A study of mesh sensitivity for crash simulations: comparison of manually and batch meshed models

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Abstract:

Most of the modern simulation techniques require a mesh on which the mathematical model, describing the physical process, is discretized. It could be a volume mesh for a CFD analysis or a surface mesh for structural investigations. The characteristics of the underlying mesh have a strong impact on the results of the numerical simulation.

In this study, the sensitivity of crash simulation results with respect to the properties of the underlying mesh is discussed in more details. The chassis of a commercial vehicle, consisting of 21 parts, is meshed manually by an expert and automatically by the BatchMesher included in the HyperWorks 7.0 environment. The longitudinal beams are discretized with different element sizes and the resulting models of the chassis are used in a front crash simulation with LS-Dyna. The effects of element size on the simulation results, e.g. variations in internal energy, in cross section forces and in buckling modes, are presented and discussed. For the hand-meshed as well as the batch-meshed models, the convergence behaviour of the solution is investigated.

Keywords:

Mesh sensitivity, batch meshed, manually meshed, buckling behaviour

1   Introduction

Most of the modern simulation techniques require a mesh on which the mathematical model, describing the physical process, is discretized. It could be a volume mesh for a Computational Fluid Dynamics (CFD) analysis or a surface mesh for a structural investigation. The characteristics of the underlying mesh have a strong impact on the results of the numerical simulation. Thus, the mesh generation process is an important and time consuming part in building up a physically reliable numerical model.

A quality mesh for Finite Element (FE) crash simulations has to represent the underlying geometry up to a certain accuracy under the restriction that the mesh elements fulfil the desired quality criteria. For example, the rate of triangular elements has to be under a certain threshold but still above zero to prevent hourglassing. Additionally, the mesh should have a quasi-orthogonal structure and the element flow should be oriented on the expected buckling behaviour.

The Altair BatchMesher, included in the Altair HyperWorks 7.0 environment, is a tool which speeds up the meshing process. Starting from a CAD geometry, the clean up and mesh generation are carried out automatically according to the user defined element criteria and clean up parameters. The BatchMesher combines the fully automated clean up and the quality index-driven meshing iteratively to generate an optimal mesh. Customized procedures can be included as pre- and post-mesh routines to set up an automated model build up process.

In [1], the robustness of hand-meshed and automatically meshed models in a crash simulation has been investigated. The automatically meshed models showed less scattering in the results than the hand-meshed models.

In this study, the sensitivity and convergence behaviour for simulation results of manually and automatically meshed models are investigated. As a test case, the chassis of a commercial vehicle, consisting of 21 parts, is used in a front crash calculation with LS-Dyna. The chassis is meshed manually by an expert and also batch-meshed with the Altair BatchMesher. For both model types, hand-meshed and batch-meshed, the rear part of the chassis is meshed with 10mm shell elements. As a variation, the front part is discretized with 10mm, 5mm and 2mm shell elements resulting in three hand-meshed models as well as three batch-meshed models. In this paper, all the element sizes refer to an average length of the elements.

The results of LS-Dyna front crash simulations are compared with respect to the internal energy and shortening lengths of the parts, the cross-section forces and the buckling behaviour. It is shown, that the results for both model types behave similarly. The differences between the simulation results of a hand-meshed model and its corresponding batch-meshed model decreases as the average element size becomes smaller.

2   Description of the models

For simplicity, the investigations are performed with the chassis of a commercial vehicle in a front crash. The initial velocity is 13.5m/s and an angle of attack between the symmetry line of the vehicle and the rigid wall of 90 degrees is used. Each model consists of 21 parts, which are primarily discretized with quads. The fully integrated element formulation is used, [2], to ensure stability in the calculations.
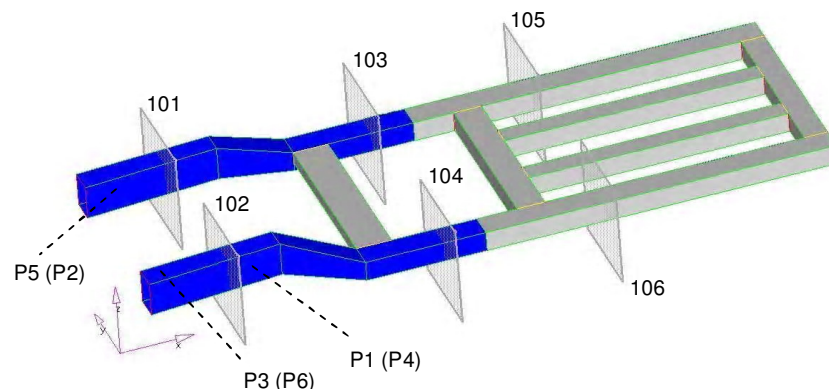

