ASPECTS OF SEAT BELT MATERIAL SIMULATION

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Summary:

The so-called D-ring dynamic overturning is an instability phenomenon occurring occasionally during car crashes. It can have a negative effect to the restraint function of the seat belt system and lead to increased seat belt forces to the occupant. In order to avoid this phenomenon the influence of different parameters has to be investigated. Therefore a simulation model has been created, using the Finite Element Code LS-DYNA 3D. Major questions to be clarified in this context are:

- Define initial geometry for the belt running through the D-ring.
- Choice of appropriate material model.
- Influence of physical parameters, i.e. D-ring geometry, friction properties, belt material, belt forces, crash pulse, etc.

The definition of the initial geometry and a feasibility study have been presented at the 2000 CAD-FEM conference [2]. The modelling method, results for a given baseline geometry, variations in different material models and the pre-simulation of a new concept of the D-ring, the so called “roller D-ring” are presented in the current paper.

Keywords:

Occupant Restraint System, Material Models, Fabric, Seat Belt, D-ring, Dynamic Overturning.

1 - Introduction

The D-ring is the D-shaped part of a safety belt system that is normally placed above the shoulder of the occupant, attached to the B pillar of the car, figure 1a. It is used to adjust the direction of the belt coming upward from the retractor going downward to the occupant. In order to provide an optimal seat belt course across the shoulder of the occupant, an additional height adjuster device for the D-ring attached to the B-pillar is used. For this paper a fixed positioning of the D-ring with respect to the B-pillar is assumed.

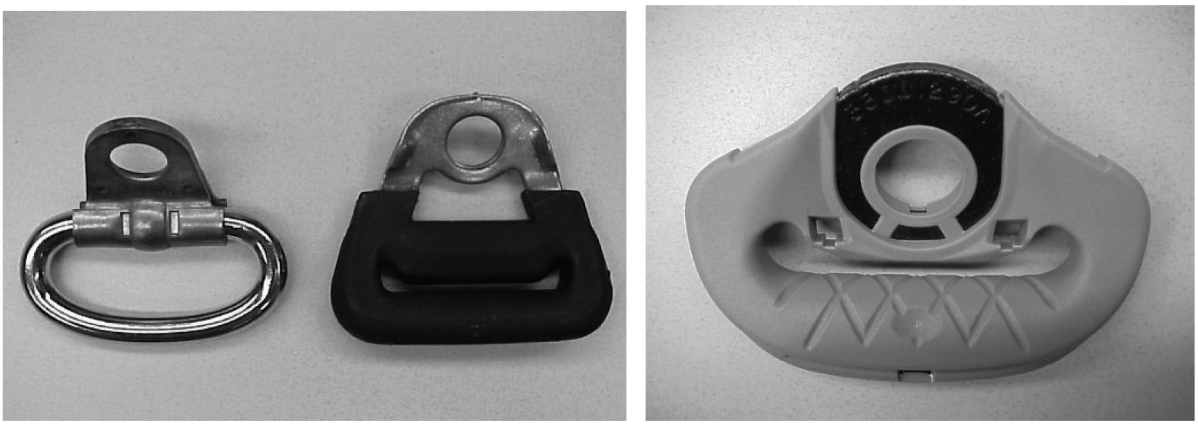

Figure 1a: Examples of a D-ring

The D-ring represents one of the three „fixed points“ for the belt system during a crash. It is the only one that experiences an extensive belt movement through it, especially if a seat belt load limiter is used.

The D-ring dynamic overturning phenomenon, that might occur during a crash, is an unwanted behavior that could increase the seat belt loads to the occupant. It can be described as follows: instead of remaining in the middle of the plane region of the D-ring, the belt slides sideward in the device, which leads to a rotation of the D-ring, figure 1b. This causes wrinkling of the belt, increased friction, and subsequently higher belt loads to the dummy. Furthermore, a high pressure to the D-ring and even rupture of the plastic cover of the D-ring can occur, depending on the resulting belt loads.

Figure 1b: Example of overturned D-ring

In order to gain a better understanding of the parameters that play an important role in this phenomenon an FEM model in LS-DYNA 3D was developed, including the belt fabric material and the D-ring itself.

