Development of the Clavicle model of the dummy EuroSID-I in PRADIS

The purpose of work: Definition of Left Clavicle body characteristics of EuroSID-I and all characteristics of its joint with parent body for dummy model in PRADIS.

1 Stages of work

1. Definition of joint coordinates and orientation of coordinate system of Left Clavicle of the dummy in the coordinate system, connected with H-point.
2. Definition of coordinates of gravity center and orientation of the coordinate system of the Left Clavicle body of the dummy in the coordinate system, connected with H-point.
3. Definition of mass-inertial characteristics of the Left Clavicle body of the dummy.
4. Development of the model for definition of stiffness and viscosity of the Left Clavicle joint with MADYMO.
5. Development of the Left Clavicle model in PRADIS, using element ROT1.
6. Validation of the Left Clavicle model, using data, received under the item 5. Definition of stiffness and viscosity of the Left Clavicle joint with PRADIS.
7. Include received data into the model of the dummy EuroSID-I in PRADIS.

2 Definition of geometrical and mass-inertial characteristics of Left Clavicle body and Left Clavicle joint

2.1 Structure of the body sequence from Pelvis to Left Clavicle.

Joint coordinates of the Left Clavicle and the coordinates of its gravity center are submitted in the Table 1. Coordinates of the objects, specifying coordinate system of the Left Clavicle body in PRADIS, are submitted in the Table 2.

Table 1. Coordinates of joints of Left Clavicle body and Left Hand.

The name of object	Coordinates, mm		
	X	Y	Z
Left Clavicle joint	-0.1270	0	0.4480
Center of gravity of Left Clavicle body	-0.0630	0.0700	0.4605
Left Hand joint	-0.0030	0.1690	0.4720

Table 2. Coordinates of the objects, specifying coordinate systems of Left Clavicle joint and Left Clavicle body.

The name of object	Coordinates, mm		
	X	Y	Z
Center of the joint coordinate system	-0.1270	0.0	0.4480
Z axis of the joint coordinate system	-0.1308	0.0	0.4676
Plane XZ of the joint coordinate system	-0.1073	0.0	0.4518
Center of the Left Clavicle body coordinate system	-0.0630	0.0700	0.4605
Z axis of the Left Clavicle body coordinate system	-0.0667	0.0700	0.4796
Plane XZ of the Left Clavicle body coordinate system	-0.0433	0.0700	0.4643

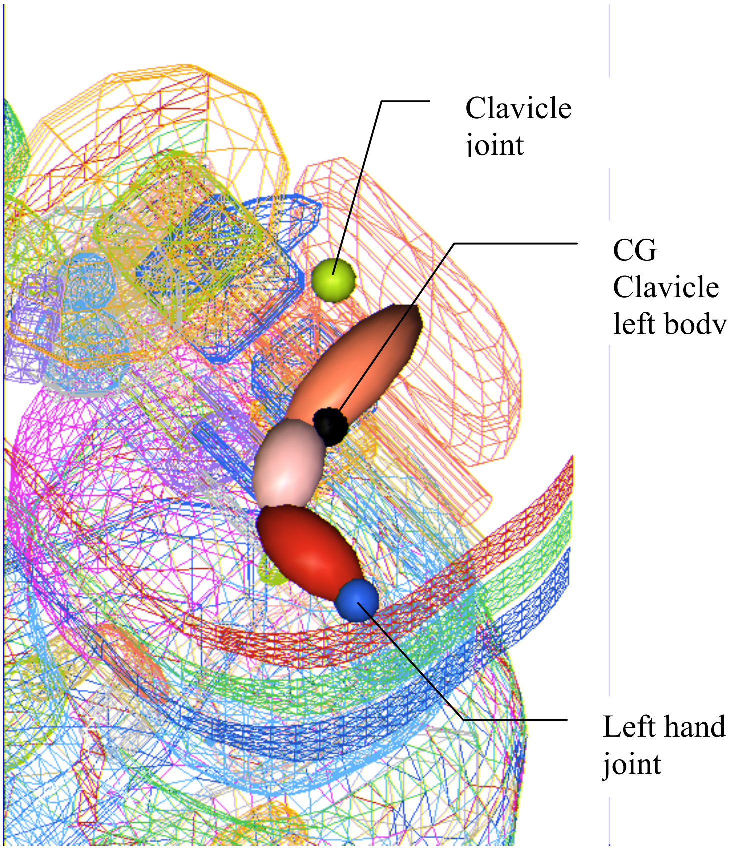


Fig. 1 Location of the objects.

Rotational angle of Left Clavicle joint coordinate system and Left Clavicle body with respect to the Pelvis coordinate system around Y axis equal -11^0.

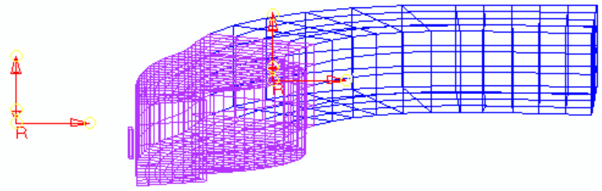
The total mass of Left Clavicle amounts 0.425 kg. Moments of inertia with respect to the axis of local coordinate system are defined as 1.5E-3 kg/m.

