General considerations for the influence of mesh density in LS Dyna

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1. Abstract/Background

Accurate and reliable CAE results are essential for the product development process in manufacturing industries. This is particularly so in the automotive industry where virtual simulation predictions are gradually replacing physical testing in the ever greater drive to reduce product development time and costs. CAE is nowadays completely integrated in the development process and critical design decisions are often based on the FEM calculations. The accuracy of predictions is very much dependent on the detail used to model physical structures; larger the models, better the results. However, larger models also demand much greater computing resources, especially for crash simulations. Model sizes are, therefore, dictated by reasonable computing times to solve the equations. At the same time, there is also a tendency to produce larger models not only for better accuracy but also as a result of use of automatic model generation to reduce time and cost for this phase of CAE analysis and to enable effective decision making based on CAE performance predictions. This background will be documented in this paper.

2. Introduction

The advent of the relatively inexpensive high performance computers and powerful pre and post processors for creating models and interpreting results has led to the use of larger models in the automotive industry (see Figure 1). These larger models lend themselves to including detail that was previously analysed as separate sub-models (for example, dummies, airbags, seats, engine parts). The larger models also mean that body panels are meshed with higher densities which result in smaller finite elements and lead to more accurate predictions. In the past, finer meshes and smaller elements would have had a very adverse effect on modeling speeds in finite element structural analysis in the automotive industry.

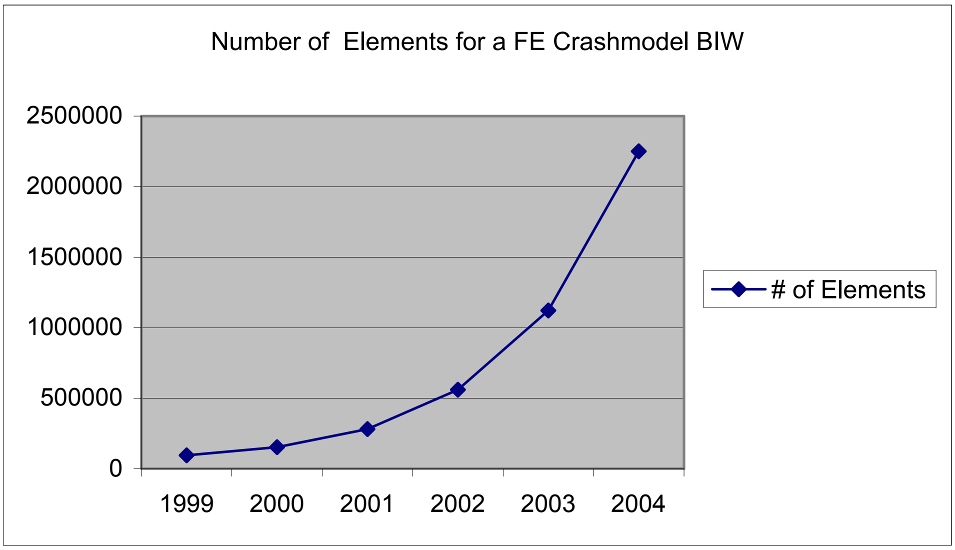


Figure 1: Number of finite Elements in a crash BIW at a European OEM

3. FE Experiments with varied parameters

Model setup

To determine the dependency of element sizes, element orientation and mapping, a finite element crashbox experiment was performed.

The varied parameters were as follows:

1. Average edge length (10, 5 and 2,5mm)
2. Mesh orientation (0 and 25 degrees)
3. Different mesh and integration methods (Belytschko-Tsay and Fully Integration)
4. Number of spotwelds
5. Mapping of stamping data (with and without)

The box is shown in Figure 2. The box has a length of xx and consists of two panel which are spotwelded together. For the mapping evaluation, stamping simulations were performed on the panels.
The process parameters were:

1. Material: Mild Steel
2. Material Model: Piecewise linear isotropic plasticity
3. Material gauge: 1mm
4. Impact velocity: 20 km/h
5. Impact wall: Rigid

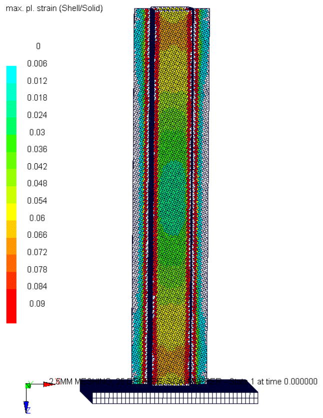


Figure 2: FE Crashbox with already mapped stamping data

Analysis of the results

- Influence on the mesh size for the same element orientation

For the element orientation of 0°, the difference in results between 10 mm 5 mm and 2,5 mm is small for the displacement output after the crash event as shown in Figure 3. The internal energy also shows similar deviation. The crash mode for the 10 mm differs significantly. For mesh orientations that follow the bucking modes, results are acceptable for coarser meshes. This effect is already defined in the literature as "super convergence".