2 - Creating the model – pre-positioning of the belt

Basically the model consists of three components: The D-ring itself, the bolt joining the D-ring to the height adjuster/car structure and the belt. The model of the D-ring has been obtained by importing the original CAD-data to the preprocessor HYPERMESH and meshing it with an automatic tetmesher. The resulting mesh represents exactly the geometry of the D-ring and of the contact surface for the belt. The contact definition between D-ring and seat belt plays an important role for the whole phenomenon. Especially the friction must be seen as one of the physical parameters having a high influence to the occurrence of the D-ring dynamic overturning. The joining bolt has been added manually in order to define correctly the appropriate contact conditions. The contact between D-ring and bolt also contains friction, and is an important physical parameter. This bolt could also be substituted by a revolute joint, always with friction.

Concerning the seat belt, one detail that has been investigated is how to define the initial geometry for the belt with respect to the D-ring. Actually it is in the present case impossible to create a CAD model that correctly represents the 3-D surface of the belt in the „belted“ position. The reason is the fact that, for most spatial orientations of the belt, the belt inside the D-ring already is slightly deformed in order to follow the shape of the D-ring, figure 2

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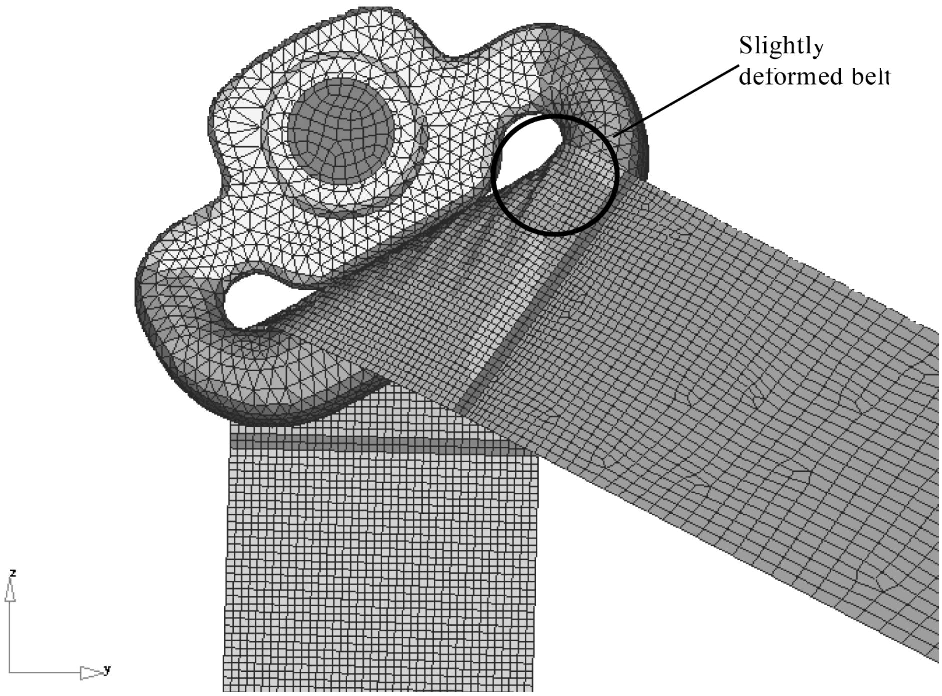


Figure 2: Typical initial configuration. Belt following the shape of the D-ring

The first approach developed in order to obtain the correct geometry has been described in [2], and, although successful, showed a few disadvantages: it required the building of a new model for each spatial orientation of the belt, and the so called "anti-wrinkling" forces were the result of a trial and error process.

For this reason the idea has been simplified and generalized: as a first improvement, one starts from a "normal" geometry, like it could come from a production CAD model, with the D-ring hanging vertically, figure 2a and 2b

