Belt Modelling in LS-DYNA®

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Abstract

Belt modelling in LS-DYNA has gone from 1D-belt elements, through hybrid belt modelling into 2D seatbelt elements. The current paper investigates recently developed features in LS-DYNA such as bending, strain-rate and orthotropic material behavior. A short description of the evolution of belt modelling is also given.
Belt modelling in LS-DYNA has in the past and in the closest future included modelling of sliprings which are points in space where the belt elements pass through. Typical, these are located at sharp directional changes in the belt routing, e.g. B-pillar, D-ring and buckle tongue.
*Currently, it is the slipring functionality that inhibits users from using an ordinary element and material, of their own selection, to model the belt. Both 1D and 2D belt elements are assigned with *MAT_SEATBELT as it is the only material compatible with sliprings. 2D belt elements in LS-DYNA is a combination of 1D-belt elements along the length direction of the belt and 2D membrane elements made of a MAT_FABRIC material created internal in LS-DYNA. The MAT_FABRIC is created based on *MAT_SEATBELT values.*
*This means current *MAT_SEATBELT in LS-DYNA do not carry any bending loads. The new feature development makes the coating functionality found for MAT_FABRIC available in *MAT_SEATBELT_2D. This enables the bending load carrying possibilities for the 2D belt elements in LS-DYNA. Apart from this feature strain-rate dependency and orthotropic material behavior have been added to the 2D belt elements.*
It will be shown that the interaction between occupant and belt is improved. It will also be shown that the behavior of an unloaded belt is improved. Finally, there is a short outline of foreseen future needs regarding belt modelling features.

Introduction

Belts are the most lifesaving innovations made ever in the vehicle history, reference [1]. Hence, the necessity of modelling belts is obvious. Over time, the evolution of belt modelling techniques used in LS-DYNA has evolved and currently the 2D belt elements are frequently used and recommended. This paper will do a brief historical picture of belt modelling and from that point show in the new belt modelling in LS-DYNA. In this paper focus is on the slipring functionality, described below, and model of the belt fabric.

Belt fabric is typically an orthotropic material which is routed through sliprings in order to obtain a beneficial position on the passengers of the vehicle to reduce the injury levels obtained during crash. In LS-DYNA there has been a feature for the sliprings as an approximation for the physical part where the belt is routed. The reason is efficiency and robustness. It is possible to model the physical slipring, but the contact situation puts requirements on the element size and timestep size in the simulation model. Hence, the use of slipring element is still standard in most situations in the automotive industry.

Historically, the belt was modelled completely with 1D elements. For the last 10-15 years the belt was modelled using a hybrid approach: 2D elements for a major part of the belt fabric but 1D elements in order to make use of the slipring functionality in LS-DYNA. The motivation for using 2D elements for part of the belt was to get a better interaction between the dummy and belt. Note that the 2D belt elements was typically modelled using membrane elements however that is not a requirement for these simulations. In recent years, 2D belt elements is the dominating choice to represent the belt fabric since the implementation of 2D sliprings introduced in R7. Due to element size decrease of the dummy model, the belt elements also need to decrease in order to be able to capture all effects in the interaction between dummy and belt. However, these elements are still membrane elements and do not carry any bending loads. Adding more elements along the width of the belt will make the belt collapse more easily.

Today, there is a possibility to add bending stiffness to the 2D belt elements in LS-DYNA. This paper shows how to add bending stiffness to belt material and still enable the use of the slipring element in LS-DYNA; demonstrates that this improves belt behavior, avoiding collapse during loading and unloading compared to current state-of-the-art material modelling. It will be showed that foreseen needs and functionalities is made available for capturing the belt fabric behavior.

Bending - Coating functionality

In LS-DYNA bending properties can be added to the membrane elements of MAT_FABRIC (034) if FORM= -14 is used, i.e. a coating functionality, reference [2].
The new extension of *MAT_SEATBELT_**2D** in LS-DYNA utilize the coating functionality in the same manner as described for MAT_FABRIC, FORM=-14. The coating functionality can be visualized as an added layer of elasto-plastic material on the surfaces of the membrane element. This extra layer enables the membrane to transfer bending loads, see **Figure 1**.

