MODELLING CARPET FOR USE IN OCCUPANT CRASH SIMULATIONS

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ABSTRACT:

Prediction of occupant injury using crash simulations can require numerical representation of materials that are not normally included within the structural model. Intuitively, it makes sense that the carpet would be required to predict the tibia index during frontal crash events; however, there appears to be little published on the topic. The tibia index is an injury criteria that needs to be predicted during IIHS frontal offset occupant simulations, but is also be looked at during unbelted FMVSS 208 simulations. Since carpet behaves quite differently during compressive and tensile loading, a numerical representation that can stably capture both regimes during occupant modelling is needed.

This paper outlines a method to model the carpet using a specific meshing method and two material models. Shell elements in combination with the *PIECEWISE_LINEAR_PLASTICITY material model are used to model the tensile load carrying capacity of the carpet, while brick elements with the *MAT_FU_CHANG_FOAM material model are used to represent the compressibility of the carpet. Validation of using this modelling method with test data is presented, as well as the application of the carpet model in larger occupant models.

KEYWORDS:

Occupant, Injury, Crash, Safety, Carpet, Material, Foam, Tibia Index

INTRODUCTION

Frontal occupant simulations typically require a wide variety of materials to be defined when creating a finite element model of the vehicle interior. The carpet supports the occupant's heels at the beginning of the event and may absorb crash energy if sufficient backing material is present. Since the carpet supports the feet during the beginning of the simulation, its presence in the finite element model can affect the kinematics of the occupant's legs, which ultimately determines the loads they can experience during a crash event.

This work highlights the steps taken to include a representation of the carpet within vehicle crash models. Samples of carpet were physically tested by cyclically loading both in tension and compression. Shell elements were used in combination with the *PIECEWISE_LINEAR_PLASTICITY material model [1] to model the tensile load carrying capacity of the carpet, while brick combined with the *MAT_FU_CHANG_FOAM material model [2] are used to represent the compressibility of the carpet.

MATERIAL TESTING

Physical tests were undertaken on the carpet material by AXEL Products [3]. The carpet was tested monotonically and cyclically to failure both in tension and compression. Figure 1 shows a sampling of the tensile loading tests, while Figure 2 shows some of the compressive loading tests. Even though the abscissa and ordinate values for both Figures have been normalized, the difference in tensile and compressive loading behaviour of the carpet is still apparent. Figure 1 shows that there is a fairly large variation in the carpet tensile strength, as each of the four samples were cut from the same piece of carpet. The variability of compressive strength is less noticeable, but still present, as shown in Figure 2.

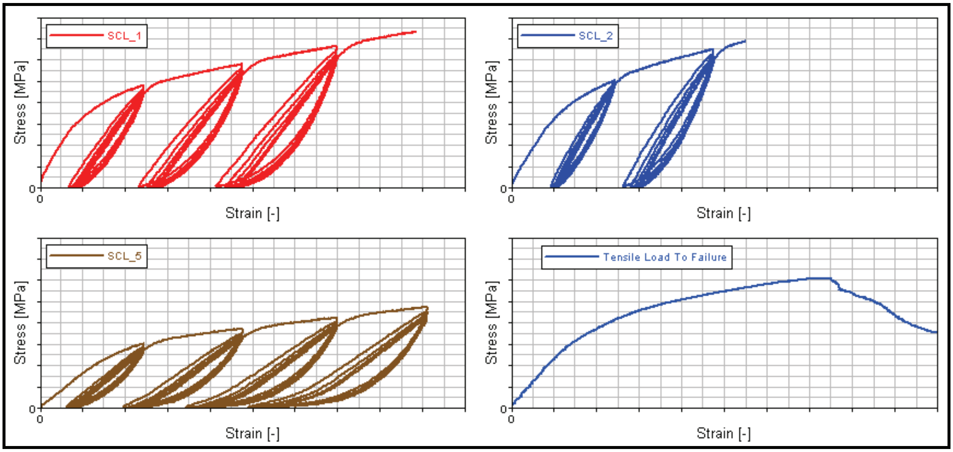

Figure 1: This figure shows the tensile loading and unloading stress versus strain curves for four samples of the same carpet. Each plot is to the same scale, which shows the large variation in tensile strength that the carpet has.

