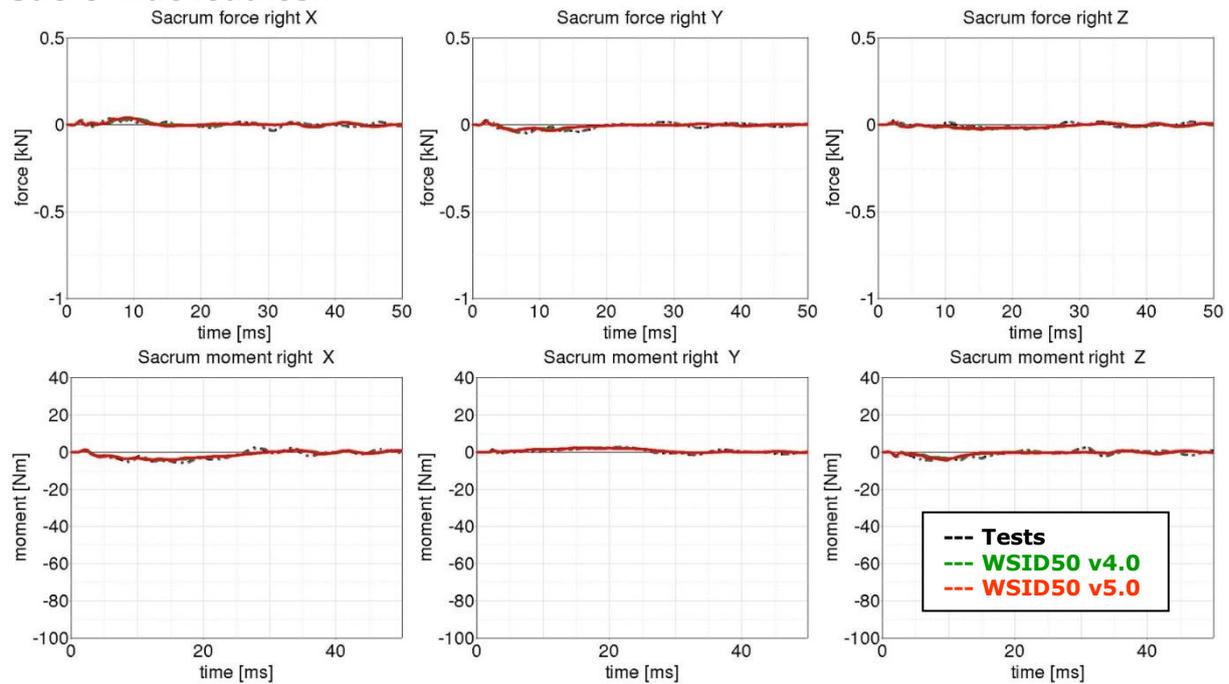
**Results of target point A, low velocity, half pelvis:**

**Pendulum accelerations**



**Figure 182:** Result of iliac wing test -- Target point A, low velocity, half pelvis (Pendulum accelerations)

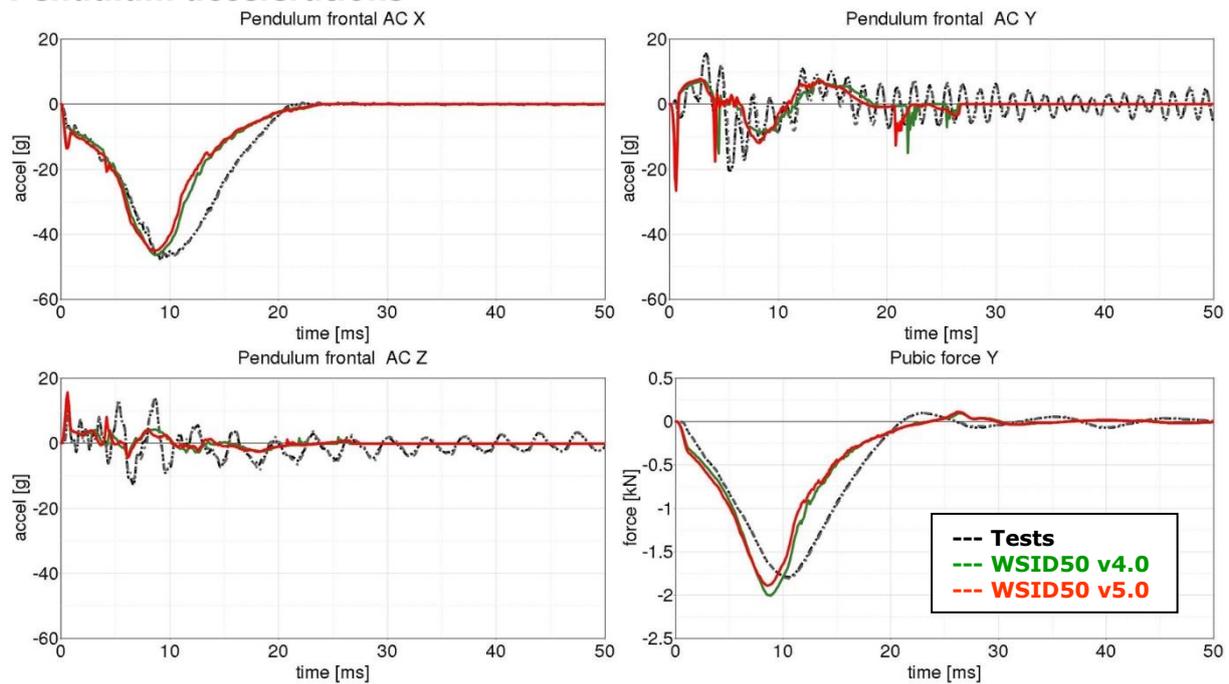
**Sacro-iliac load cell**



**Figure 183:** Result of iliac wing test -- Target point A, low velocity, half pelvis (Sacro-iliac load cell)

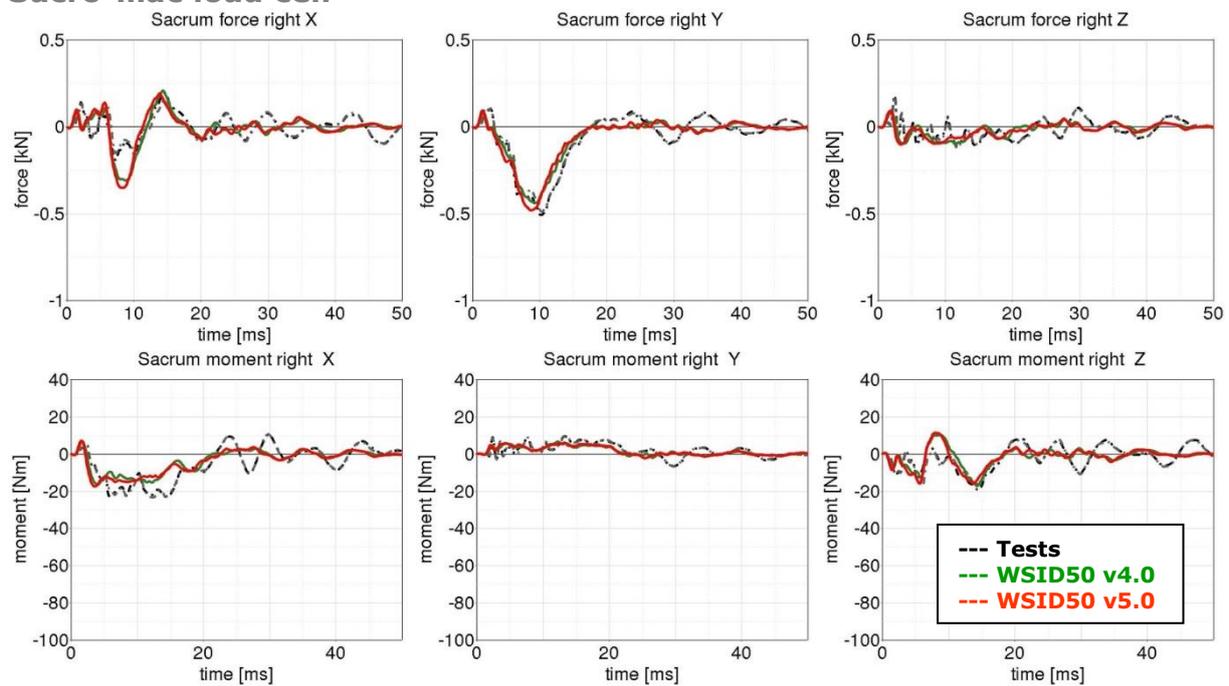
### Results of target point A, high velocity, half pelvis:

#### Pendulum accelerations



**Figure 184:** Result of iliac wing test -- Target point A, high velocity, half pelvis (Pendulum accelerations)

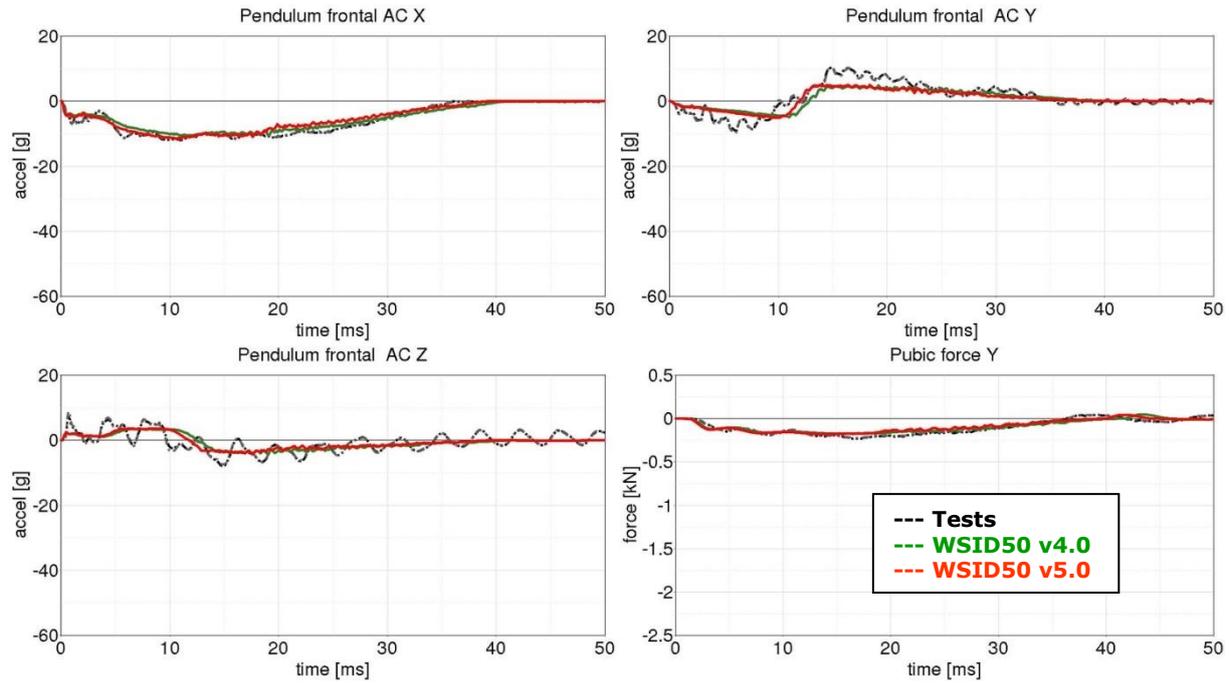
#### Sacro-iliac load cell



**Figure 185:** Result of iliac wing test -- Target point A, high velocity, half pelvis (Sacro-iliac load cell)

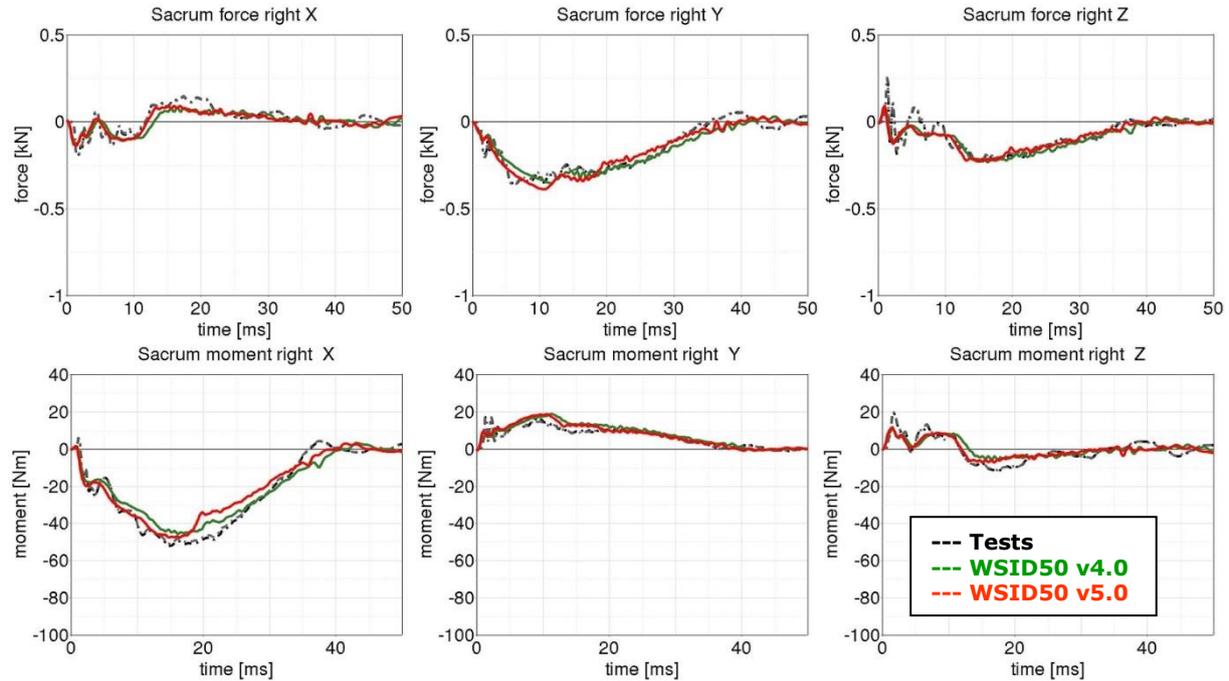
**Results of target point B, low velocity, half pelvis:**

**Pendulum accelerations**



**Figure 186:** Result of iliac wing test -- Target point B, low velocity, half pelvis (Pendulum accelerations)

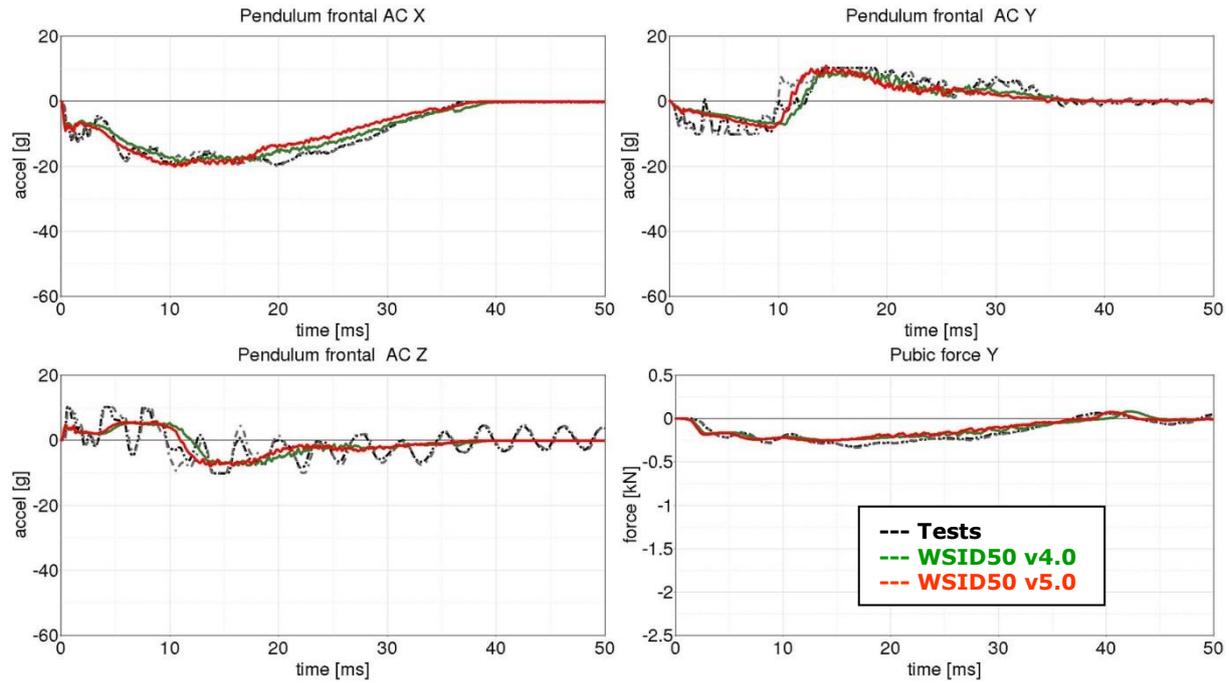
**Sacro-iliac load cell**



**Figure 187:** Result of iliac wing test -- Target point B, low velocity, half pelvis (Sacro-iliac load cell)

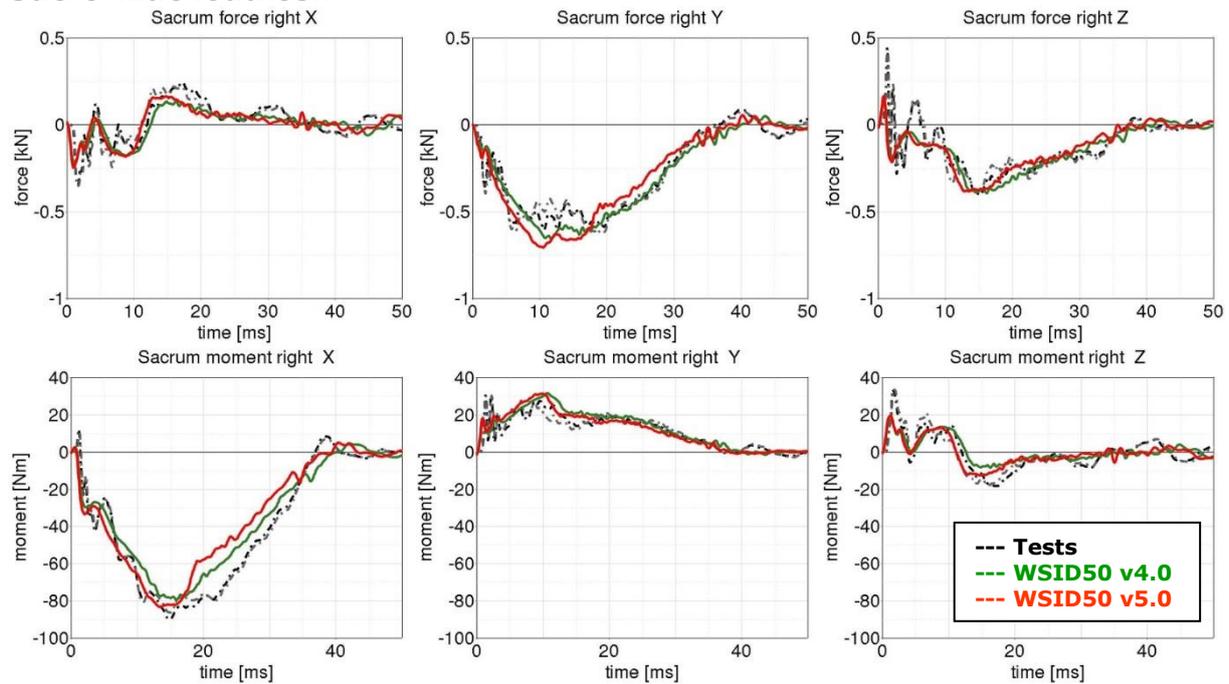
**Results of target point B, high velocity, half pelvis:**

**Pendulum accelerations**



**Figure 188:** Result of iliac wing test -- Target point B, high velocity, half pelvis (Pendulum accelerations)

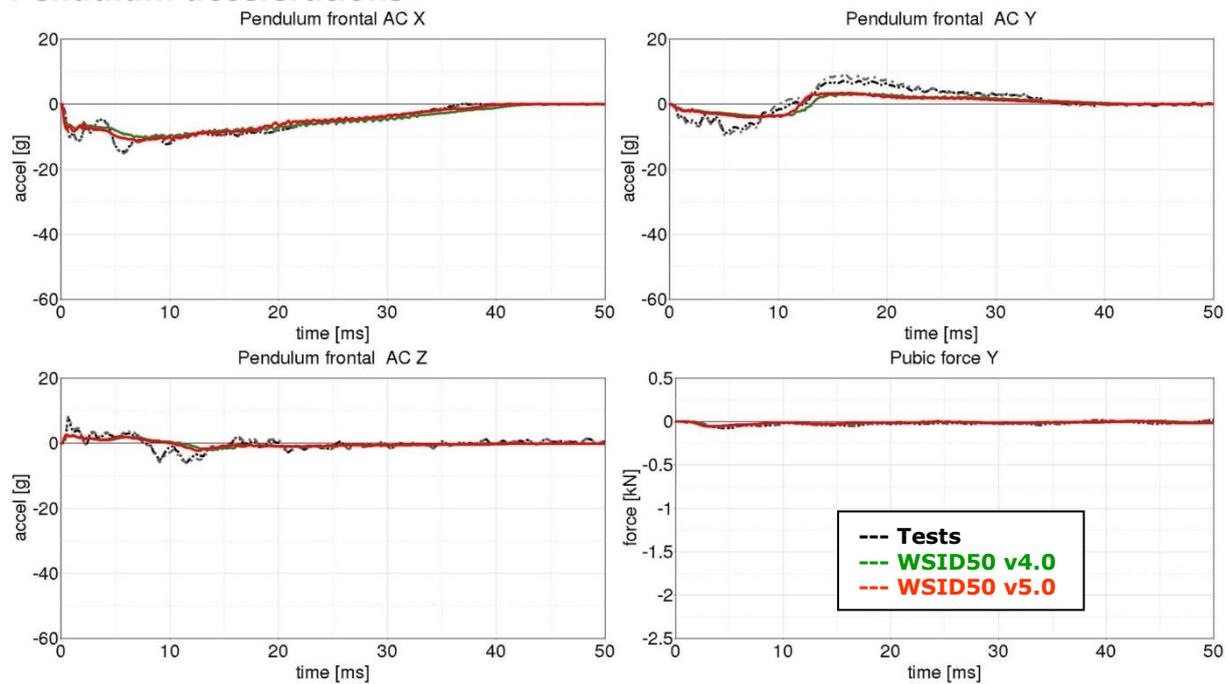
**Sacro-iliac load cell**



**Figure 189:** Result of iliac wing test -- Target point B, high velocity, half pelvis (Sacro-iliac load cell)

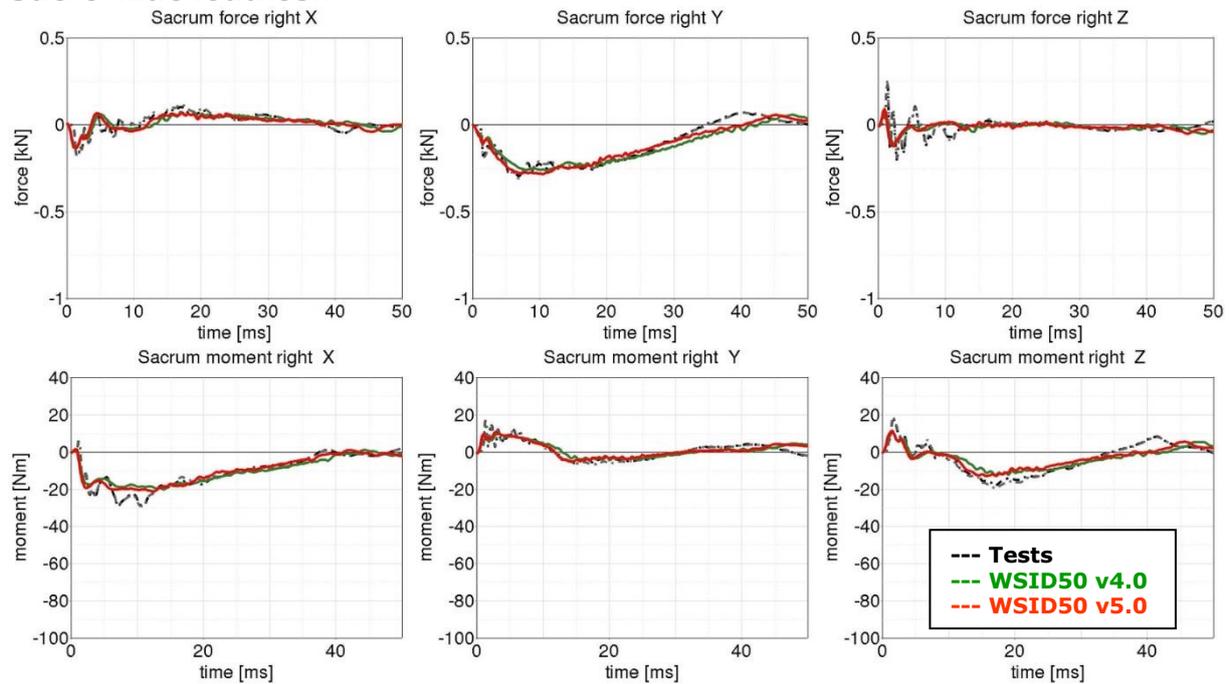
**Results of target point B, low velocity, full pelvis:**