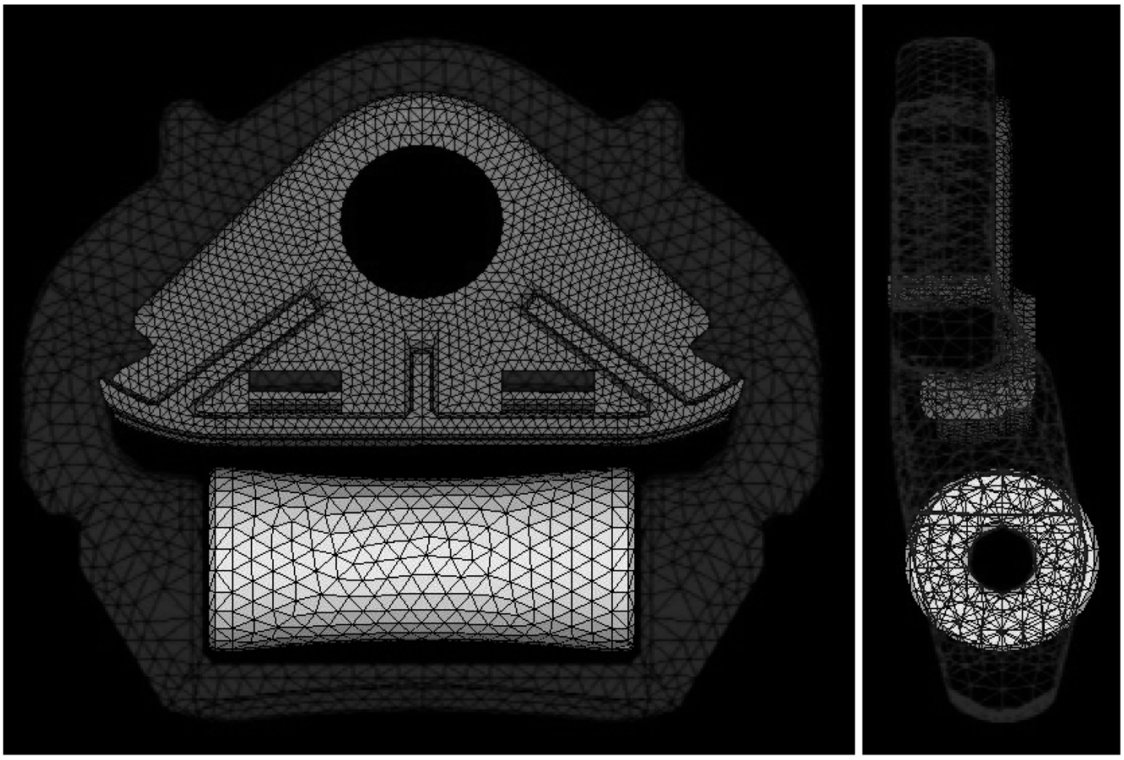


Figure 2a, 2b: Initial position for the pre-simulation procedure

A segment of belt is then created at the preprocessing level, perfectly parallel to Cartesian axes, in a suitable position, possibly with no contact with any D-ring or roller feature, figure 2c