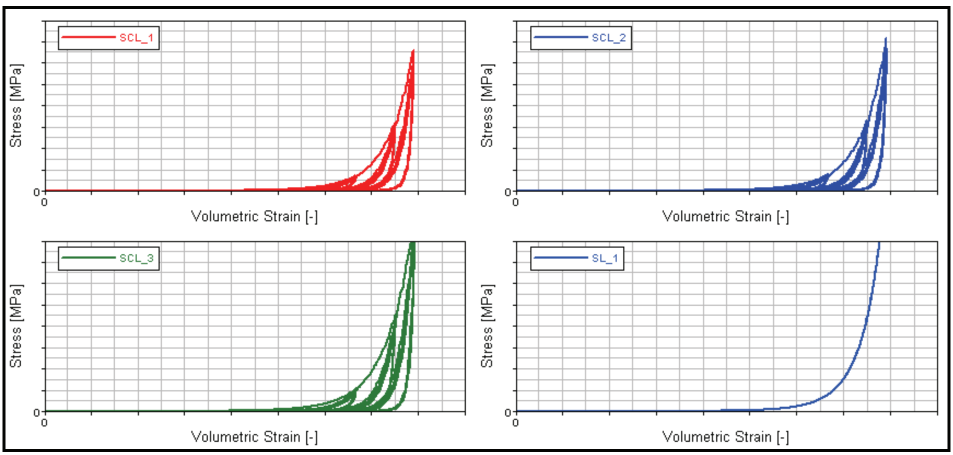

Figure 2: This figure shows the cyclic compressive loading curves for three samples of carpet and one monotonic loading compression curve. Each plot is drawn to the same scale.

LS-DYNA MATERIAL MODEL CREATION

From analysis of Figures 1 and 2, one can see that the carpet behaves quite differently during tensile and compressive loading. During a frontal crash event, the carpet can be both in tension, and compression. For example, inertial loads placed on the carpet creates tension that must be reacted internally (by the carpet), towards the attachment points of the carpet to the vehicle. In other regions, such as underneath the feet of the occupants, the carpet can be compressed during the crash event.

In order to match this behaviour, a unique approach was created that allows both the tensile and compressive behaviour of the carpet to be modelled. Figure 3 shows a cross section of a typical carpet construction used in vehicles. It was felt that the majority of tensile strength of the carpet comes from the outer layers, while the majority of compressive compliance comes from the pile and middle layer. For these two reasons, it was chosen to model the carpet using a three ply construction, whereby the outer layers provide the tensile stiffness and the middle layer provides the compressive compliance. In this manner, the behaviour of the carpet could be matched during different loading regimes. The tensile behaviour of the carpet appeared to yield, but carries an increasing amount of load prior to failure. This behaviour is similar to metals, so the LS-DYNA *MAT_PIECEWISE_LINEAR_PLASTICITY material model was chosen to represent the outer layers. The compressive loading behaviour of the carpet looked similar to that of typical foams, so the LS-DYNA *MAT_FU_CHANG_FOAM material model was chosen to represent the middle layer.

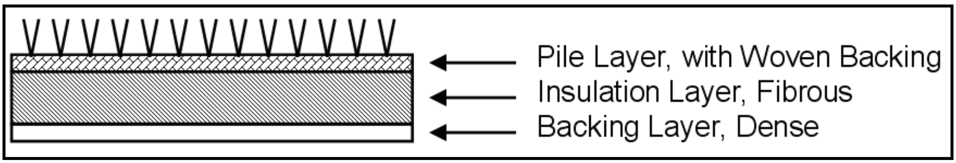

Figure 3: This figure shows the construction of typical automotive carpet. The pile layer has a woven fabric backing; the insulation layer is made from recycled, randomly oriented fibres while the backing layer is a dense, elastomer - like substance.

Figure 4 shows the manner in which the carpet must be meshed for this method to work. For the carpet that was tested, 2mm thick shell elements were used for the top and bottom layers, while a 6mm thick layer of brick elements are used for the middle. For clarity, in Figure 4 the shells are shown with the LS-PRE/POST [4] thickness option, so they appear as brick elements.

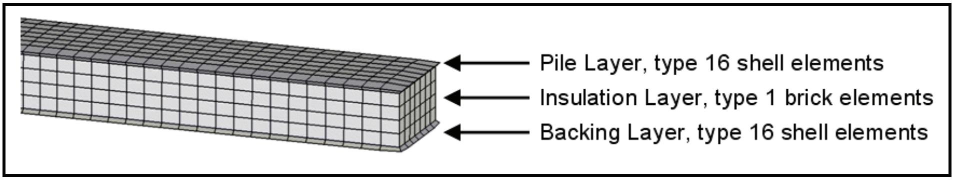

Figure 4: This Figure shows the meshing method for the carpet. The outer layers are meshed as shell elements, while the inner layer is meshed as brick elements.