**Pendulum accelerations**



**Figure 190:** Result of iliac wing test -- Target point B, low velocity, full pelvis (Pendulum accelerations)

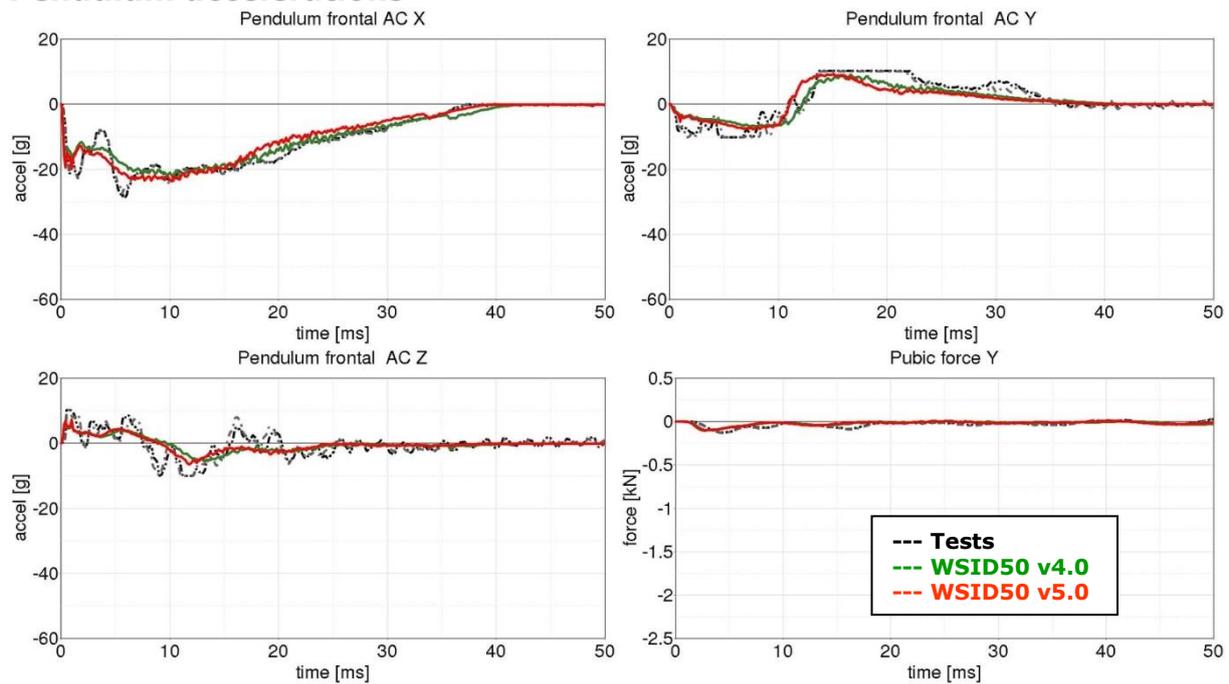
**Sacro-iliac load cell**



**Figure 191:** Result of iliac wing test -- Target point B, low velocity, full pelvis (Sacro-iliac load cell)

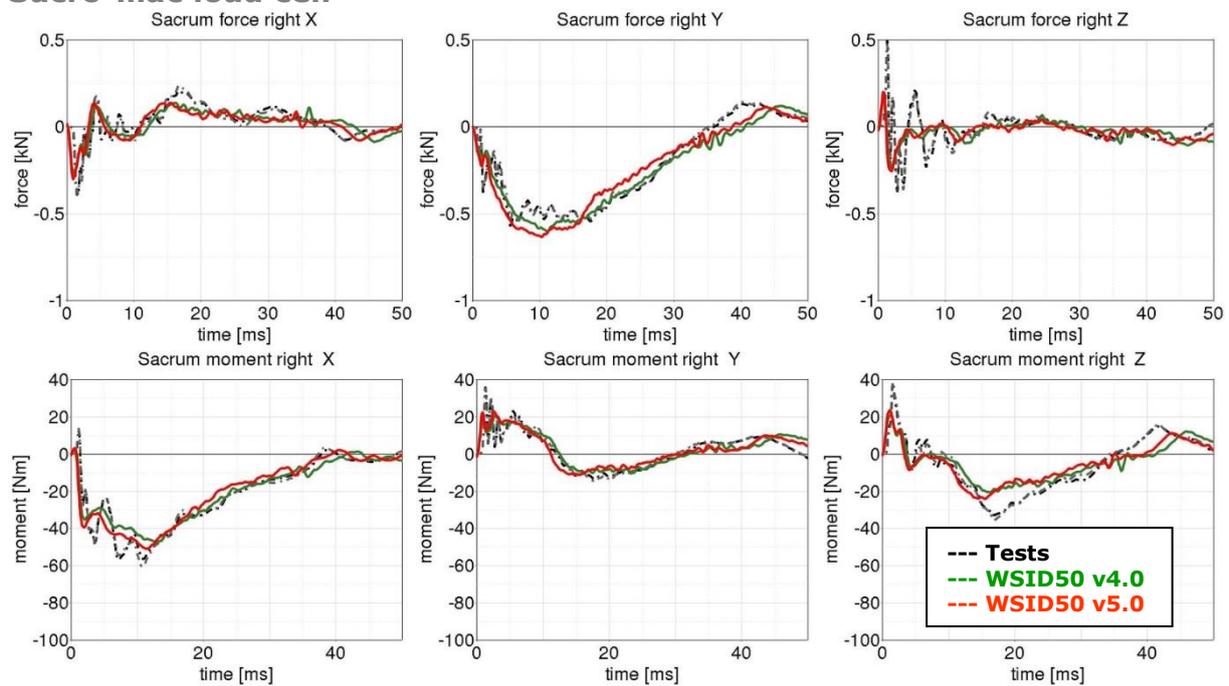
### Results of target point B, high velocity, full pelvis:

#### Pendulum accelerations



**Figure 192:** Result of iliac wing test -- Target point B, high velocity, full pelvis (Pendulum accelerations)

#### Sacro-iliac load cell



**Figure 193:** Result of iliac wing test -- Target point B, high velocity, full pelvis (Sacro-iliac load cell)

## 8.2 Calibration tests

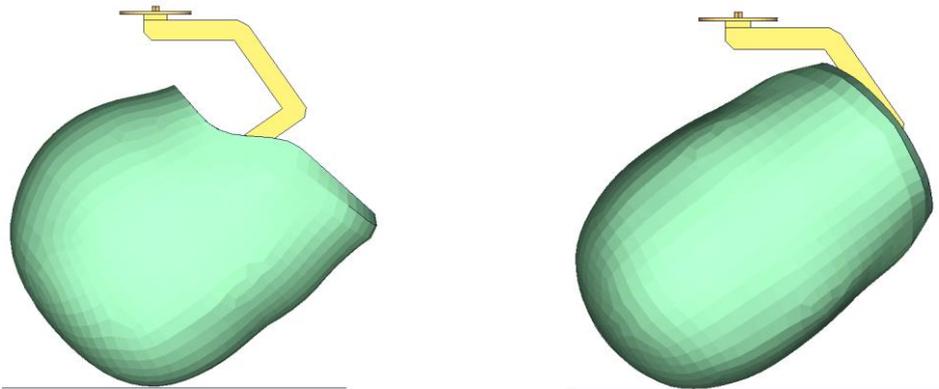
The calibration tests are also used to validate the WorldSID model. The tests are used as described in the WorldSID manual of the physical dummy (Road vehicles – Design and performance specifications for the WorldSID 50th percentile male side-impact dummy, Part 1-4, ISO 15830-1 to 15830-4).

For each test, a short description of the test configuration is given in each single section. For more detailed information of the test setup please use the hardware manual of the WorldSID.

### 8.2.1 Head drop test

The disconnected head drops on a rigid plate. Then the head accelerations are measured.

Two configurations are used: frontal and lateral drop test. The configurations are depicted in the following figure.



**Figure 194:** Head drop test, Left: Frontal test, Right: Lateral test

The results and the corridors are shown in the following 2 plots:

### Results of frontal head drop test

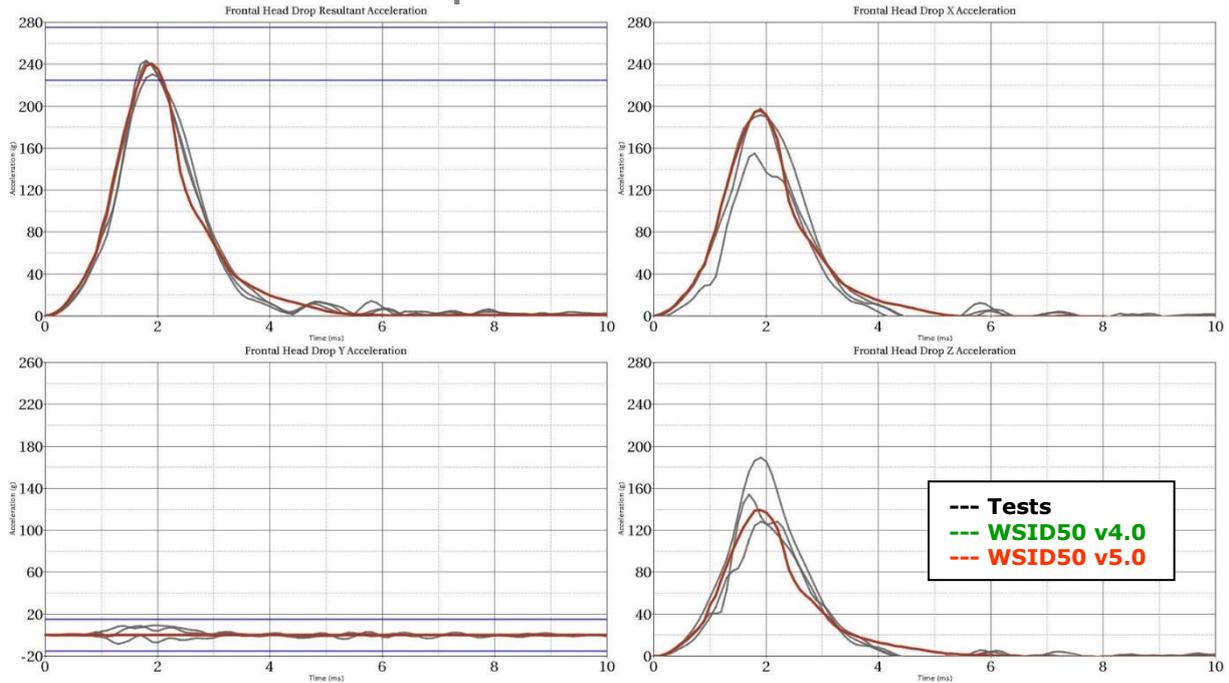


Figure 195: Results of frontal head drop test

### Results of lateral head drop test

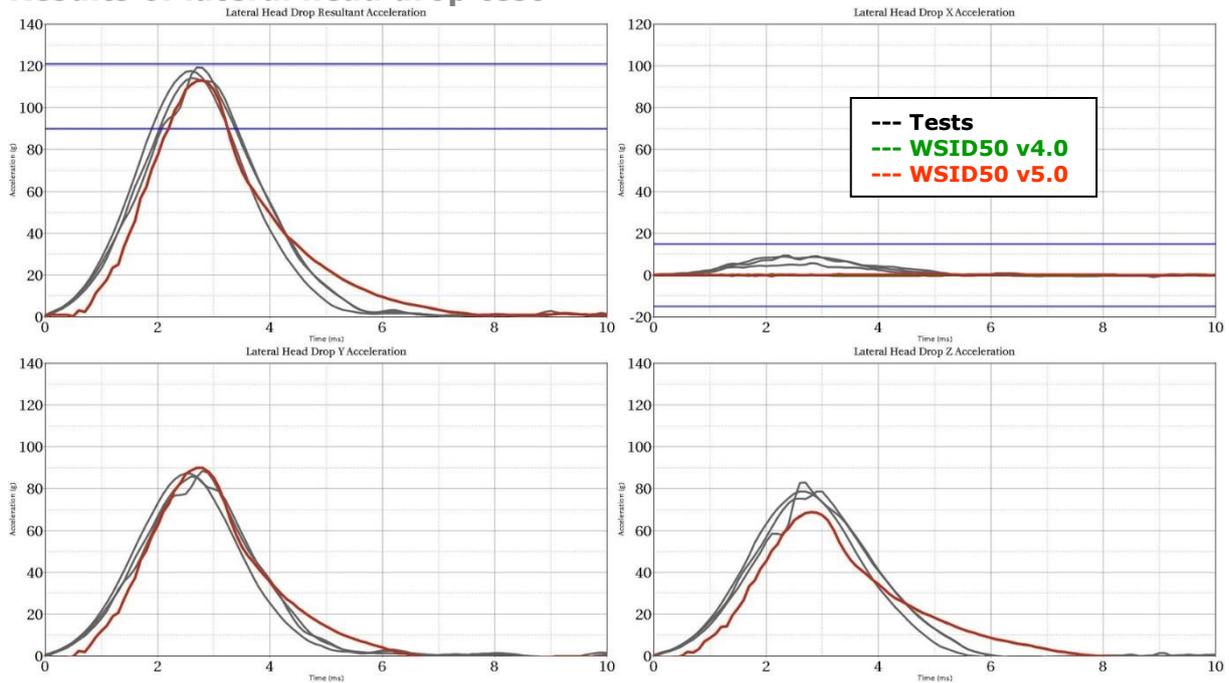
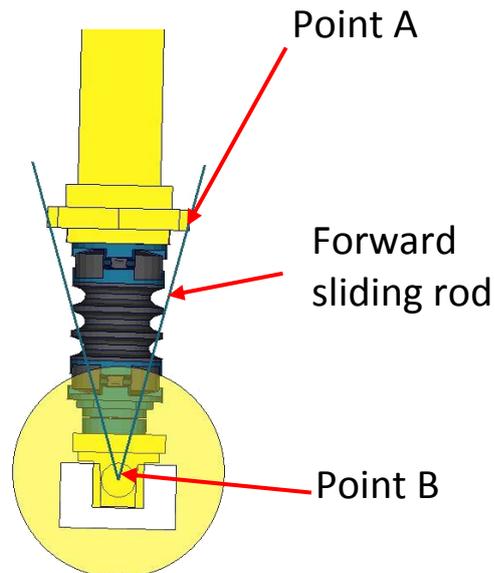


Figure 196: Results of lateral head drop test

### 8.2.2 Neck pendulum test

The neck calibration test is simulated as described in the WorldSID manual ISO-15830 part 2. The test setup is depicted in the figure below. The neck is adapted to a long pendulum. The pendulum runs into a part of honeycomb to get decelerated, thereby causing the neck to bend against the load direction. As mass replacement, the head form is used instead of the original head.

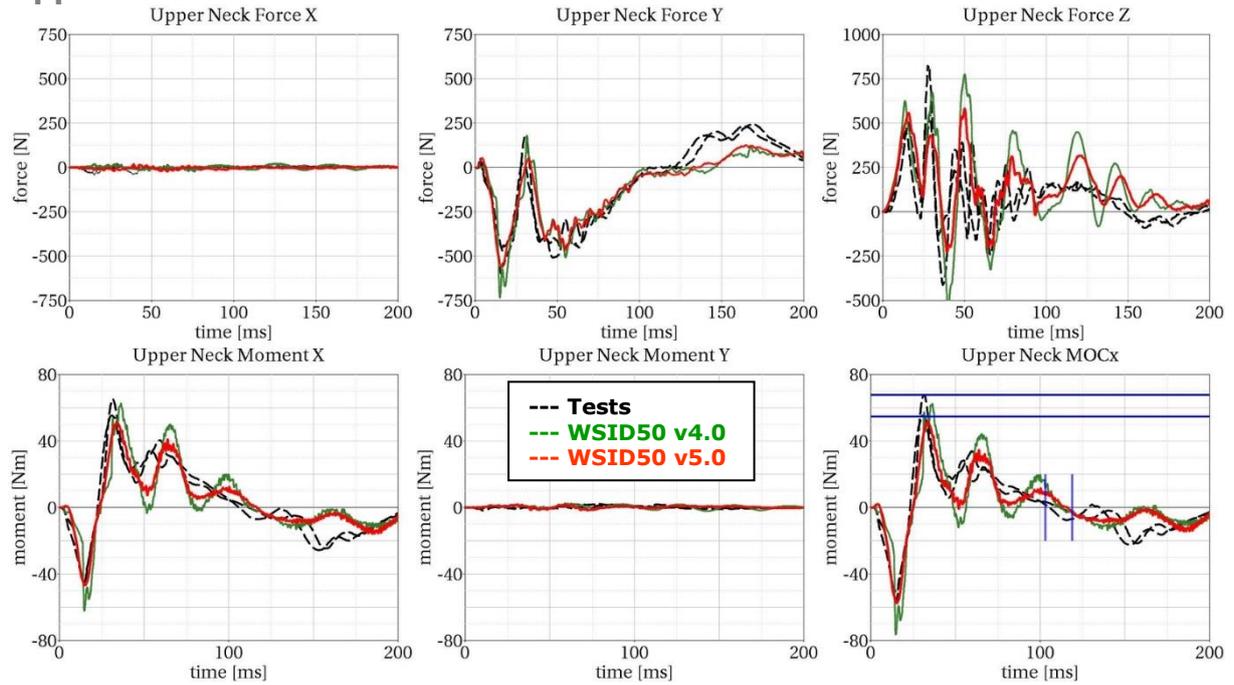


**Figure 197:** Neck pendulum calibration test setup

In the test, the load cell forces and moments are measured and the rotations of the points A and B are used to describe the kinematics of the neck.

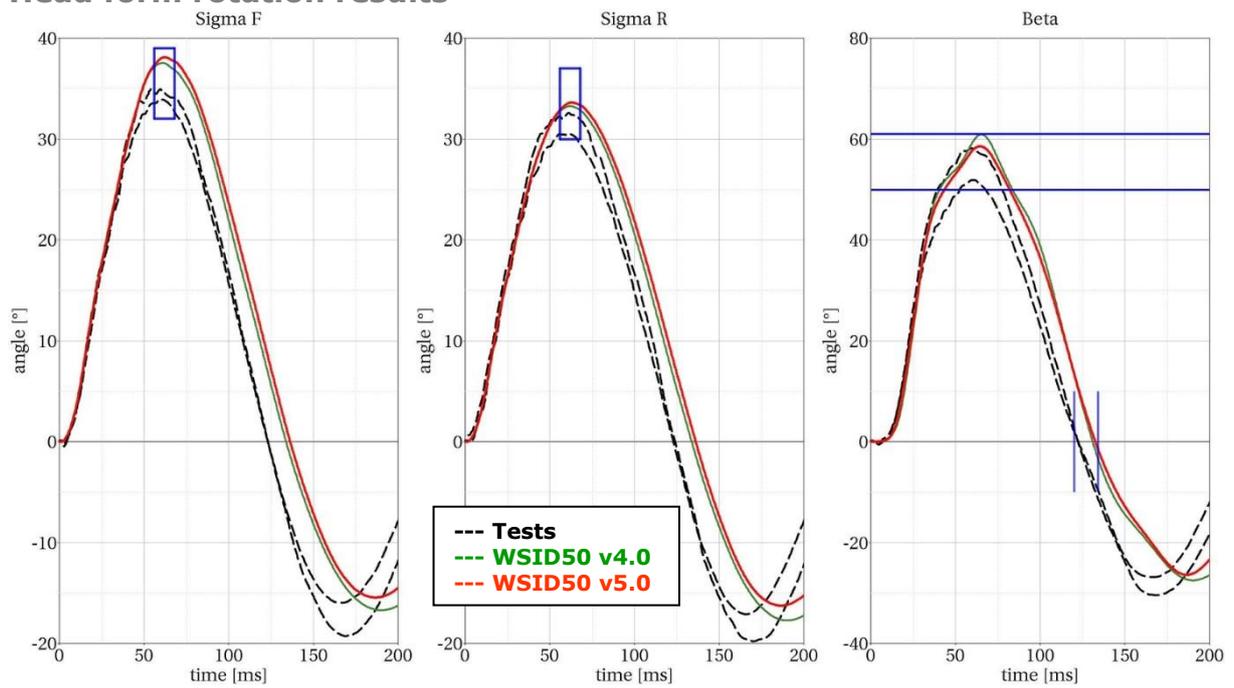
The results and the corresponding calibration corridors are shown in the following figures.

### Upper neck load cell results



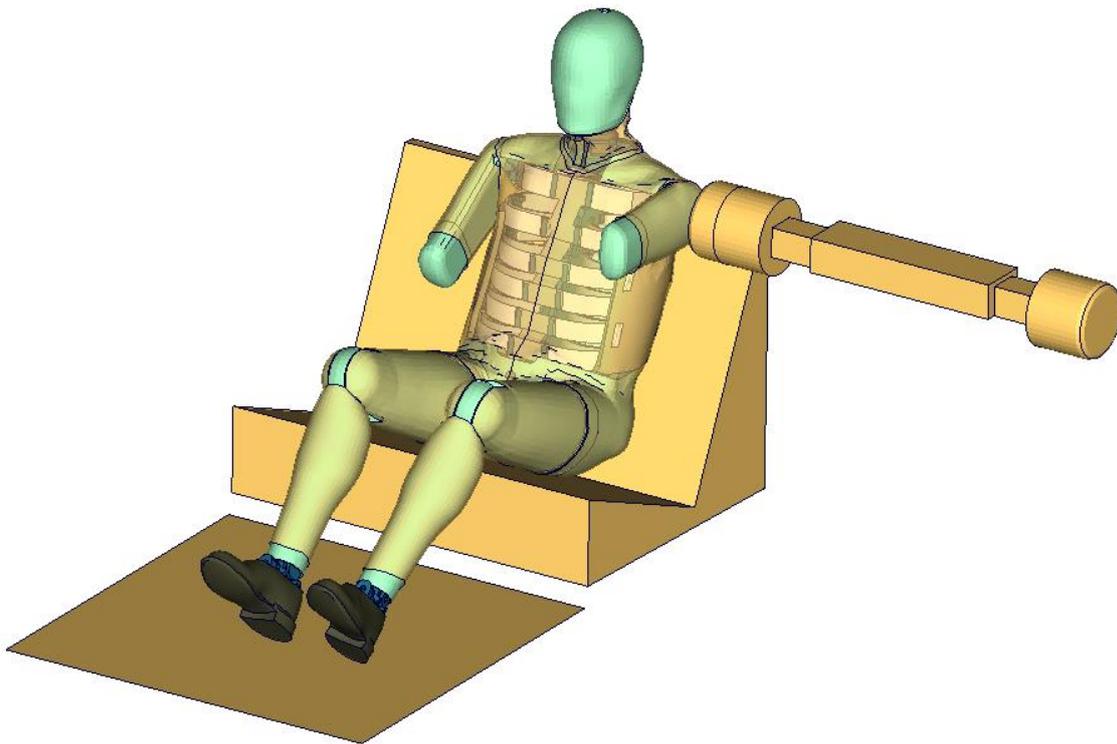
**Figure 198:** Result of neck calibration test upper neck load cell

### Head form rotation results



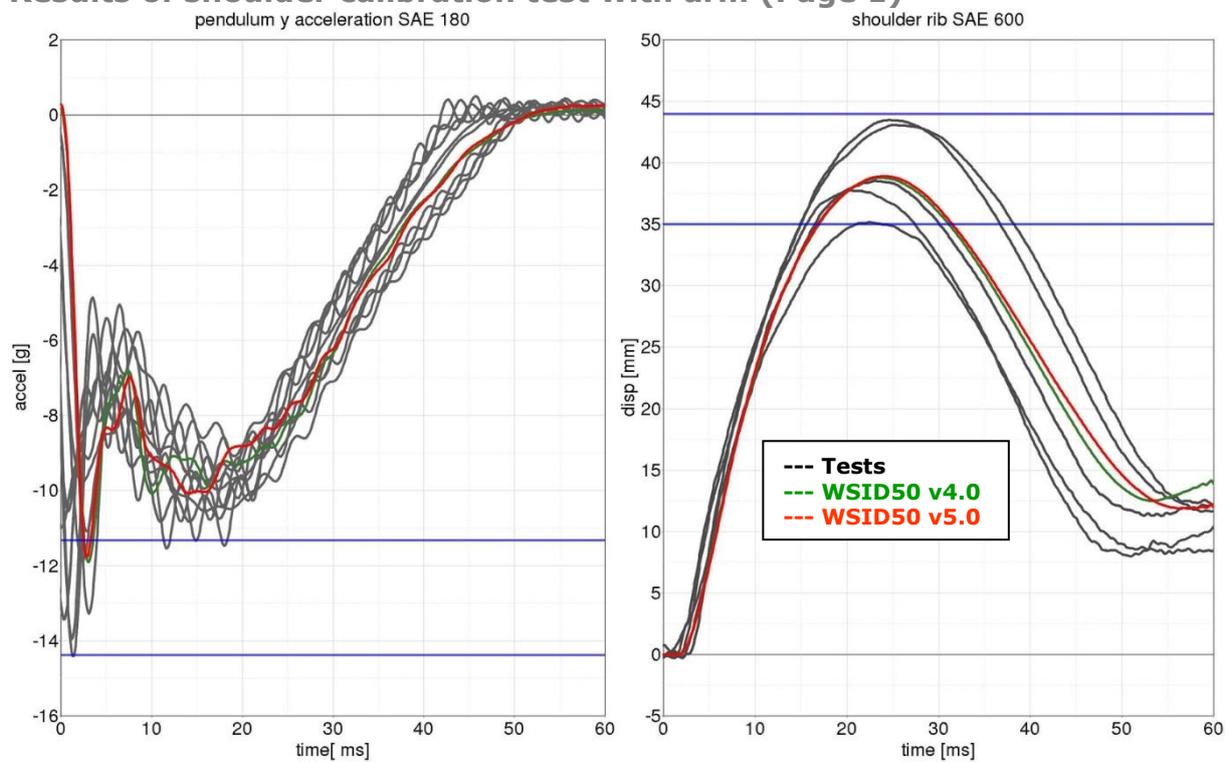
**Figure 199:** Result of neck calibration test head form rotations

### 8.2.3 Shoulder pendulum test



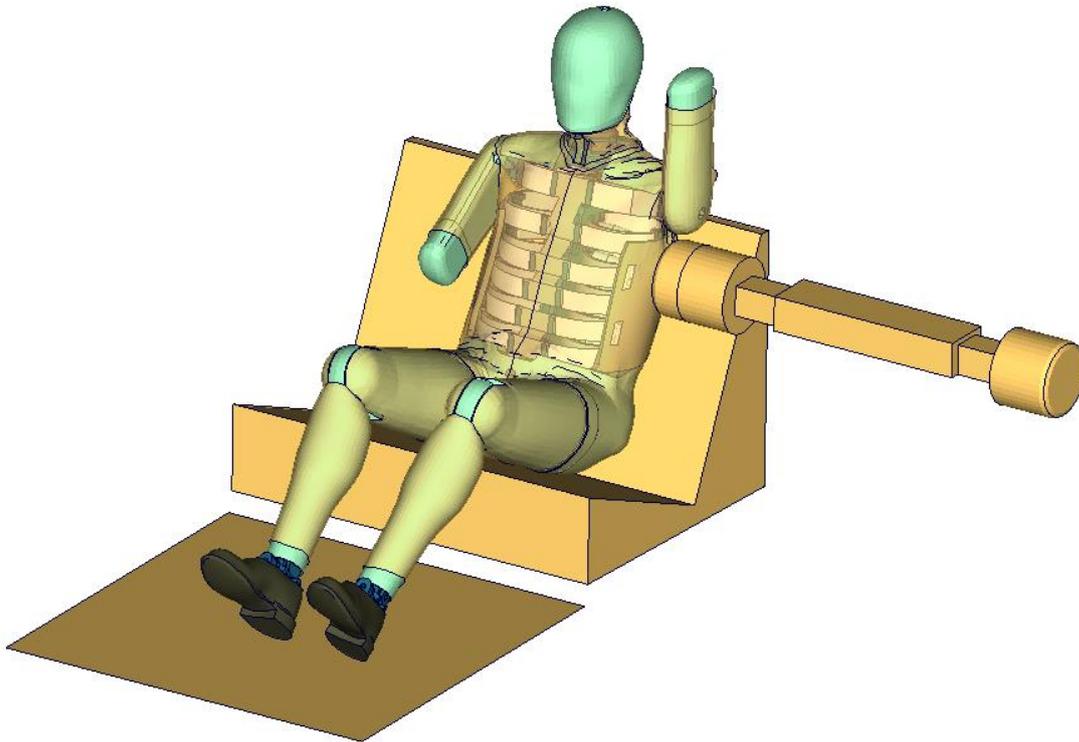
**Figure 200:** Shoulder calibration test setup

