HBM4VT – WG 2
Sled simulation setup

Forman et al. 2013

SCIENCE
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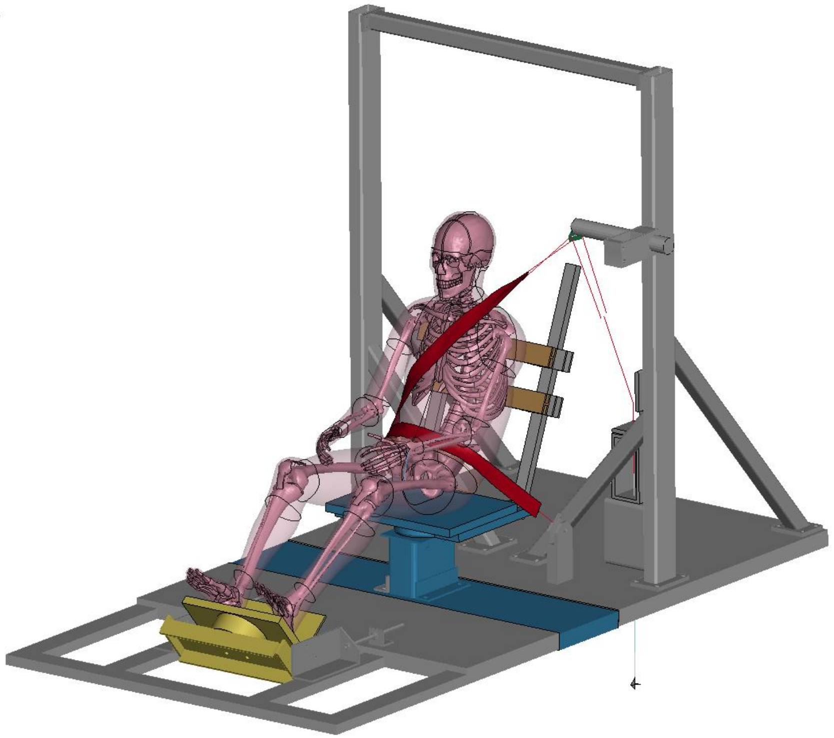
General Overview

Model Setup

Sled tests by Forman et al. 2013



Key factors to replicate from PMHS tests:

- HBM seated on rigid seat
  - Seat belt fitted
  - Hands on lap
  - Lower extremities on footrest
- Lateral and oblique load case with two severities
- Variation of D-ring position, pretensioner and pelvis block
- Head, shoulder and pelvis trajectory measured

Development notes

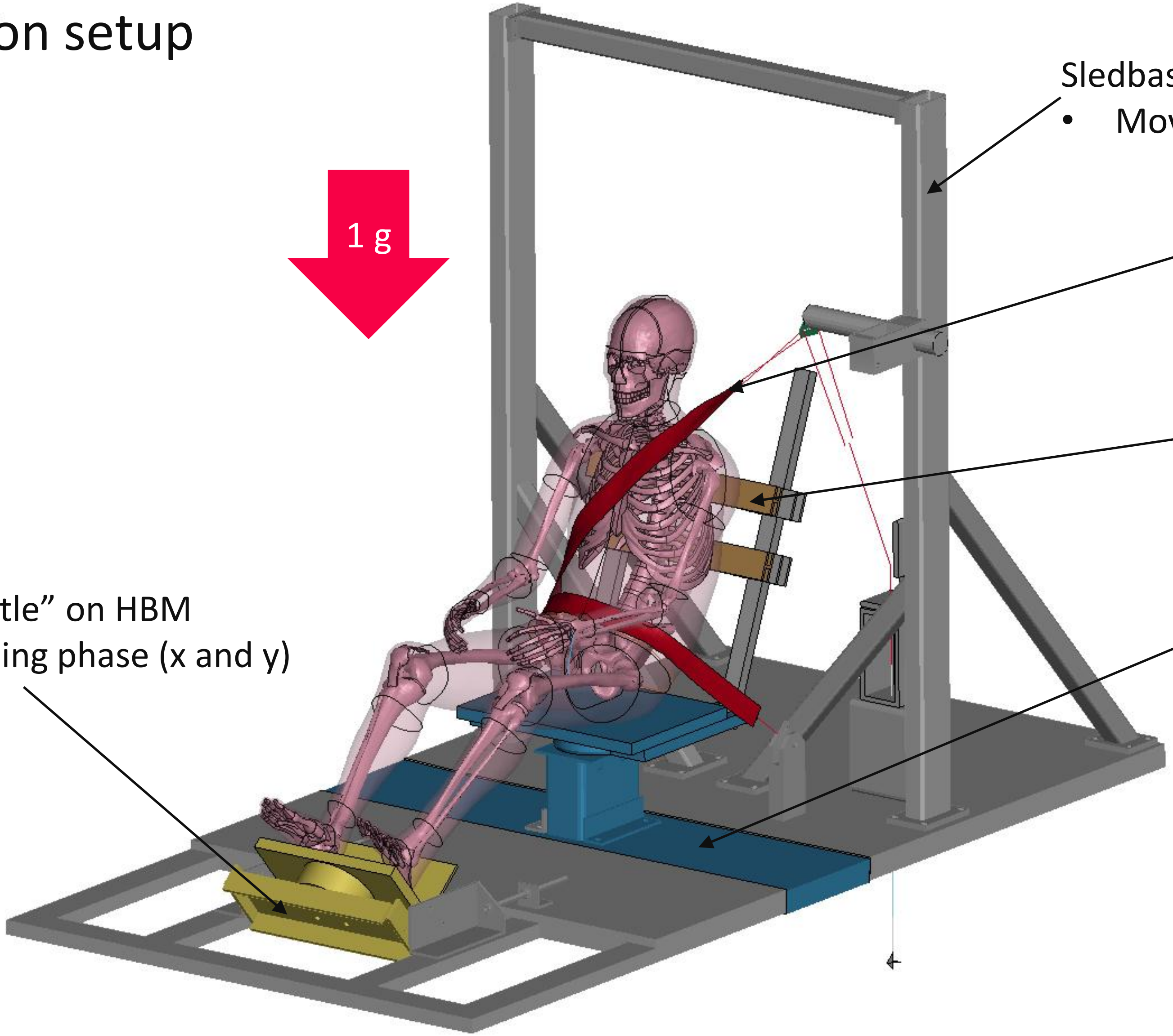
LS-Dyna version used for development:

- R12.2_217 mpp single precision (R12.2-217-gfcd6dde0c9)
- Time step: dt2ms = -4.44E-4 ms (tssfac = 0.9)

HBMs used in testing:

- THUMS v4.1 50th percentile male
- THUMS v4.1 95th percentile male
- VIVA+ v1.0.0 50th percentile female

Simulation setup



Sledbase
- Moves in loading phase (x)

Belt
- Fitted via load node

Backrest
- Moves to “settle” on HBM
- Moves in loading phase (x and y)

Sledbase – seat
- Moves to “settle” on HBM
- Moves in loading phase (x and y)

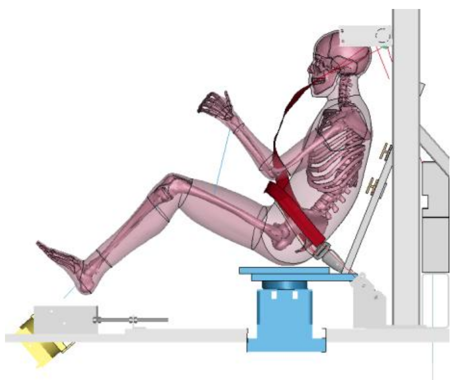
Footrest
- Moves to “settle” on HBM
- Moves in loading phase (x and y)

Simulation phases

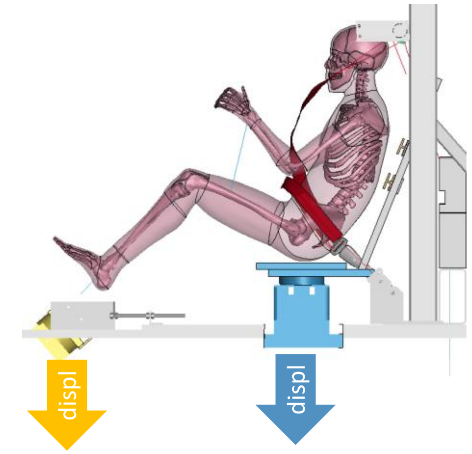
Initial model

HBM positioned in target position

- Rotation to reach target torso angle



Seat and footrest transformation



Seat

- Seat is moved downwards

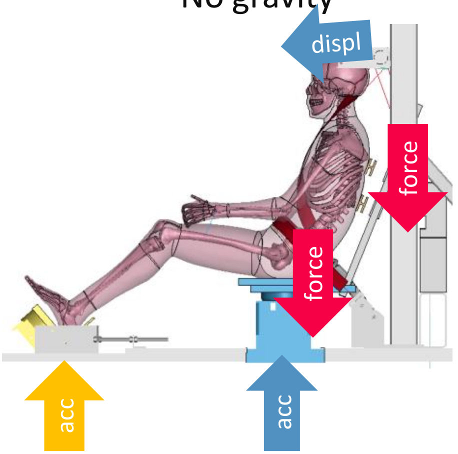
Footrest

- Footrest is moved downwards

Settling phase

Testbed settling and belt fit

- HBM pelvis and spine constraint
- No gravity

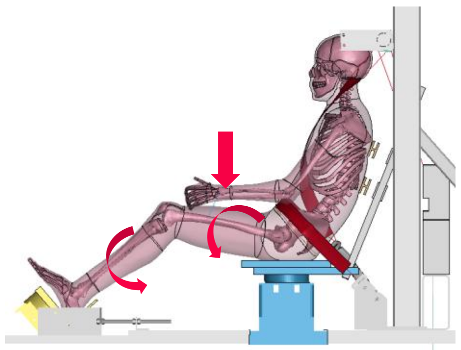


Testbed

- Seat is accelerated upwards with 1g
- Footrest is accelerated upwards with 1g
- **Belt fit**
- Pretension is applied to fit belt to HBM
- D-ring is moved to target position

Hand and leg positioning

- HBM pelvis and spine constraint
- No gravity



Hands

- Hands move to target position

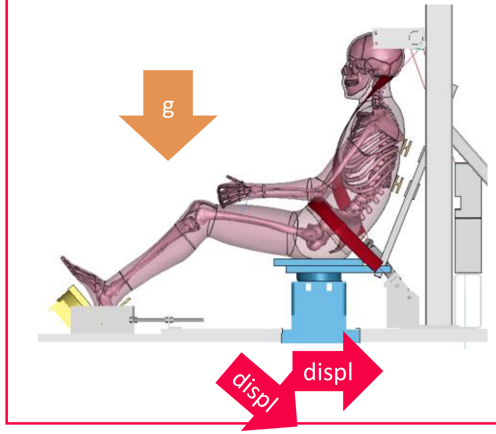
Lower extremities

- Femur is rotated to reach target orientation
- Tibia is rotated to reach target orientation

Loading phase

Load application

- HBM constraints released
- Gravity applied
- Sled loading applied



Load

- Sled displacement applied in x and y direction
- Gravity applied
- Belt load limiter

Simulation phases

Velocity of all HBM nodes set to 0

Settling phase	Loading phase
Pelvis and thorax of HBM constraint	No constraint
Femur rotates to target angle	Positioning beams deleted
Tibia rotates to target angle	Positioning beams deleted
Hands move to target position on thighs	Positioning beams deleted
1g applied on seat and footrest to “settle” on HBM	Load movement applied
D-ring moves to target position	Moves with testbed
100N pretension force applied	Load limiter in shoulder belt
Contact between HBM and testbed	Gravity applied

Time

SetHBM | *tload*

loadSt

Overview – belt load case

00_Master_Sled.k → Single file to be changed
Follow the descripted procedure

- **_HBM**
  - "HBM_include".k → Add your HBM-include in the folder „_HBM"
- **_env**
  - 00_Database_Control.k
  - 01_Testbed.k
  - 01a_Testbed_Seat_Side_Plate.k → Include this file, if the side plate is desired to be in the simulation
  - 02_Belt.k (02_Belt_longer) → Longer belt model provided in case of intersections of "02_Belt.k" to HBM. Use only if necessary.
  - 02_Belt_GenFunctRetractor_PT.key
  - 03_Boundary_Condition.k
  - 04_Position_springs.k
  - 05_Calculations.k