The cyclic tensile test data shown in Figure 1 was post-processed to find an average Young's and Tangent modulus for the loading portion of the curves only. The carpet generally is not loaded cyclically during the crash event, so the unloading portions and the hysteresis loops were neglected in this work. The Young's and Tangent modulus values were used to create a simple *MAT_PIECEWISE_LINEAR_PLASTICITY LS-DYNA material model which matched the average tensile strength of the carpet. Figure 5 shows the resulting bi-linear approximation along with test data from a monotonically loaded sample of carpet. This material model is prescribed to two outer shell layers of the carpet shown in Figure 4.

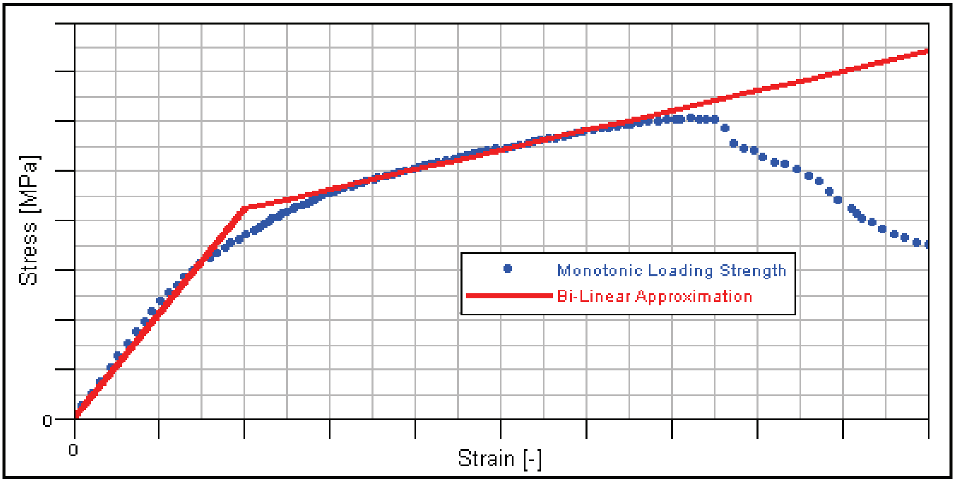

Figure 5: This figure shows how the use of a bi-linear stress-strain curve provides a reasonable approximation of the carpet's tensile strength, up to the point of failure.

The compressive test data was post-processed to create a *MAT_FU_CHANG_FOAM material model. Average compressive loading and unloading curves were calculated, smoothed and then extrapolated to 99% volumetric strain using a Hyperbolic function to smoothly extend the data. This technique, suggested by Du Bois [5] relates the rate of change of yield strength with respect to strain:

$$\left.\frac{\partial\sigma}{\partial\varepsilon}\right|_i = \left(\left.\frac{\partial\sigma}{\partial\varepsilon}\right|_{\varepsilon_o}\right)\left(\frac{1.0-\varepsilon_o}{1.0-\varepsilon_i}\right)^n \qquad \text{(Eq. 1)},$$

where ε_o is the strain value from which the extrapolation starts. The exponent n is usually chosen to be between 2 and 3, but can also be calculated from the test data for strain points below ε_o to get an idea of what the value should be. The extrapolated yield strength values are given by:

$$\sigma_{i+1} = \sigma_i + \left.\frac{\partial\sigma}{\partial\varepsilon}\right|_i \Delta\varepsilon \qquad \text{(Eq. 2)}$$

Using this method extrapolated compressive load and unload curves for the material model were calculated. This material model is prescribed for the inner brick layer of the carpet shown in Figure 4.

LS-DYNA MATERIAL MODEL VALIDATION

A simple LS-DYNA simulation model was created that tested the resulting material models in both tension and compression. Figure 6 shows the simulation model. As described earlier, the meshes of both the tensile and compressive sample are created by extruding brick elements between two shell meshes. The shell meshes have a thickness of 2mm and the thickness of the bricks is 6mm. Prescribed motion is used to first pull on the tensile sample, and then return to its original position. The compression sample is first compressed and then returned to its original position.