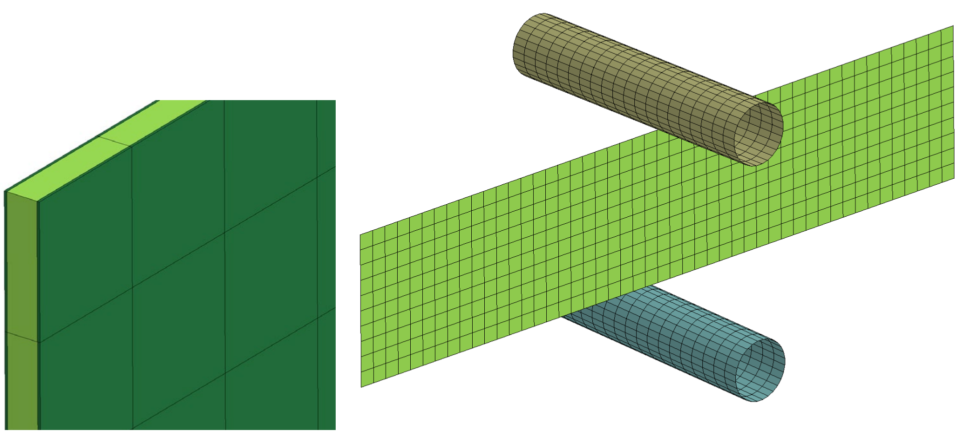

Figure 1: *Visualization of coating functionality, to the left. To the right, suggested setup for determining the coating isotropic elasto-plastic hardening material parameters, i.e. thickness, Youngs modulus and yield strength.*

It should be noted that the stress contribution from the coating cannot be measured using *DATABASE_CROSS_SECTION.

To determine the parameters of the coating it is suggested that one make use of one strip of the belt at a selected load level of tension. The tension load of the belt is selected to the typical load level of the belt, during crash loading, when it is crucial to capture the bending stiffness of the belt.

Results

Bending properties for belt material

The two major result achieved by adding the coating to the belt is the improved performance in bending over the width belt, see Fig. 2, and the more stable unloading behavior, see Fig. 3. The effect becomes more obvious if the belt is finely meshed.

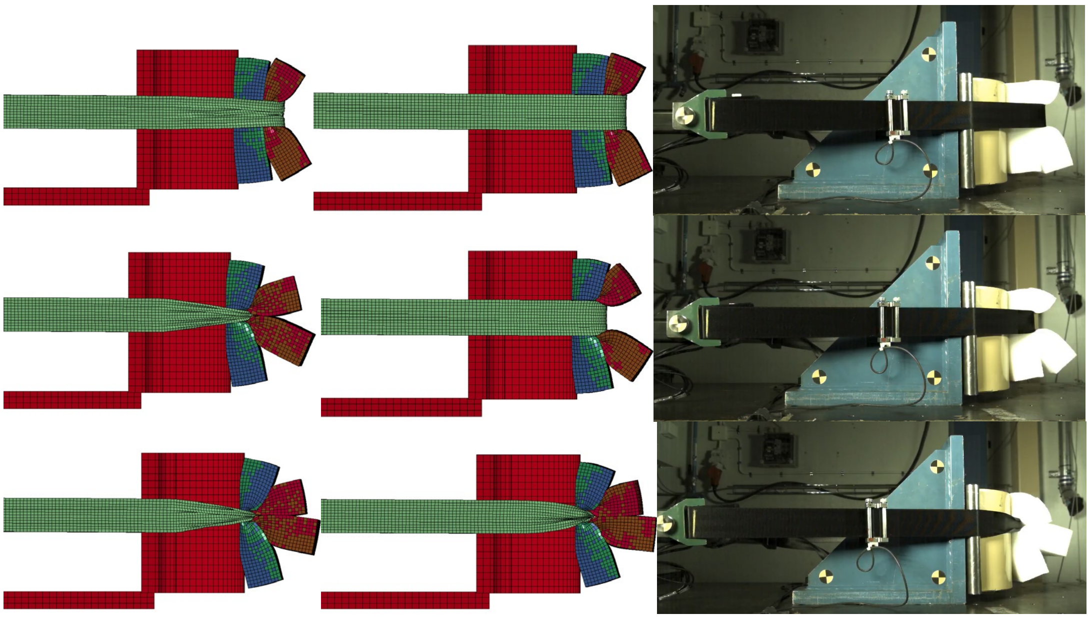

Figure 2: *Loading of belt into foam blocks at three instants of time. Left: FORM=0, Middle: FORM=-14 with coating and Right: physical test.*