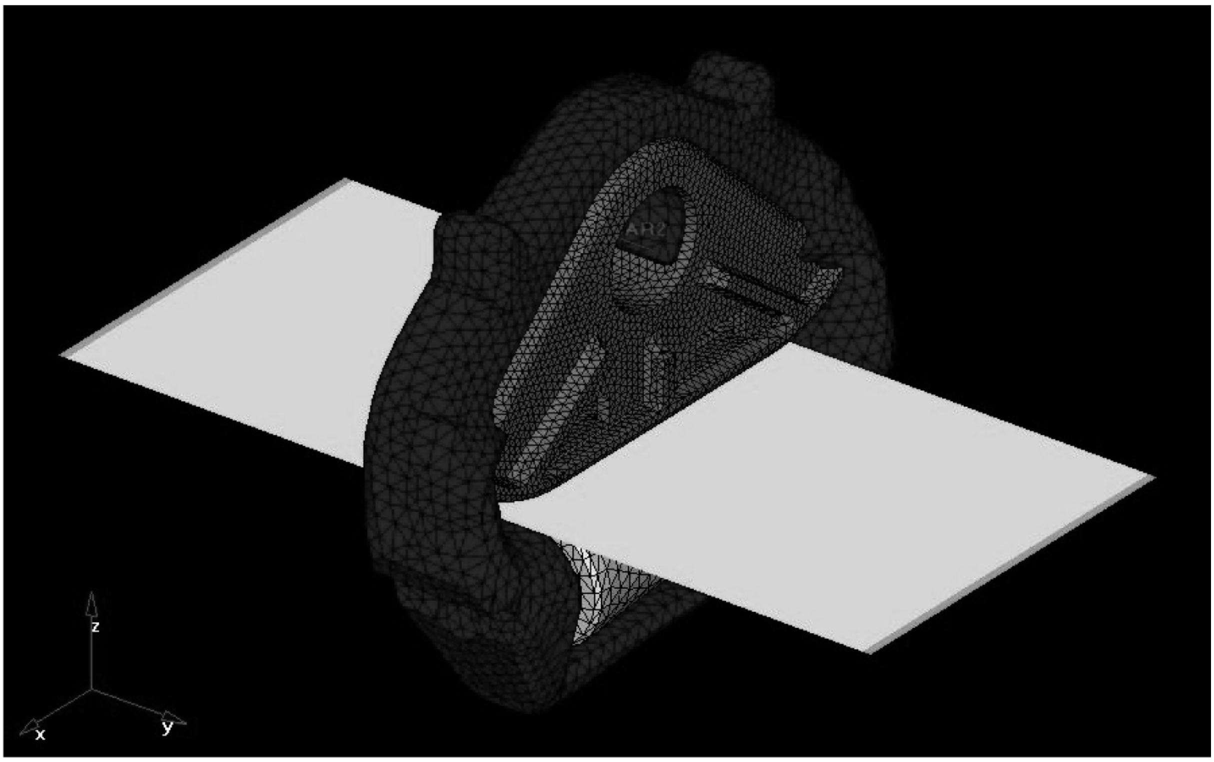


Figure 2c: the segment of belt used in the pre-simulation contains about 10000 elements

Then, in the same simulation, only two sets of forces are applied: one for each rigid end of the belt segment: their magnitude has been calibrated in order to easily bend the fabric material without stretching it. Their direction is simply the desired space orientation of the two belt segments, as measured or computed.

To avoid the need for anti-wrinkling forces, the material is taken as simply elastic, with a sufficiently low Young's modulus, and a dummy thickness that facilitates the bending. This will be switched back to the right values only at "simulation" time.

During the simulation the D-ring rotates around its pivot (that also, for the sake of simplicity, has been substituted with an LS-DYNA revolute joint), finding the appropriate equilibrium position, and at the same time the belt adheres to any feature of the lower part of the slot, figure 2d.