Figure 7 shows the behaviour of the carpet model for the tensile loading and unloading / pushing cycle. The simulation results are shown as a red line, while the test results are shown as blue dots. The test was performed to failure, whereas the simulation model does not fail, but unloads and then pushes in compression until the carpet specimen buckles. One can see that when the carpet is loading up in tension, the simulation closely matches the test data. Generally, the carpet does not fail during a crash test, so it was most important to capture the loading curve, and not the failure of the carpet. Also shown in Figure 7 is how the carpet unloads from tension, and then buckles, because of the strain that has occurred during loading. This buckling behaviour is important to capture otherwise the response would be too stiff, which could cause numerical inaccuracies to occur.

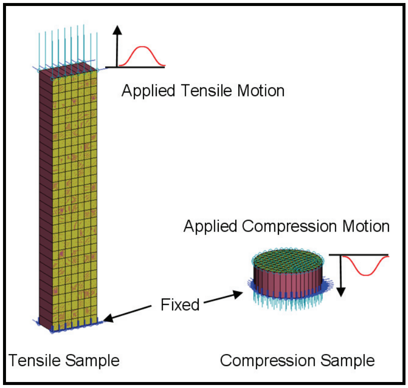

Figure 6: This figure shows the simulation model that was created to validate the response of the carpet material models during tension and compression. The tensile sample is shown on the left, while the compression sample is shown on the right.

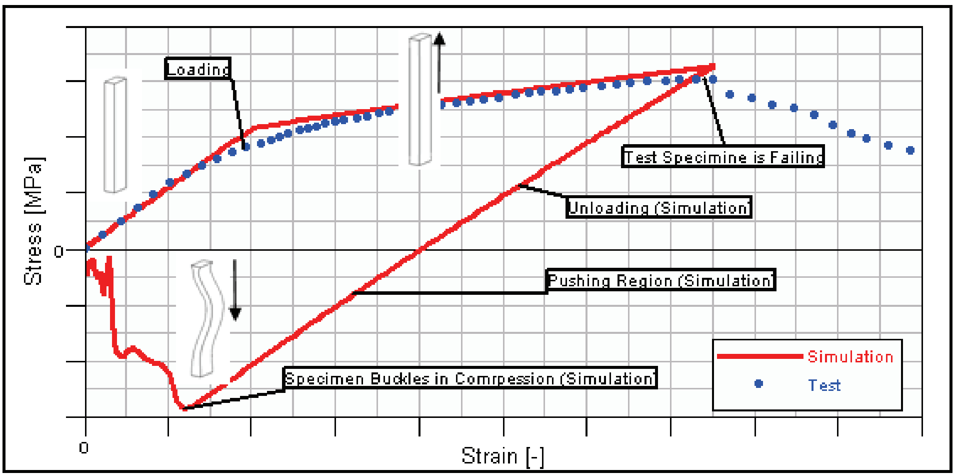

Figure 7: This figure shows the simulation of the tensile test compared with the test result. The simulation is unloaded at the point where the test sample starts to fail. Since failure of the carpet is generally not observed during a crash test, the material model is expected to behave similarly.

Figure 8 shows the behaviour of the carpet model for the compressive loading and unloading cycle. The simulation is shown as a red curve, while the test is shown as a dotted blue curve. The simulation model is matching the compression phase nearly exactly, as shown by the highlighted region of the curves. The unloading curve as predicted by the simulation model is also shown in this zoomed section. When Figures 7 and 8 are combined to show both the compressive and tensile loading behaviour of the carpet as shown in Figure 9, the large difference between the tensile and compressive strengths of the carpet are apparent. In Figure 9, the compressive region is shown in the negative stress-strain quadrant.