3 Drawing of joint coordinate system and Left Clavicle body in the model of dummy EuroSID-I in LS-DYNA

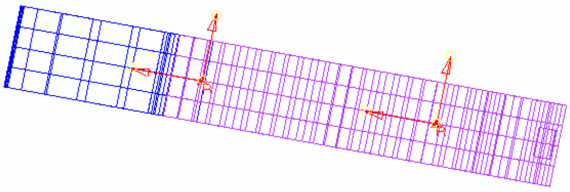
In order to check above-defined geometrical data (See Section 2), the model of dummy, developed in LS-DYNA is used. In this model H-point of the dummy is located in the node with coordinates (0, 0, 0) in global coordinate system. Rotational angle of Pelvis is equal 0^0. Rotational angle of the dummy Thorax around Y axis is equal 6^0, which conforms to this data in MADYMO. With such position of the dummy the coordinates, received in PRADIS, conform to the geometry of the dummy Left Clavicle. Three views of the Left Clavicle of the LS-DYNA dummy are displayed at the drawings, displayed in the Table 3. The coordinate systems are displayed at the drawings also.

As it is shown at the drawings, the position of the Left Clavicle joint, CG of Left Clavicle body and the rotational angle of the coordinate systems conform to the FEM model of this part of the LS-DYNA dummy.
It confirms that the coordinates, submitted at the Table 1, can be used in the dummy model, developed with PRADIS.

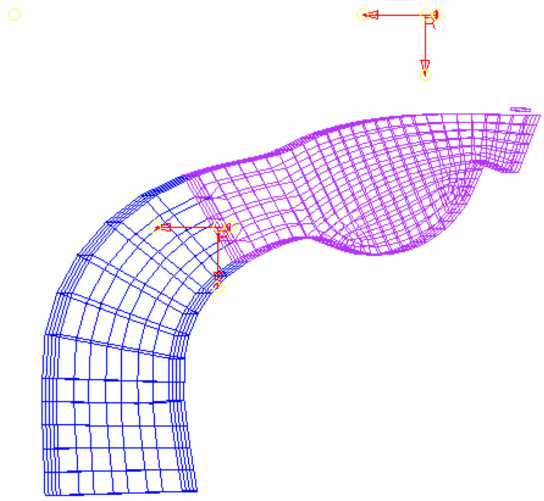
Table 3. FEM of Left Clavicle of LS-DYNA dummy and coordinate systems of Left Clavicle joint and Left Clavicle body.



Front view



Left view



Top view

4 Model of Left Clavicle rotation, developed in MADYMO

In order to carry out certification test of the model of Left Clavicle joint in PRADIS, the model of the dummy EuroSID-I, developed at the firm TNO, was used. The left hand of the dummy was disconnected, because it could distort the results of calculations. Sphere of diameter of 10 mm was located at the point of connection of the Left Clavicle with Left Hand. This sphere was used for contact interaction.

All the dummy joints, except of Left Clavicle join, were locked.

Impactor model.

Impactor model was developed as a plane, vertically orientated. This plane is attached to a body with mass equal to 10 kg.

Initial velocity along Y axis was applied to the impactor body. The size of velocity determined the applied force and had some values: 0.01 m/s, 0.05 m/s, 0.1 m/s, 0.5 m/s, 1 m/s, 2 m/s, 3 m/s, 4 m/s, 5 m/s, 6 m/s, 7 m/s, 8 m/s, 9 m/s.

Description of the interaction of the impactor and the dummy.

The impactor plane contacts with the sphere, which is located in the Left Hand joint. The contact stiffness is high, equals to 1E7 N/m in order to minimize penetration the sphere and the plane during contact.

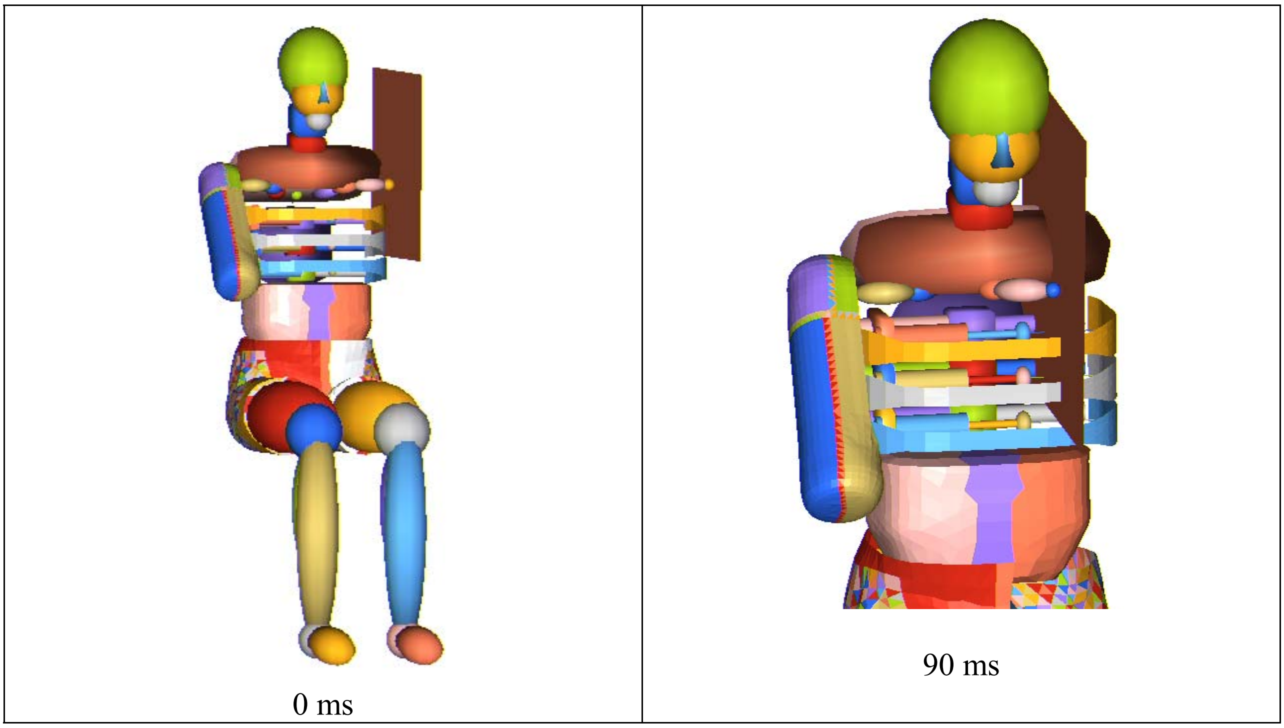


Fig. 2 Model of the test.