Fig.1: Sketch of the model with cross sections

In Fig.1, a sketch of the model is shown. The dark parts belong to the front section and are discretized with 10mm, 5mm or 2mm shell elements. Whereas the rear section consists of the lighter parts and is discretized with 10mm elements. The parts are named P1, P2 and P3 for the left longitudinal beam and P4, P5 and P6 for the right longitudinal beam. The mirrored parts are denoted in brackets, e.g. P4 is the mirrored part of P1.

Six cross sections, denoted by the grey planes, are defined to investigate the maximal section forces in x direction. Four of the sections are located in the front part with varying discretizations and two sections are in the rear part with a constant discretization. The cross sections 101 and 102 are defined in the front part, near the buckling positions of the two longitudinal beams. On the border between front and rear part, meaning the border between the fine and coarse discretizations, the cross sections 103 and 104 are located. Sections 105 and 106 are defined in the rear part of the vehicle.

Tab.1 shows the statistics of the models where, for example, bm_2 denotes the batch-meshed model with a 2mm discretization in the front part, analogous for the hand-meshed models denoted with hm. The number of quad elements for corresponding models is approximately the same, whereas the 5mm and the 10mm batch-meshed models have slightly more trias than the hand-meshed models. Generally speaking, the finer the discretization the lower is the percentage of trias in the model. No mass scaling is applied and the time step is computed according to the CFL-condition. The spotweld positions are the same for all models due to the mesh-independent spotweld realization.

	bm_2 / hm_2	**bm_5 / hm_5**	**bm_10 / hm_10**
#Quads	580000 / 588000	120000 / 120000	56000 / 55000
%Trias	0.4 / 1.0	1.5 / 1.3	2.1 / 1.6
Min. elem (mm)	0.9 / 0.9	3.2 / 2.0	3.0 / 4.0

Tab.1: Statistics of the models

2.1 Stability investigation

In order to investigate the robustness of the model, the initial conditions are slightly varied and the effects of the variations on the simulation results are analysed. The velocity is changed by 4%, $\delta v = 0.5$, and the angle of attack is changed by 1%, $\delta \alpha = 1^{\circ}$. For each variation, the internal energies of six parts and the max. section forces in six cross sections are compared with the results of the original model.

Tab.2 shows the results of the stability investigation. A variation of the angle of attack by $\delta \alpha = 1^{\circ}$ results in a change of the internal energy by 2.1% and in a change of the max. section forces by 1.4%.

More influence has the variation of the initial velocity. A δv of 0.5m/s causes a change in the internal energy of 6.8%. This relatively large variation is due to the quadratic contribution of the velocity to the kinetic energy of the vehicle. In a crash, the kinetic energy is partially transformed into internal energy. The max. section forces only vary by 1% for a change of 0.5m/s in the initial velocity.

	$\delta v=0 , \delta \alpha=1^{\circ}$	$\delta v=0.5 , \delta \alpha=0$
Int. Energy	2.1%	6.8%
Max secforce	1.4%	1.1%