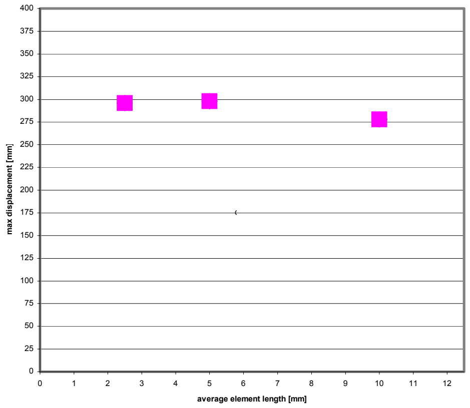


Figure 3: Max displacement for the 2,5 mm, 5 mm and 10 mm with 0° mesh rotation

- Influence of 25° mesh orientation

The mesh of the crashbox was recreated so that the element edges were orientated at 25 degrees to the horizontal. The displacement and the buckling modes now change from the 0° mesh in that they do not agree with the collapse modes. The deviation is higher for the coarse mesh. Pictures of the different collapse modes can be found in the attachment.

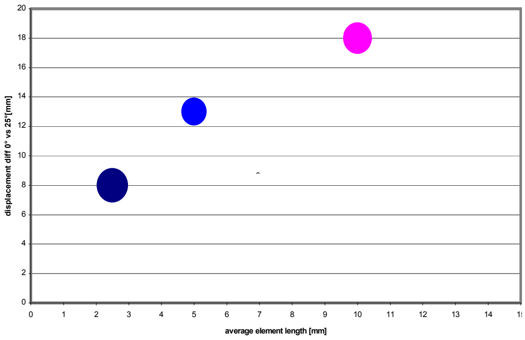


Figure 4: Max displacement difference for the 2,5 mm, 5 mm and 10 mm with 25° mesh orientation

Influence of using triangular elements

It is a well known fact within the crash user community that triangular elements have a stiffening effect on structural response. This is especially true of coarse meshes. To study the effect of triangular elements on response, the crashbox example was meshed with such elements. The collapse of box corresponding to the 10 mm mesh is found to be significantly different from that of the QUAD mesh; the displacement reduces by almost 25%. This difference is much smaller for the 5 mm element and 2,5 mm element meshes (11% and 4% respectively).

- Influence of manufacturing process

One of the end effects of manufacturing car body panels using stamping techniques is that the thickness and the amount of plasticity varies across the stamped panel. It is, therefore, common and necessary these days to map scalar manufacturing data such as thickness and plasticity onto the crash models for more accurate modelling and better results. However, the models used for stamping analysis tend to be fine to include all the pertaining detail for accurate prediction, while the crash models in comparison are usually coarser. Hence, it is necessary to “map” the results from the stamping simulation to crash models.

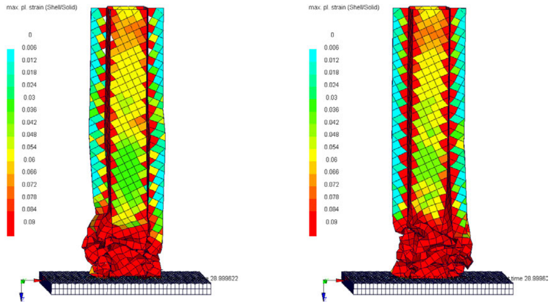
The crashbox used for previous study provided a good model to study the effect of both mapped and unmapped results on the response of the structure, as well as to make a comparison between two of the more common mapping methods; that is, Dynain and SCAI-MPCCI.