Outputs of the model.
As the result parameters were defined following parameters:
- displacements of the sphere along the X, Y, Z axis;
- contact force in the plane – ellipsoid contact;
- rotational angel of the Left Clavicle joint around rotational axes.

5 Development of the Clavicle model with PRADIS

Clavicle is modeled by the element MJ3E as a rigid body with geometrical and mass-inertia characteristics, defined in Section 2. The model of Clavicle is connected with Thorax by the joint model ROT1.
In order to define the joint parameters (to get functions of joint stiffness and viscous) the model of certificate test was developed in PRADIS. This model conforms to that which was developed in MADYMO (See the Section 4).
The calculation results, received in the Section 4 were used as reference values of target parameters.

Impactor model.
The impactor was modeled as an inertial element M with mass of 10 kg, which influences on the Clavicle at the point of its connection with Left Hand as an element UPRL. The contact stiffness of the contact element is the same as in MADYMO, namely: 1E7 N/m. Initial velocity along the Y axis is applied to the impactor. The size of velocity has following values: 0.01 m/s, 0.05 m/s, 0.1 m/s, 0.5 m/s, 1 m/s, 2 m/s, 3 m/s, 4 m/s, 5 m/s, 6 m/s, 7 m/s, 8 m/s, 9 m/s.

Outputs of the model.
As the result parameters were defined following parameters:
- displacements of the degrees of freedom of the element MJ3E along the X, Y, Z axis;
- rotational angel of the Left Clavicle joint around rotational axis.

Model validation in PRADIS was carried out step-by-step, starting from the small impact velocities.

As a result dependence of the elastic rotation moment on the rotation angle of Clavicle and dependence of viscous rotation moment on the rotation velocity have been defined.

The received results are shown at the Graphs of Fig. 3 and 4. The received functions are included into the file of the dummy model (See Appendix B).

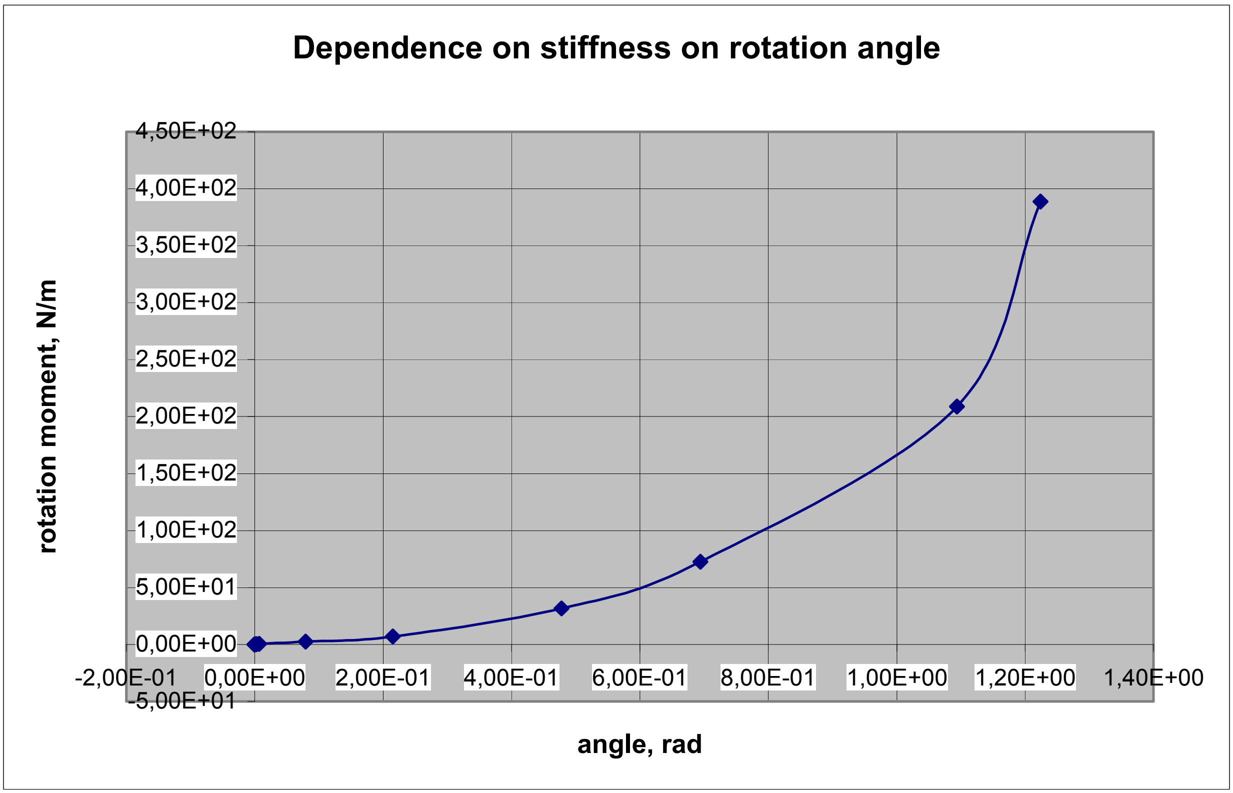


Fig. 3 Dependence of the elastic rotation moment on the rotation angle.