Tab.2: Variations in the results for varying initial condition

The investigations have shown, that the general behaviour of the model does not change significantly when the initial conditions vary slightly. Therefore the model is considered to be sufficiently robust to perform the following mesh sensitivity investigations.
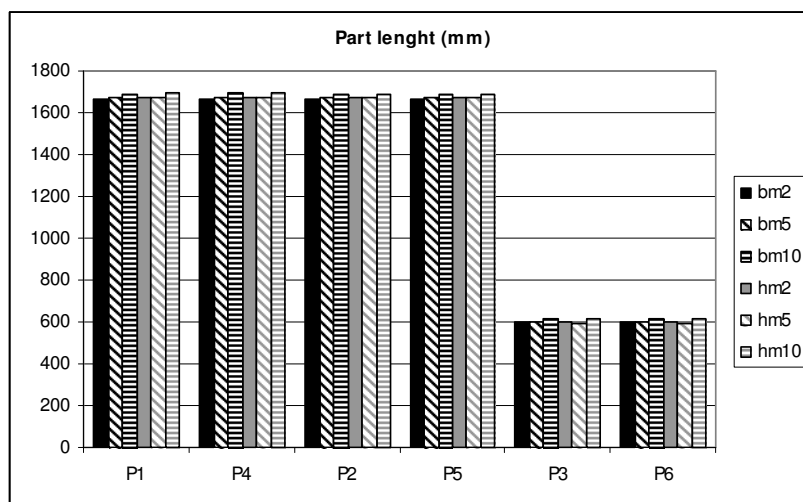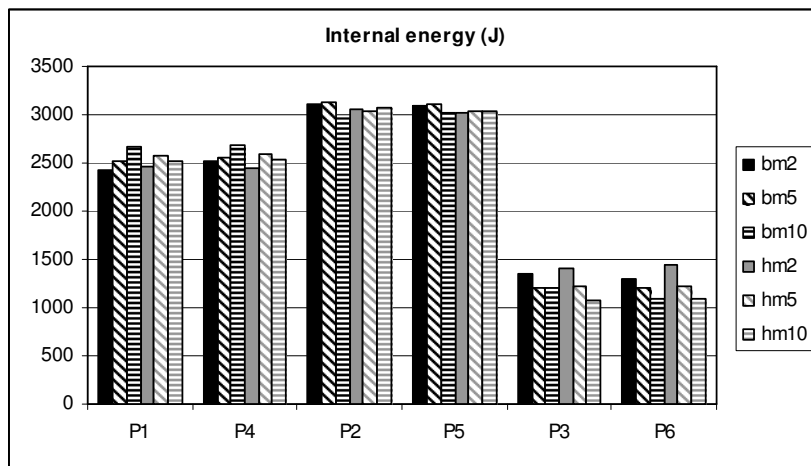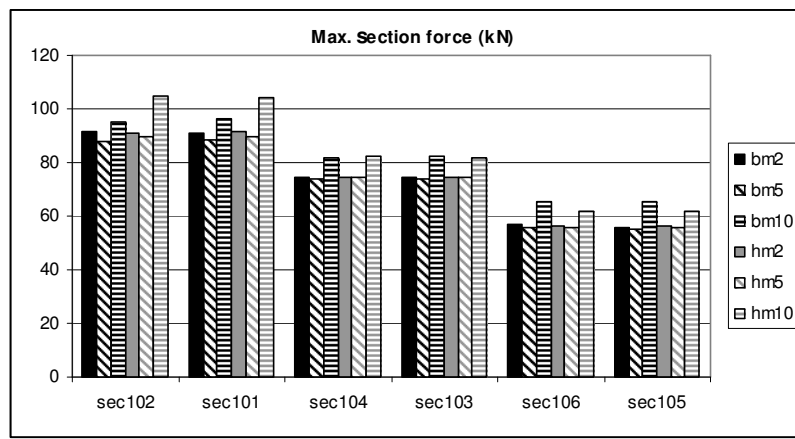
3 Results

All the simulations are performed on a Linux cluster with 16 CPUs and the LS-Dyna version 970, revision 5109 was used. The CPU-times range from 1.5h up to 60h for the first 60ms of the crash simulation with time steps in between $1*10^{-4}$ and $4*10^{-4}$ms. After 2ms, the vehicle gets into contact with the rigid wall and the deformation starts.

In Fig.2, the absolute values of the simulation results for max. section force, internal energy and part length are shown. The internal energy and the part length are determined at the end of the simulation.

Fig.2: Absolute values of the simulation results for hand-meshed (hm) and batch-meshed (bm) models with different discretizations.