Differences mapped/unmapped:

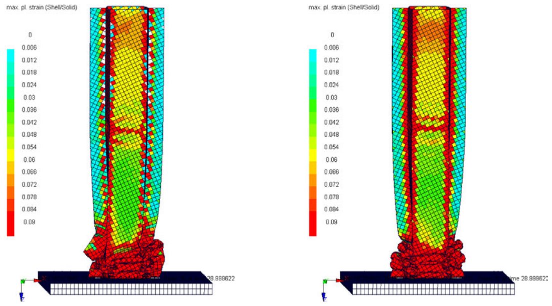
In general, the effect of mapping results from stamping simulation had the expected outcome that the crashbox was stiffer and produced a lower overall displacement. Mapped plasticity was found in the corners of the box from the stamping process. The stiffening effect was much higher for the coarse meshes (10 mm element size with 0 degree orientation gave a reduction in displacement of 43 mm) and the smallest for the fine mesh (2,5 mm element size at 0 degree orientation produced a reduction in displacement of just 3 mm). The mapping technique used for this comparison was the MPCCI mapping.

Differences MPCCI mapping/ Dynain mapping

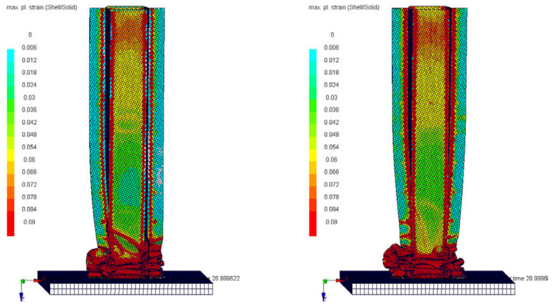
Even though the mapping data look different (see Figure 5), its effect on the displacement and internal energy results was negligible for the different mesh sizes and orientation; for example, for 5mm element size mesh: 0 mm difference in displacement for 0° and 25° orientation and 1% difference in the internal energy for the 0° orientation, 3% for the 25° orientation; for the 10 mm element size mesh: 15 mm for the 0° orientation and 10 mm for the 25° orientation difference in displacement, and 3% internal energy difference for the 0° orientation, 0.05% for the 25° orientation).



10 mm mesh
MPCCI Dynain



5 mm mesh
MPCCI Dynain



2.5 mm mesh
MPCCI Dynain

Figure 5: Comparison between the mapping and crash pattern for 25° element orientation meshes.

Results

The results of the different runs made with the crashbox can be summarised as follows:

- Results for the displacement and the internal energy seem to be smooth and stable in a range from 15 mm to 2,5 mm for orthogonal element orientation
- Different element orientation gives different results for coarser meshes
- Finer mesh is not sensitive for different element orientation and mapping (see Figure 6)
- SCAI MPCCI Mapping tool is easy to use for Crash coupling. It is code independent and produces similar results to other mapping tools

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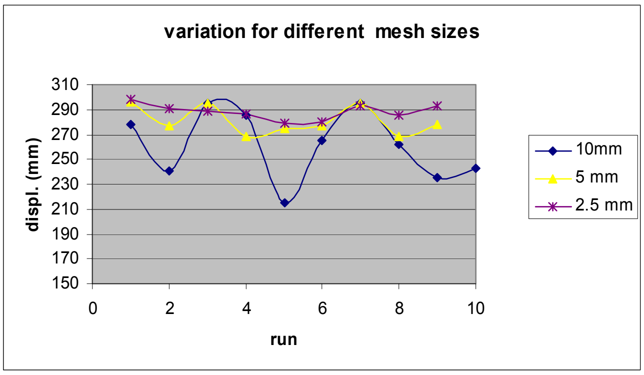


Figure 6: Comparison of the result deviation for different mesh sizes.

Conclusion

The results obtained of the crashbox using varying modelling parameters can be summarised as follows:

- If a prior knowledge of the collapse of a structure is known, then it is possible to use a coarse mesh to model such a structure with elements orientated so that they are orthogonal with respect to the collapse direction (to achieve what is termed "super convergence")
- If no prior knowledge of the collapse mode of a structure is known, then a fine mesh must be used to obtain reliable results
- The exact collapse modes of all components of a complex vehicle are difficult to predict beforehand
- Meshing rules in respect of orthogonality, Mapping and Integration schemes are important for coarser meshes but insignifant for finer meshes.
- Creation of finer meshes can be automated by TEC-ODM!