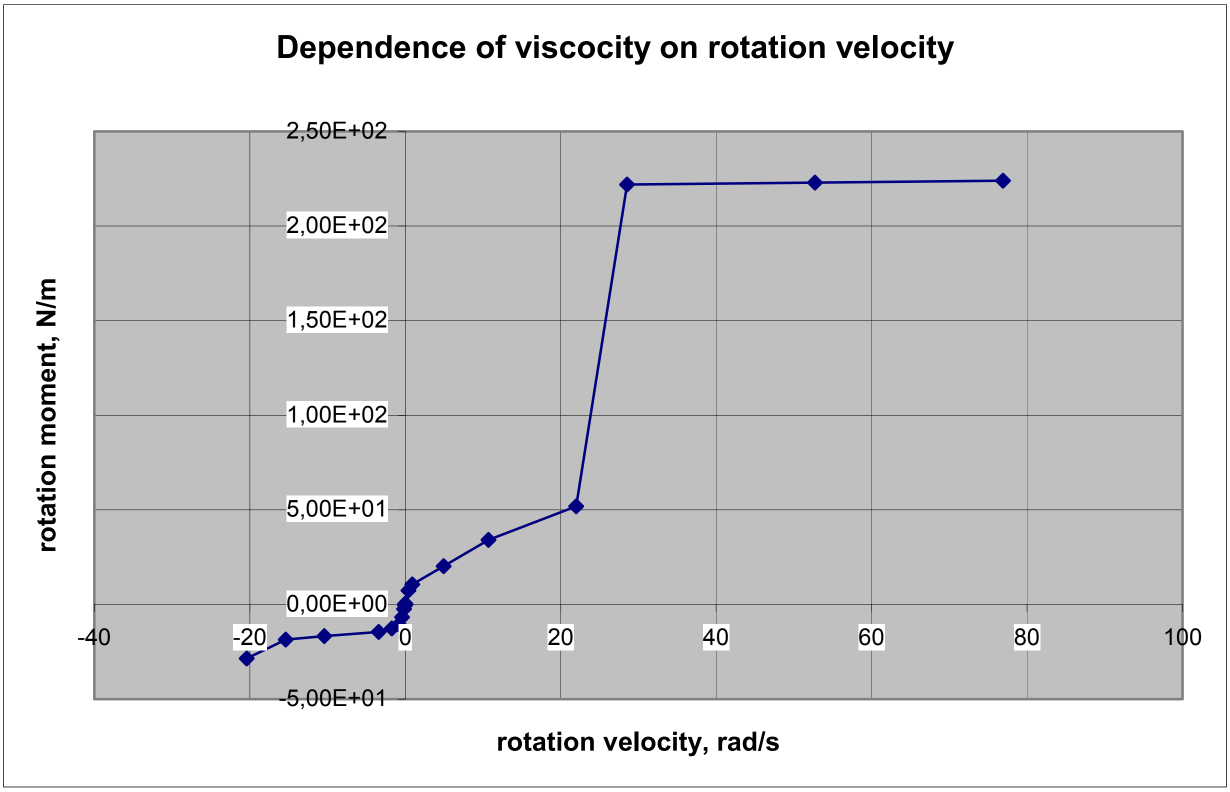


Fig. 4 Dependence of viscous rotation moment on the rotation velocity.

Figures 5, 6, 7 show the graphs of output parameters models, calculated in PRADIS and MADYMO: dependencies of rotation angles of Clavicle depending on time at the impact velocities of 1 m/s, 2 m/s, 4 m/s. It can be seen in Figures, that the form of the graphs is similar.
Table 4 represents difference between the results of calculation of rotation angle with different models.

Table 4 Difference between the results

Impact velocity, m/s	Error of time of curve max value, %	Error of curve max value, %
0,1	12,00	1,52
0,05	**12,12**	0,62
0,1	3,30	0,14
0,5	0,00	0,02
1	0,00	0,20
2	**6,74**	0,58
3	1,23	0,01
4	0,00	**4,00**
5	2,82	**7,17**
6	10,29	6,39
7	11,29	4,68
8	10,71	4,17
9	6,00	3,81