#### Results of shoulder calibration test with arm (Page 1)



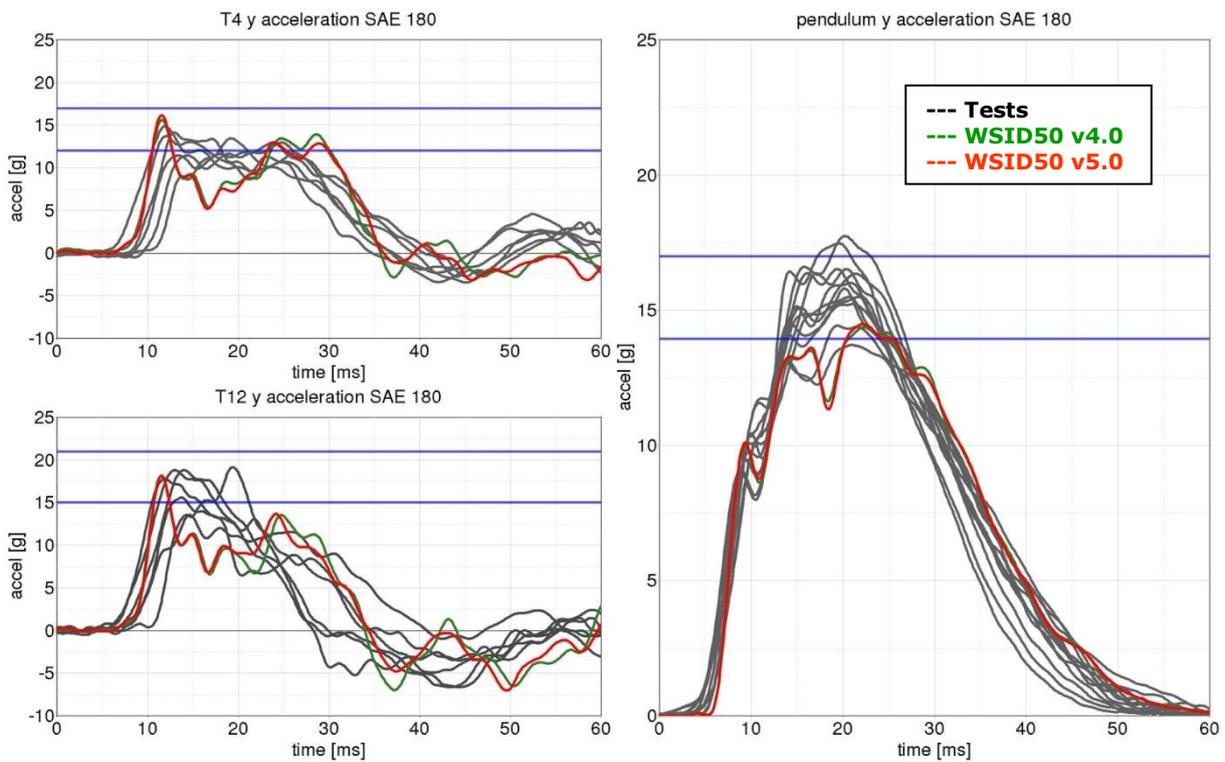
**Figure 201:** Shoulder calibration test results with arm (Page 1)

### 8.2.4 Thorax pendulum test without arm



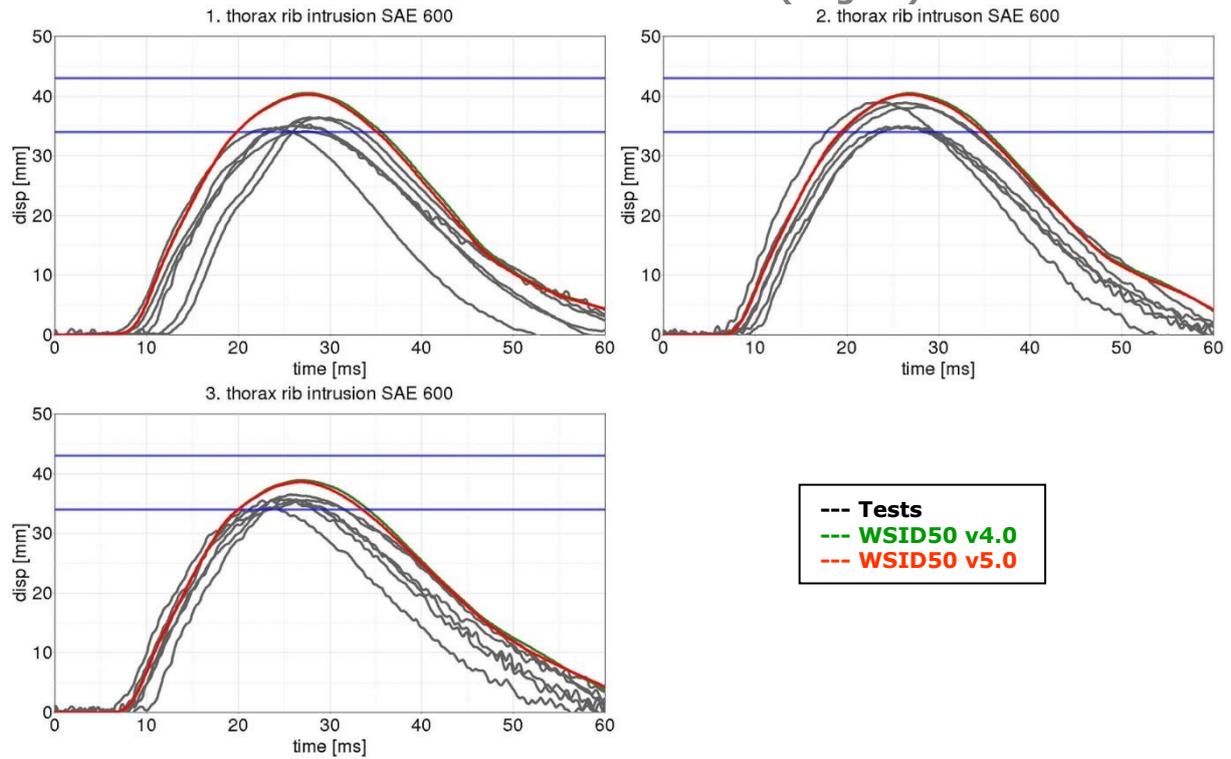
**Figure 202:** Thorax calibration test setup without arm

#### Results of thorax calibration test without arm (Page 1)



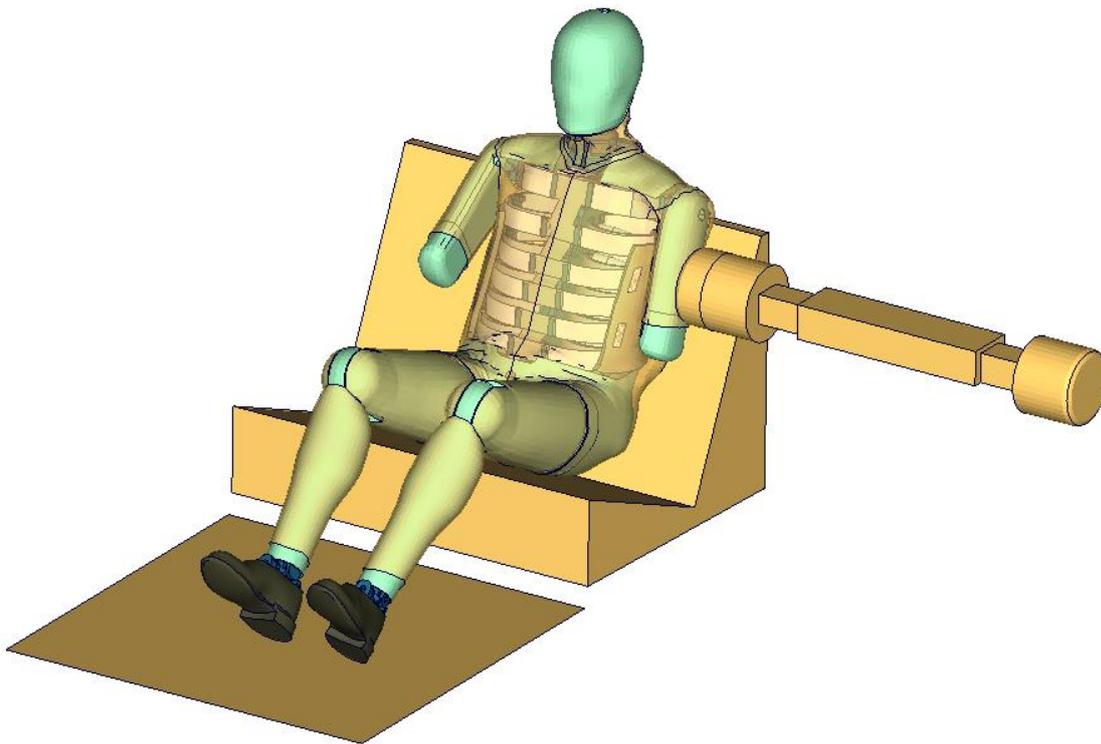
**Figure 203:** Thorax calibration test results without arm (Page 1)

### Results of thorax calibration test without arm (Page 2)



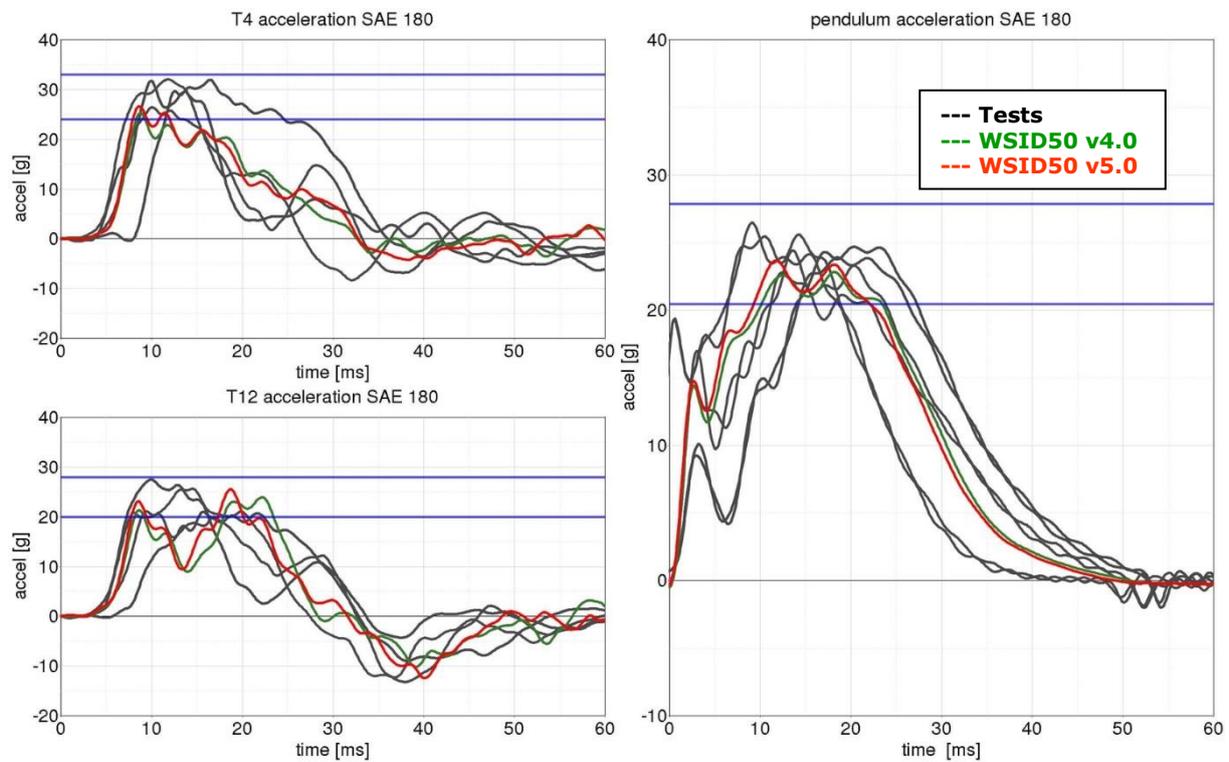
**Figure 204:** Thorax calibration test results without arm (Page 2)

### 8.2.5 Thorax pendulum test with arm



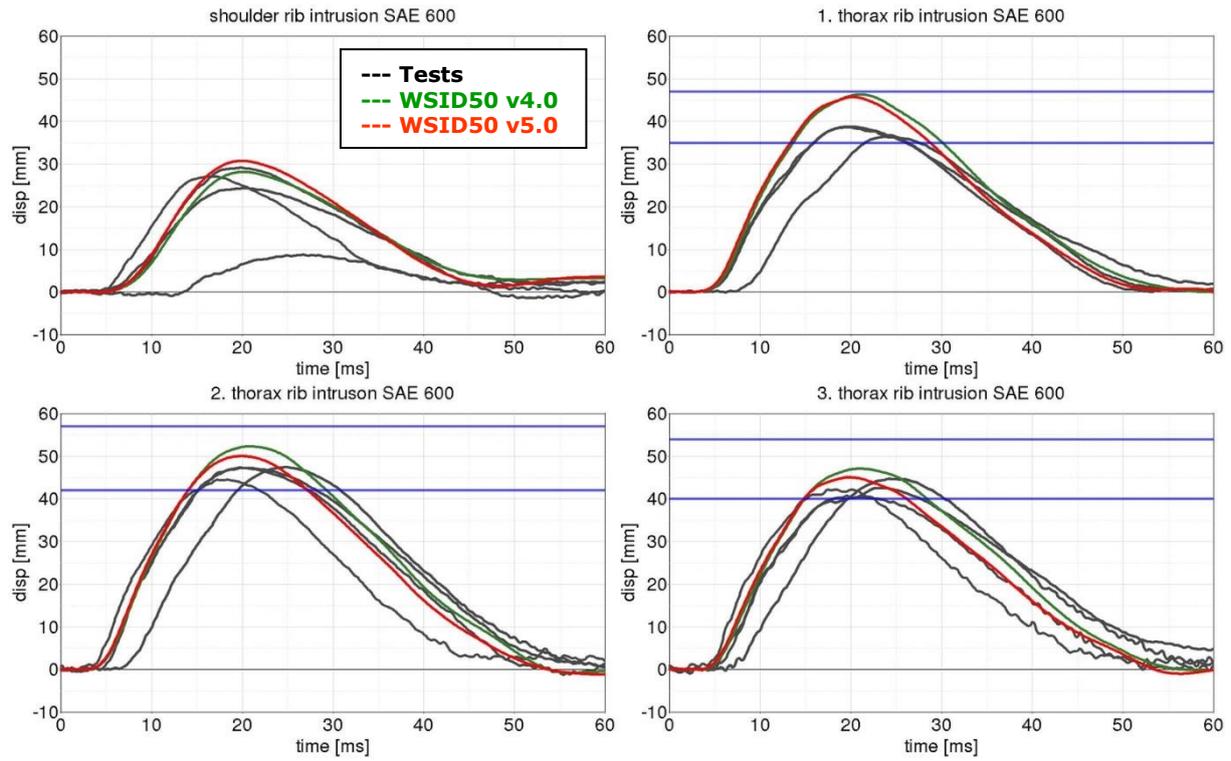
**Figure 205:** Thorax calibration test setup with arm

#### Results of thorax calibration test with arm (Page 1)



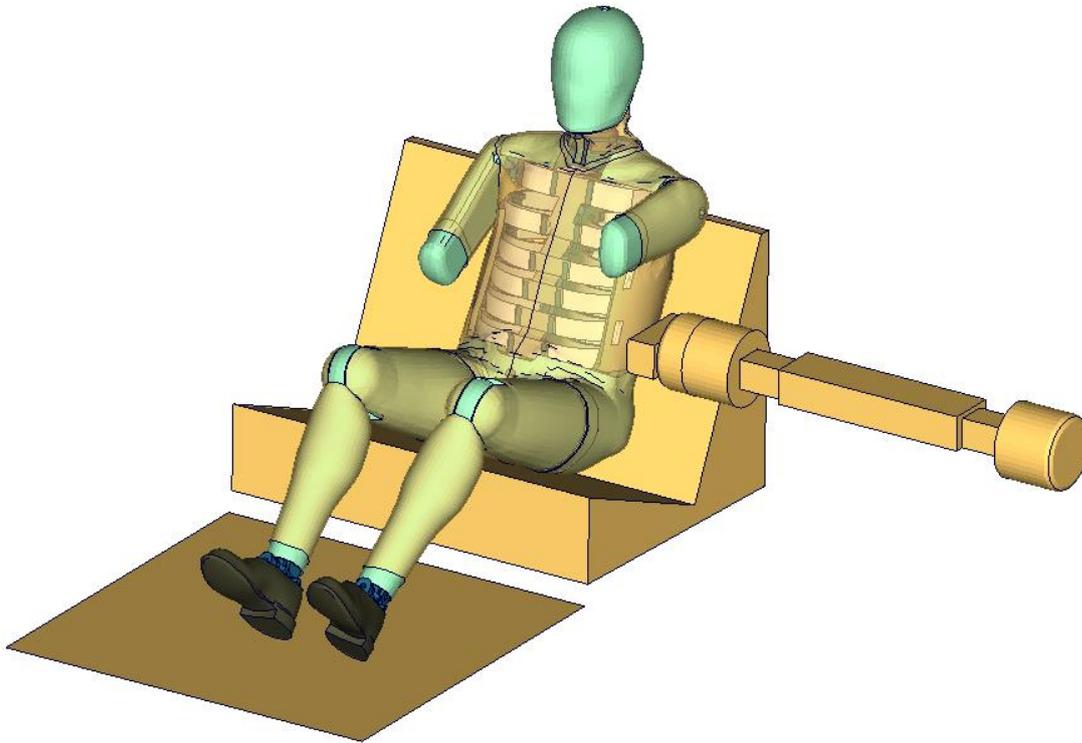
**Figure 206:** Thorax calibration test results with arm (Page 1)

### Results of thorax calibration test with arm (Page 2)



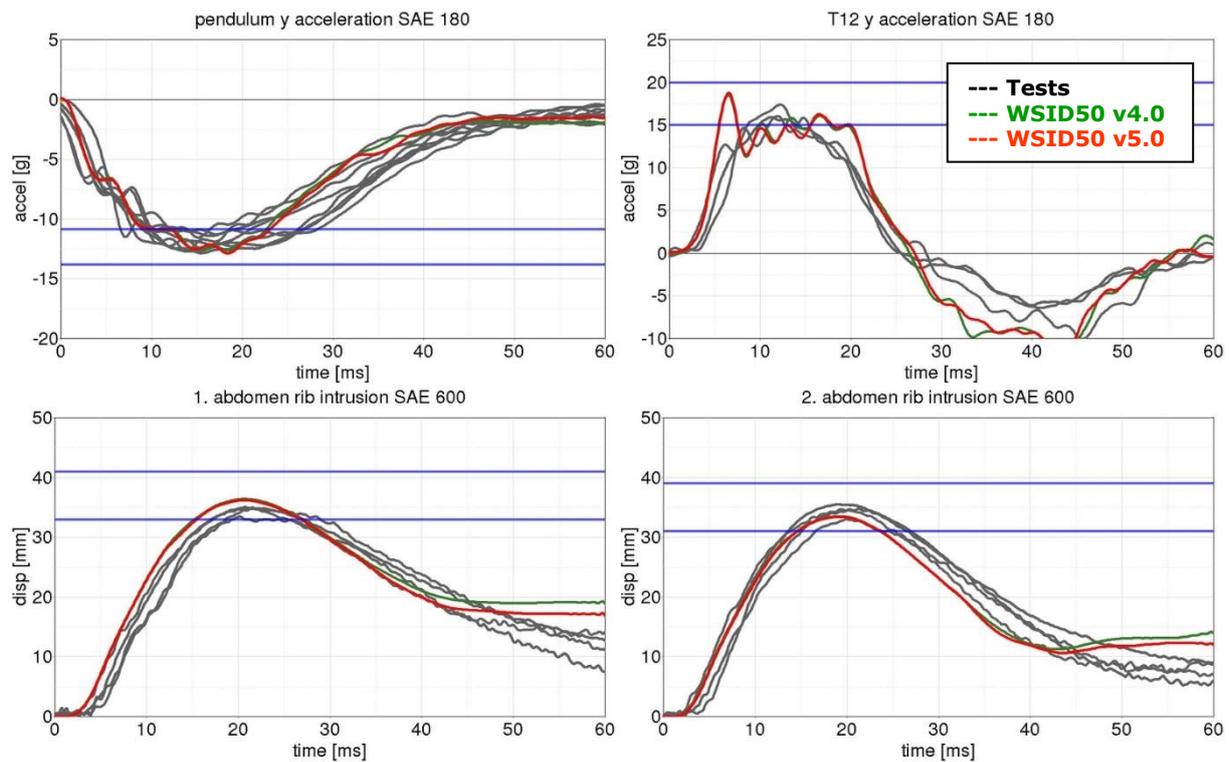
**Figure 207:** Thorax calibration test results with arm (Page 2)

### 8.2.6 Abdomen pendulum test



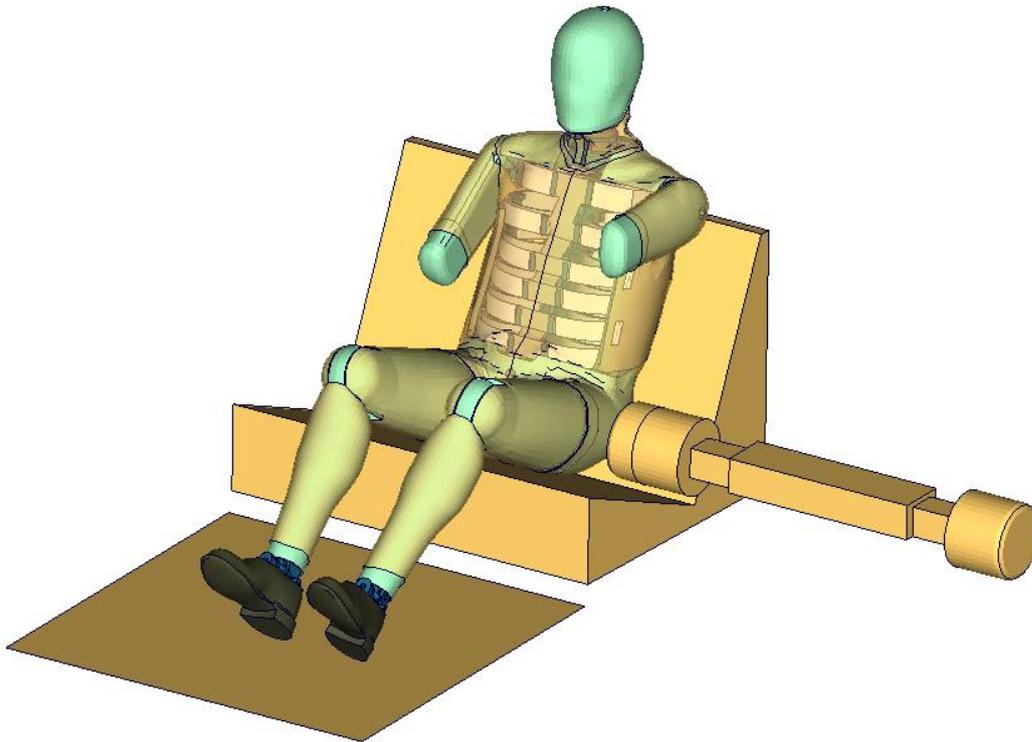
**Figure 208:** Abdomen calibration test setup

#### Results of abdomen calibration test with arm (Page 1)



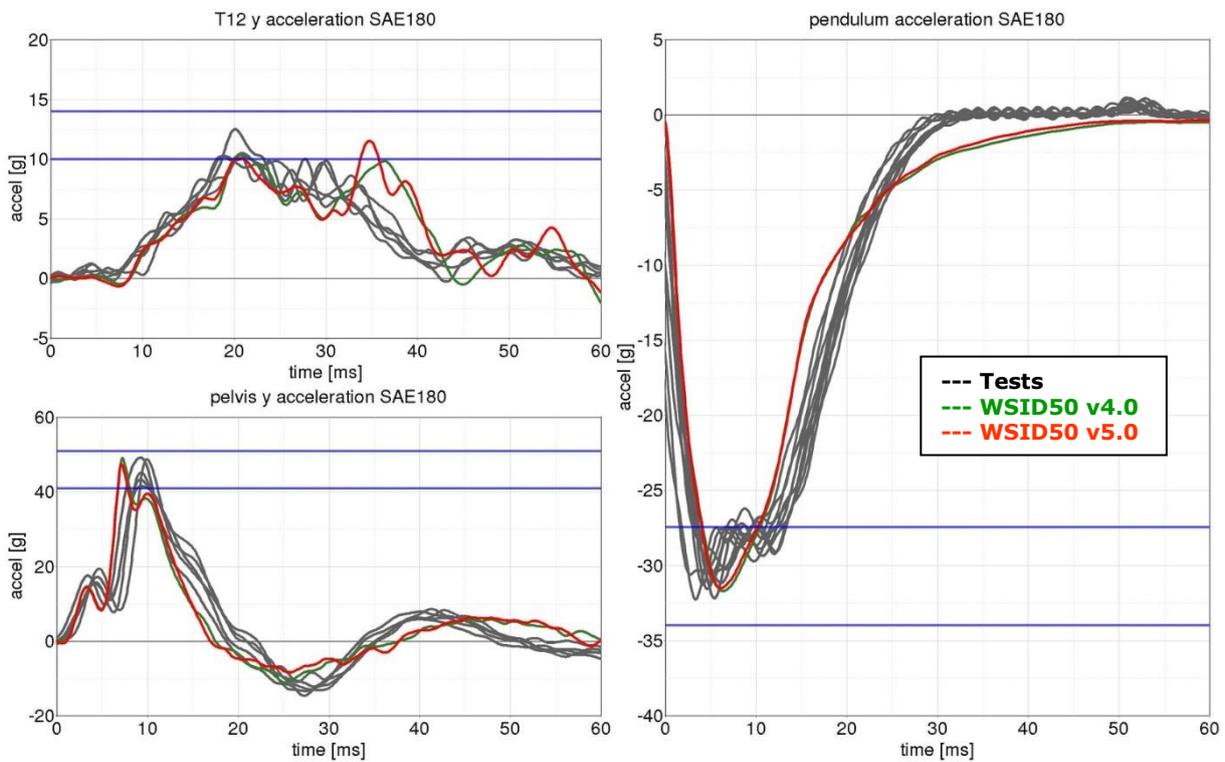
**Figure 209:** Abdomen calibration test results with arm (Page 1)

### 8.2.7 Pelvis pendulum test



**Figure 210:** Pelvis calibration test setup

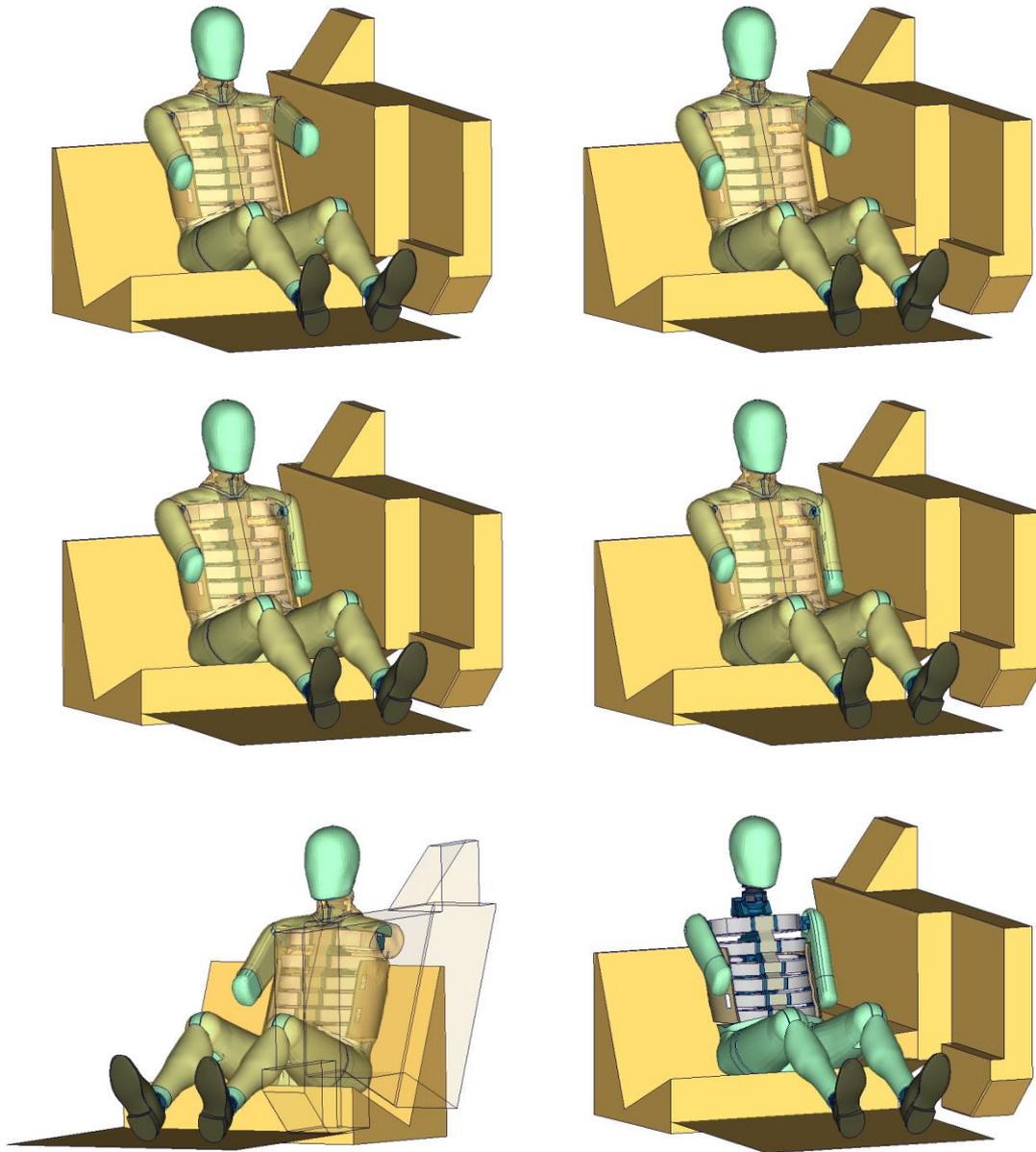
#### Results of pelvis calibration test with arm (Page 1)



**Figure 211:** Pelvis calibration test results with arm (Page 1)

### 8.3 Sled Tests

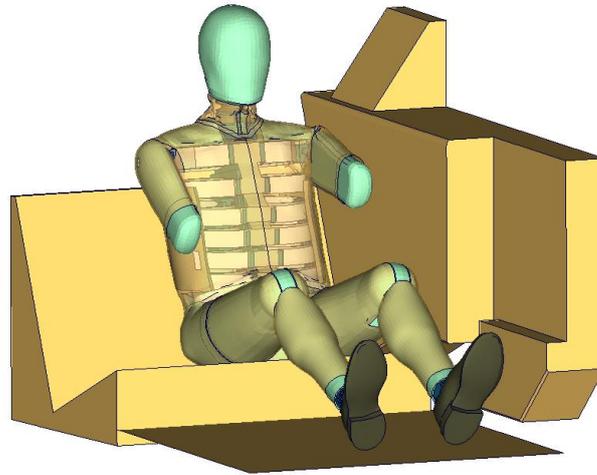
The following sled tests are used for validation. There are two different sled shapes and for each shape two different arm positions. In addition one test is done without the jacket and one without the Arm.