4. Auto meshing with TEC-ODM

Nowadays, body-in-white finite element models with a million elements is not unusual if they are to include all the relevant detail for structural analysis. The main drawback against even larger models is the current limitations of the hardware; bigger models demand more memory, disk space and CPU time to solve the larger number of equations. On the other hand, bigger models with greater detail provide better accuracy of simulations and, at the same time, lend themselves to ease of meshing and model generation as illustrated in the following images.

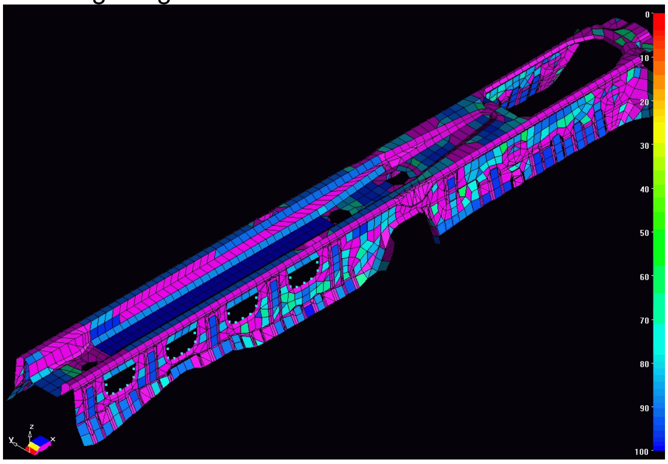


Figure 7: Mesh Quality for coarse mesh

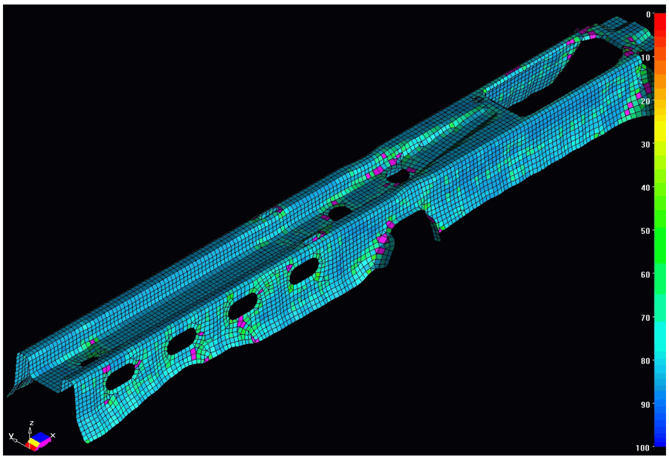
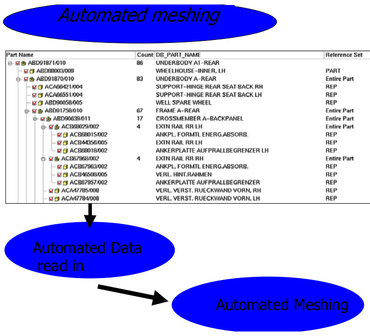


Figure 8: Mesh Quality for fine mesh

Considering the fact that a reduction in the element size of 50 percent would result in models that are approximately four times larger, an automated meshing process as described in this paper will give body-in-white models of two to 5 million elements. These models would demand much greater CPU power to solve the equations that result from the large number of elements and smaller time-steps for crash simulation. It is possible to overcome some of the constraints by making use of commercially available crash analysis programs that take full advantage of special computer architecture such as vector processing and Linux clusters.

The automated meshing process



Part Name	Count	DB_PART_NAME	Reference Set	Layer	Re	M
ABD91871/010	86	UNDERBODY A1-REAR				
ABD88003/009		WHEELHOUSE-INNER, LH	PART	Original		
ABD91870/010	83	UNDERBODY A-REAR	Entire Part	Original		
ACA66421/004		SUPPORT-HINGE REAR SEAT BACK RH	REP	Original		
ACA66551/004		SUPPORT-HINGE REAR SEAT BACK LH	REP	Original		
ABD90058/005		WELL SPARE WHEEL	REP	Original		
ABD91758/010	67	FRAME A-REAR	Entire Part	Original		
ABD90639/011	17	CROSSMEMBER A-BACKPANEL	Entire Part	Original		
ACB68029/002	4	EXTN RAIL RR LH	Entire Part	Original		
ACB68015/002		ANKPL. FORMTL ENERG.ABSORB.	REP	Original		
ACB44356/005		EXTN RAIL RR LH	REP	Original		
ACB68018/002		ANKERPLATTE AUFPRALLBEGRENZER LH	REP	Original		
ACB67968/002	4	EXTN RAIL RR RH	Entire Part	Original		
ACB67963/002		ANKPL. FORMTL ENERG.ABSORB.	REP	Original		
ACB46508/005		VERL. HINT.RAHMEN	REP	Original		
ACB67957/002		ANKERPLATTE AUFPRALLBEGRENZER	REP	Original		
ACA47785/008		VERL. VERST. RUECKWAND VORN, RH	REP	Original		
ACA47784/008		VERL. VERST. RUECKWAND VORN, LH	REP	Original		