Procedure

Setting the parameters

Set the include file

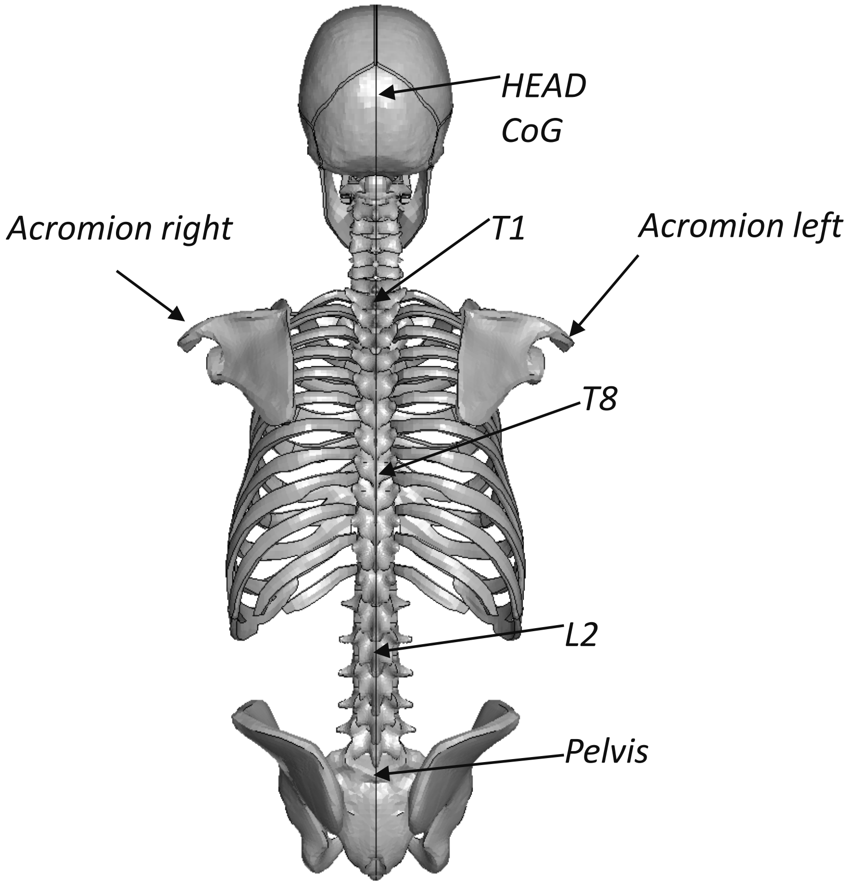
1) Put the main HBM file in the folder directory "_HBM"
2) Open the main HBM file in a pre-processor
3) Open the file 00_Master_Sled.k in a text editor
4) Define the main HBM file in the I N C L U D E S section
5) Follow the instructions from STEP 1 to STEP 8

- Note: If you need to change previously defined parameters, walk through the subsequent steps again and check if parameters need to be updated. E.g. the coordinates of the landmarks need to be updated, if the position of the HBM changes.

Instrumentation requirements

- Equip your HBM with the required output
  - Head CoG
    - *ELEMENT_SEATBELT_ACCELEROMETER required to provide local output
  - T1, T8, L2 and Pelvis
    - *DATABASE_HISTORY_NODE_ID
    - Refer to following public documents:
      - Vertebrae: [TB024 Pedestrian Human Model Certification, Annex B]
      - Pelvis: [Report on PMHS 494, 492. ATD Thoracic response test development, NHTSA, 2011]
  - Acromion
    - *DATABASE_HISTORY_NODE_ID on acromion (right & left)
  - Strains in cortical bones of pelvis and ribs

- Note: make sure your output rate is at least 10kHz for contact and nodal outputs since CFC filtering is applied in Jupyter notebook
- Update all node IDs in the HBM ID-file in "…\data\metadata" accordingly (see THUMS/VIVA+ files for examples)



Overview on stepwise simulation setup (see following slides)

1) Definition of the load case
2) Definition of the unit system of the HBM
3) Definition of the HBM position and orientation
4) Set ID for contact sets and constraints
5) Define torso angle, distances and ID offset
6) Define attachment nodes for positioning beams
7) Check for intersections and measure angles
8) Estimate D-ring position
9) Run simulation and check results

Overview on stepwise simulation setup (see following slides)

1) Definition of the load case

Goal:

- Define the desired load case
    - 6 configurations available

Overview on stepwise simulation setup (see following slides)

1) Definition of the load case
2) Definition of the unit system of the HBM
3) Definition of the HBM position and orientation

Goal:

- Set factor to scale environment to the unit system of the HBM
- Define the position and orientation of the HBM
- Use this point as origin and rotate HBM to bring it in supine position

Overview on stepwise simulation setup (see following slides)

1) Definition of the load case
2) Definition of the unit system of the HBM
3) Definition of the HBM position and orientation
4) Set ID for contact sets and constraints
5) Define torso angle, distances and ID offset

Goal:

- Define sensible HBM contact set
- Define parameters for positioning of the HBM

Overview on stepwise simulation setup (see following slides)

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2) Definition of the unit system of the HBM
3) Definition of the HBM position and orientation
4) Set ID for contact sets and constraints
5) Define torso angle, distances and ID offset
6) Define attachment nodes for positioning beams

Goal:

- Define how extremities are moved during settling

Overview on stepwise simulation setup (see following slides)

1) Definition of the load case
2) Definition of the unit system of the HBM
3) Definition of the HBM position and orientation
4) Set ID for contact sets and constraints
5) Define torso angle, distances and ID offset
6) Define attachment nodes for positioning beams
7) **Check for intersections and measure angles**

Goal:

- Check for intersection of the HBM to the sled and measure angles

Overview on stepwise simulation setup (see following slides)

1) Definition of the load case
2) Definition of the unit system of the HBM
3) Definition of the HBM position and orientation
4) Set ID for contact sets and constraints
5) Define torso angle, distances and ID offset
6) Define attachment nodes for positioning beams
7) Check for intersections and measure angles
8) **Estimate D-ring position**

Goal: Define D-ring location to achieve target shoulder belt angle

Overview on stepwise simulation setup (see following slides)

1) Definition of the load case
2) Definition of the unit system of the HBM
3) Definition of the HBM position and orientation
4) Set ID for contact sets and constraints
5) Define torso angle, distances and ID offset
6) Define attachment nodes for positioning beams
7) Check for intersections and measure angles
8) Estimate D-ring position
9) Run simulation and check results

Goal: Adapt settling or load time if necessary

STEP 1

Definition of the load case

Define the desired load case by setting 1 for the load case to be simulated. Set only on flag to 1 and keep 0 for the remaining load cases