**Figure 212:** Sled tests for next WorldSID release. Left hand side: Plane sled.  
Right hand side: Plane sled with pelvis pusher

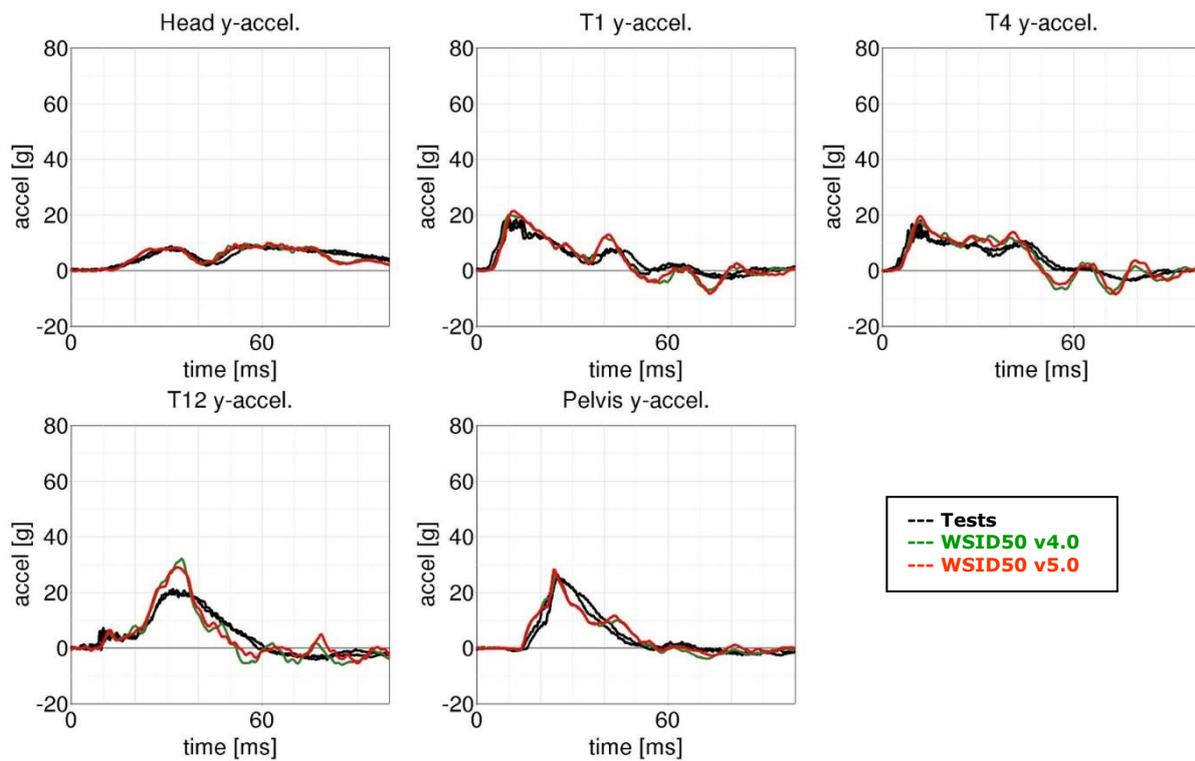
### 8.3.1 Flat barrier

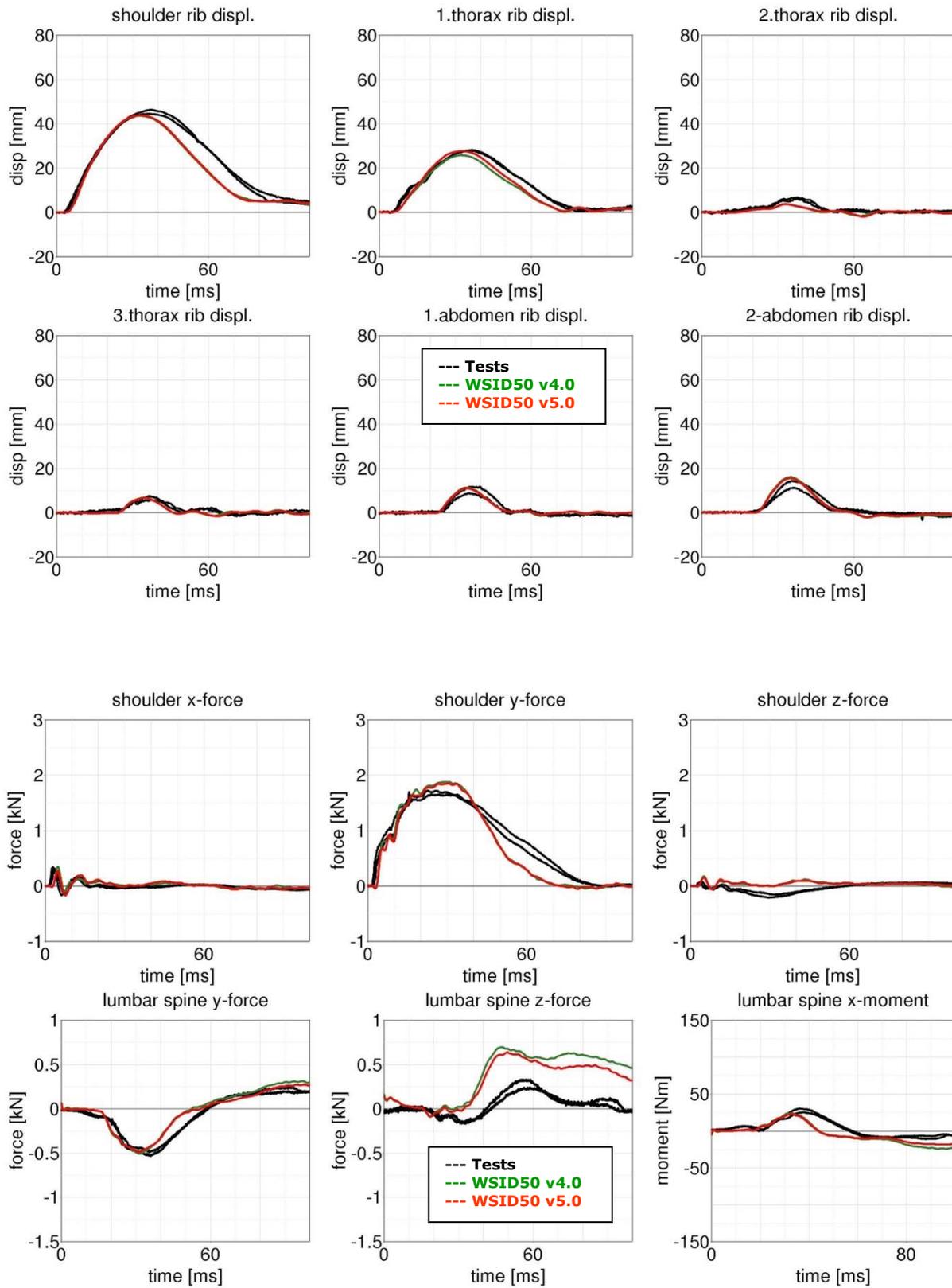
#### 8.3.1.1 Arm position second notch

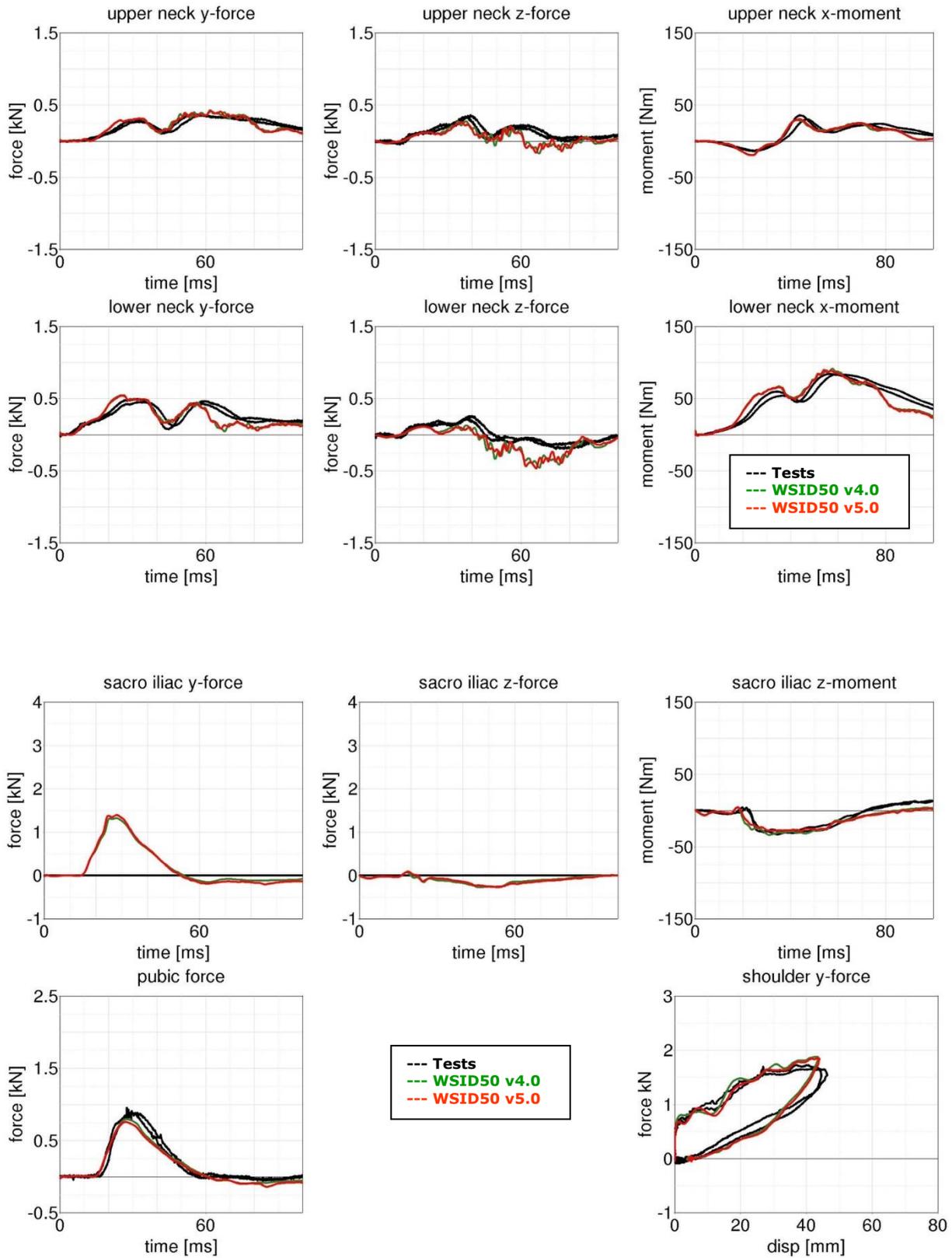


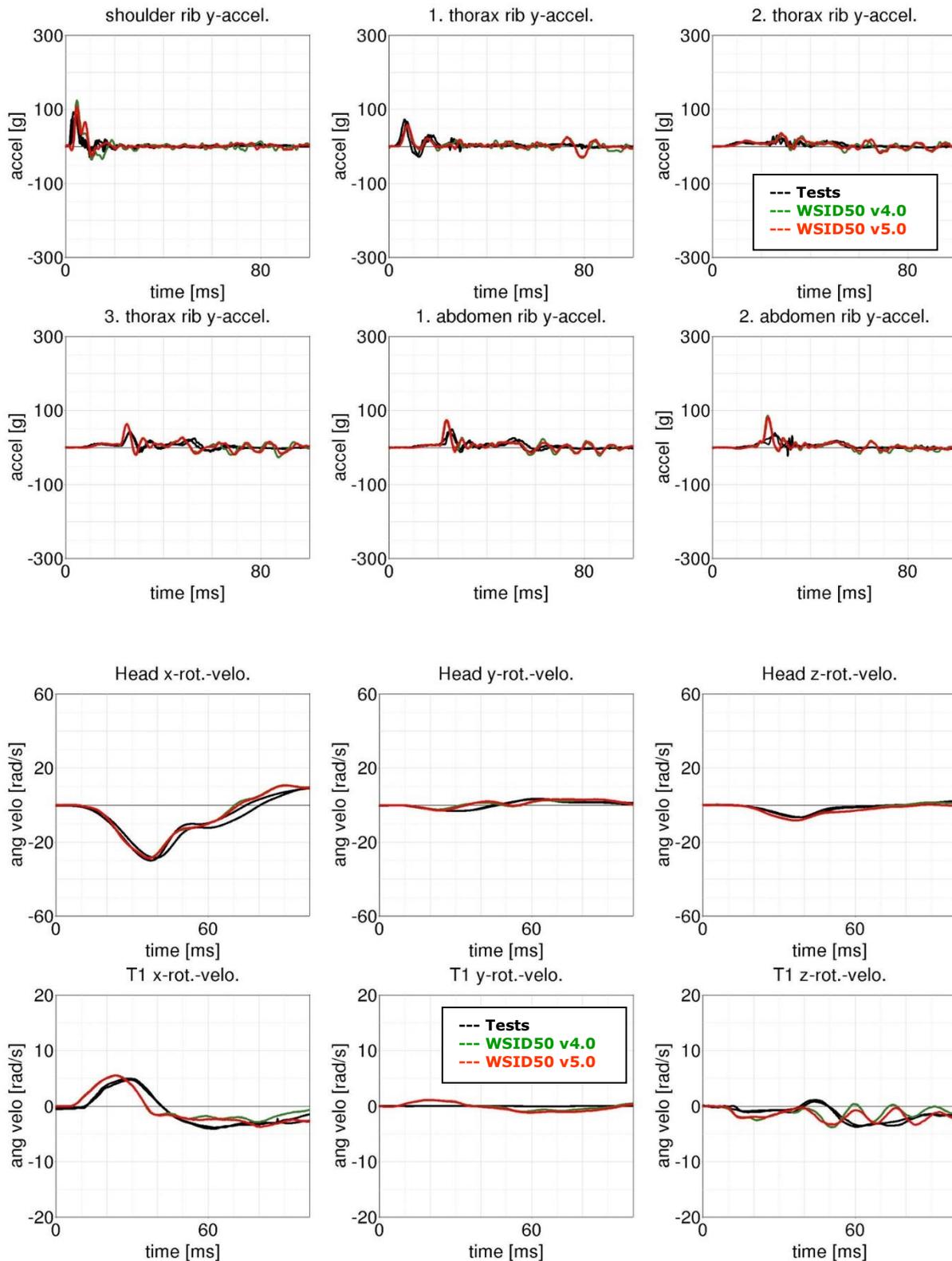
**Figure 213:** Flat barrier and arm second notch.