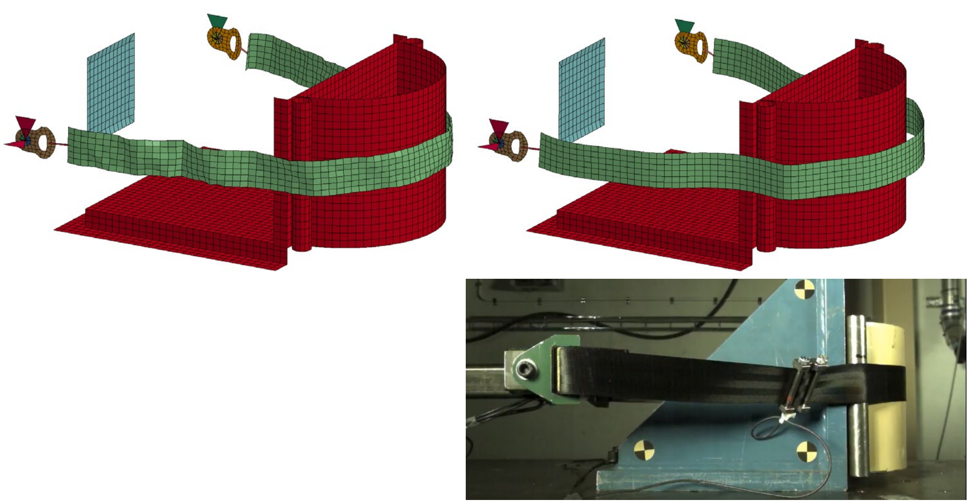

Figure 3: *Top row: After peak load behavior using FORM=0 to the left and FORM=-14 with coating to the right. Bottom row: Physical test*

The advantage of coating feature in *MAT_SEATBELT can also be seen in belt interaction with dummy pelvis assembly as shown in Fig. 4. The updated material model clearly captures the behavior better as in test.

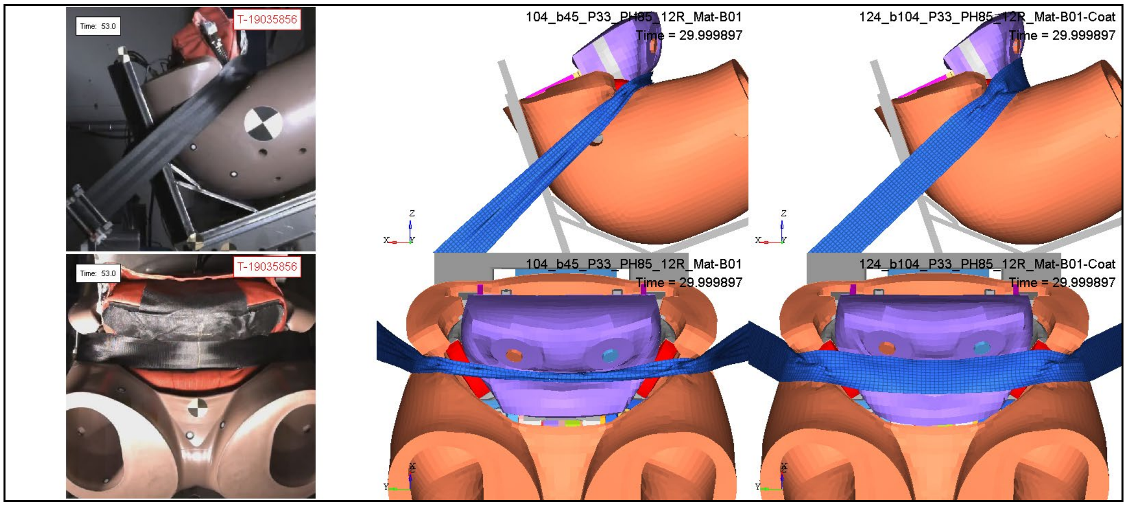

Figure 4: *Comparison of belt behavior at 40 ms into the event, between test (left), seatbelt without coating (middle) and seatbelt with coating (right).*

Strain-rate effect

The strain-rate effect for 1D belt element has been used and strain-rate dependency is now available for 2D belt elements, see Fig. 5. The strain-rate effect enables to capture the behavior and injury levels at different impact speeds.

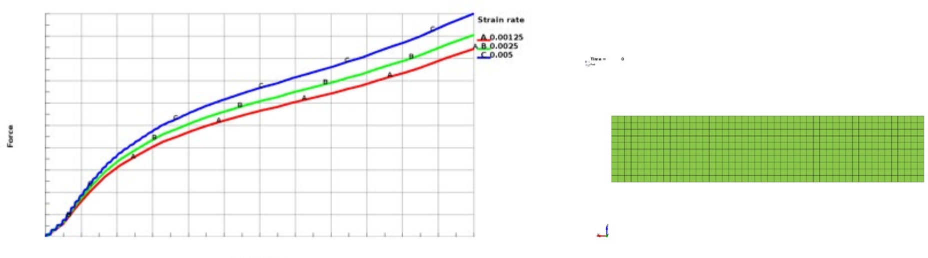

Figure 5: *The implemented strain-rate effect for MAT_SEATBELT_2D in a simplified test case.*

Orthotropic membrane material properties

A belt has orthotropic membrane behavior and that is now made available also for 2D belt elements. The user controls the material properties to be applied in the perpendicular direction of the belt using the parameters, EB, PRAB, PRBA and GAB, further described in the Appendix. The orthotropic membrane properties are illustrated in Fig. 6.