The top part of Fig.2 shows the max. section force in various cross sections for different discretizations of the hand-meshed and batch-meshed models. Regarding the batch-meshed models, the results show a monotonous converging behavior in the sense that the differences between the results from the 10mm to the 5mm model is greater than the differences between the results from the 5mm to the 2mm model. An analogous behavior shows the hand-meshed models.
For all cross sections, the results of the hand-meshed and batch-meshed 2mm meshed models are more similar than the ones of the two 10mm meshed models.
Comparing the section forces of the two 10mm models shows that the hand-meshed model leads to higher values in the front part, section 101 and 102, than the batch-meshed model. Whereas in the rear part, section 105 and 106, the batch-meshed model yields slightly higher values than the hand-meshed model. In the intermediate cross sections, section 103 and 104, the values are approximately the same.
The hand-meshed as well as the batch-meshed 10mm model yield higher values in all cross sections than the models with a finer discretization. This might be due to a stiffer behavior of the 10mm models compared to the finer ones.

In the middle part of Fig.2, the internal energies of the vehicle's parts are shown. For the results of the batch-meshed models, a similar convergence behavior as for the cross section forces can be observed. The differences in the internal energies between the 10mm and the 5mm model are greater than the differences between the 5mm and the 2mm model. Whereas for the majority of parts of the hand-meshed models, the internal energies of the 10mm and the 5mm model are more similar than the internal energies of the 5mm and the 2mm models.
Assuming that the results for both model types converge as the discretization becomes finer, the batch-meshed models show a monotonous convergence behavior for the internal energy whereas the hand-meshed models exhibit a non-monotonous convergence.

The bottom part in Fig.2, shows the part lengths after the rebound of the vehicle. For all parts, the differences between the results of a hand-meshed model and its corresponding batch-meshed model are negligible.
A similar convergence, as for the previously discussed section forces, can be observed. The results of both model types converge monotonously and become more similar as the mesh becomes finer.
Generally speaking, the parts of the 10mm meshed models are not as compressed as the parts of the finer discretized models. Again this might be, due to the stiffer behavior of the coarse elements compared to the 5mm or 2mm elements.