	Load direction	Sled pulse	D-ring position	Pretensioner	Side plate
Config 1	Oblique	14g	Intermediate	Active	No
Config 2	Oblique	6.6g	Intermediate	Inactive	No
Config 3	Oblique	6.6g	Intermediate	Active	No
Config 4	Oblique	6.6g	Back	Active	Yes*
Config 5	Lateral	6.6g	Forward	Active	No
Config 6	Lateral	14g	Intermediate	Active	No

*For configuration 4 include the side plate include “01a_Testbed_Seat_Side_Plate.k“ in the “I N C L U D E S” section

STEP 2

Definition of the unit system of the HBM

Define the scale factors depending on the unit system of the HBM

- *U_Scal*: 0.001 for unit system t-mm-s
- *U_Scal*: 1 for unit system kg-mm-ms

→ The testbed environment will be scaled by *U_Scal* to the preferred unit system

Define the correct unit system in the assessment Jupyter notebook

- ms_mm_kg
- s_mm_ton

Attention: all parameters in the **main key file** need to be defined in the unit system **kg-mm-ms**

Define if the used HBM wears shoes or not

- *Shoes:* set to 0 if HBM wears shoes
- *Shoes:* set to 10 if HBM wears NO shoes

→ Footrest is positioned +10mm in x and z direction if HBM doesn‘t wear shoes (represents thickness of sole)

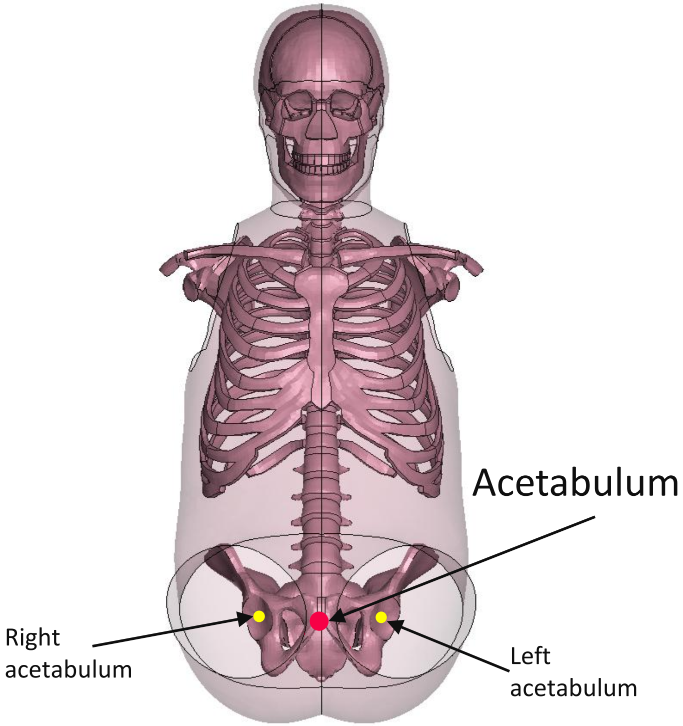
STEP 3

Definition of the HBM position and orientation

Define the coordinates of the location of the acetabulum centre point (AC) between the left and right acetabulum (in midsagittal plane):

- *x_AC*: x-coordinate of acetabulum in the default HBM position with respect to the global coordinate system
- *y_AC*: y-coordinate of acetabulum in the default HBM position with respect to the global coordinate system
- *z_AC*: z-coordinate of acetabulum in the default HBM position with respect to the global coordinate system

→ The HBM will be transferred to the H-point of the seat



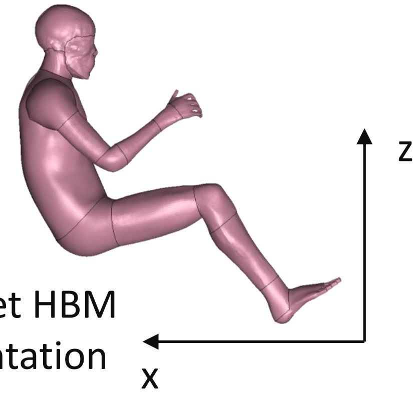
Default HBM position

Check the actual HBM orientation and compare to the target orientation as illustrated

Define the flag to 1 or -1 for all axes:

- *x_rt*: “1” for correct axis orientation and “-1” to rotate the model 180deg about the x axis
- *y_rt*: “1” for correct axis orientation and “-1” to rotate the model 180deg about the y axis
- *z_rt*: “1” for correct axis orientation and “-1” to rotate the model 180deg about the z axis

→ HBM will be rotated to reach target orientation



Target HBM orientation

STEP 4

Set ID for contact sets and constraints

Define the part set of the HBM

- *P_hbm*: ID of the set including all HBM parts

→ This part set will be damped

Define the part set of all skin parts of the HBM

- *P_ski*: ID of the set including all skin parts of the HBM

→ This part set will be in contact to the testbed

Define the part set of the HBM body without arms and lower legs

- *P_bdy*: ID of the set including the HBM body without arms and lower legs

→ This part set will be in contact to the belt in the settling phase

Define the mass of the HBM without legs

- *M_HBMt*: Mass of the HBM without legs in [kg]

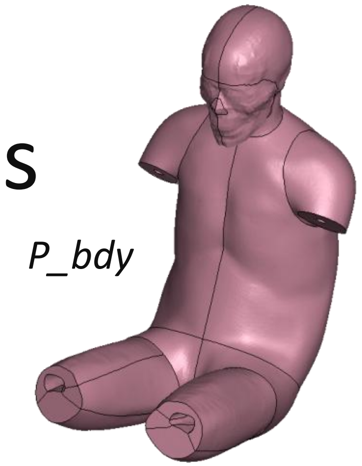
→ The mass of the seat will be matched to the mass of the HBM without legs to reproduce a realistic settling behaviour

Define the node set including several nodes on the bones of the pelvis and the thorax (e.g. choose three nodes per bone, not all nodes of a bone are required to be constrained)

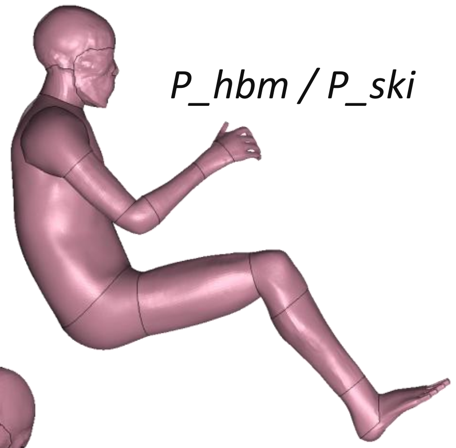
- N_bone: ID of the set including nodes on bones of pelvis, spine and ribs