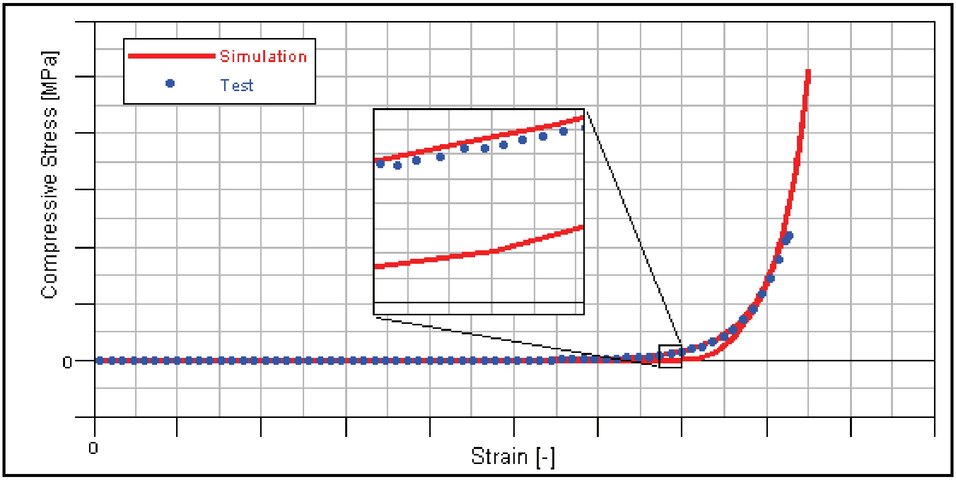

Figure 8: This figure shows the simulation of the compression test compared with the test result. The simulation matches the loading portion of the test curve quite well and remains stable at higher values of compression. The zoomed portion shows the unloading curve which lies below the loading curves.

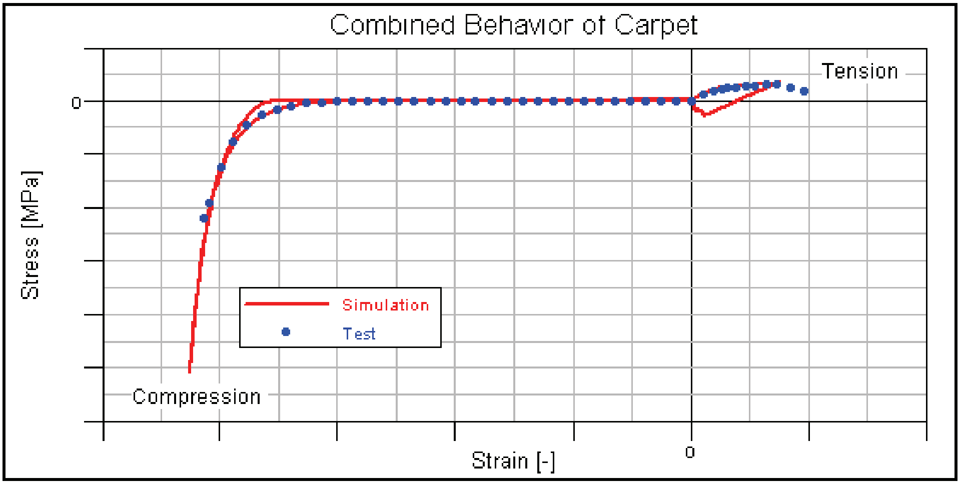

Figure 9: This figure shows the behaviour of the carpet in compression and tension. The simulation curves are shown as solid red curves, while the test date is shown as blue dots.

APPLICATION IN OCCUPANT CRASH MODELS

For a model of the carpet to be included within the occupant crash models, several steps should be taken. The carpet should be meshed as described previously, with a layer of shell elements sandwiching one or more layers of brick elements. Contact of the occupant with the carpet should be allowed to initialize prior to the crash event. This can be performed by allowing the dummy to settle under gravity, or by prescribed motion of the occupant to its equilibrium or initial position. Figure 10 shows an example of the carpet in an unbelted occupant simulation model. This simulation model represents the unbelted 40km/hour United States Government crash test specified in the Code of Federal Regulations [5]. This simulation model was run twice, once with the carpet and once without the carpet to show the importance of simulating the carpet when predicting lower leg injury. Figure 11 shows the left Tibia Index of the occupant for these two simulations compared to test data. The Tibia Index is a function of the axial load and resultant bending moments that the lower leg experiences during a crash test. From this figure, one can see that the Tibia Index prediction from the simulation model with the carpet was considerably closer to the actual test than the simulation model without the carpet.