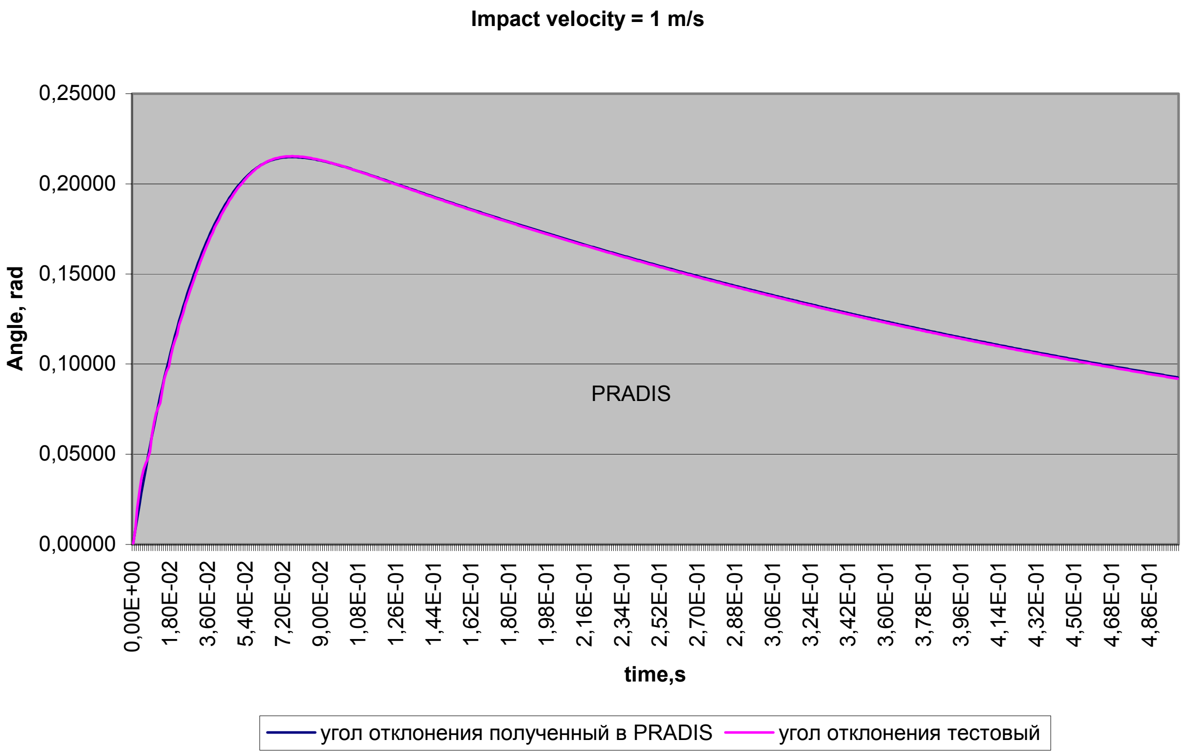


Fig. 5 Rotation angle of the Clavicle at the impact velocity of 1 m/s.

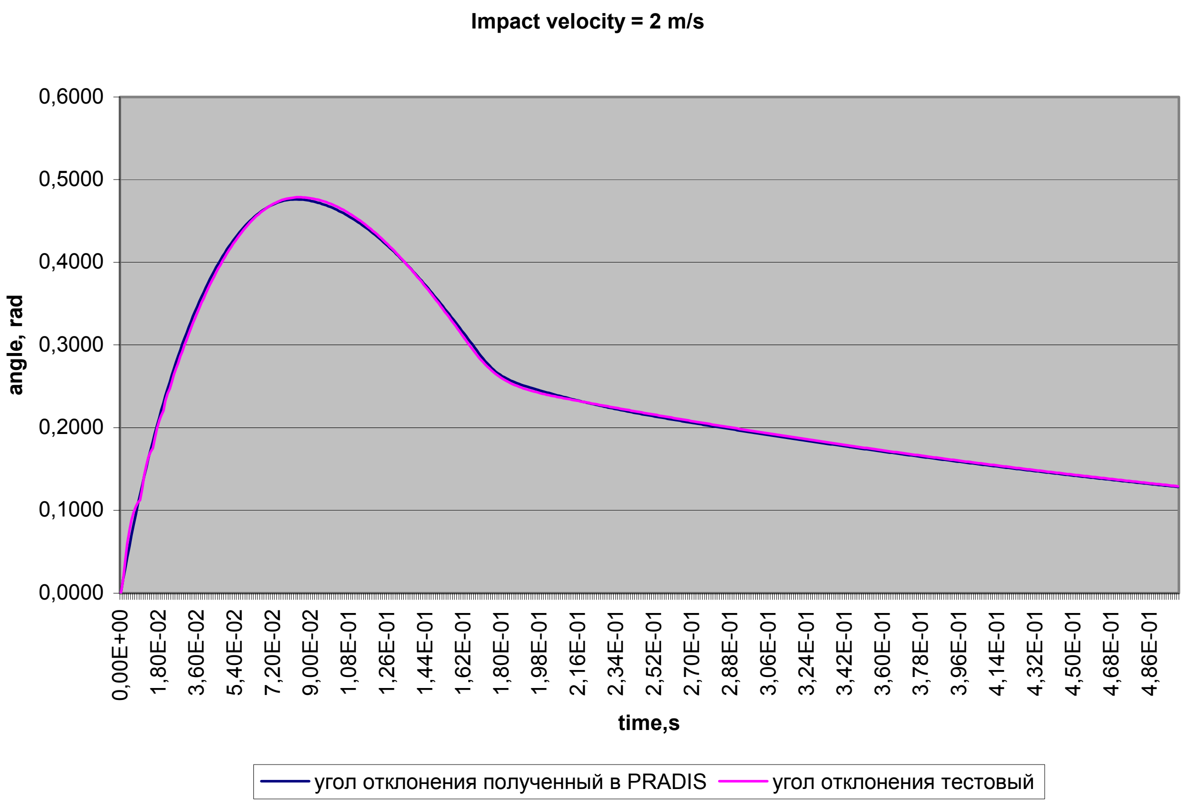


Fig. 6 Rotation angle of the Clavicle at the impact velocity of 2 m/s.