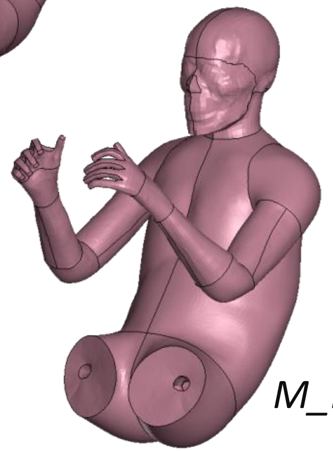
→ This node set will be constrained in the settling phase (do not choose nodes belonging to rigid materials or rigid bodies)

P_bdy

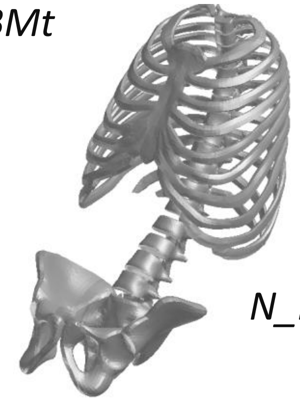


P_hbm / P_ski





M_HBMt



N_bone

STEP 5

Define sternum angle, distances and ID offset

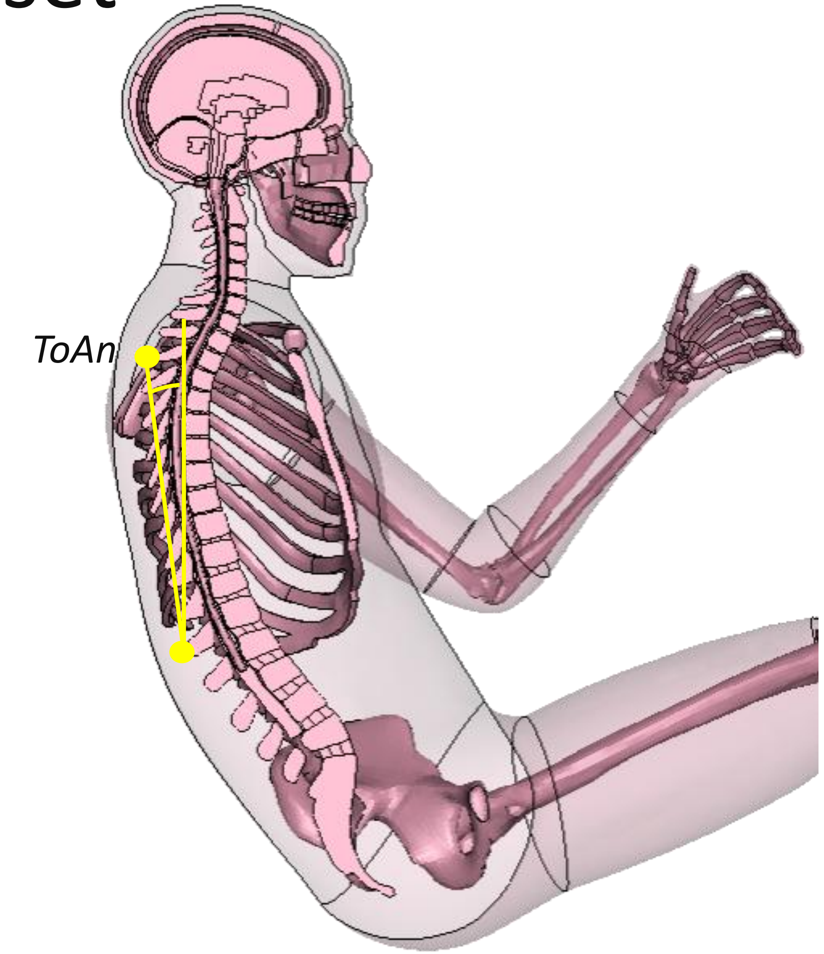
Measure the thorax angle between T3 and L1 relative to the frontal plan

- *ToAn*: angle in default posture of HBM used here

→ The HBM will be rotated to achieve a thorax angle of 12.2° against the vertical plane

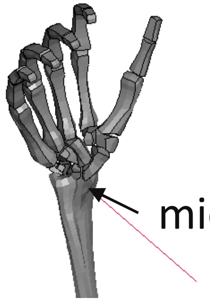
IF the testbed shares node IDs with HBM, set an ID offset for the HBM

- *IDoff*: default: 0.

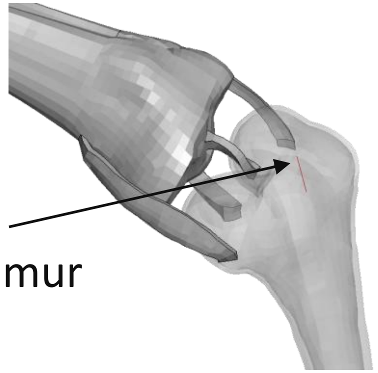


S T E P 6

Define attachment nodes for positioning beams



Save the file “00_Master_Sled.k” and open it in a pre-processor



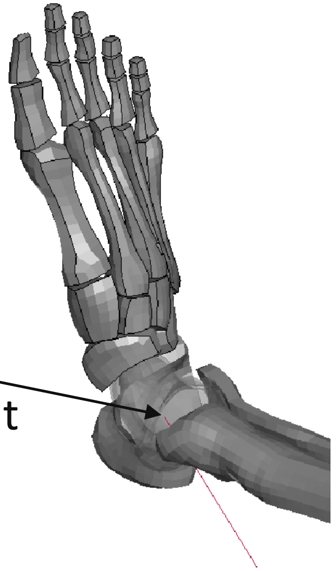
Node IDs for the landmarks to be positioned