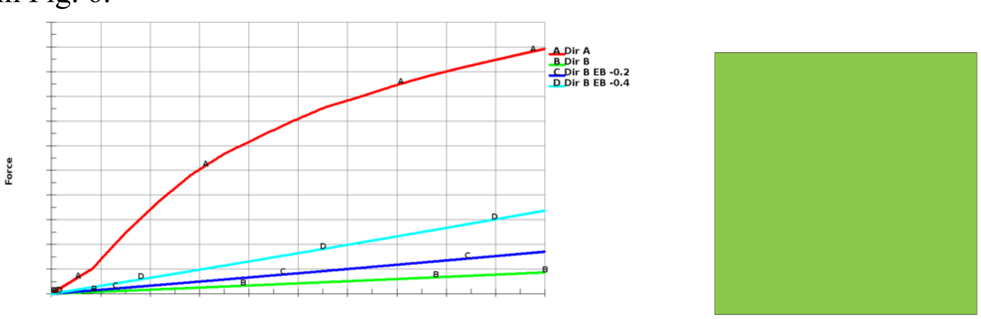

Figure 6: *The implemented orthotropic material properties for MAT_SEATBELT_2D in a simplified test case.*

Conclusion

The new implementation of *MAT_SEATBELT_2D allows for orthotropic membrane behavior, isotropic bending behavior, strain-rate effects and use of sliprings. By using the coating functionality for 2D belt elements in LS-DYNA it has been shown that the belt behavior of a belt loaded in bending is more robust. It is also indicated that behavior during unloading is more robust. This enables the use of 2D seatbelt elements in new belt modelling.

Future needs

It is foreseen that in the future and for detailed analysis of sliprings a traditional model utilizing normal contact definition will be used. Hence, a need for a coupled material/element model to separate the bending/tension will be needed. Currently, this will have to be accomplished with double layered elements (membrane/shell for in-plane/bending properties, respectively).

References

[1] Kahane, C. J. (2015, January). Lives saved by vehicle safety technologies and associated Federal Motor Vehicle Safety Standards, 1960 to 2012 – Passenger cars and LTVs – With reviews of 26 FMVSS and the effectiveness of their associated safety technologies in reducing fatalities, injuries, and crashes. (Report No. DOT HS 812 069). Washington, DC: National Highway Traffic Safety Administration.
[2] T Borrvall, C Ehle, T Stratton: 'A Fabric material model with stress map functionality in LS-DYNA', 10th European LS-DYNA User's Conference, Würzburg, 2015.
[3] LS-DYNA Keyword User's Manual, Vol 1, Livermore Software Technology Corporation, 2019.

Appendix: Parameter setting in LS-DYNA for 2D belt modelling

When using 2D belt elements in LS-DYNA there are many parameters which are determined by LS-DYNA automatically. In this section a brief explanation is made for some of the most common parameters that should be set by the engineer.

The parameters that need to be set on *SECTION_SHELL, *MAT_SEATBELT_2D are given in Figure 7 & 8.

SECTION_SHELL:

When using FORM=-14, set ICOMP=1 and B1/B2=0/90. The edgset is a structured nodeset and T1 is the belt thickness. The under-integrated membrane element (elform=5) is recommended.

Card 1	SECID	ELFORM	~~SHRF~~	~~NIP~~	~~PROPT~~	~~QR/IRID~~	ICOMP	~~SETYP~~
Card 2	T1	T2	T3	T4	~~NLOC~~	~~MAREA~~	~~IDOF~~	EDGSET
Card 3	B1	B2						

Figure 7: *Section shell with highlighted parameters that are interesting for modelling 2D belt element systems.*

MAT_SEATBELT_2D:

To make use of the coating functionality set FORM=-14. The three new parameters E-, T- and S-COAT determines the bending properties. If TCOAT is set to a negative value, the coating does not contribute to the membrane in plane stresses. It is recommended to make use of all three parameters. For the in-plane membrane behavior four new parameters are introduced: EB, PRBA, PRAB and GAB, which enables control of the orthotropic material behavior, see figure 8. Apart from that, the strain-rate effects for 2D seatbelt elements is activated through the LLCID parameter referencing a table instead of a load curve.

Card 1	MID	MPUL	LLCID	ULCID	LMIN	CSE	DAMP	~~E~~
Card 2	~~A~~	~~I~~	~~J~~	~~AS~~	~~F~~	~~M~~	~~R~~	
Card 3	P1DOFF	FORM	ECOAT	TCOAT	SCOAT	EB	PRBA	PRAB
Card 3	GAB							

Figure 8: *Mat seatbelt with highlighted parameters that are interesting for modelling 2D belt element systems.*