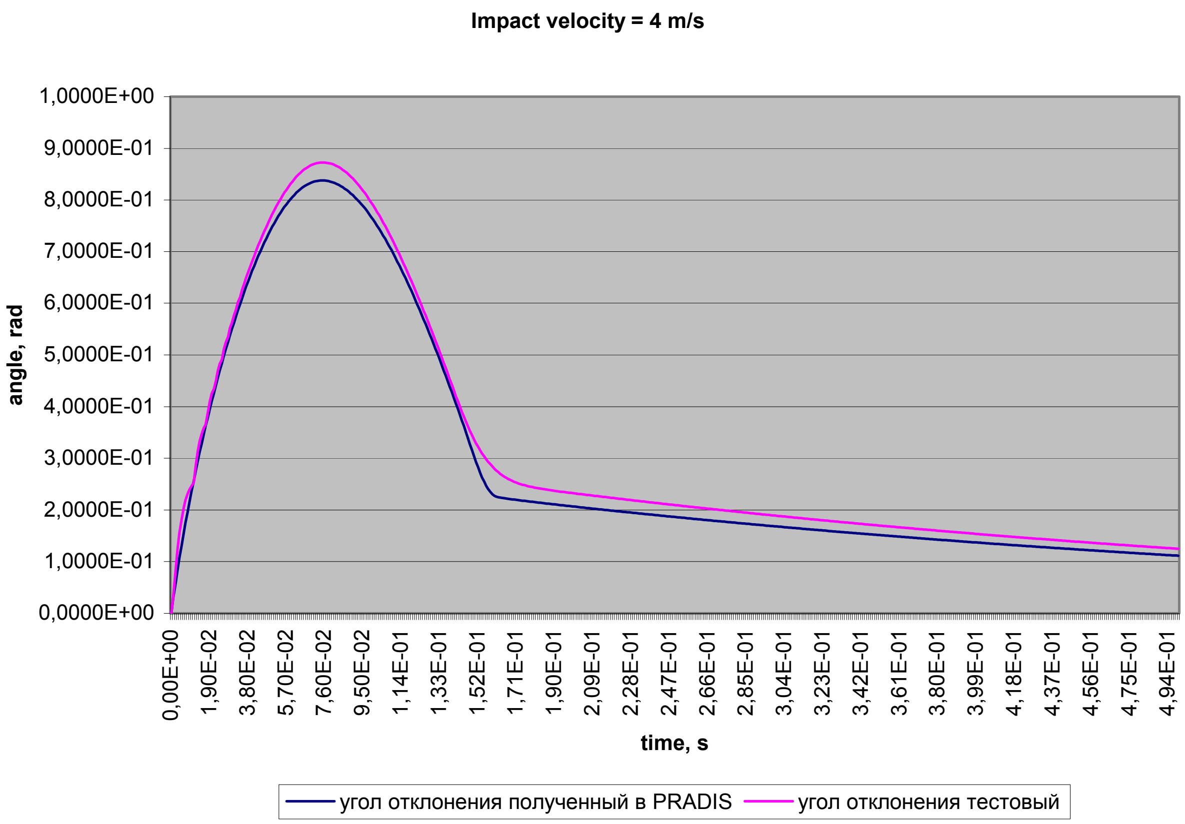


Fig. 7 Rotation angle of the Clavicle at the impact velocity of 4 m/s.

6 Conclusions

1. During the working process all characteristics of Clavicle body of the dummy EuroSID-I and all characteristics of its joint with parent body have been defined for dummy model in PRADIS:
   - Coordinates of joint, coordinates of Left Clavicle body and there orientation in the coordinate system of the H-point of dummy are defined. The received coordinates conforms to geometry of Clavicle of the dummy.
   - Mass-inertia characteristics of Left Clavicle body are defined.

2. Due to physical tests of the examined part of the dummy are not stipulated by the manufacturer and are not carried out at AVTOVAZ, the model of virtual test of Clavicle has been developed with the MADYMO dummy model.
As the outputs of the test model were defined following parameters:
- displacements of the sphere along the X, Y, Z axis;
- contact force in the plane – ellipsoid contact;
- rotational angel of the Left Clavicle joint around rotational axes.

These results were used for validation of the PRADIS model of the Left Clavicle.

3. The Clavicle model was developed in PRADIS, using the element model ROT1. As a result of validation process the Left Clavicle joint characteristics, such as stiffness and viscosity have been defined in PRADIS.
The graphs of output parameters, received in the result of work of the Clavicle models in PRADIS and MADYMO are very closed to each other.
Погрешности работы модели ключицы в PRADIS для скоростей удара, выбранных для валидации модели, не превышают следующие значения:
- Относительная погрешность по времени пика – **12,12%**
- Относительная погрешность по величине пика – **7,17%**

Max errors of the results at the different impact velocities do not exceed following values:
- Error of time of curve max value – 12,12%
- Error of curve max value – 7,17%

Large errors occur at the too small and too big impact velocities, which hardly take place in the real physical test. So it is reasonable to examine the errors, which could occur under real conditions.
In view of the aforesaid the errors do not exceed following values:
- Error of time of curve max value – 6,74%
- Error of curve max value – 4,00%