**Low velocity:**

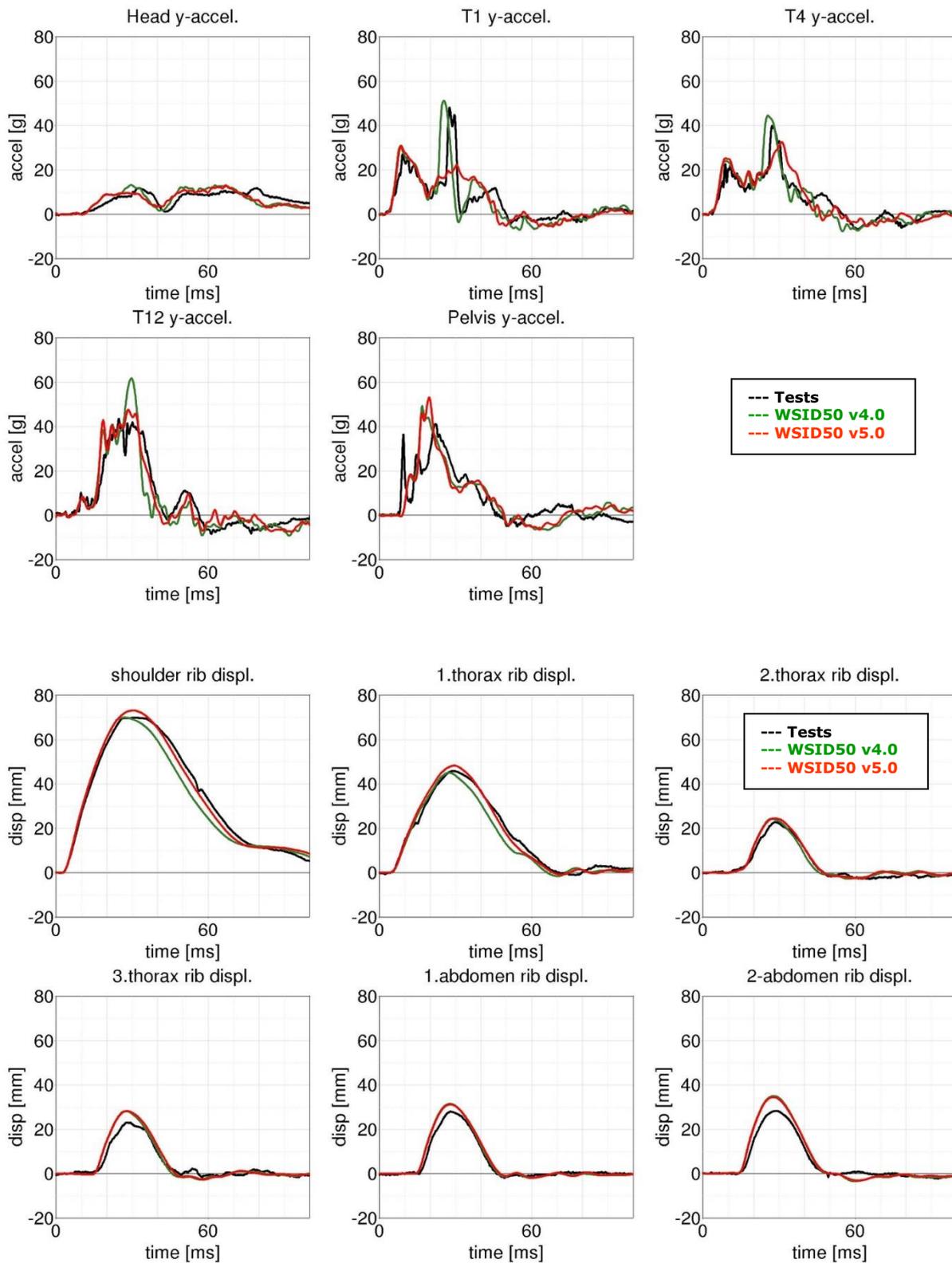


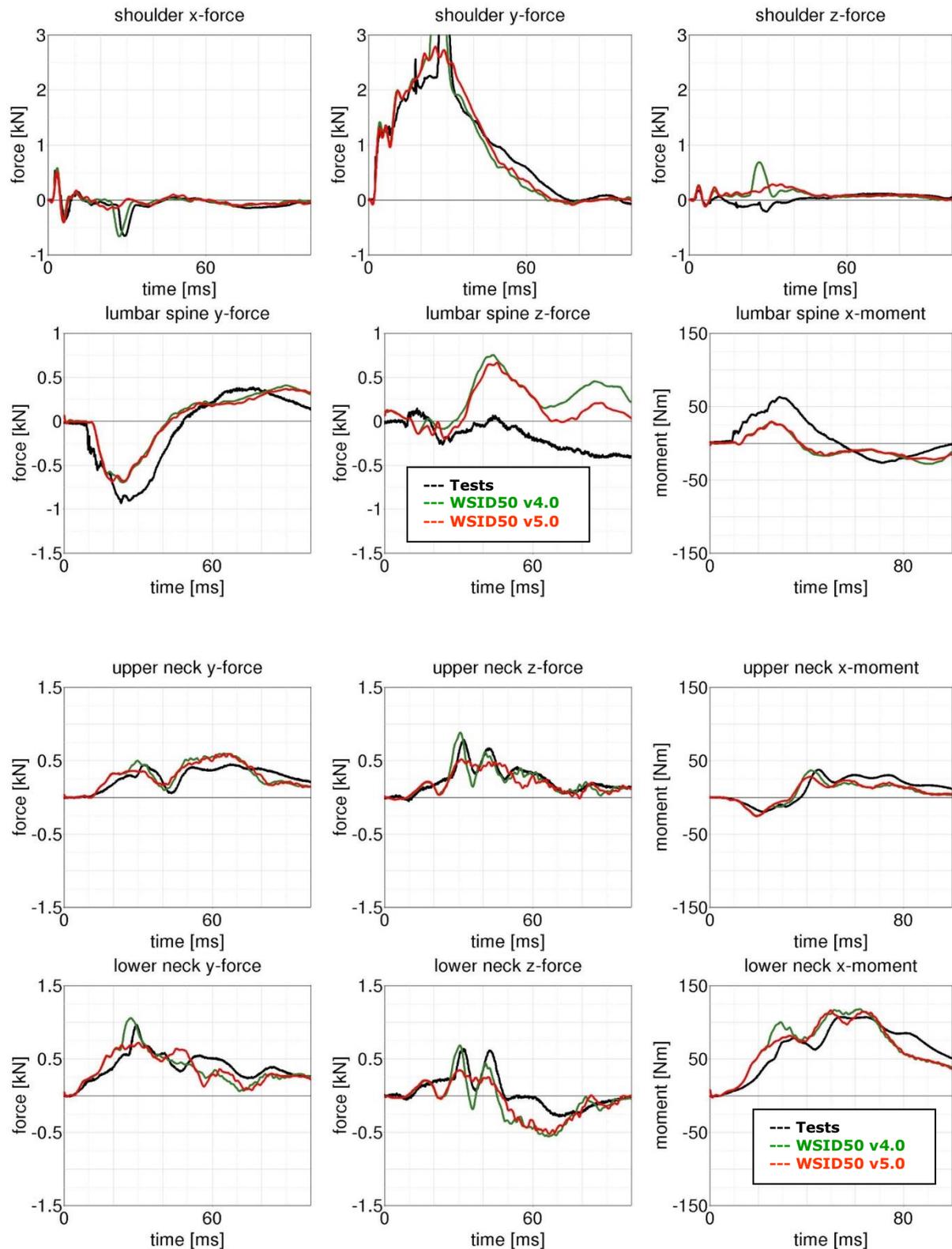


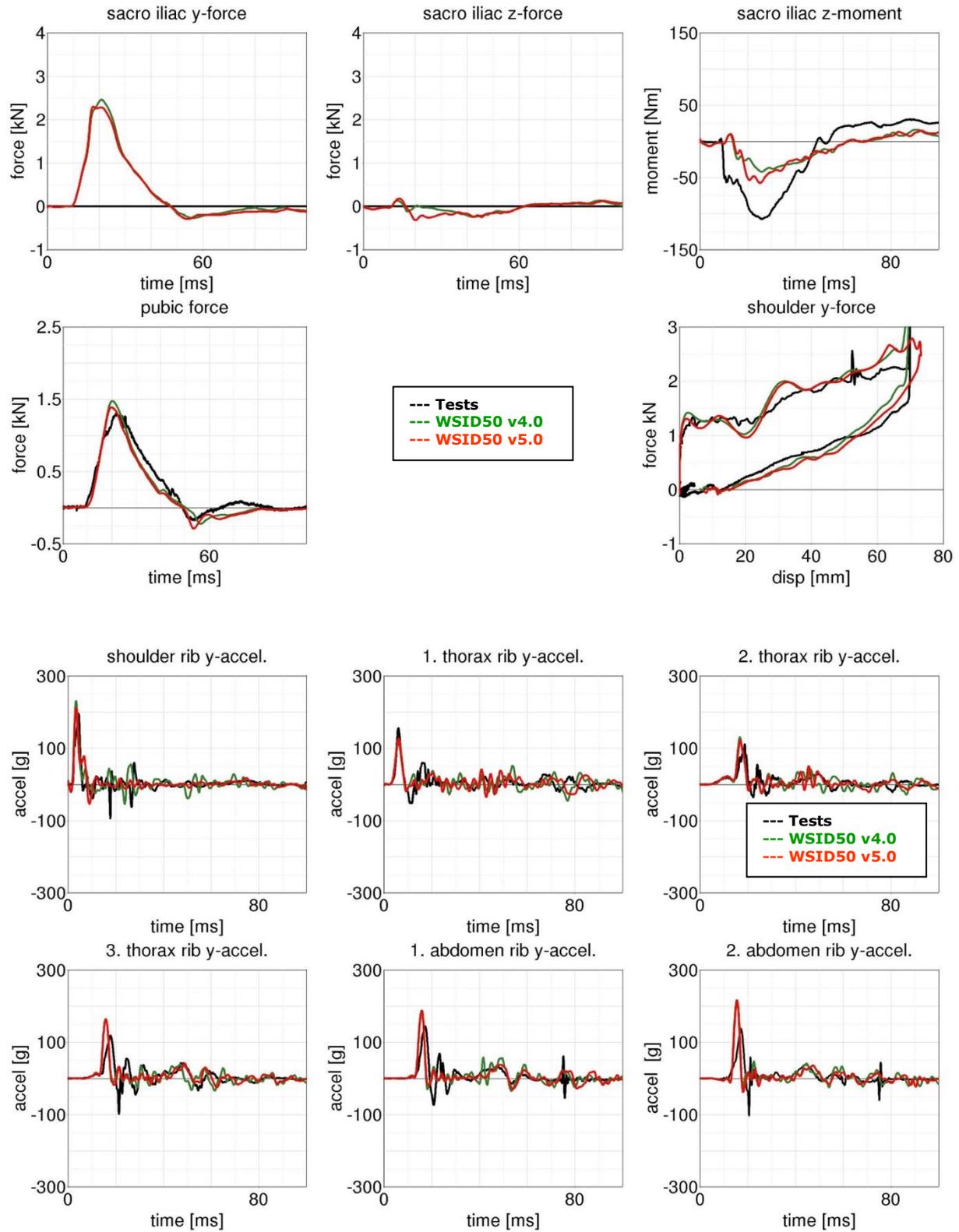


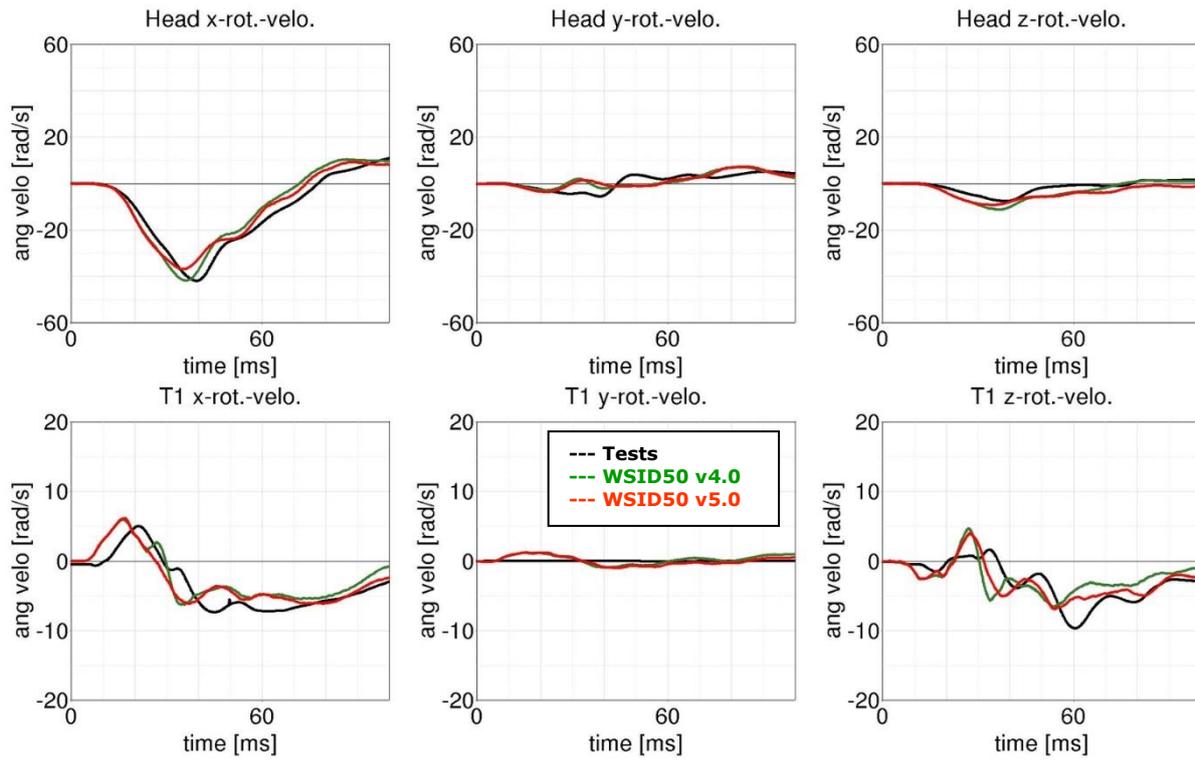


**High velocity:**

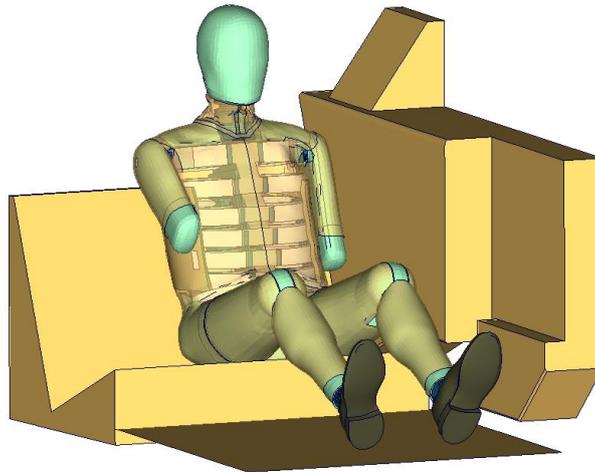






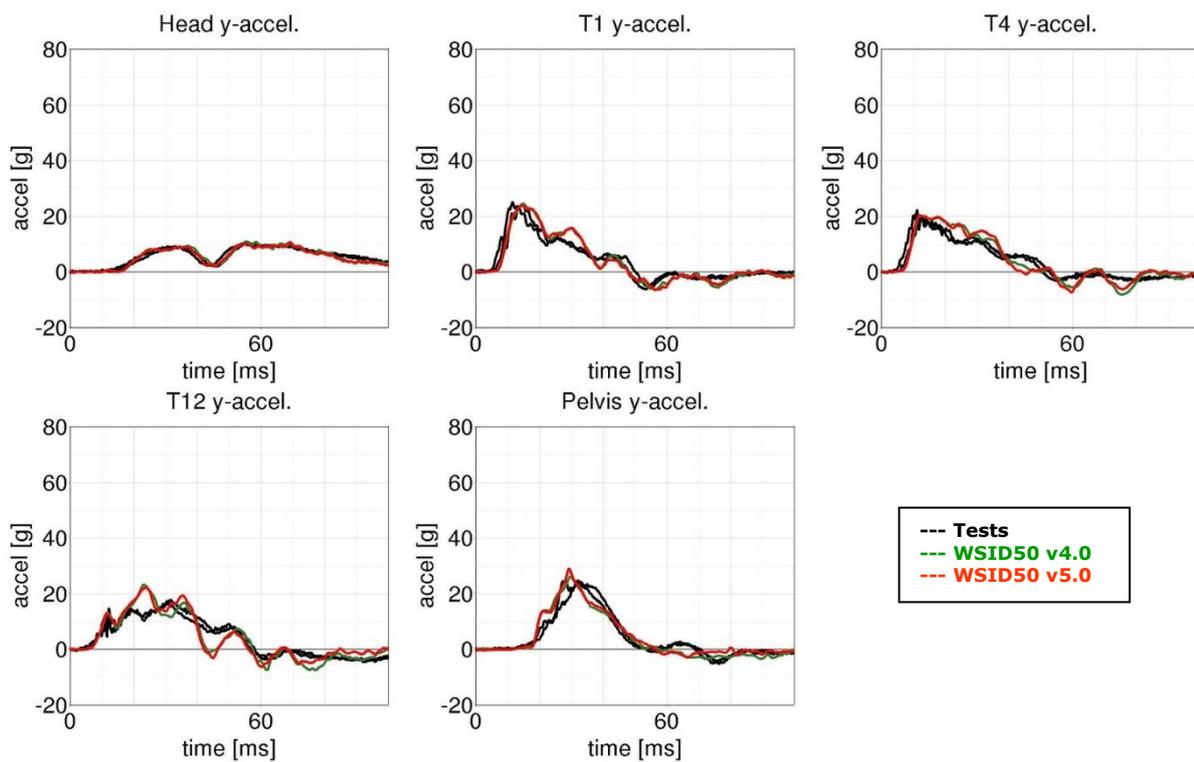


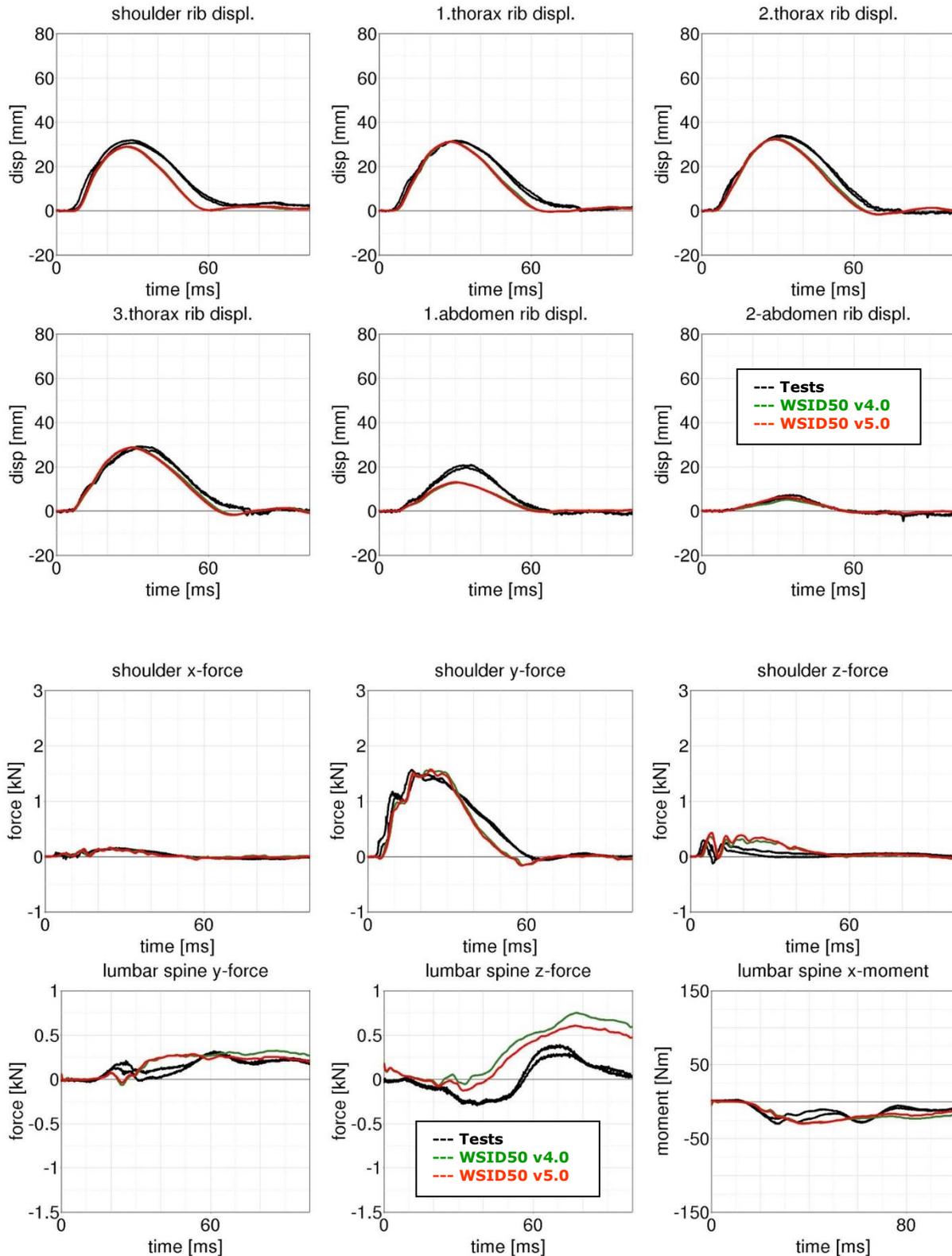
### 8.3.1.2 Arm position first notch

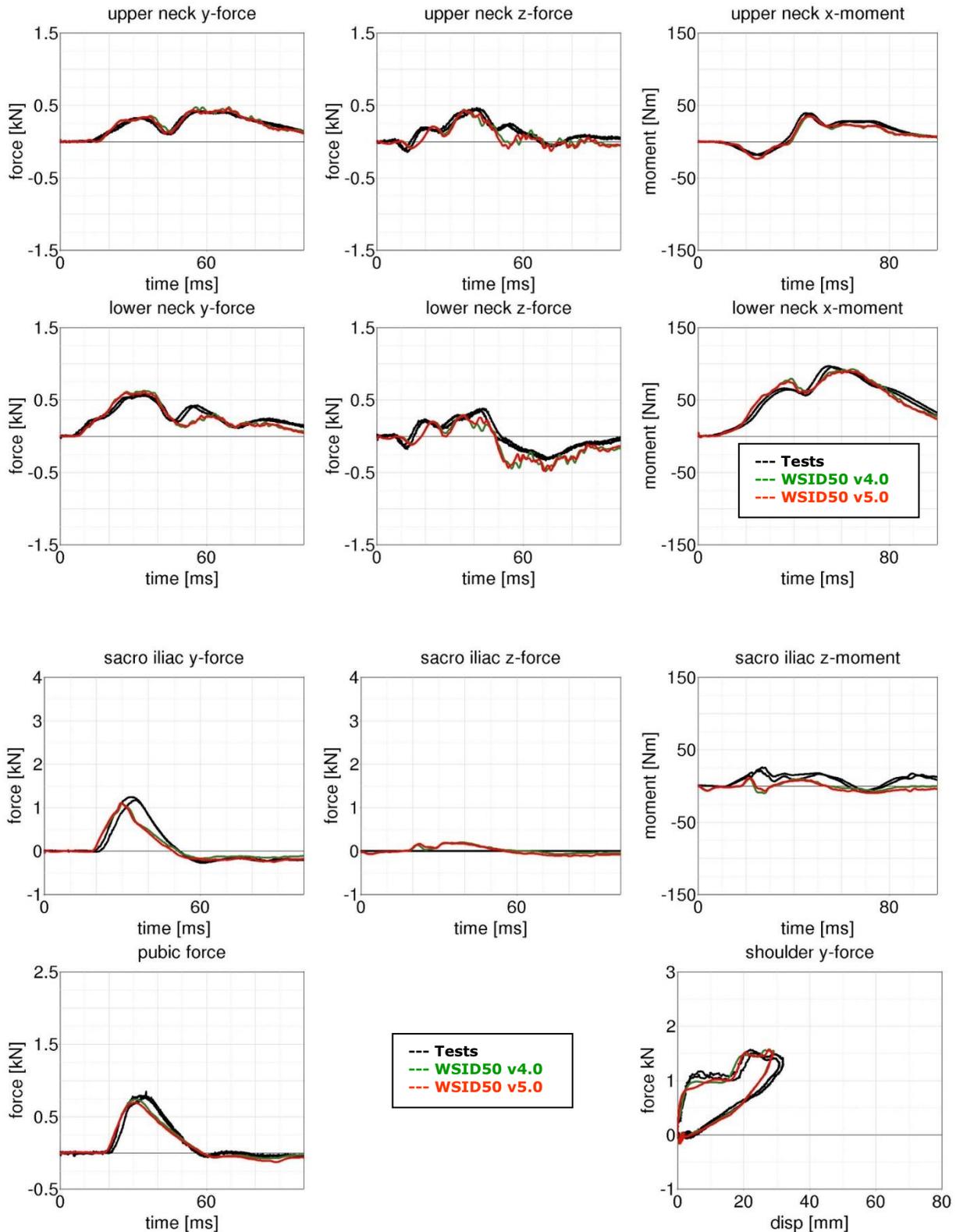


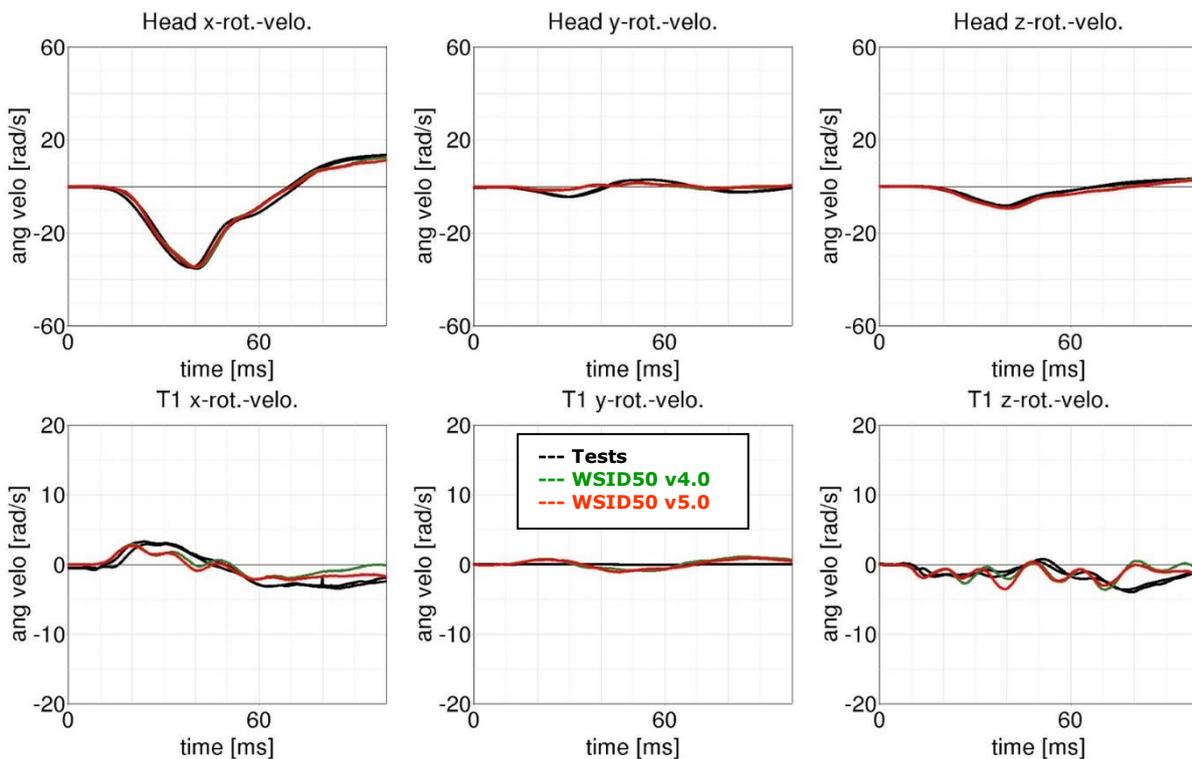
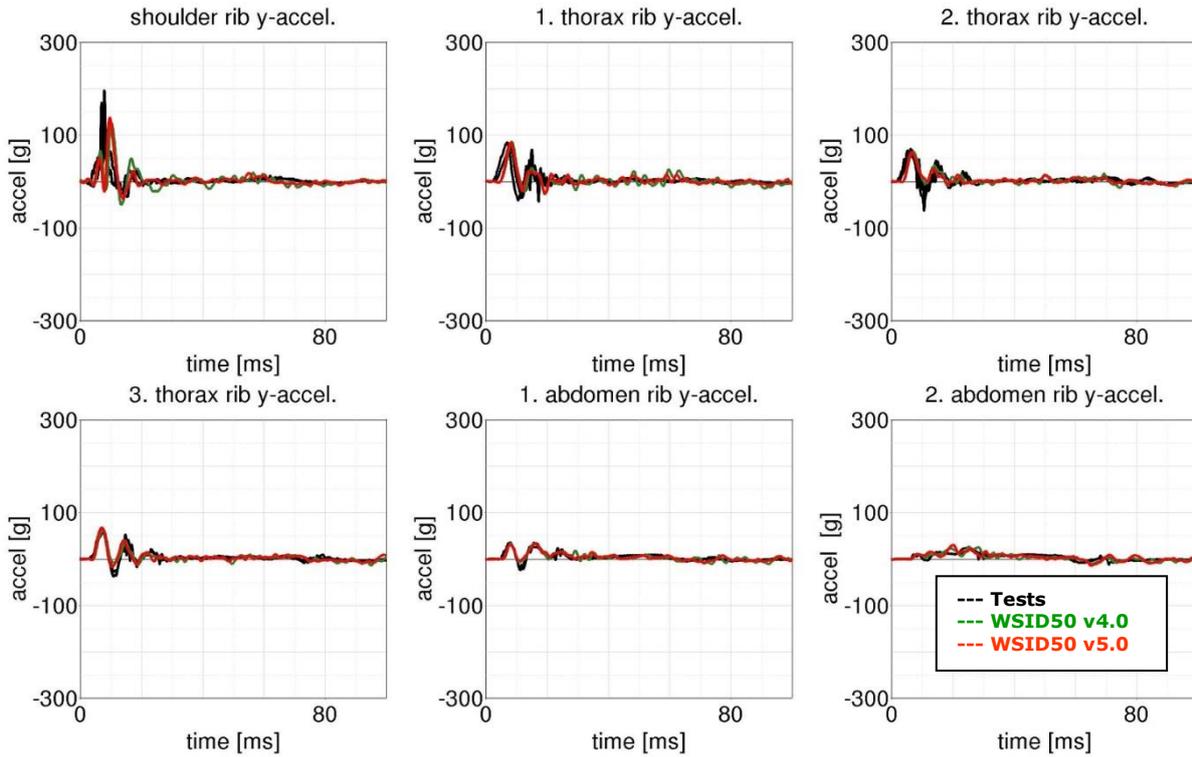
**Figure 214:** Flat barrier and arm first notch.