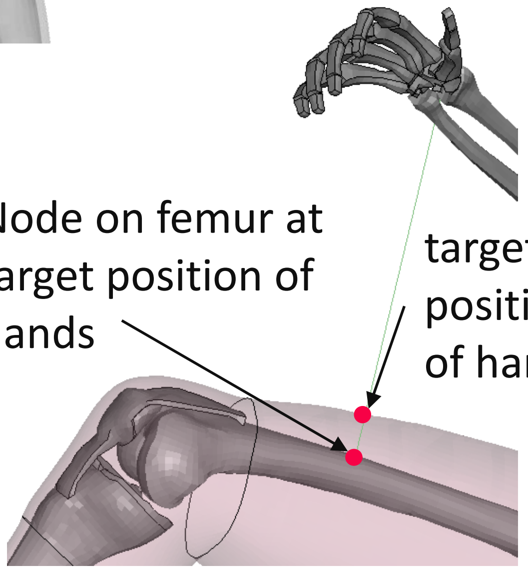
ri = right, le = left

- *N_rari/N_rale*: Node at mid of distal radius
- *N_tari/N_tale*: Node on femur at target position of hands
- *N_feri/N_fele*: Node at mid of distal femur
- *N_anri/N_anle*: Node at mid of ankle joint

Coordinates of landmark nodes in updated “00_Master_Sled.k” file

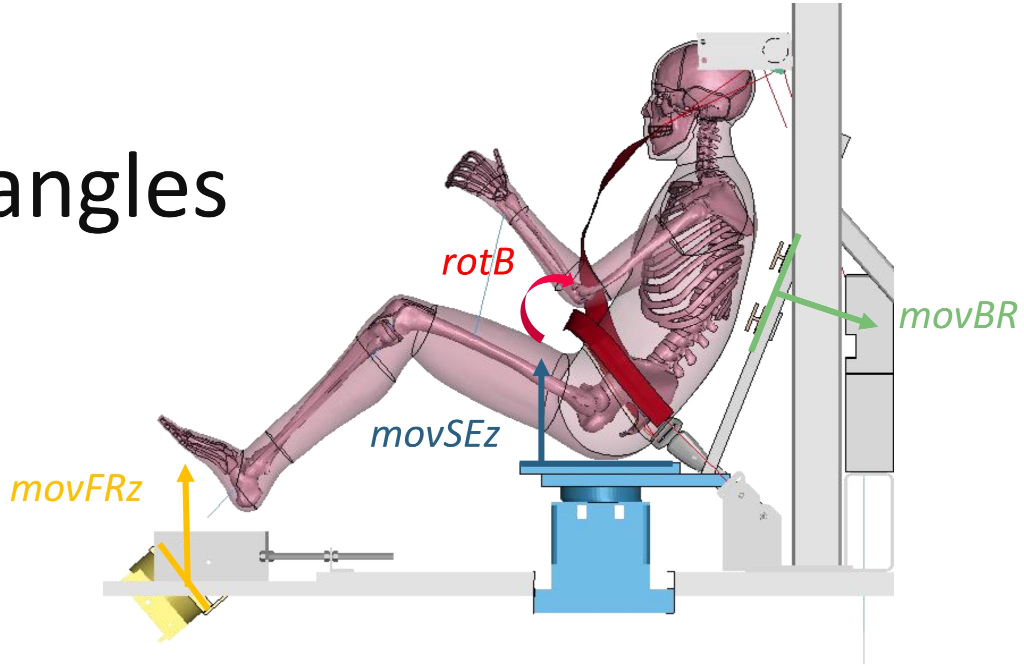
- X...: x-coordinates of chosen landmarks in positioned model
- Y…: y-coordinates of chosen landmarks in positioned model
- Z…: z-coordinates of chosen landmarks in positioned model





STEP 7

Check for intersections and measure angles



Save the file “00_Master_Sled.k” and open it in a pre-processor

IF backrest has intersections to the HBM, move backrest in joint direction

- *movBR*: moving distance of backrest in joint direction (positive value = backrest moves away from HBM)

IF the HBM has intersections to the seat, move seat in z

- *movSEz*: moving distance of seat in z (positive value = upwards)

IF the HBM has intersections to the foot rest, move the foot rest in z

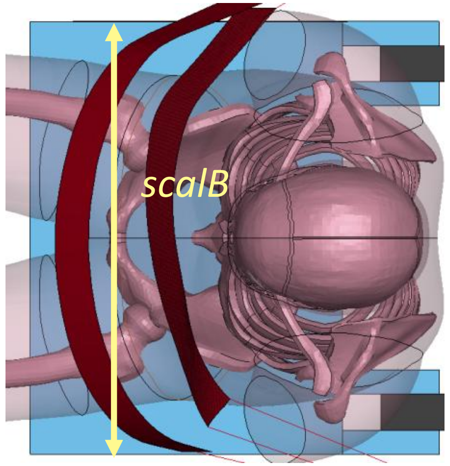
- *movFRz*: moving distance of foot rest in z (positive value = upwards)

IF the shoulder belt has intersections to the HBM (e.g. AM95), use the longer belt model

- update the name of the belt include “02_Belt.k” in the file “00_Master_Belt.k” to “02_Belt_longer”

IF the lap belt has intersections to the HBM:

- rotate the lap belt about the y-axis
  - *rotB*: rotation angle in degrees about y axis (positive value = rotation upwards)
- scale the lap belt in y-axis
  - *scalB*: scale factor of lap belt in y-axis (positive value = lap belt extends to the side)



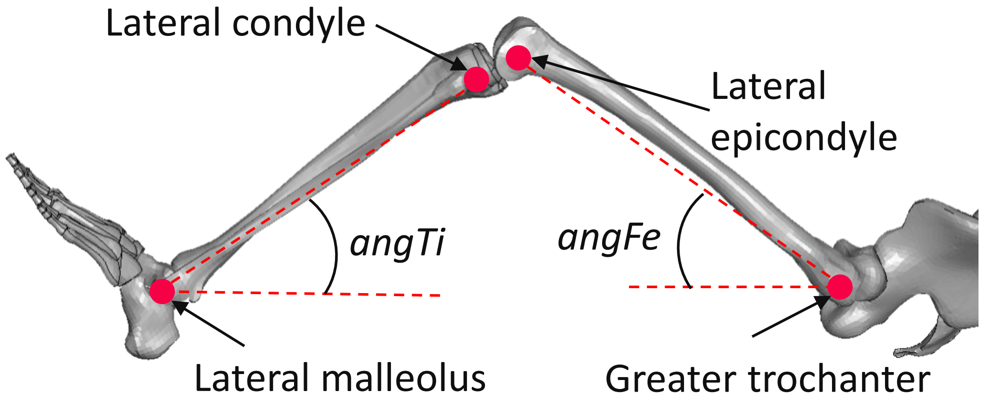
STEP 7

Check for intersections and measure angles

Measure the femur and the tibia angle to the horizontal axis in the x-z plane in the positioned HBM on the sled