4. The Left Clavicle model, developed in PRADIS, can be used in the model of dummy EuroSID-I.

Appendix A. Fragment of the text of the MADYMO model


```
<JOINT.FREE ID="1" NAME="Dummy_jnt">
        <CRDSYS_REF_1 CRDSYS_REF="Dummy_Attachment"/>
        <CRDSYS_OBJECT_2 BODY="Pelvis_bod" POS="0.0 0.0 0.0"/>
</JOINT.FREE>

<JOINT.BRAC ID="6" NAME="LumbarSpineLowLC_jnt">
        <CRDSYS_OBJECT_1 BODY="Pelvis_bod" POS="-0.074 0.0 0.076" ORIENT="jnt_ori1_6"/>
        <CRDSYS_OBJECT_2 BODY="LumbarSpineLowLC_bod" POS="0.0 0.0 0.0"
ORIENT="jnt_ori2_6"/>
</JOINT.BRAC>
<ORIENTATION.SUCCESSIVE_ROT ID="57" NAME="jnt_ori1_6" AXIS_1="X" R1="3.1415927"/>
<ORIENTATION.SUCCESSIVE_ROT ID="58" NAME="jnt_ori2_6" AXIS_1="X" R1="3.1415927"/>

<JOINT.BRAC ID="7" NAME="LumbarSpineLow_jnt">
<CRDSYS_OBJECT_1 BODY="LumbarSpineLowLC_bod" POS="0.0 0.0 0.0"
ORIENT="jnt_ori1_7"/>
<CRDSYS_OBJECT_2 BODY="LumbarSpine_bod" POS="0.0 0.0 0.0" ORIENT="jnt_ori2_7"/>
</JOINT.BRAC>
<ORIENTATION.SUCCESSIVE_ROT ID="59" NAME="jnt_ori1_7" AXIS_1="Y" R1="-
0.10471976"/>
<ORIENTATION.SUCCESSIVE_ROT ID="60" NAME="jnt_ori2_7" AXIS_1="Y" R1="0.0"/>

<JOINT.FREE ID="8" NAME="LumbarSpine_jnt">
<CRDSYS_OBJECT_1 BODY="LumbarSpine_bod" POS="0.0 0.0 0.068" ORIENT="jnt_ori1_8"/>
        <CRDSYS_OBJECT_2 BODY="AbdomenInsert_bod" POS="0.0 0.0 0.0"
ORIENT="jnt_ori2_8"/>
</JOINT.FREE>
<ORIENTATION.SUCCESSIVE_ROT ID="61" NAME="jnt_ori1_8" AXIS_1="Y" R1="-
1.57079633"/>
<ORIENTATION.SUCCESSIVE_ROT ID="62" NAME="jnt_ori2_8" AXIS_1="Y" R1="-
1.57079633"/>

<JOINT.BRAC ID="9" NAME="ThoraxSpineLowLC_jnt">
<CRDSYS_OBJECT_1 BODY="AbdomenInsert_bod" POS="0.0 0.0 0.053" ORIENT="jnt_ori1_9"/>
<CRDSYS_OBJECT_2 BODY="ThoraxSpineLowLC_bod" POS="0.0 0.0 0.0" ORIENT="jnt_ori2_9"/>
</JOINT.BRAC>
<ORIENTATION.SUCCESSIVE_ROT ID="63" NAME="jnt_ori1_9" AXIS_1="X" R1="3.1415927"/>
<ORIENTATION.SUCCESSIVE_ROT ID="64" NAME="jnt_ori2_9" AXIS_1="X" R1="3.1415927"/>

<JOINT.BRAC ID="10" NAME="ThoraxSpineLow_jnt">
        <CRDSYS_OBJECT_1 BODY="ThoraxSpineLowLC_bod" POS="0.0 0.0 0.014"/>
        <CRDSYS_OBJECT_2 BODY="ThoraxSpine_bod" POS="0.0 0.0 0.0"/>
</JOINT.BRAC>

<JOINT.REVO ID="11" NAME="ThoraxSpineUp_jnt">
<CRDSYS_OBJECT_1 BODY="ThoraxSpine_bod" POS="-0.014 0.0 0.24" ORIENT="jnt_ori1_11"/>
<CRDSYS_OBJECT_2 BODY="Shoulder_bod" POS="0.0 0.0 0.0" ORIENT="jnt_ori2_11"/>
</JOINT.REVO>
<ORIENTATION.SUCCESSIVE_ROT ID="65" NAME="jnt_ori1_11" AXIS_1="Z" R1="1.57079633"
AXIS_2="X" R2="-0.0873"/>
<ORIENTATION.SUCCESSIVE_ROT ID="66" NAME="jnt_ori2_11" AXIS_1="Z" R1="1.57079633"
AXIS_2="X" R2="0.0"/>
```

<JOINT.REVO ID="28" NAME="ClavicleL_jnt">
<CRDSYS_OBJECT_1 BODY="Shoulder_bod" POS="0.0 0.0 0.0" ORIENT="jnt_ori1_28"/>
<CRDSYS_OBJECT_2 BODY="ClavicleL_bod" POS="0.0 0.0 0.0" ORIENT="jnt_ori2_28"/>
</JOINT.REVO>
<ORIENTATION.SUCCESSIVE_ROT ID="99" NAME="jnt_ori1_28" AXIS_1="Y" R1="-1.57079633"/>
<ORIENTATION.SUCCESSIVE_ROT ID="100" NAME="jnt_ori2_28" AXIS_1="Y" R1="-1.57079633"/>

<JOINT.BRAC ID="29" NAME="ClavicleLCL_jnt">
<CRDSYS_OBJECT_1 BODY="ClavicleL_bod" POS="0.127 0.143 0.0" ORIENT="jnt_ori1_29"/>
<CRDSYS_OBJECT_2 BODY="ClavicleLCL_bod" POS="0.0 0.0 0.0" ORIENT="jnt_ori2_29"/>
</JOINT.BRAC>
<ORIENTATION.SUCCESSIVE_ROT ID="101" NAME="jnt_ori1_29" AXIS_1="X" R1="3.1415927"/>
<ORIENTATION.SUCCESSIVE_ROT ID="102" NAME="jnt_ori2_29" AXIS_1="X" R1="3.1415927"/>

<JOINT.BRAC ID="32" NAME="ClavicleLCR_jnt">
<CRDSYS_OBJECT_1 BODY="ClavicleR_bod" POS="0.127 -0.143 0.0" ORIENT="jnt_ori1_32"/>
<CRDSYS_OBJECT_2 BODY="ClavicleLCR_bod" POS="0.0 0.0 0.0" ORIENT="jnt_ori2_32"/>
</JOINT.BRAC>
<ORIENTATION.SUCCESSIVE_ROT ID="108" NAME="jnt_ori2_32" AXIS_1="X" R1="3.1415927"/>
<ORIENTATION.SUCCESSIVE_ROT ID="109" NAME="jnt_ori1_33" AXIS_1="Z" R1="1.5097098"/>

<BODY.RIGID ID="28" NAME="ClavicleL_bod" MASS="0.2" CENTRE_OF_GRAVITY="0.065 0.07 0.0" INERTIA="1.000000E-03 1.000000E-03 1.000000E-03 0.0 0.0 0.0"/>
<BODY.RIGID ID="29" NAME="ClavicleLCL_bod" MASS="0.225" CENTRE_OF_GRAVITY="0.0 0.0 0.0" INERTIA="5.000000E-04 5.000000E-04 5.000000E-04 0.0 0.0 0.0"/>