#### Low velocities:

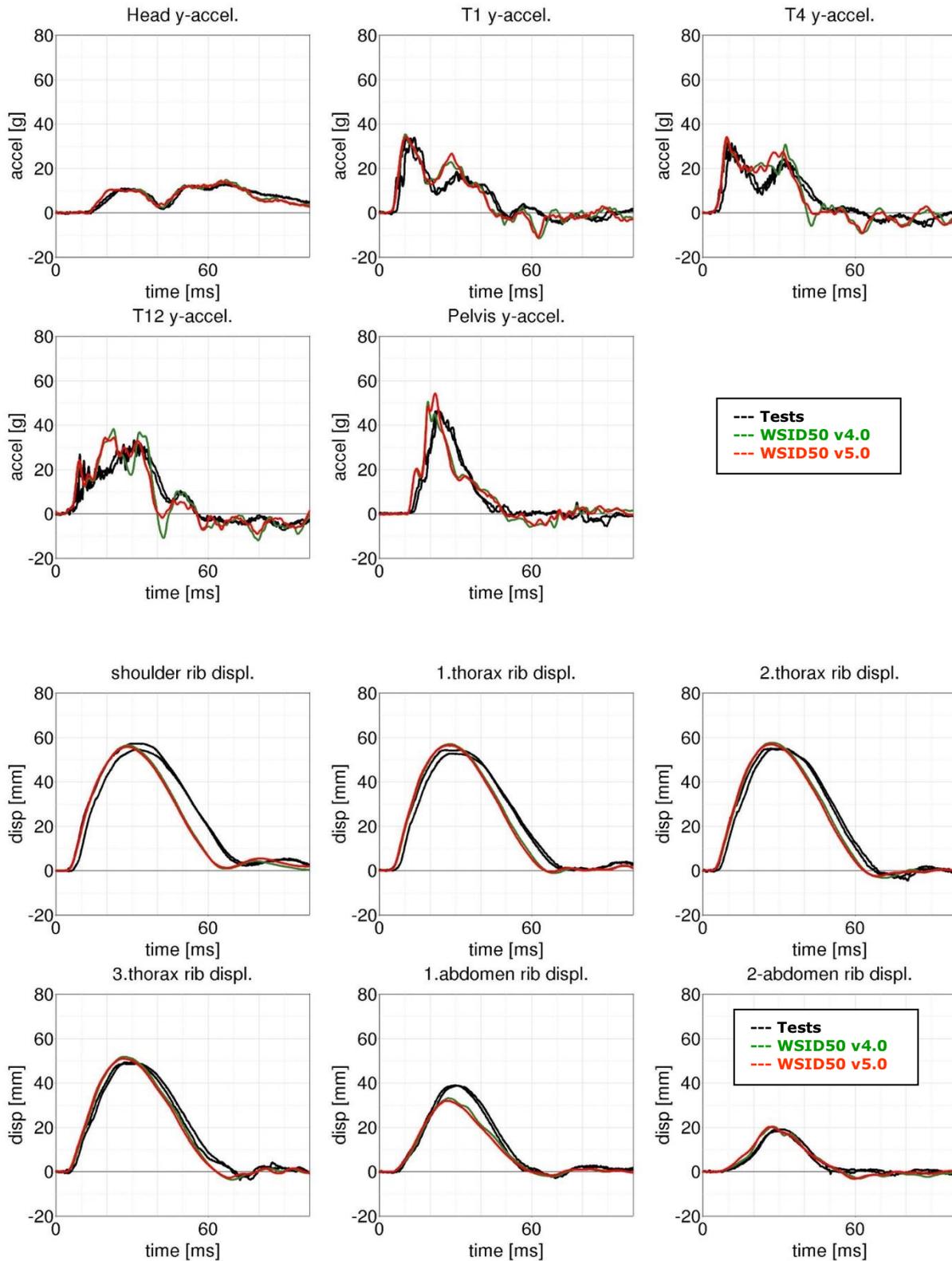


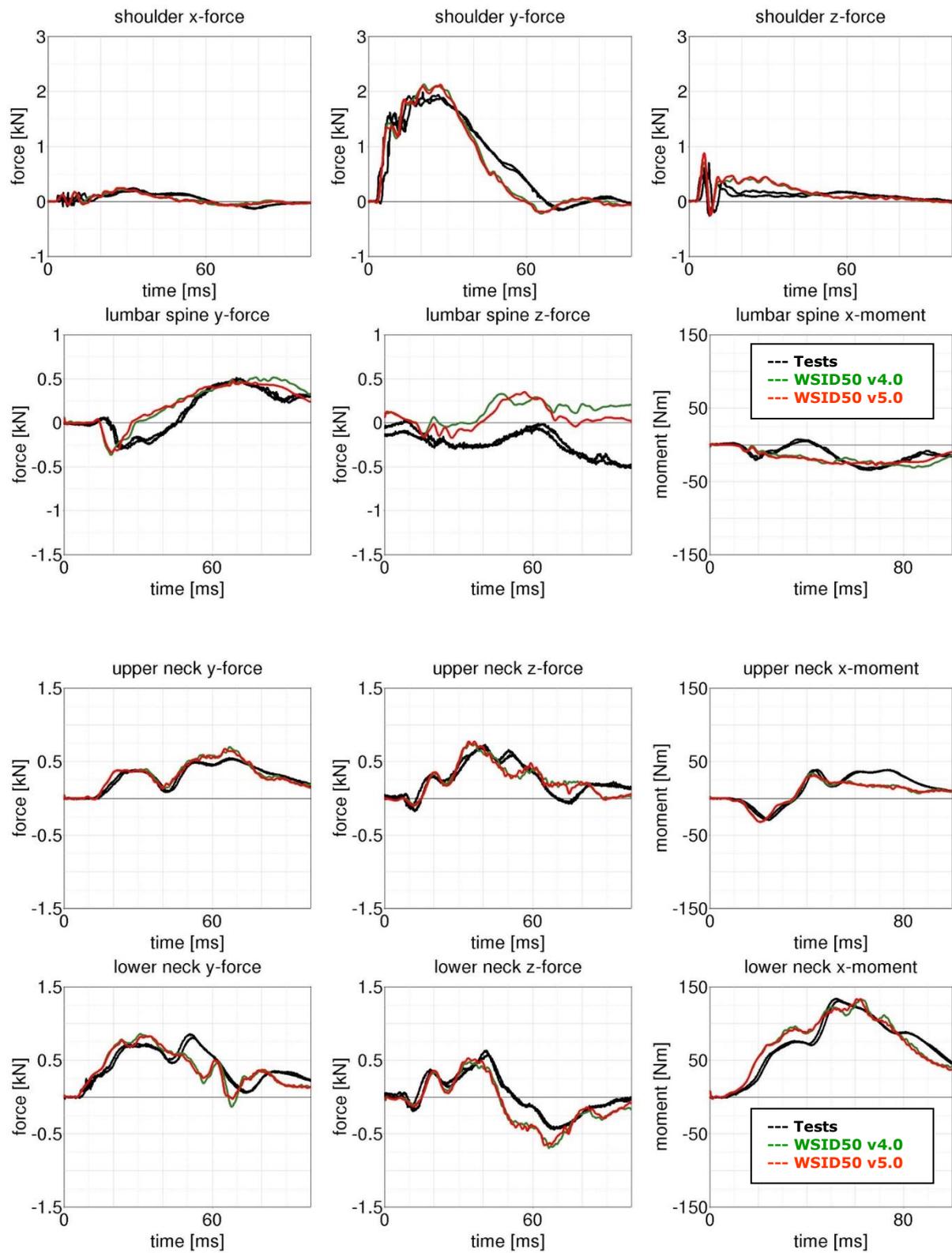


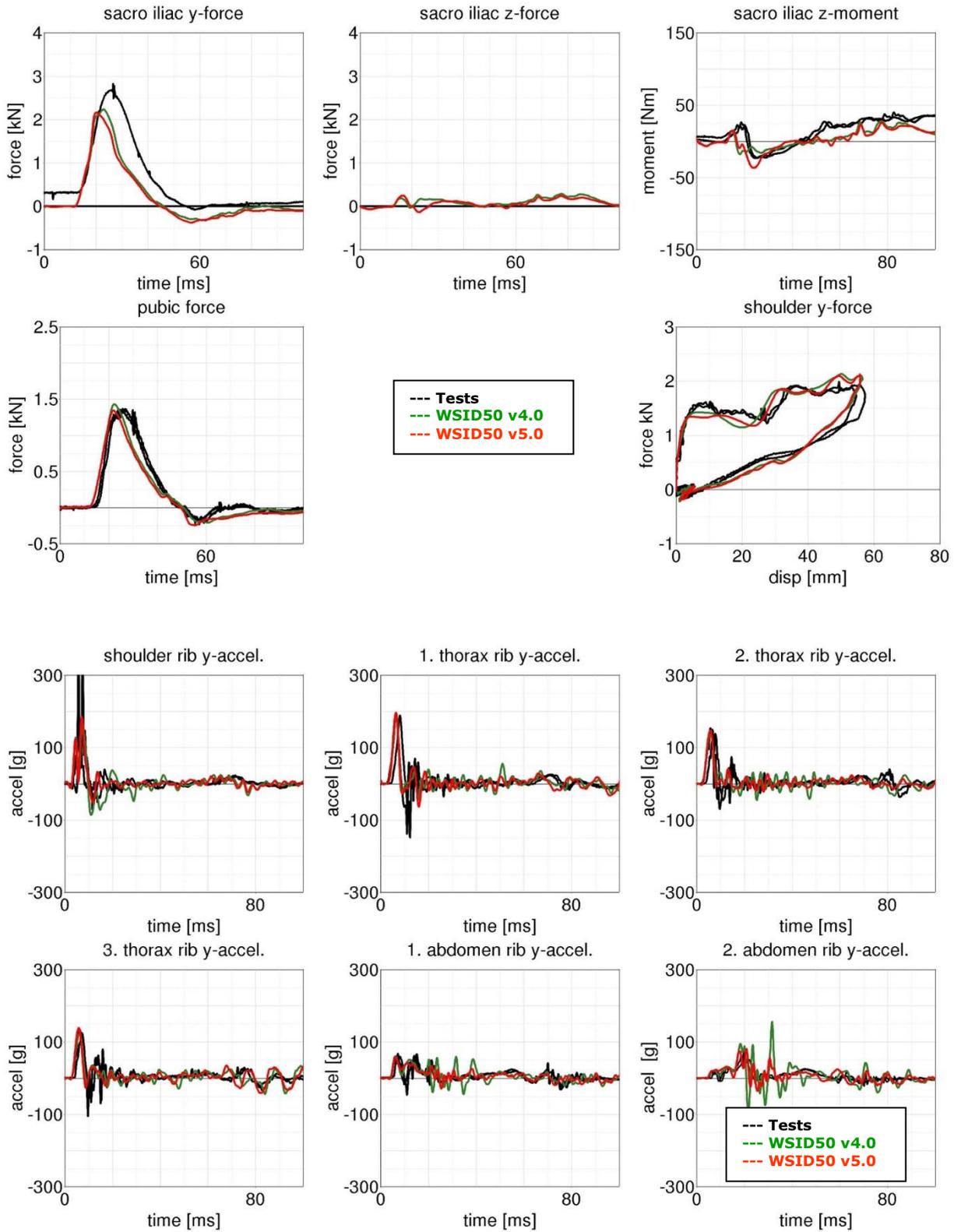


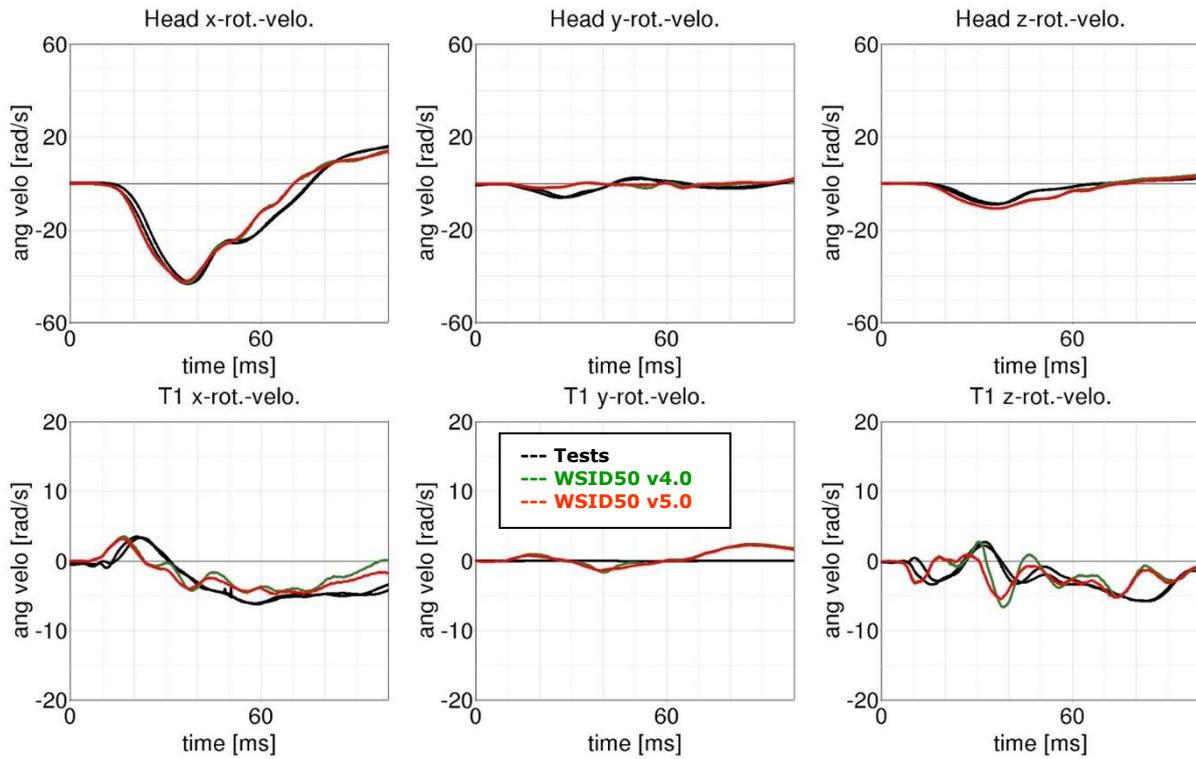


**High velocity:**



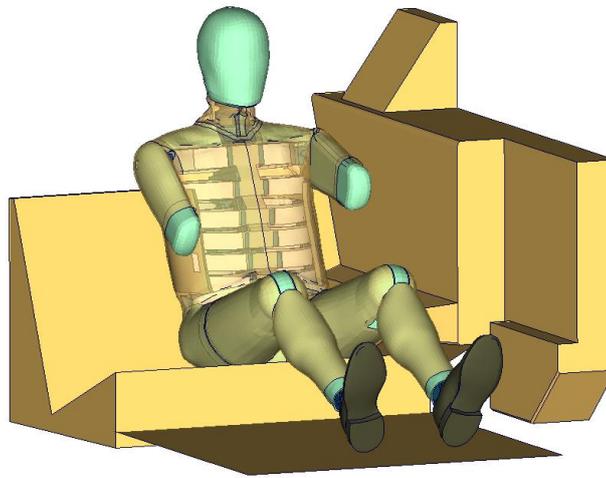






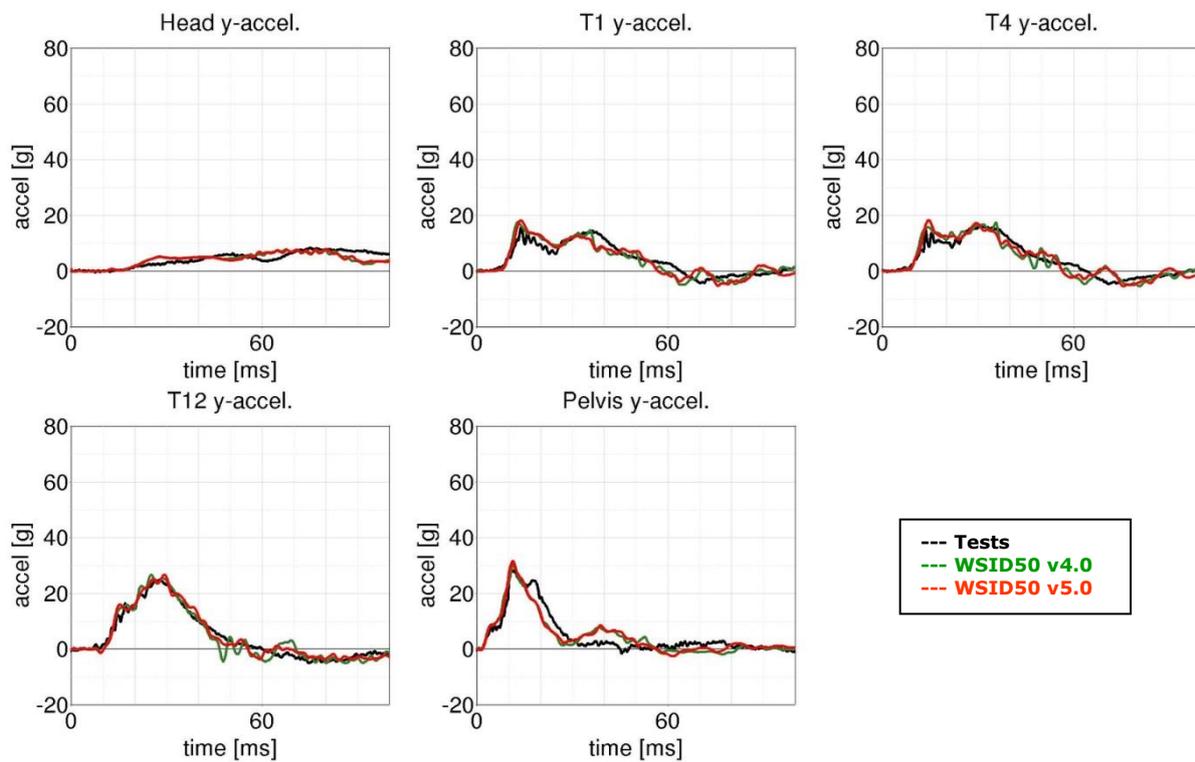
### 8.3.2 Pelvis shape barrier

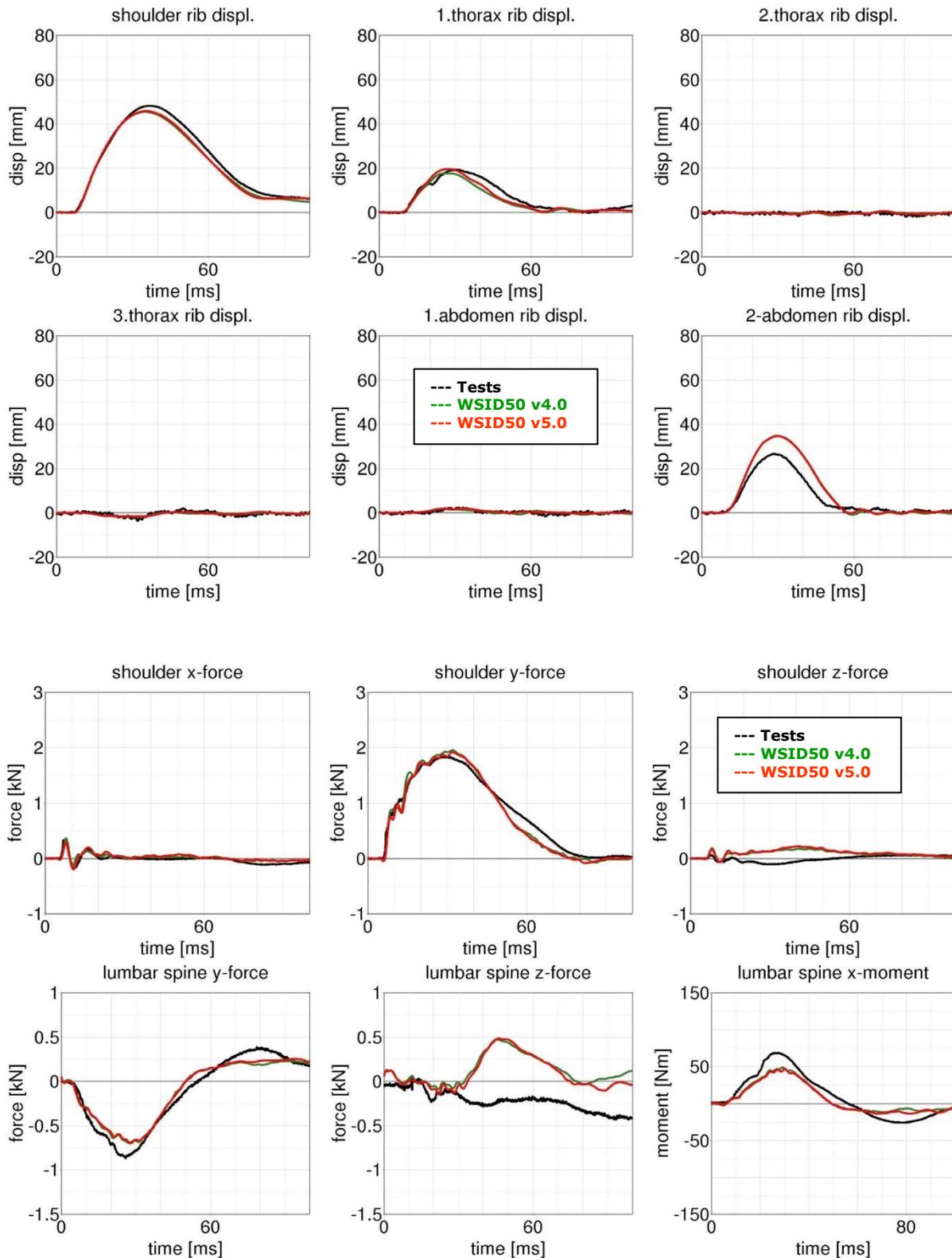
#### 8.3.2.1 Arm position second notch

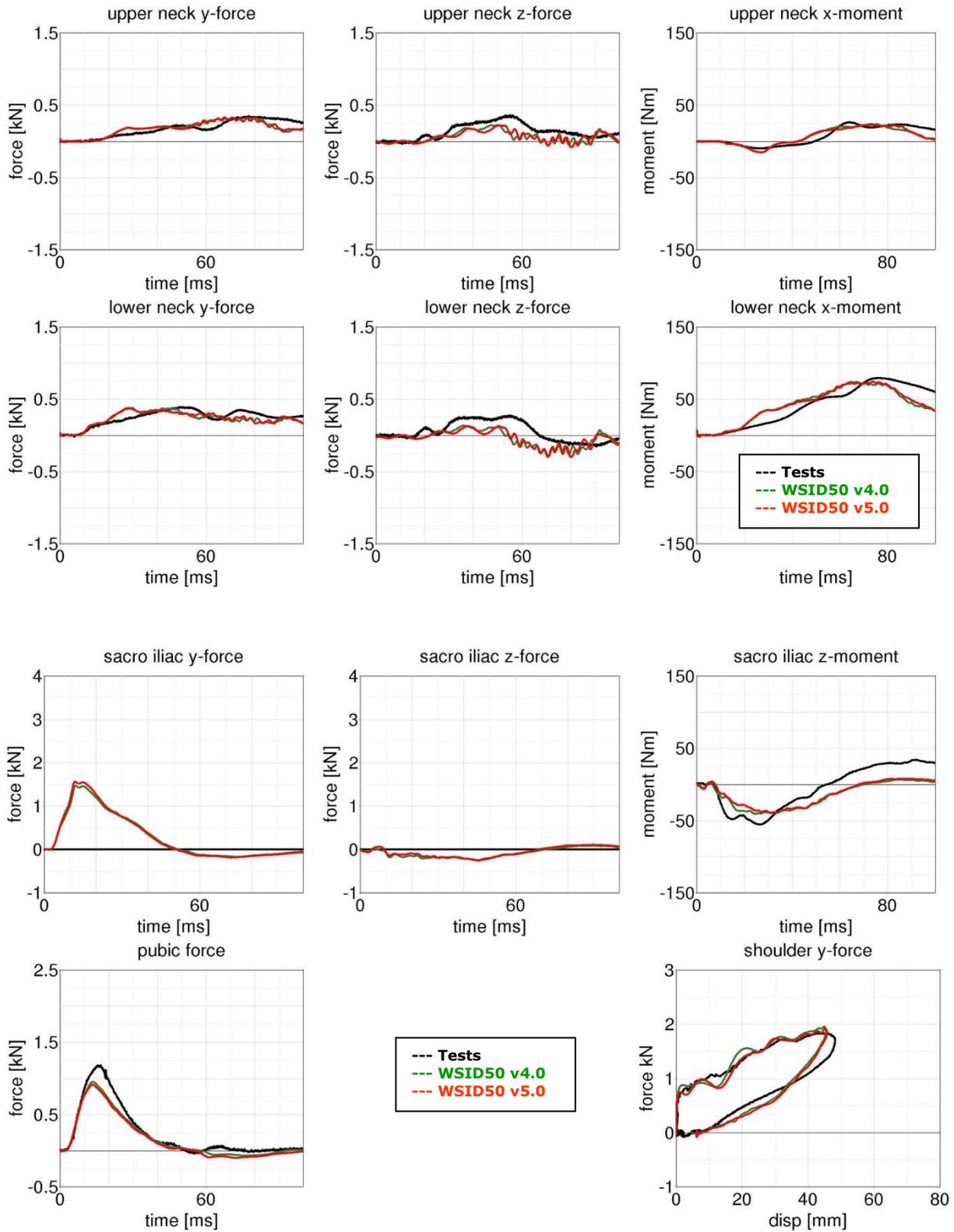


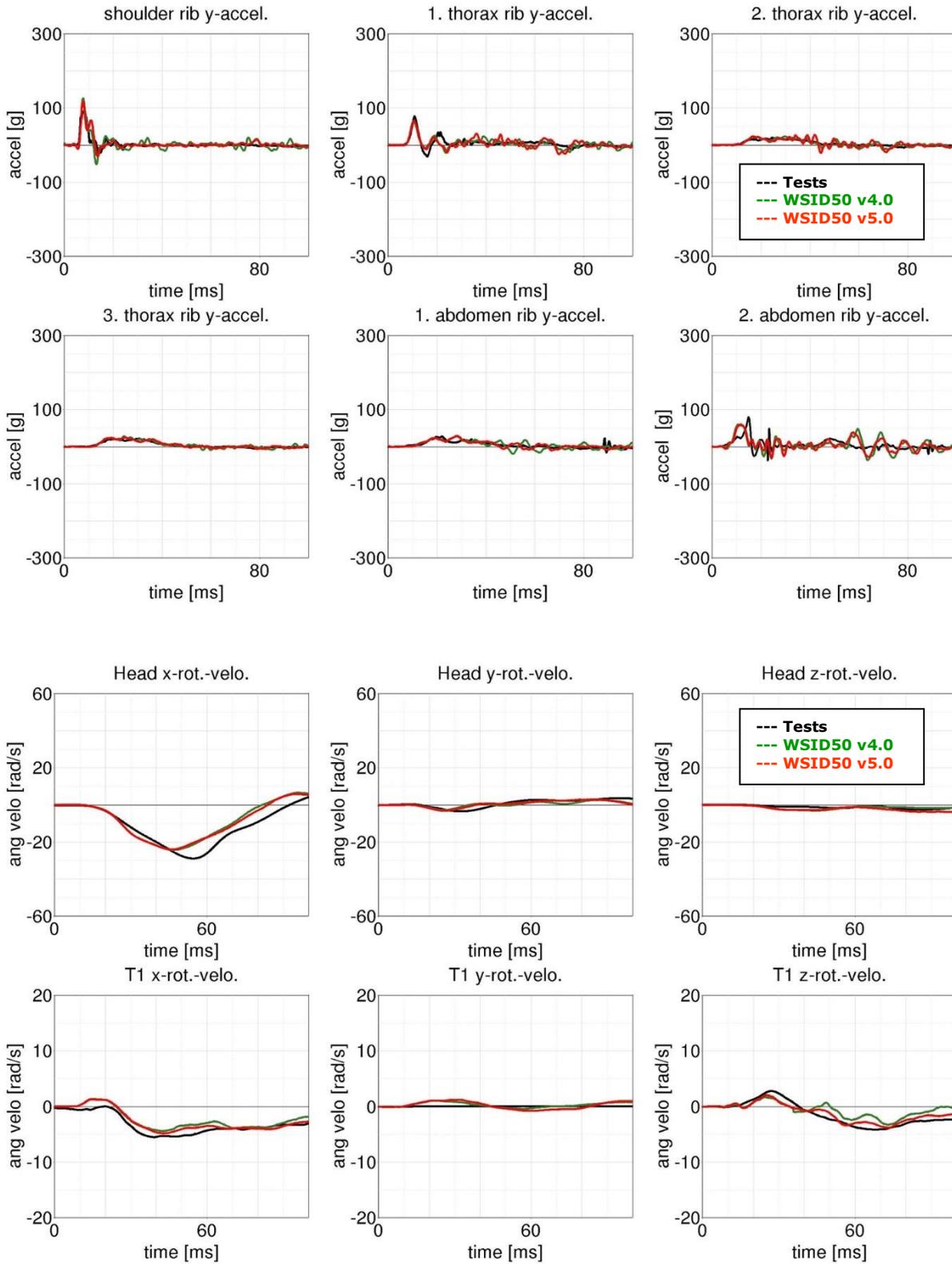
**Figure 215:** Pelvis barrier and arm second notch.