Figure 9: Automated Meshing Process

The process developed by Tecosim and presented in this paper, consists of the following process:

CAD data enhancement

To transform raw CAD data so it is suitable for finite element meshing, a procedure was developed to help the CAE engineer through this process with the help of a customised toolbox. Typically, the time needed for this transformation is not more than 10 to 15 minutes per part.

Auto meshing process

Once the CAD data is suitably transformed with appropriate level of quality, the actual meshing is performed fully automatically. A computer program has been developed to perform the following tasks using a high level of automation:

Automated data read in

The CAD data is read in the pre-processor while retaining the original CAD file hierarchy.

Automated meshing

Once the CAD data is read in, the actual meshing is performed automatically by the TEC-ODM pre-processor using existing auto meshing features. The meshed parts are written out into a database.

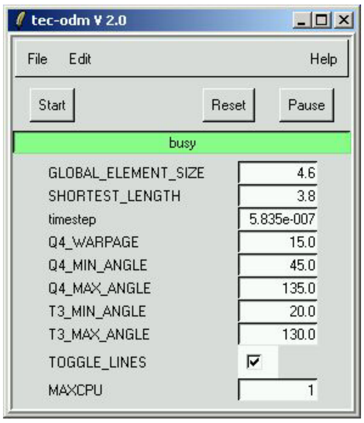
FE model quality check

The batch meshing process can be done overnight on suitable computer hardware (a PC with appropriate level of resources is sufficient). The end result is a fully assembled finite element model. To give the end user satisfaction in terms of quality, the whole model must be checked. Therefore, tools were developed to guide the CAE engineer quickly through this process. Overall time for this phase is less than 5 minutes per part.

Realised product

TEC-ODM process software

TEC-ODM was developed to drastically reduce the time needed for the meshing. It creates larger FE models which require further investment in hardware for their solution. However, the meshing process itself can be run on small computers. The meshing process itself is ready to use.



GLOBAL_ELEMENT_SIZE	4.6
SHORTEST_LENGTH	3.8
timestep	5.835e-007
Q4_WARPAGE	15.0
Q4_MIN_ANGLE	45.0
Q4_MAX_ANGLE	135.0
T3_MIN_ANGLE	20.0
T3_MAX_ANGLE	130.0
TOGGLE_LINES	☑
MAXCPU	1

Figure 10: TEC-ODM GUI

TEC-ODM process software performance

Benchmark results for TEC-ODM

Computer processing for TEC-ODM on different OS and platforms on a test file (one part) for one processor:

Athlon XP 2400+ 2.0GHz Os	Windows	Run Time: 5000 sec.
Athlon XP 1900+ 1.6GHz Os	Linux	Run Time: 2500 sec.

Itanium 2 64bit 1.6GHz Os	UNIX	Run Time: 3100 sec
NEC SX6I	UNIX	Run Time: 22700 sec

Benchmark results for the model build with TEC ODM

Number Crunching of the 5 million-element model with LS Dyna

Itanium 2 64bit 1.6GHz; 8Gb memory,	Run Time: 1530h (~64 days)
16 Proc.; AMD 2400+ 32 bit; 2GB memory each	Run Time: 190h (~8 days)

Summary

The processes developed by Tecosim and described in this paper have been used to demonstrate significant increase in speed for meshing and model-build. These stages in the CAE process used to previously take four to 6 weeks to complete have been accomplished in one week. The automated meshing techniques produce larger meshes that require more computer resources to solve and more effort in handling the resulting data that is generated. The process can be made feasible by using supercomputer hardware platforms, especially for the commercially available crash simulation programs.