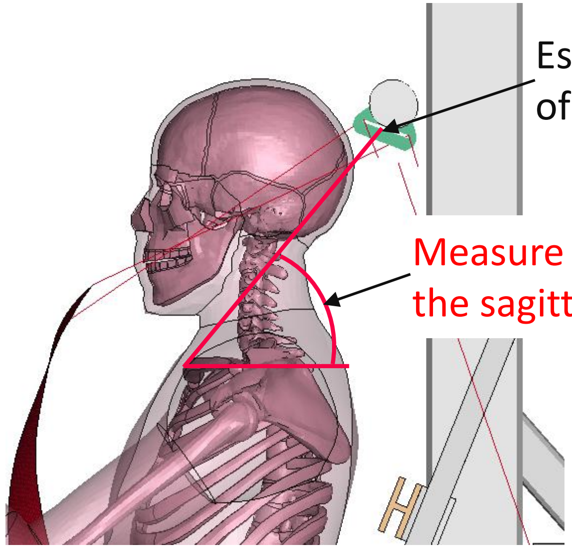
- *angFe*: femur angle defined as a positive value
- *angTi*: tibia angle defined as a positive value

→ The target positon of the knee and the ankle will we defined to achieve a femur angle of 11° and a tibia angle of 40° to the horizontal plane



STEP 8

Estimate D-ring position



Information on the procedure:

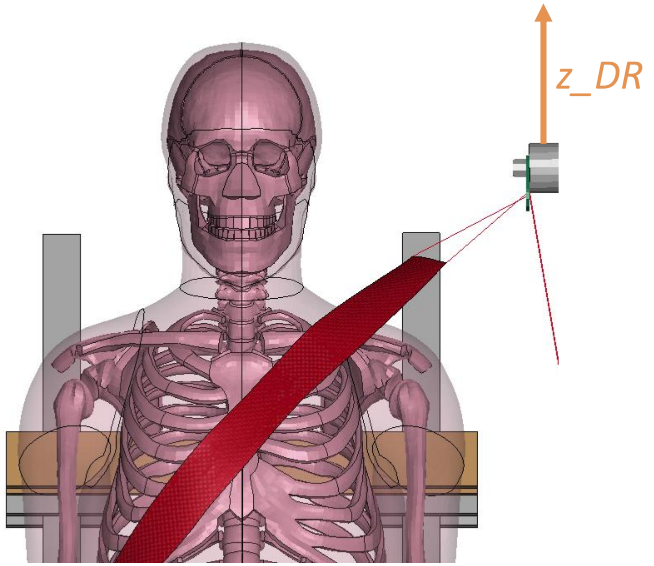
The position of the D-ring must be determined in order to achieve a specific shoulder belt angle. As it is not possible to measure this angle before the belt is fitted, it must be estimated (step 8). This is done by measuring the angle between the D-ring and the location on the clavicle, where the belt is assumed to detach from the HBM .

Once the simulation has been run (step 9), the actual shoulder belt angle is measured between the D-ring and the end of the 2D belt.

Measure the belt angle between the clavicle* and the D-ring in the sagittal plane. If the belt angle is within the given range (depending on the configuration), do not change *z_DR*.

Configuration depending target angles:

- Conf1, Conf2, Conf3 and Conf6: belt angle between 26 deg and 37 deg
- Conf4: belt angle between 24 deg and 33 deg
- Conf5: belt angle between 28 deg and 40 deg



If the belt angle is not within range, estimate the necessary D-ring location in z direction to achieve the target angle (in the settled model) and adopt z_DR accordingly:

- *z_DR*: z translation of the D-ring (positive z value: D-ring moves upwards)

*Note that, depending on the anthropometry of the used HBM, the point on the torso where you would expect the belt to detach from the HBM might differ. Choose a suitable node for your HBM (not necessarily on the clavicle).

STEP 9

Run simulation and check results

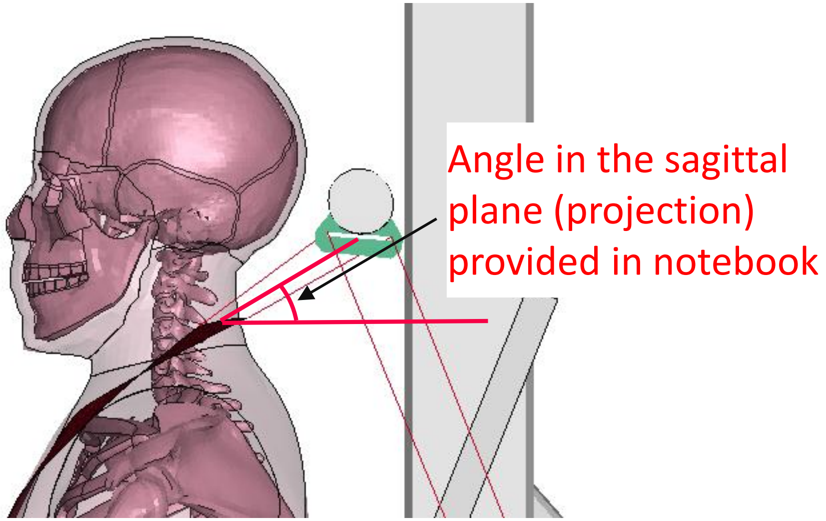
Measure the belt angle again between the end of the 2D shoulder seat belt and the D-ring in the sagittal plane (Calculation procedure is integrated in the assessment notebook).If the belt angle is NOT within the given range (depending on the configuration), change z_DR accordingly in step 8.