#### Low velocity:

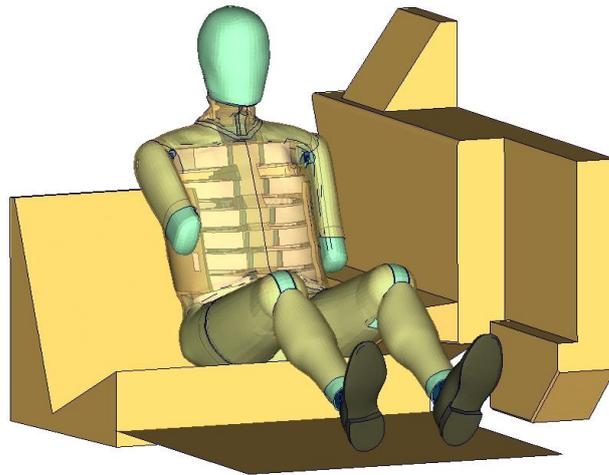






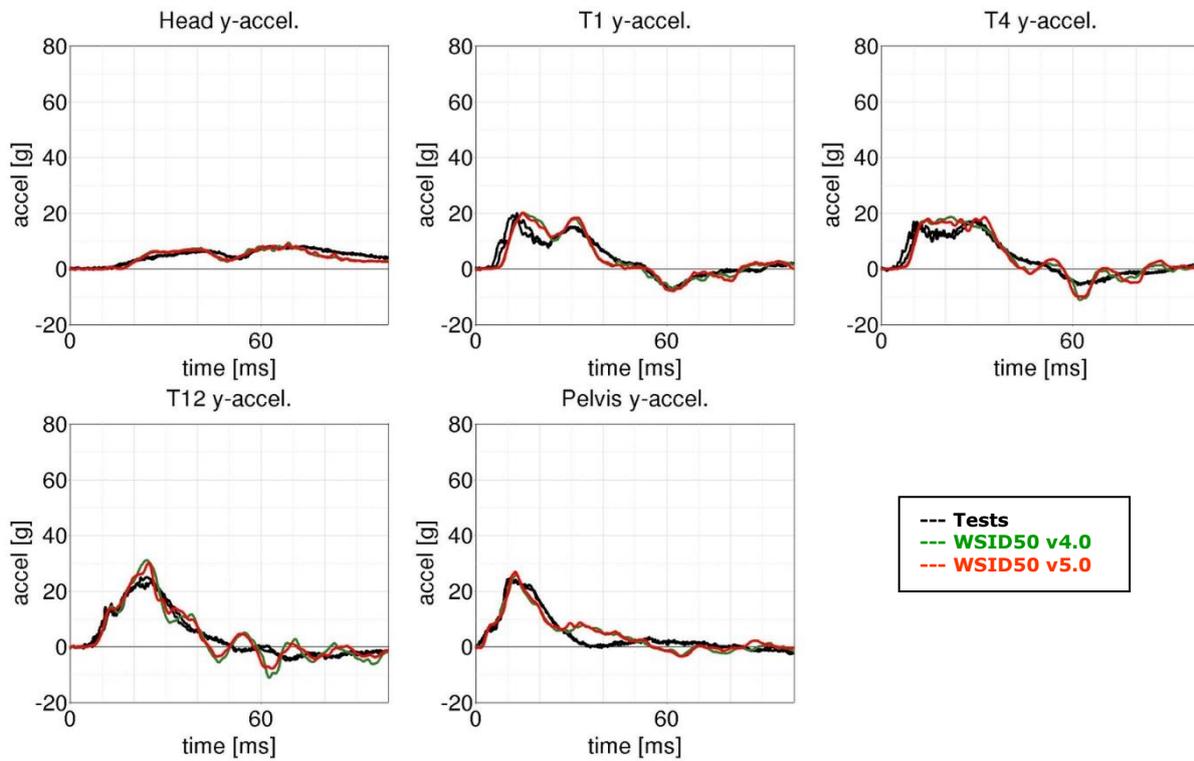


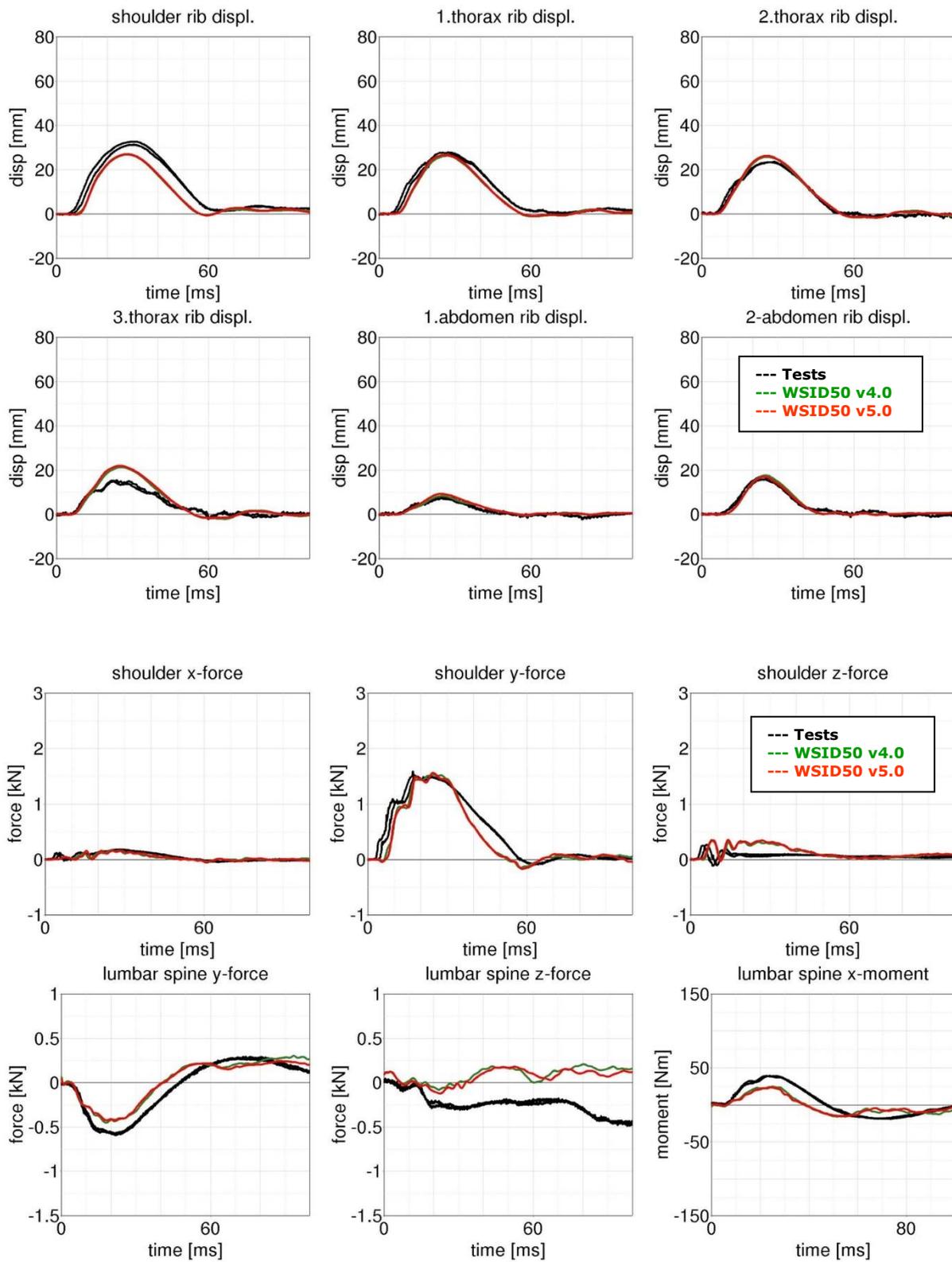
### 8.3.2.2 Arm position first notch

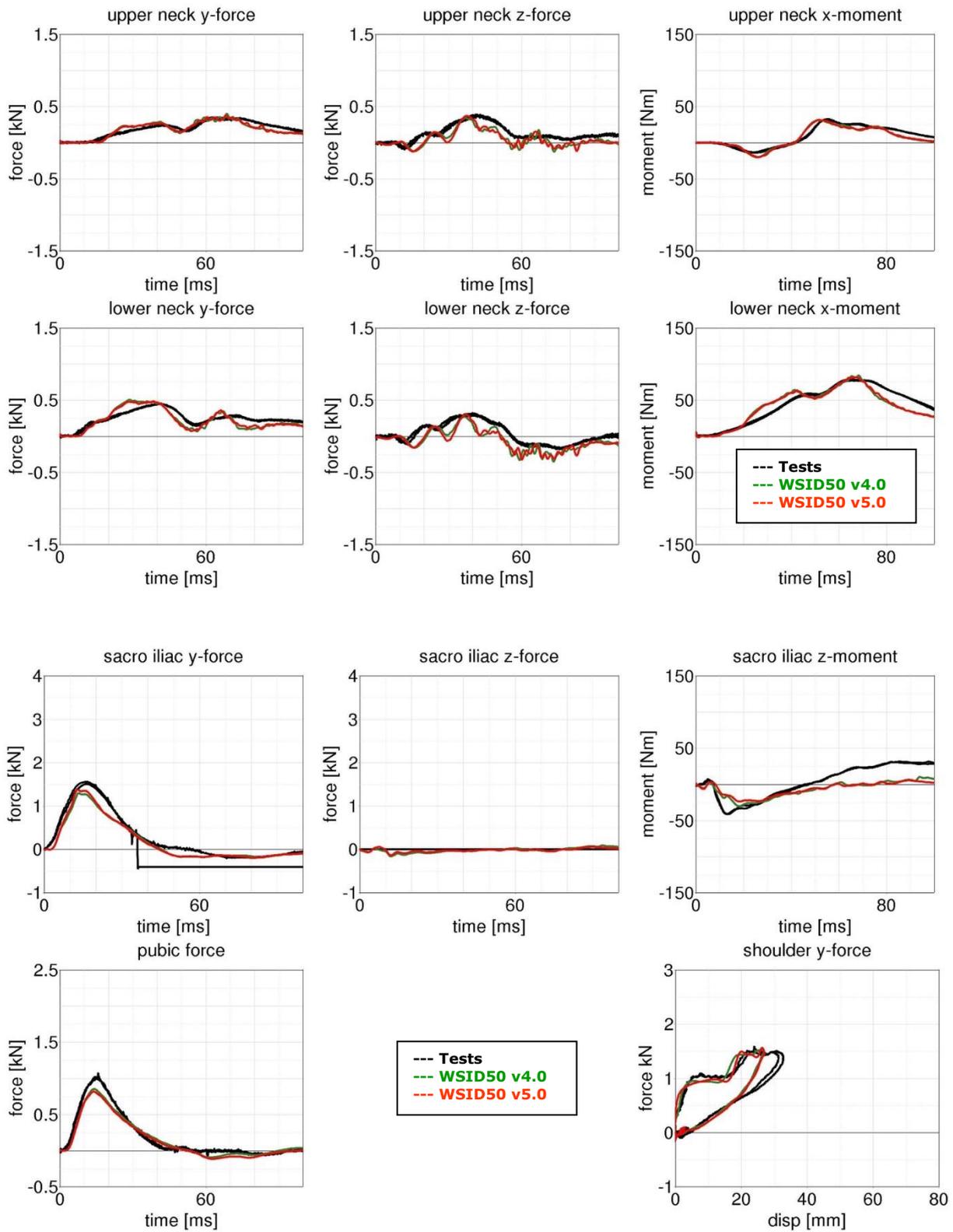


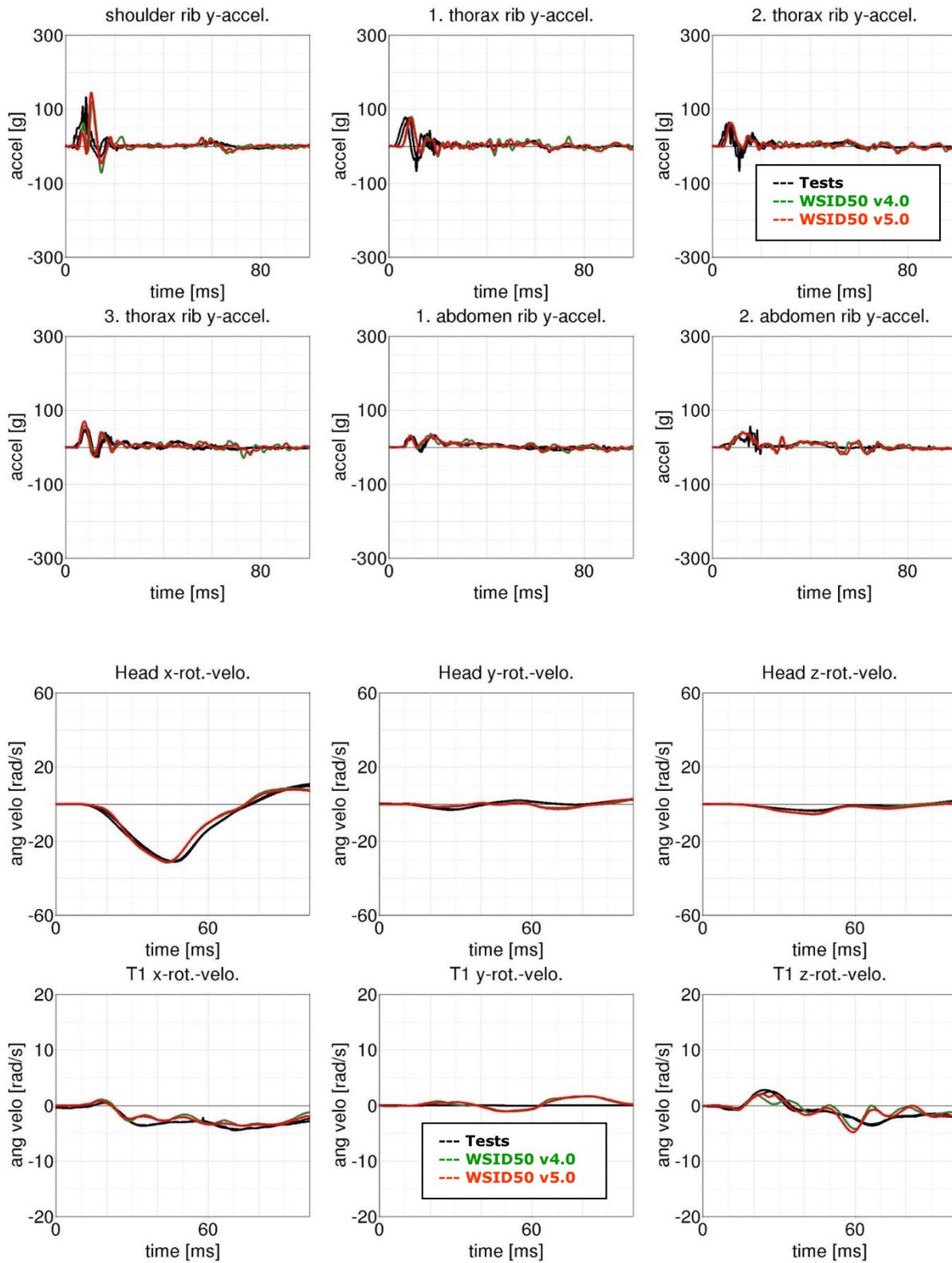
**Figure 216:** Pelvis barrier and arm first notch.