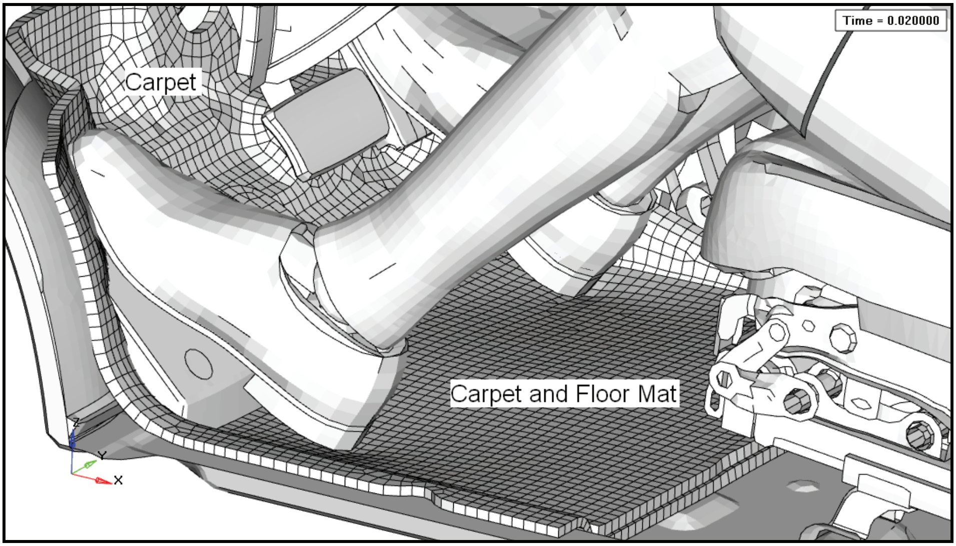

Figure 10: This figure shows the carpet, and floor mat being modelled within an unbelted occupant sled model.

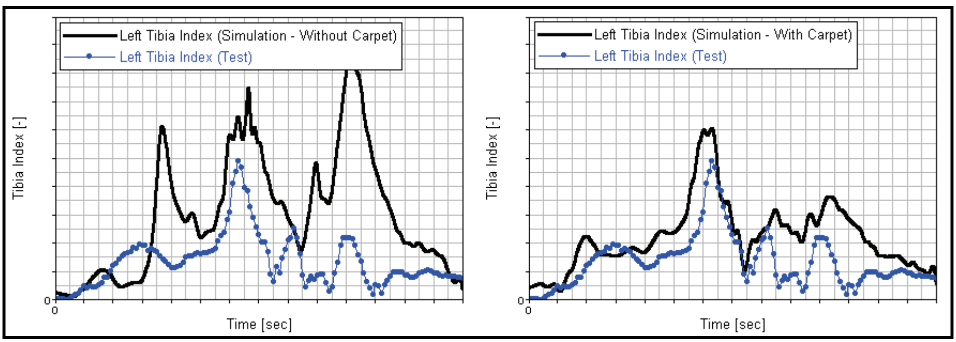

Figure 11: This Figure shows the Left Tibia Index predictions from two simulation models compared to the same test. The plot on the left shows the simulation that did not include the carpet, while the plot on the right shows the simulation that included the carpet. The model that included the carpet was clearly closer to the actual test.

CONCLUSIONS

A method of modelling the carpet during a frontal crash simulation has been developed. This method presents the development of two material models, one for the outer surfaces of the carpet, and one for the compressible portion. The outer surfaces are to be meshed as 2mm thick shell elements, while the inner portion is to be meshed as brick elements. When this new method is followed, the simulation is able to reproduce the behaviour of the carpet during tension and compression, both loading and unloading. Furthermore, improved predictions of lower leg injury have been obtained when this carpet model has been used within occupant injury models.

REFERENCES

1. Hallquist, J. O., LS-DYNA. Keyword User's Manual. Version 971, Livermore Software Technology Corporation, Livermore, 2007.

2. Chang, F.S., "Constitutive Equation Development of Foam Materials," Ph.D. Dissertation, submitted to the Graduate School, Wayne State University, Detroit, Michigan (1995).

3. AXEL Products, Inc. 2255 S. Industrial Hwy. Ann Arbor, Michigan 48104 USA. http://www.axelproducts.com

4. Hallquist, J. O., LS-PRE/Post v1.0 Manual. Livermore Software Technology Corporation, Livermore, 27 August 2002.

5. Du Bois, P.A., "Crashworthiness Engineering Course Notes" Livermore Software Technology Corporation, Livermore, 2004.

6. United States Code of Federal Regulations, Title 49 - Transportation, Chapter V - National Highway Traffic Safety Administration, Department of Transportation, Subpart B - Federal Motor Vehicle Safety Standards, Section 571.208 - Standard Number 208; Occupant Crash Protection. [49CFR571.208]