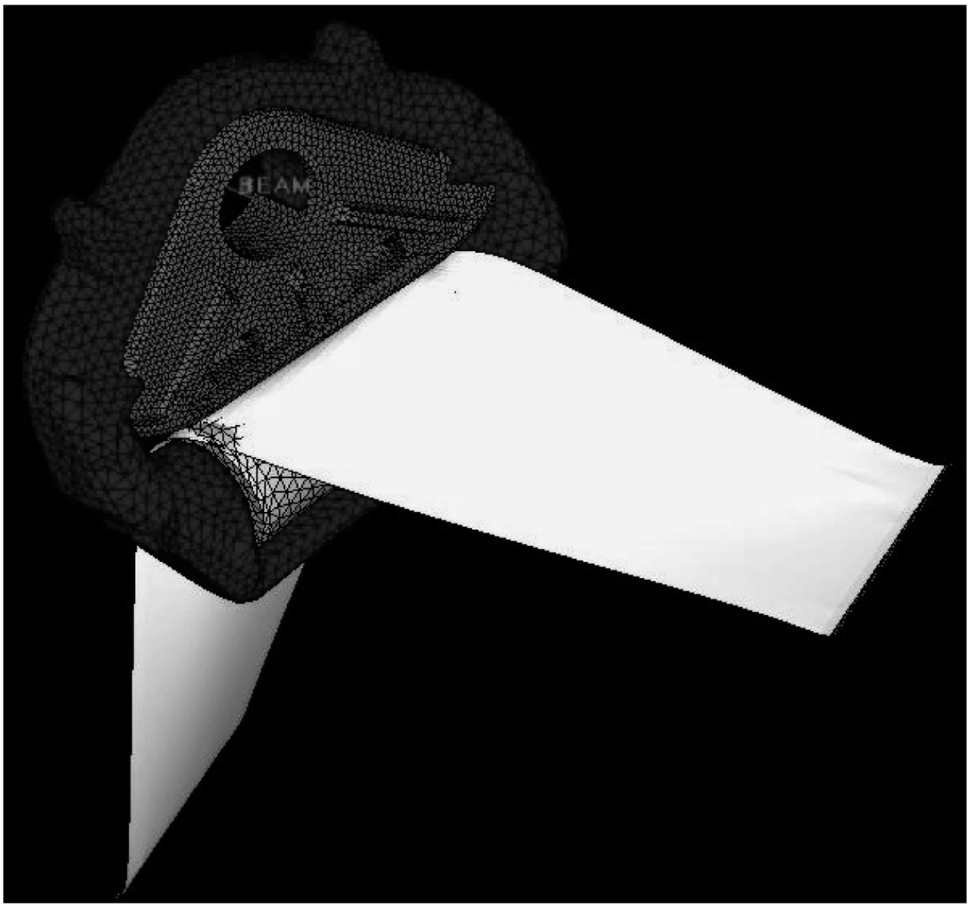


Figure 2d: Final position of the pre-simulation (note that the D-ring has rotated about 20 degrees)

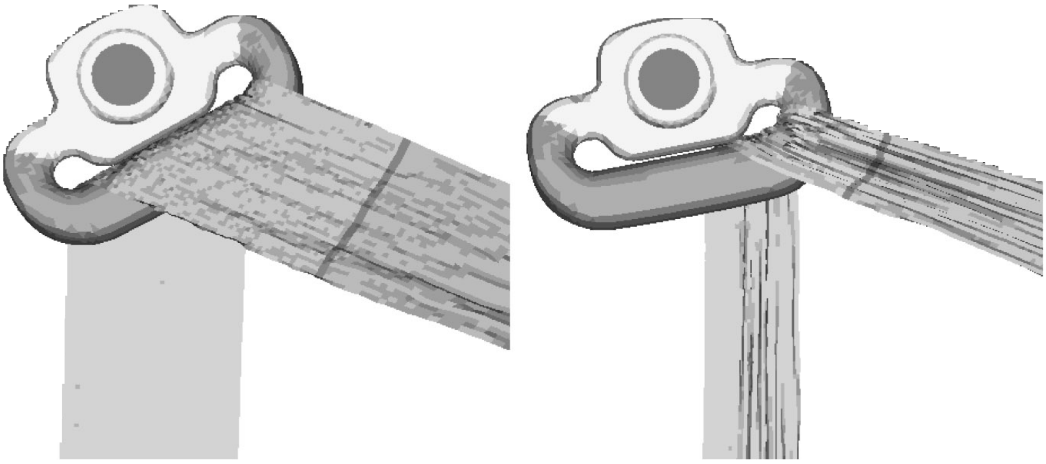
3 - Simulation of the belt movement during the crash

Starting from the pre-folded geometry, the simulation had to take into account the material behavior, the loading conditions during the crash, as well as contact and friction definitions.

Due to the different order of magnitude of the stiffness of the D-ring, of the roller, and the joining bolt compared to the belt fabric material, these two parts have been chosen to be rigid. In order to reproduce the experimental behavior of the safety belt as correct as possible, the material data for the used „*FABRIC" statement of LS-DYNA [1] has been validated experimentally. This means, that for a given belt type the material stiffness in different orientations have been determined, and the required elastic constants fitted by using a small FEM model of the tensile specimen.

Boundary conditions like retractor force, shoulder movement and crash deceleration pulse vs. time curves have been taken from MADYMO [3] simulations. They are used to apply a 3-D spatial motion to one end of the belt and the retractor force to the other end. The crash deceleration was applied as a body load to the whole model.

Automatic single surface contact between D-ring and belt (or between roller and belt) has given good results, although with modification of the default parameters. Friction behavior has been used both for the belt to D-ring contact and for the pivoting bolt. Figure 3a shows a typical position of the D-ring and the safety belt in an intermediate position, and figure 3b shows the system after the occurrence of the angular instability.



Figures 5a and b: Snapshots of the overturning, for the simple D-ring

The phenomenon that takes place could be described as follows: the action line of the resultant force of the two segments of belt that pull the D-ring is initially very near to the pivoting axis (the axis of the bolt).