**Low velocity:**

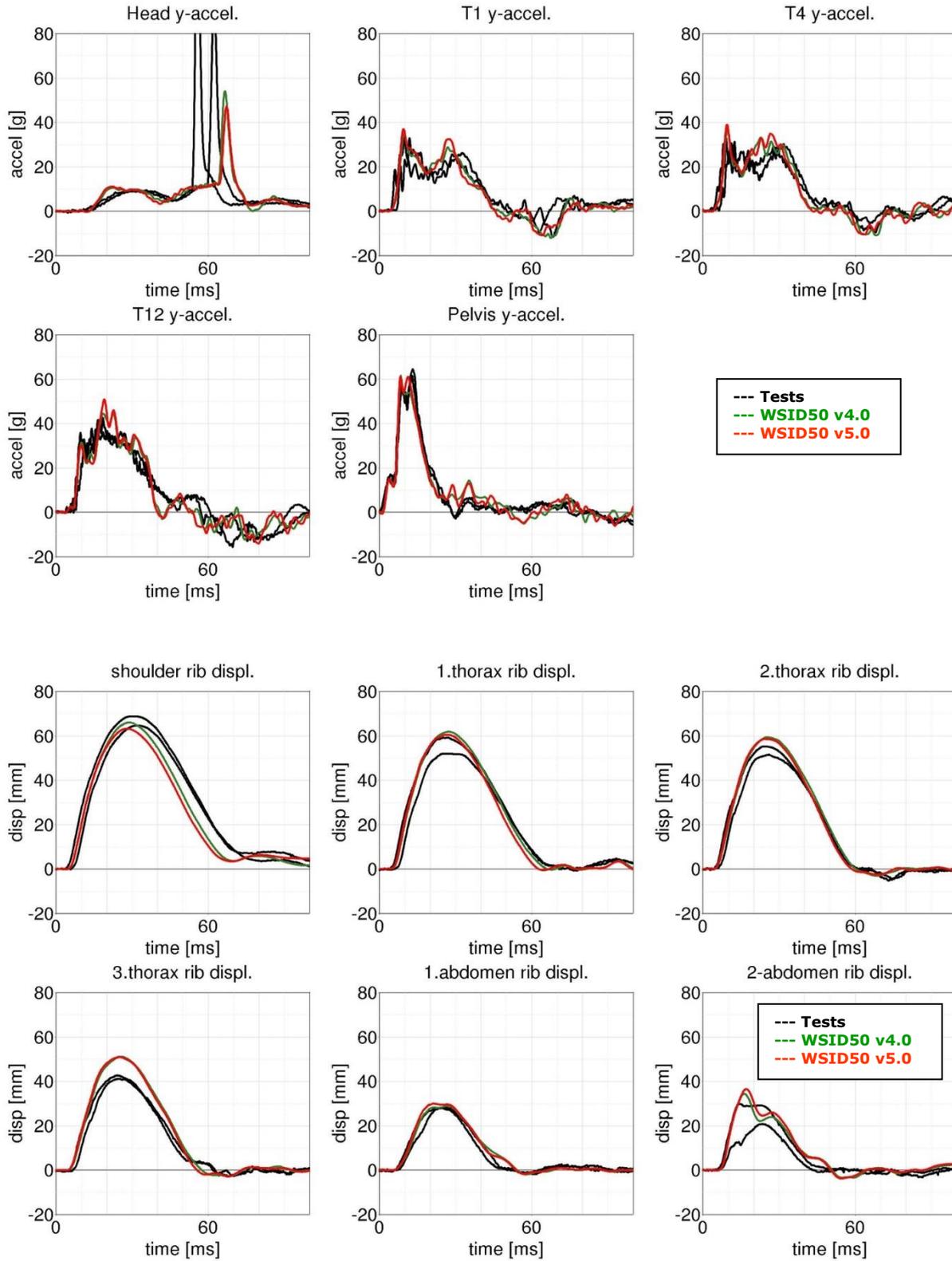


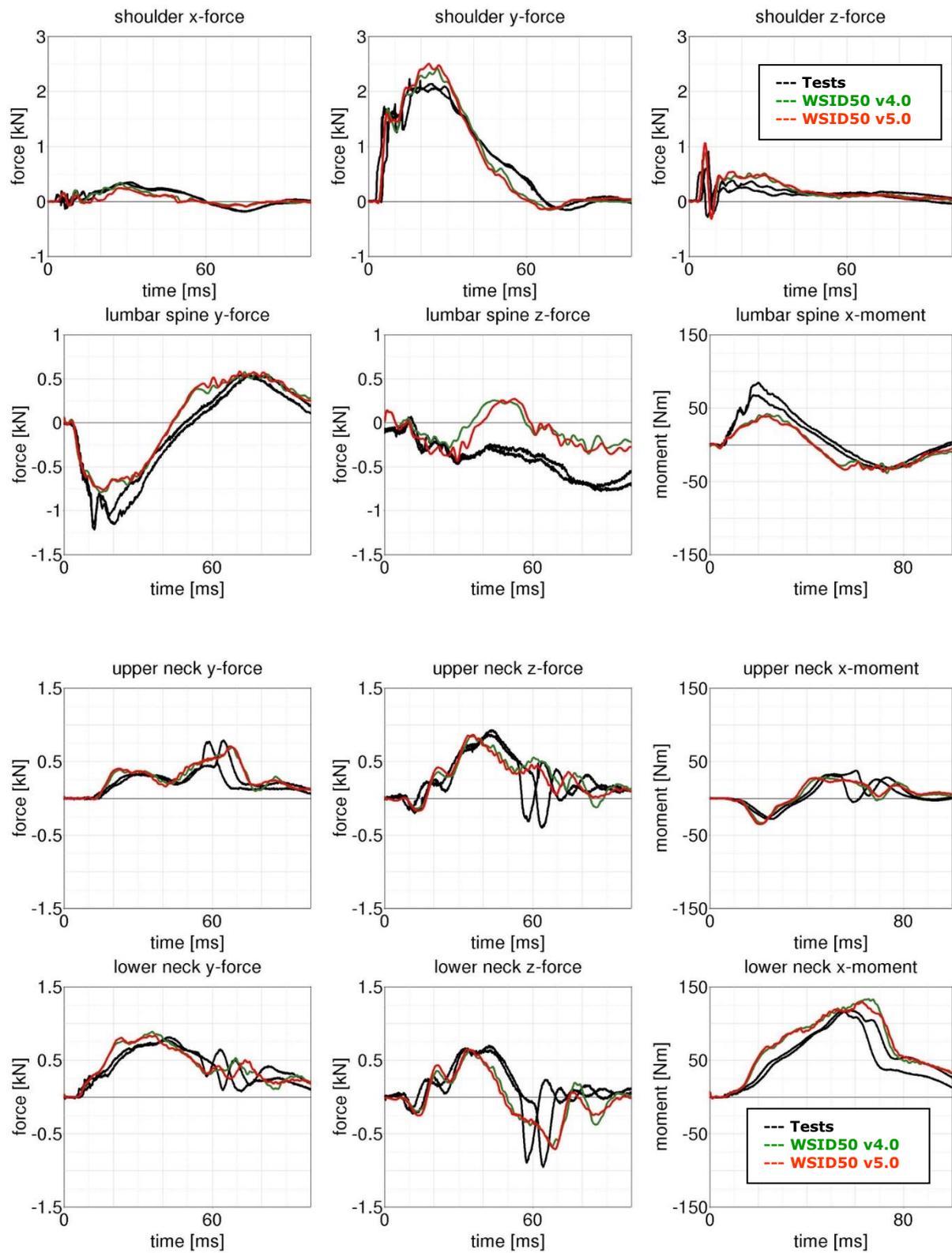


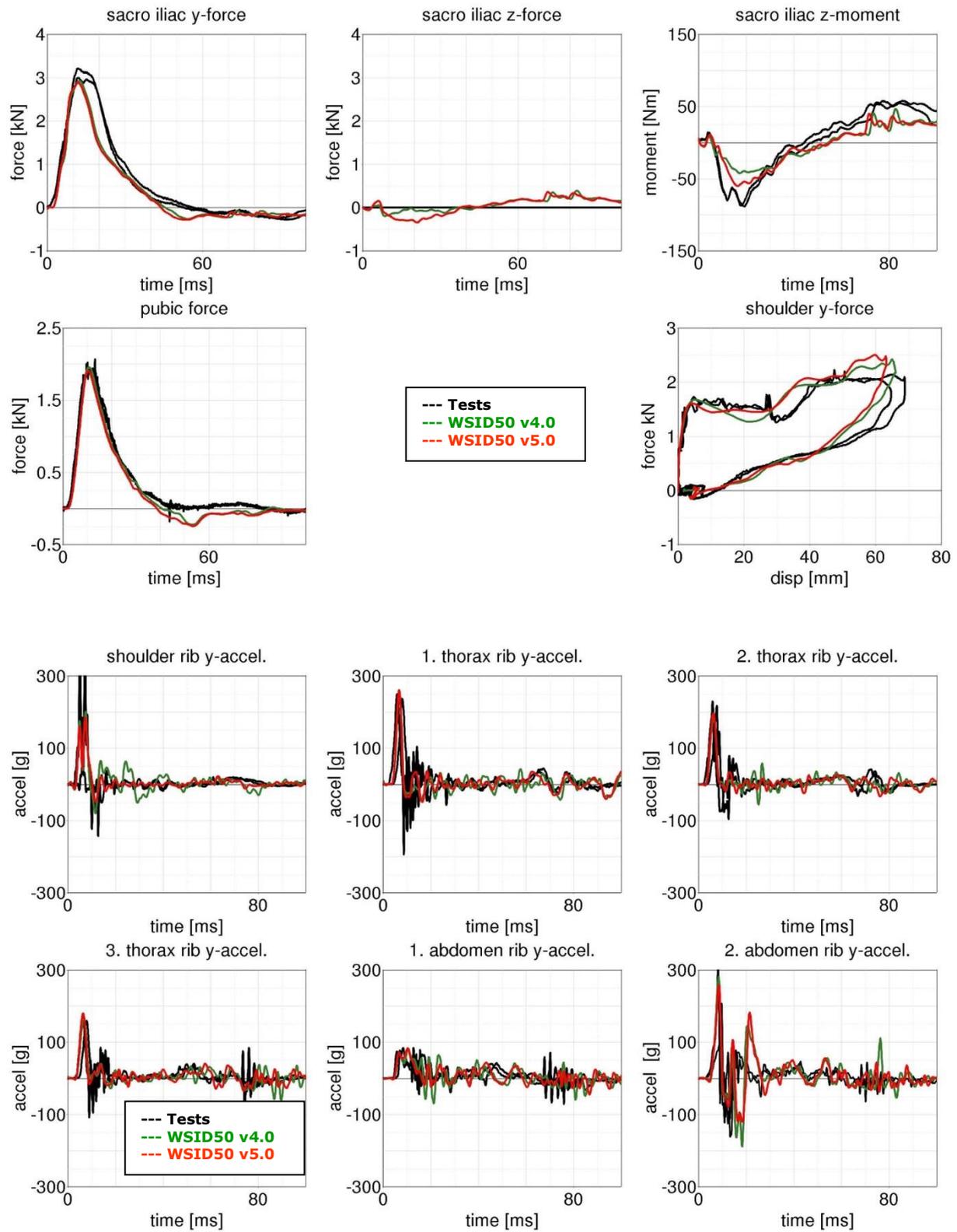




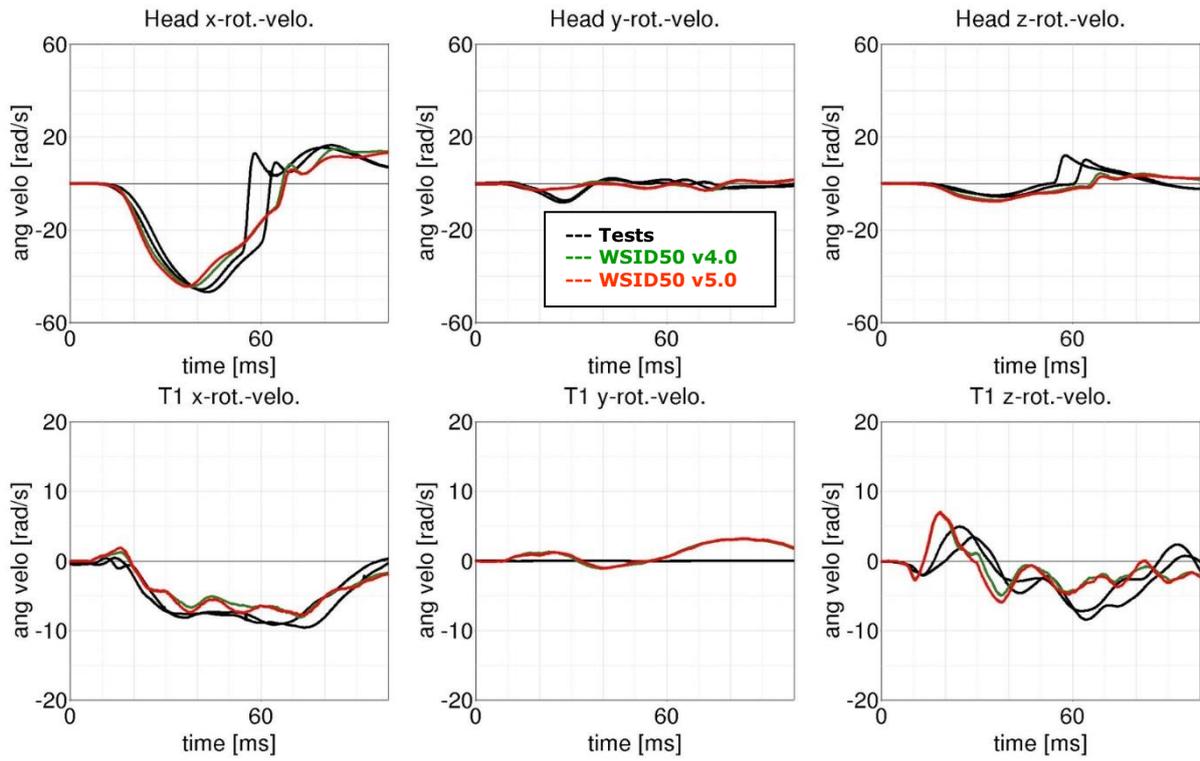
**High velocity:**



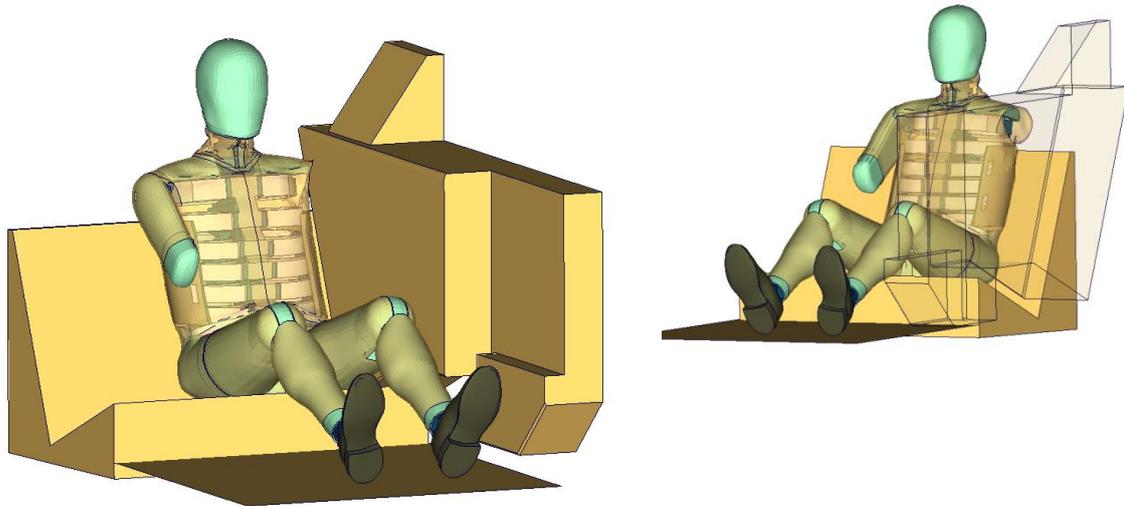




Performance – sled tests

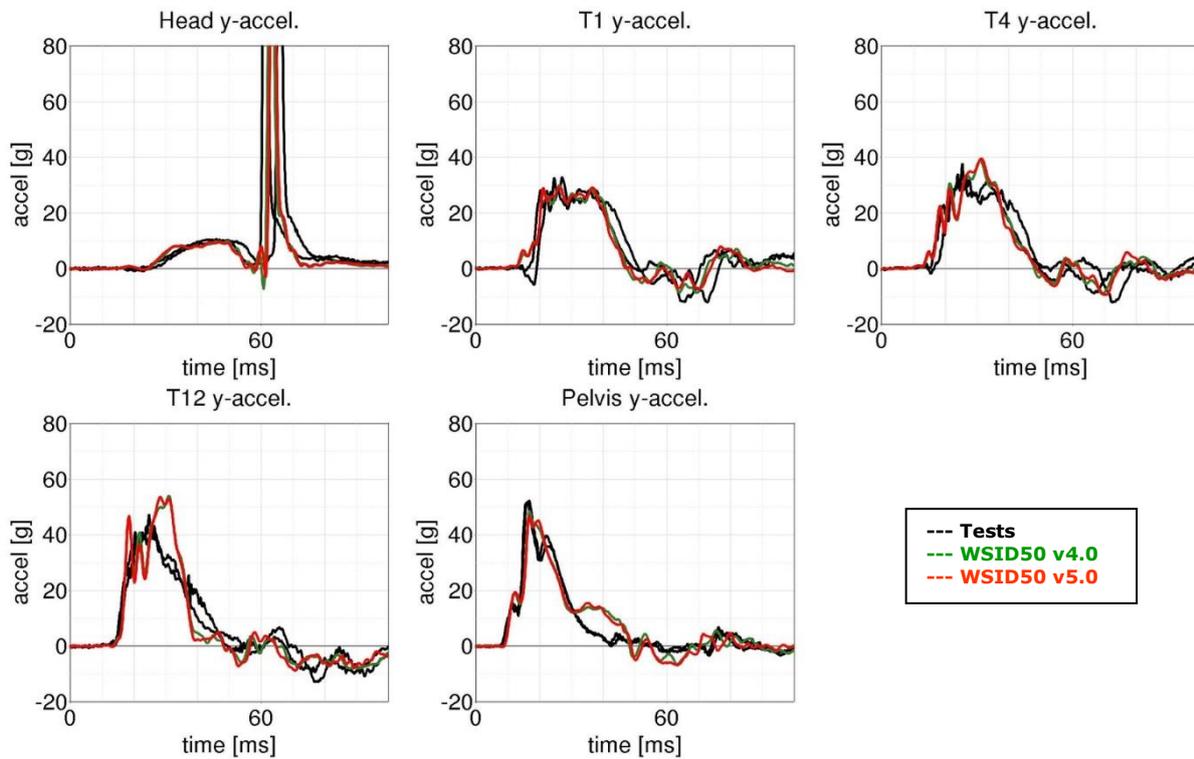


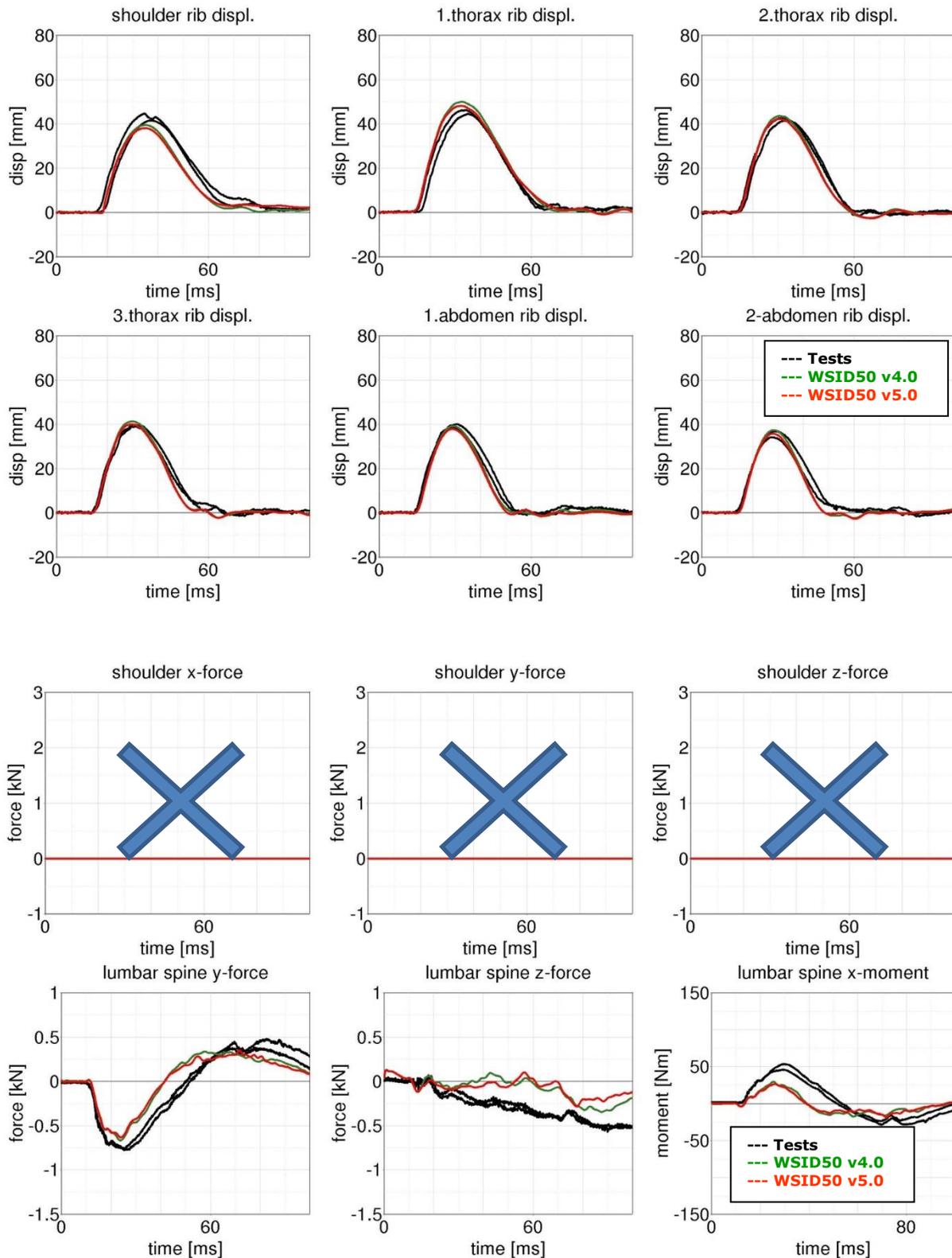
### 8.3.3 Flat barrier and WorldSID without arm

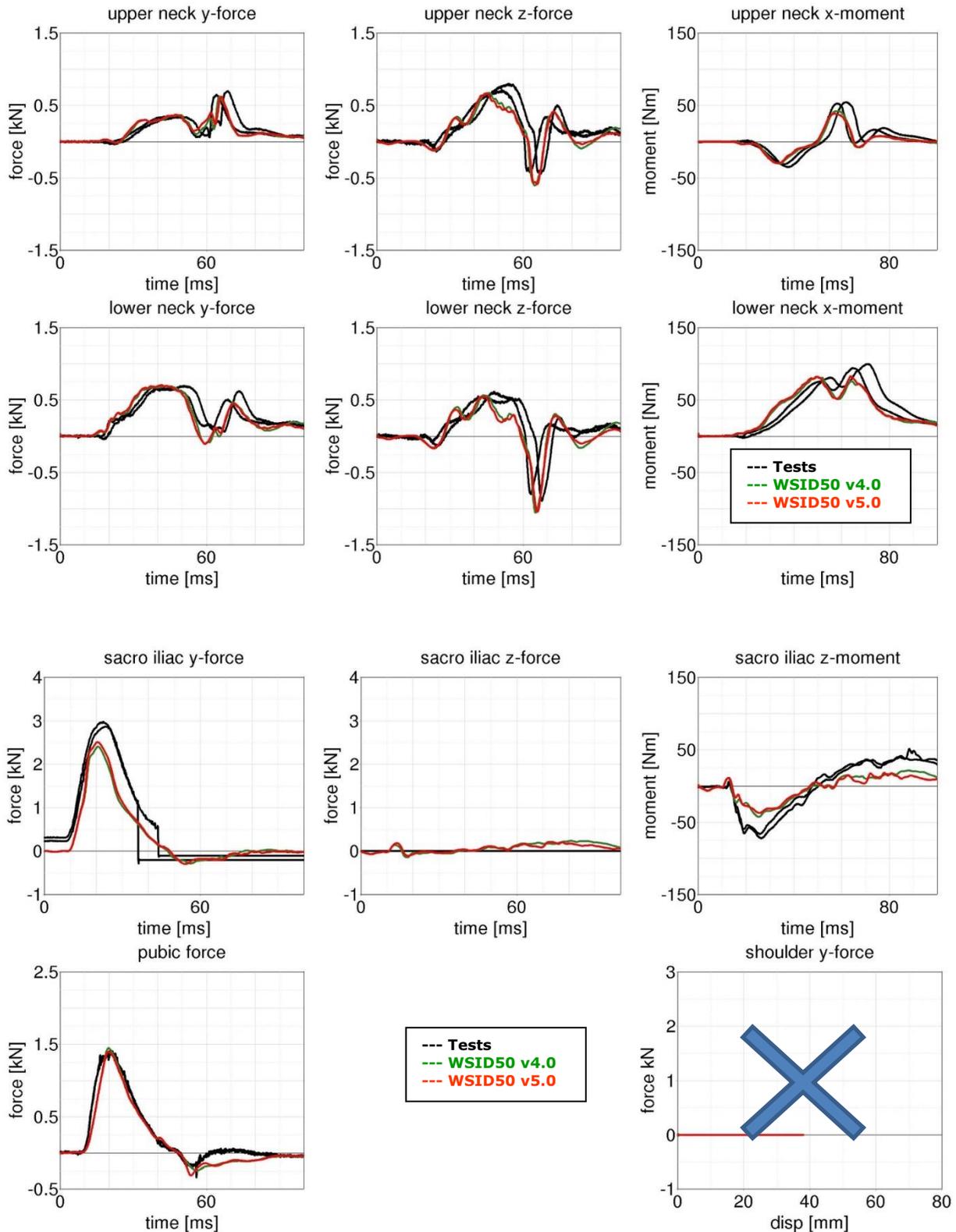


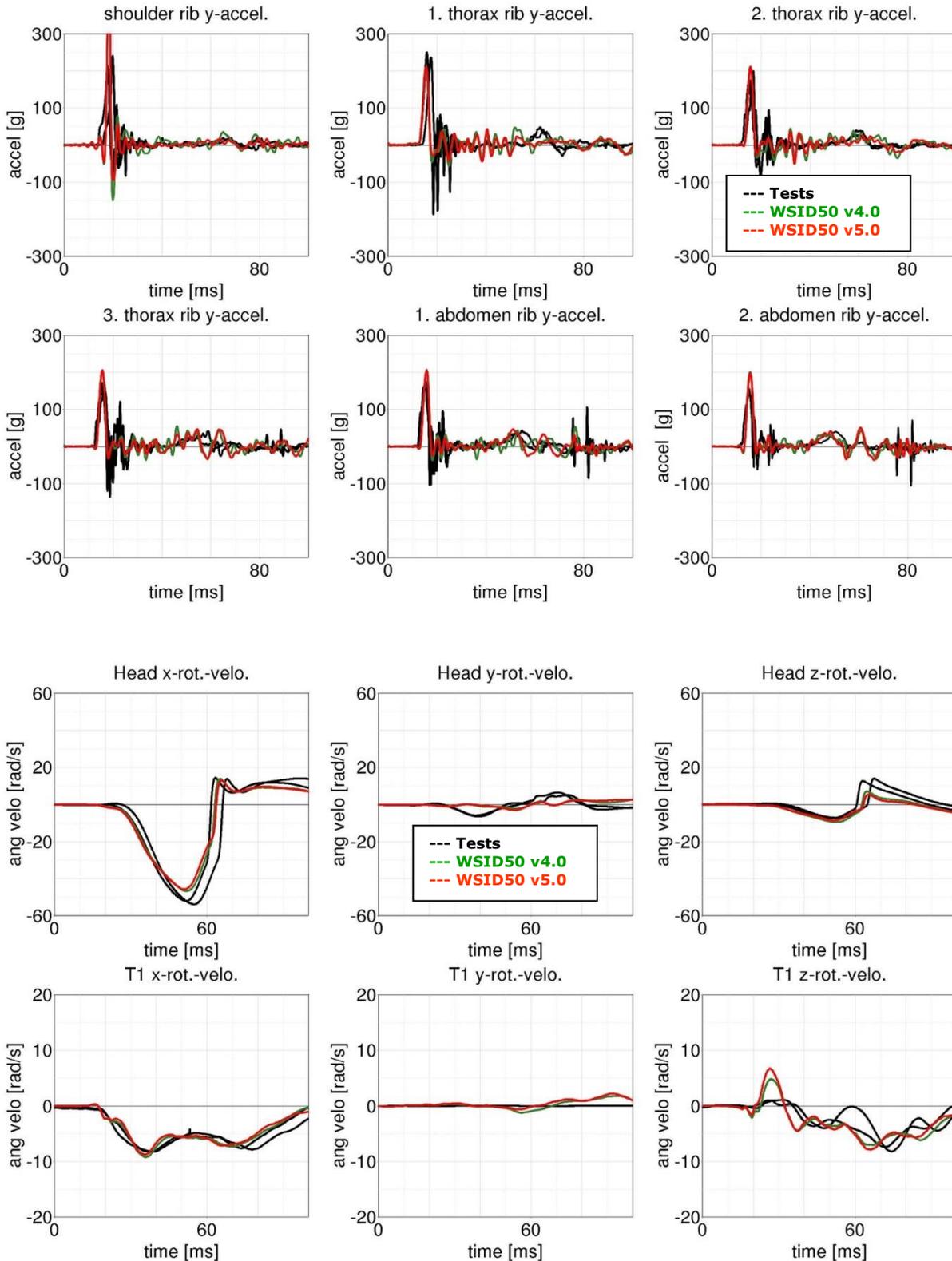
**Figure 217:** Flat barrier and without arm.

#### High velocity:



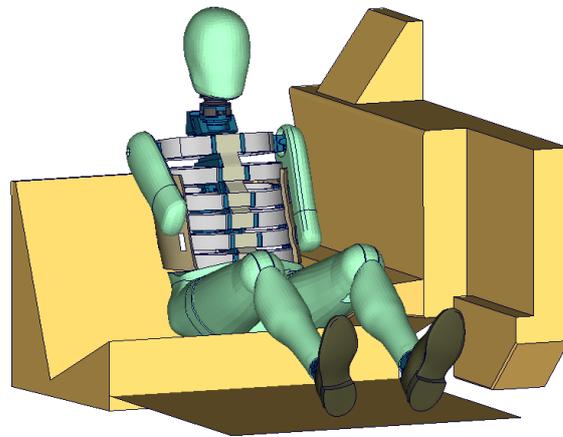




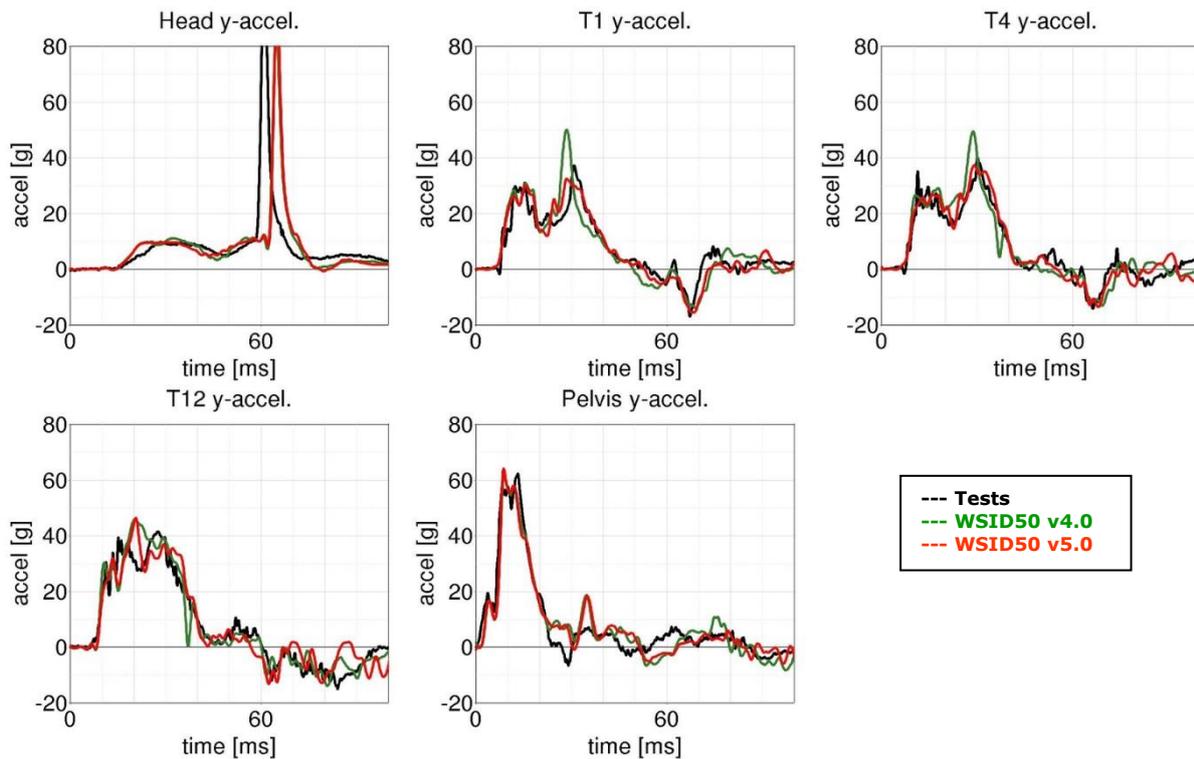


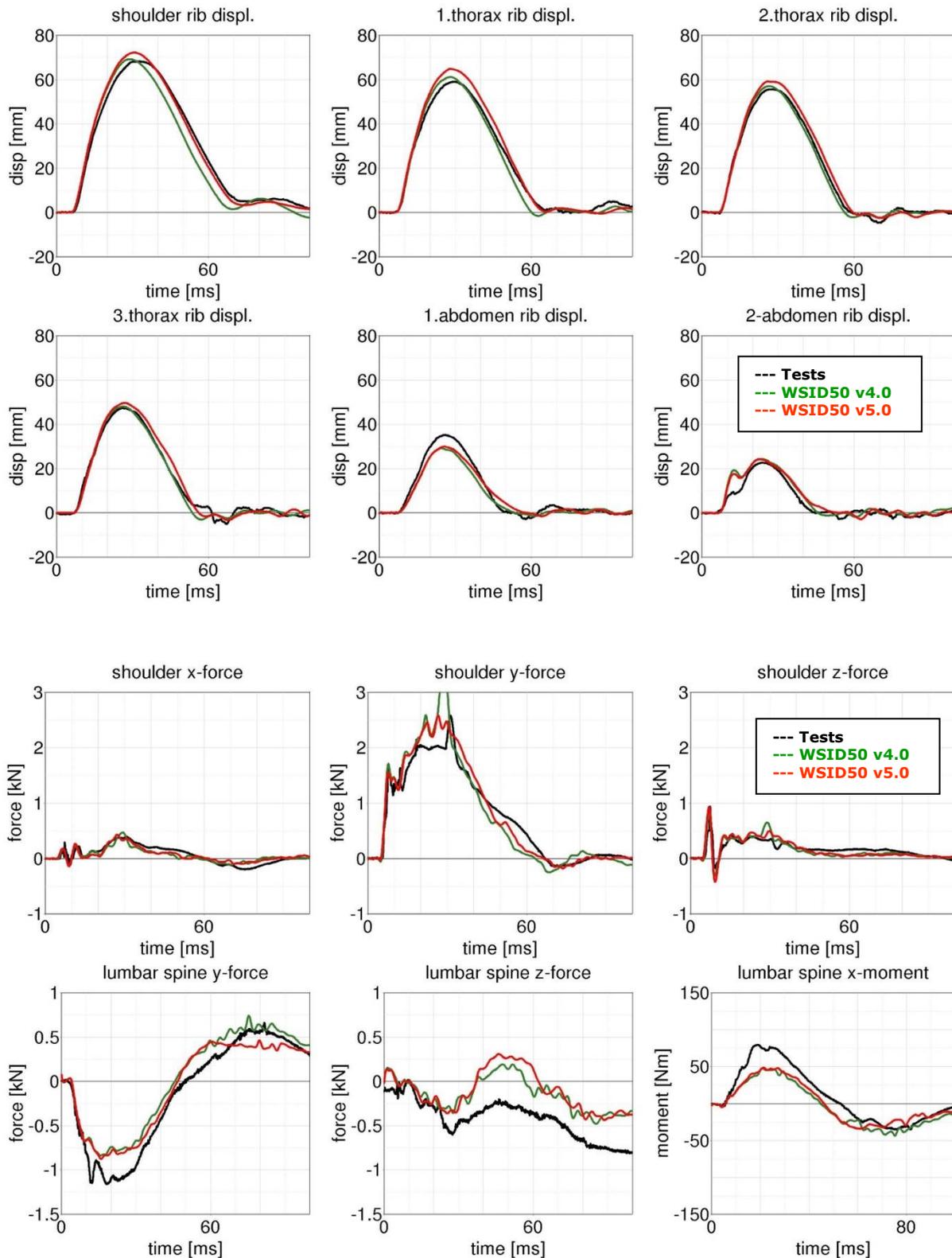
### 8.3.4 Pelvis shape barrier and WorldSID without Jacket

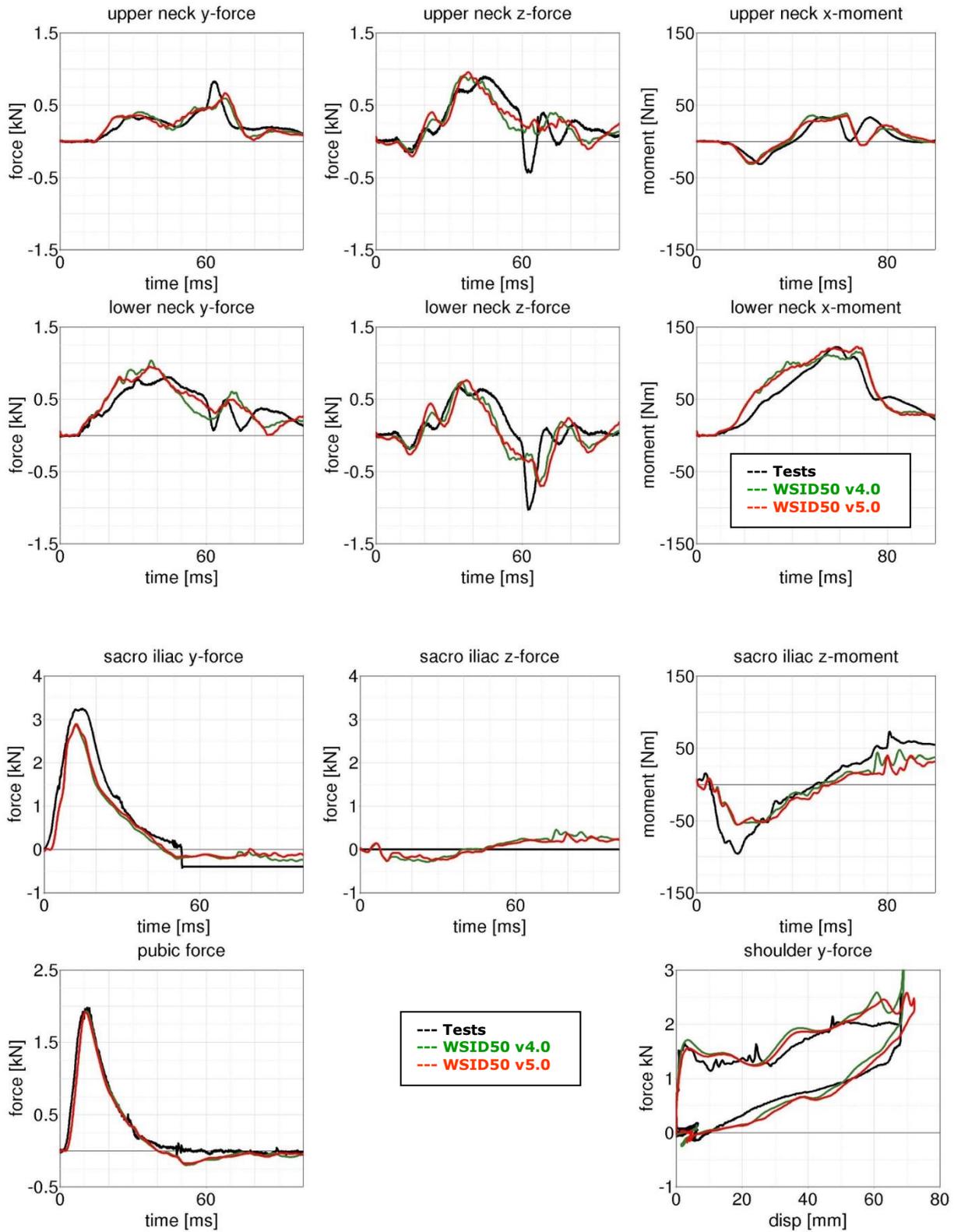
**Figure 218:** Pelvis barrier and arm first notch without jacket.

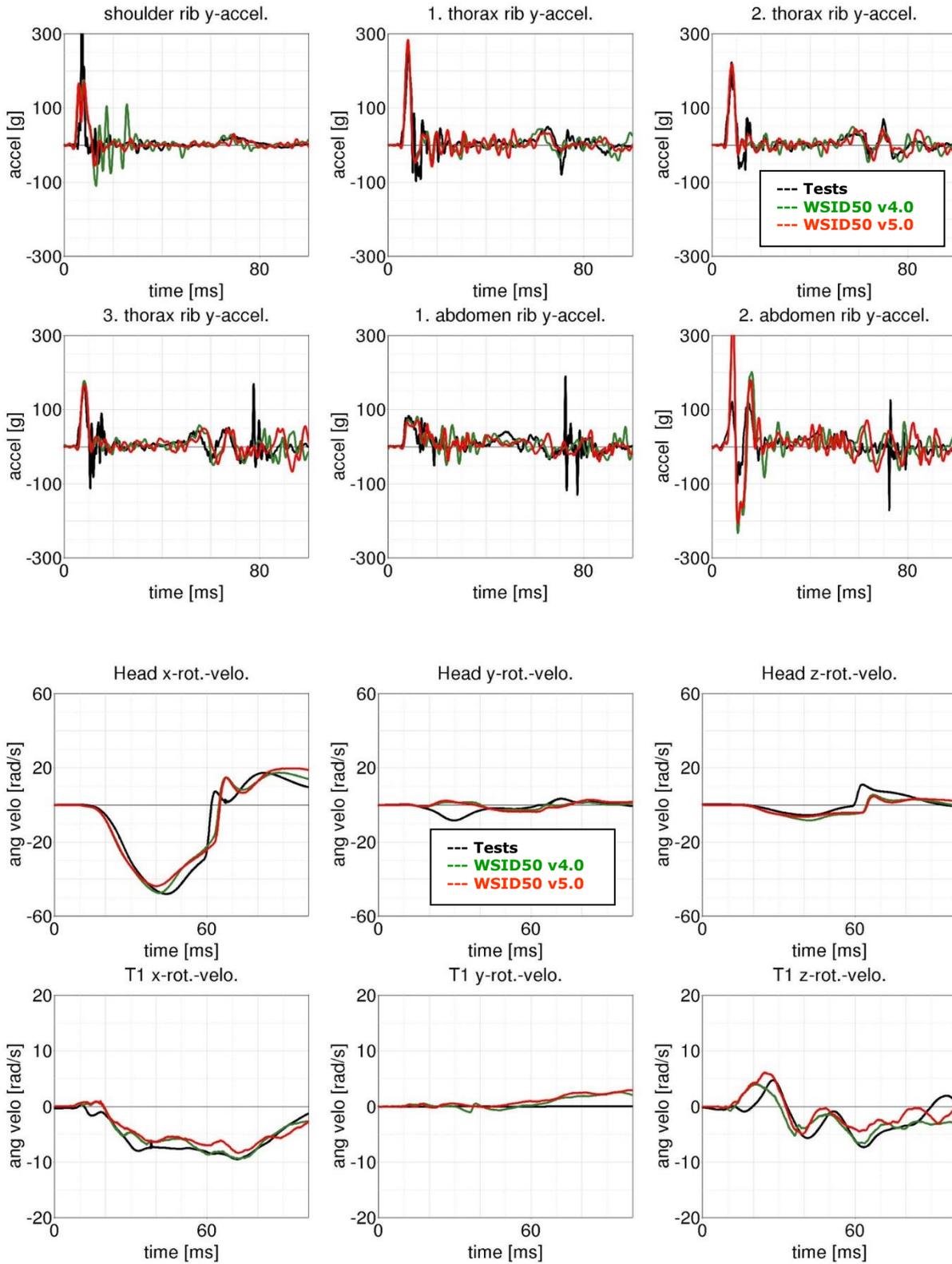


**High velocity:**









## 9. Literature

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- [6] S. Stahlschmidt, A. Gromer, M. Walz: "WorldSID 50th vs. ES-2. A Comparison Based on Simulations", 11th International LS-DYNA® Users Conference, 2010, Detroit.