Appendix B. Text of the PRADIS model

```
$DATA:
   длина оси шарнира            = 0.01
   параметры изображения1 = длина оси шарнира
   диаметр окружности1           = 0.35
   центр экрана1                 = -0.1270,    0.0000,    0.4480
   вспомогательная точка оси Zs1  = -0.1270,    0.0000,    1.4480
   вспомогательная точка оси Xs1  = -1.1270,    0.0000,    0.4480
   цвет слоя1                  = 0
   параметры слоя1 = диаметр окружности1,
             центр экрана1,
             вспомогательная точка оси Zs1,
             вспомогательная точка оси Xs1,
             цвет слоя1
   диаметр окружности21           = 0.7
   центр экрана21                 = -0.05,0,0
   вспомогательная точка оси Zs21  = 1, 0,0
   вспомогательная точка оси Xs21  = 0,0,-1
   цвет слоя21                  = 0
   параметры слоя21 = диаметр окружности21,
             центр экрана21,
             вспомогательная точка оси Zs21,
             вспомогательная точка оси Xs21,
             цвет слоя21
  pb8 =         -0.1270,    0.0000,    0.4480
  pb16df =      -0.003000,    0.169,    0.4720
  pb16 =     - 0.063000,    0.070,    0.4605
  pb16zx =      -0.0433,    0.0700,    0.4643
  pb16z =      -0.0667,    0.0700,    0.4796
  param_b16 = 0.425, .0015, .0015, .0015
  pc11 =          -0.1270,    0.0000,    0.4480
  pc11z =        -0.1308,    0.0000,    0.4676
  char_C11    =    1.0E10 ,  1.0E7,  1.0E10,
                1E100,   { зависимость упругого крутящего момента от угла поворота }
               -5.3e-4,     -16.0e-2,
                0  ,           0,
                5.3e-4,       0.0125e1,
                3.0e-3,       0.0266E1,
                6.9e-3,       0.040E1,
                7.9e-2,       0.248e1,
                0.215 ,       0.706e1,
                0.478,        3.18e1,
                0.694,        7.28e1,
                1.094,        20.88e1,
                1.224,        38.88e1,
                1E100,   { вязкого крутящего момента от угловой скорости }
              -20.4000,   -2.8566e1,
              -15.4000,   -1.8566e1,
              -10.4000,   -1.6666e1,
              -3.4000,    -1.4565e1,
              -1.7000,    -1.2565e1,
              -0.8000,    -1.0565e1,
              -0.4160,    -0.6655e1,
              -0.1540,    -0.2303e1,
              -0.0145,    -0.0335e1,
              -0.0106,    -0.026420e1,
```

```
                  -0.0047,     -0.006020e1,
                   0  ,            0 ,
                   0.0286,      0.0568e1,
                   0.40644,    0.075e2,
                   0.93   ,       0.106e2,
                   4.95,          0.2028e2,
                   10.70,        0.342e2,
                   22.00,        0.52e2 ,
                   28.52,        2.22e2,
                   52.72,        2.23e2,
                   76.92,        2.24e2
  скорость ударника = -1

$ FRAGMENT: Clav_L

# BASE: 1

# STRUCTURE:
B16_Clavical_L    'MJ3E(607,608,609, 610,611,612;   pb16df, pb16, pb16z, pb16zx, param_b16)
C11_B8_B16   'ROT1 (1,1,1, 1,1,1,  607,608,609, 610,611,612; pb8, pb16df, pc11, pc11z, char_C11)
Massa Impactor   'M (1608;10)
Impactor      'VN(1608;скорость ударника)
Cont      'UPRL(608, 1608; 0, 1e7)
               'M(1000;1)
перемещение по X 'ATABL (1000,1;100,
                  $INCLUDE: 5_CFC_x.tab
                   )
               'M(1001;1)
перемещение по Y 'ATABL (1001,1;100,
                  $INCLUDE: 5_CFC_y.tab
                   )
               'M(1002;1)
перемещение по Z 'ATABL (1002,1;100,
                  $INCLUDE: 5_CFC_z.tab
                   )
               'M(1003;1)
угол             'ATABL (1003,1;100,
                  $INCLUDE: 5_angle.tab
                   )

#MAP:
#OUTPUT:
Motion_Arm_X  'S (607; 1)
Motion_Arm_Y  'S (608; 1)
Motion_Arm_Z  'S (609; 1)
vel_arm_Y 'V(608;1)
Clav_jnt_rot   'X(W: C11_B8_B16 (4);1)
Clav_jnt_vel   'X(W: C11_B8_B16 (5);1)
Clav_jnt_mu   'X(W: C11_B8_B16 (10);1)
Clav_jnt_k    'X(W: C11_B8_B16 (9);1)
тест перемещение по X 'A (1000;1)
тест перемещение по Y 'A (1001;1)
тест перемещение по Z 'A (1002;1)
тест угол             'A (1003;-1)

$SHOW
       'LAYER(C11_B8_B16(GSV;параметры изображения1); параметры слоя1)
```

```
     'LAYER(ST1;параметры слоя1)
     'LAYER( ST2;параметры слоя1)
     'LAYER(ST3;параметры слоя1)

$RUN:
  'SHTERM (END=0.5, DABSI=1, {MAX=0.01,}CONTROL=1.E-4, SCALE=1, DEBUG=11)

$PRINT:
  'DISP(;Motion_Arm_X,
         тест перемещение по X)
  'DISP(;Motion_Arm_Y,
         тест перемещение по Y)
  'DISP(;Motion_Arm_Z,
         тест перемещение по Z)
  'DISP(;Clav_jnt_rot,
         тест угол)
  'TABL(OUT=0.001;Clav_jnt_rot,
                    тест угол )

$END
```