During the crash the belt has a tendency to slide sideward (opposed only by the friction). This sideward movement of the belt will lead to a displacement of the line of action of the resultant force, giving birth to an increasing torque on the D-ring itself. As soon as this torque is high enough to overcome the friction momentum in the joining bolt, a rotation will initiate, and instability in the angular position will follow.

The D-ring undergoes only very limited rotational motion, of the order of 1°, until the instability occurs. The time of the sharp rise in angular movement can be taken as a standard numerical "measure" of the intensity of the "overturning" phenomenon, and will be used for comparison between different designs.

4 - Aspects of material modeling

The FABRIC material of LS-DYNA is actually a variation of a standard composite material model with orthotropic stiffness properties, including additionally a membrane shell element formulation that is appropriate for big deformations typical of airbags [1]. The only valid reason to use it for a belt, is that a belt too is a fabric, woven material like an airbag. But, although of course "bending" resistance should not be very important for any fabric, the 1.2 mm thickness of a typical belt webbing are certainly stiffer to bend than the 0.3 mm thickness of a typical airbag fabric. For this reason, it has been tried to understand if the fabric material model, and its properties, could influence somehow the behavior of the overturning.

To this purpose, a few variations have been tried:

- FABRIC material, but with isotropic properties: that is, E modulus in all directions the same, and in particular equal to the stiffer one (the "along the belt" direction); G modulus computed from E and Poisson's ration
- ORTHOTROPIC ELASTIC material, with the same properties of the fabric (different E modulus at 0° and 90°)
- ELASTIC isotropic material, again with the stiffer E modulus

The interest of the last two derives from the using of a complete shell formulation (not only membrane), i.e. including also bending stress. Figure 4a shows, for the remaining two variants, a comparison on the displacement of a node of the D-ring vs. time (proportional to the angle of rotation).