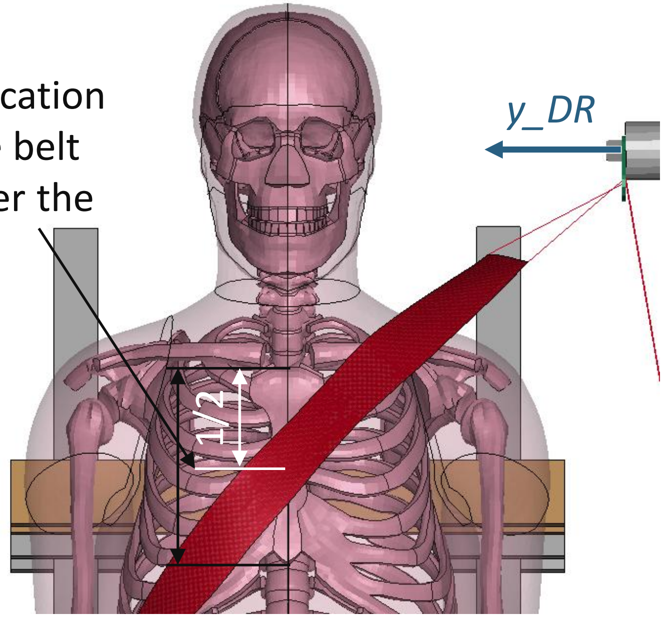
Configuration depending target angles:

- Conf1, Conf2, Conf3 and Conf6: belt angle between 26 deg and 37 deg
- Conf4: belt angle between 24 deg and 33 deg
- Conf5: belt angle between 28 deg and 40 deg

IF seat belt does not pass over the mid sternum, adjust y-position of D-ring

- *y_DR*: y translation of D-ring (positive y value: D-ring moves towards HBM)





S T E P 9
Run simulation and check results

Check the d3plot and adapt the parameter if needed:

Measure the distance between the seat base and the sled base in the settled model
- Distance < 5mm: neither a change of z_set nor a rerun of the simulation is required.
- Distance > 5mm: insert the measured value for *z_set*, update the z-coordinates of the nodes in step 7 and rerun the simulation.
  - *z_set*: distance in z (insert a positive value, if the seat base is below the sled base)

→ After the settling phase, the seat will be at the same height as is the PMHS tests

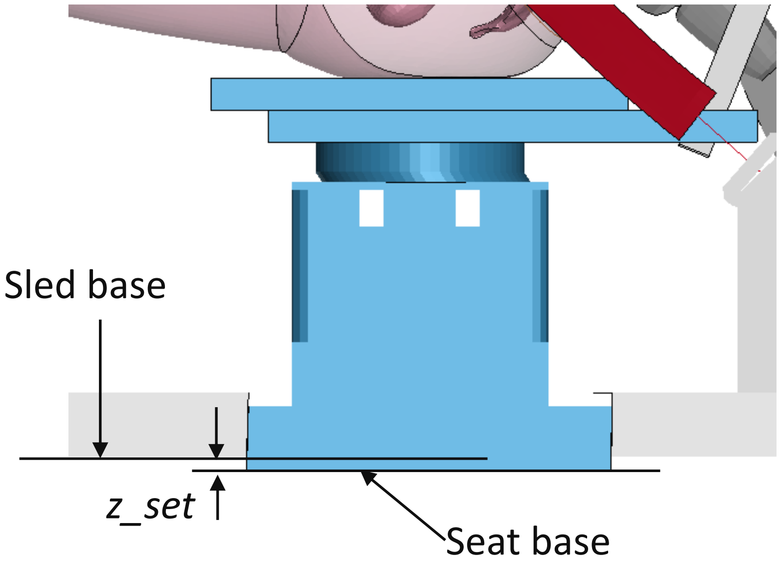
IF the position of the footrest is not satisfying, change x position
- x_FR: distance in x (positive value: footrest moves towards HBM)

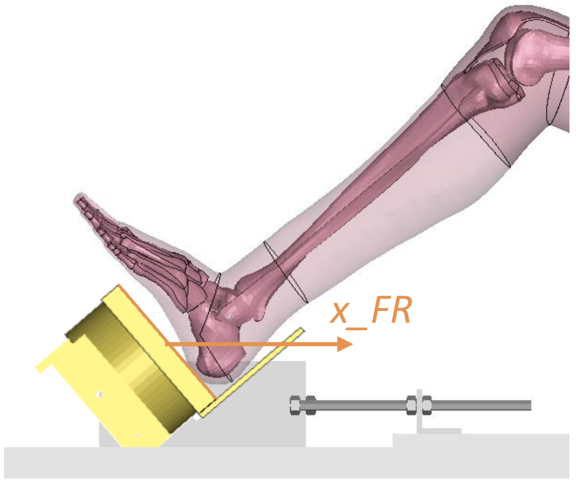
IF settling phase is not long enough, change duration
- *SetHBM*: duration of settling phase (default: 400ms)

IF positioning beams do not fully compress, increase tension force (insert value in kN)
- *Fbeam*: default: 0.3 kN

Duration of testbed movement in ms. Change only IF load curve duration changes
- *tload*: duration of loading curve (default 200ms)

IF contact issues occur, modify DEPTH flag for contact HBM to environment
- *Depth*: default: 23





Final checks

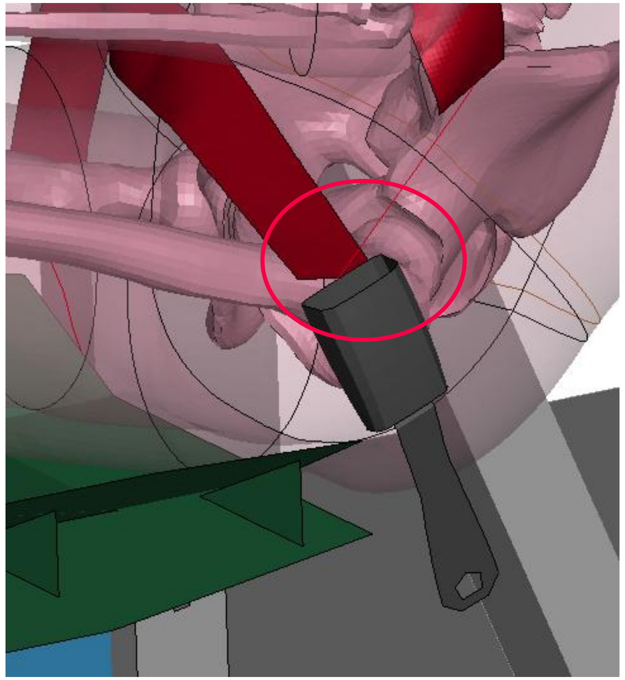
Check following values in the settled model (@ tSetHBM)

	Shoulder belt angle [°]	distance between seat base and sled base [mm]
Conf1, Conf2, Conf3 and Conf6	26 – 37	± 5
Conf4	24 – 33	± 5
Conf5	28 - 40	± 5

Error termination guide

“belt segment has free end“

- Issue: 2D belt is being pulled into slip ring
- Procedure: *Check simulation duration*
  - *IF the issue occurs when* the rebound phase has been reached:
    - Simulation results may be utilised for assessment purposes
  - *ELSE*
    - Check if arms are not included in part set *P_bdy*
    - Check for initial penetrations between the belt and the HBM, which may cause sticky nodes



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