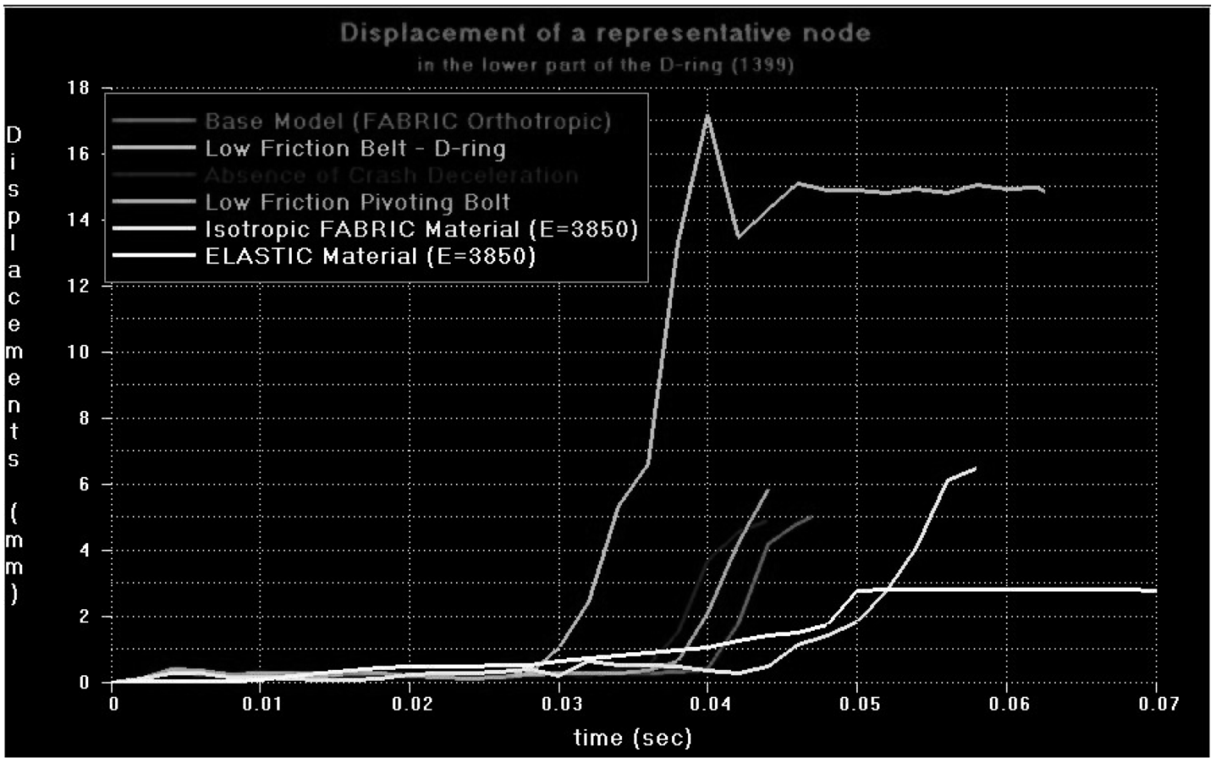


Figure 4a: Effect of material modeling on the displacement of a point in the simple D-ring (for comparison purposes, also a few other variants already described in [2] are here given)

As it can be observed, both the use of a fabric with a transversal stiffness equivalent to the longitudinal, and the introduction of bending stress have beneficial effect on the insurgence of the overturning. The elastic variant, although interesting, is much more expensive, and forced to use triangular elements, time step reduction factors, and a higher amount of nodal damping, in order to achieve a stable solution without hourglassing or instabilities.

The elastic material variant it is actually the only one that, for this sample, do not produce any significant overturning: the simulation reaches its regular end, pulling the whole belt through, with a stationary configuration shown in figure 4b.

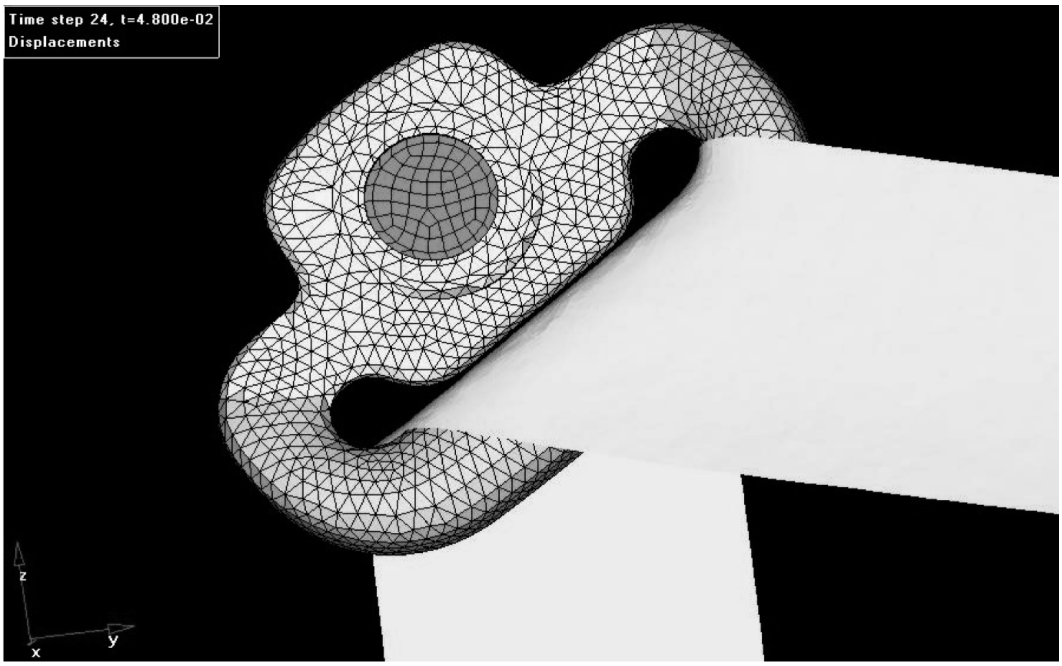


Figure 4b: Stationary configuration of the "elastic" material belt: obviously the bending stiffness prevents further wrinkling of the belt around the upper "ear" of the slot.

5 - Conclusions

It has been shown, that the phenomenon of D-ring dynamic overturning can be reproduced in a detailed model using LS-DYNA 3D. A standard pre-simulation step was used to obtain the correct initial geometry of the seat belt. The choice of material model have been shown to be important, together with the accurate determination of orthotropic elastic constants.

6 - Acknowledgements

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7 - References

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