Fig.3 shows the relative differences of the max. section force and the internal energy between a hand-meshed and a batch-meshed model with the same element size. The plots are based on the values in the above discussed Fig.2.
In the left part, the max. section force is shown. The differences between the results of two corresponding 10mm models is for every cross section greater than the differences for two corresponding 2mm meshed models. The right part shows the relative differences in internal energy. For the majority of parts, the differences in the results of the 10mm meshed models are greater than the ones of the 2mm meshed models.
For both result types, no general convergence behavior can be observed. However, it should be emphasized, that the finer the discretization becomes, the closer are the simulation results for the hand-meshed and the batch-meshed models.
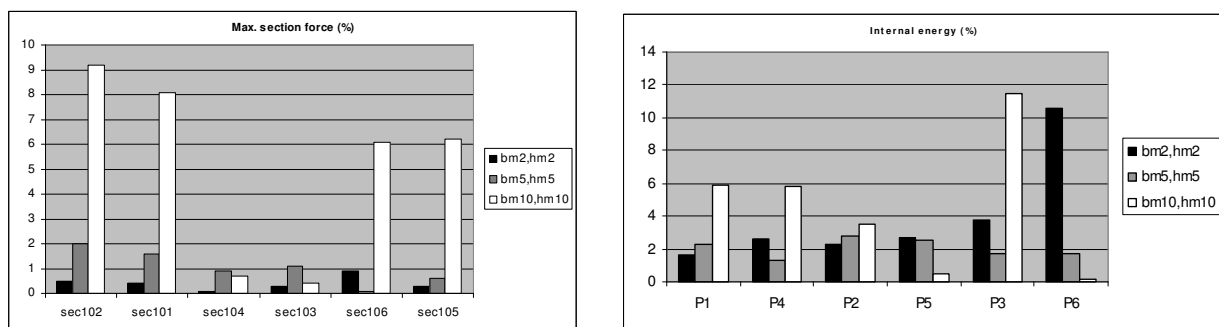
Fig.3: Relative differences of the simulation results for corresponding hand-meshed (hm) and batch-meshed (bm) models with different discretizations, max. section force (left) and internal energy (right).
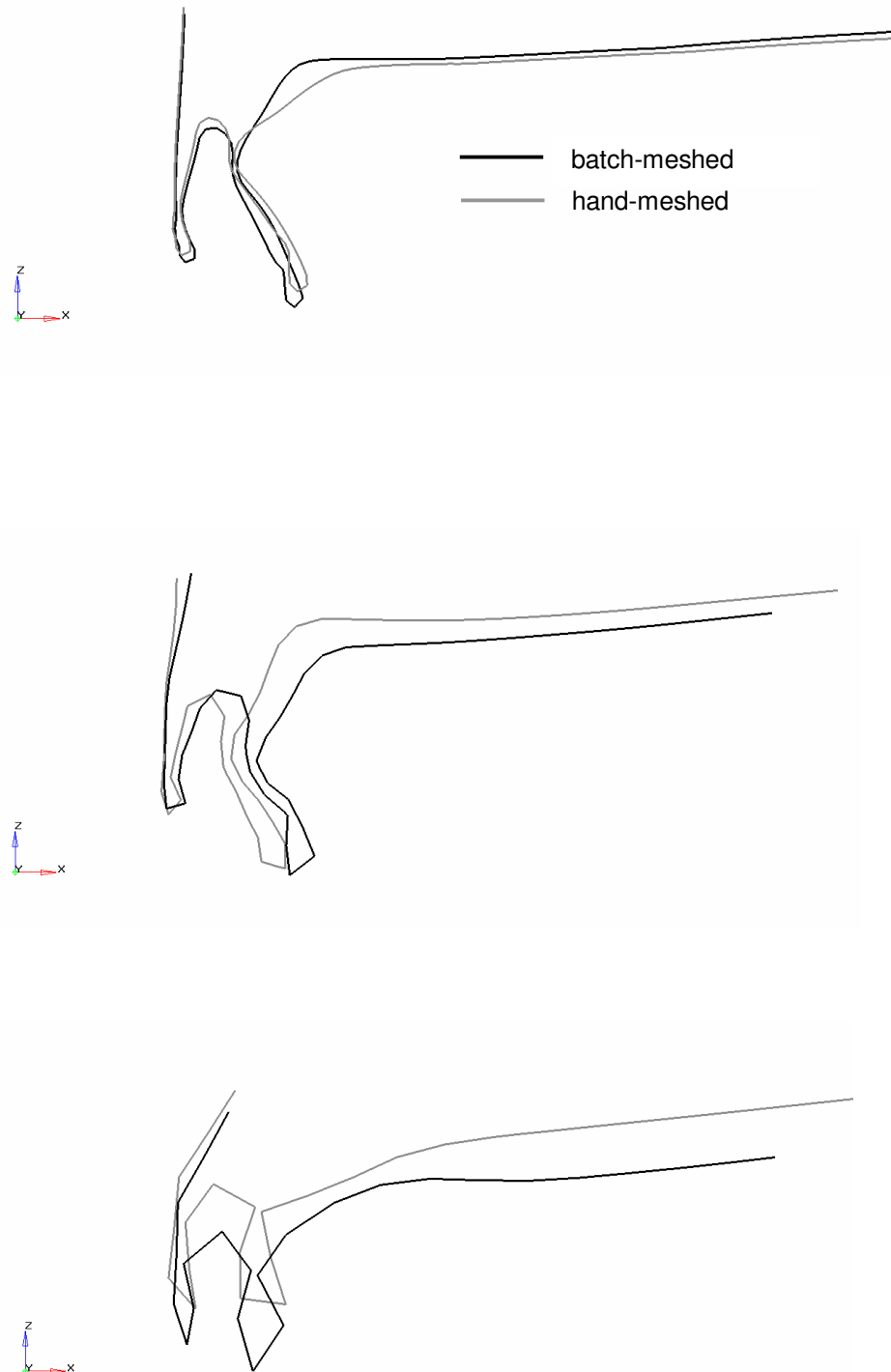
Fig.4: Buckling of the hand-meshed (hm) and the batch-meshed (bm) part P3 for 2mm (top), 5mm (middle) and 10mm (bottom) discretization, section view
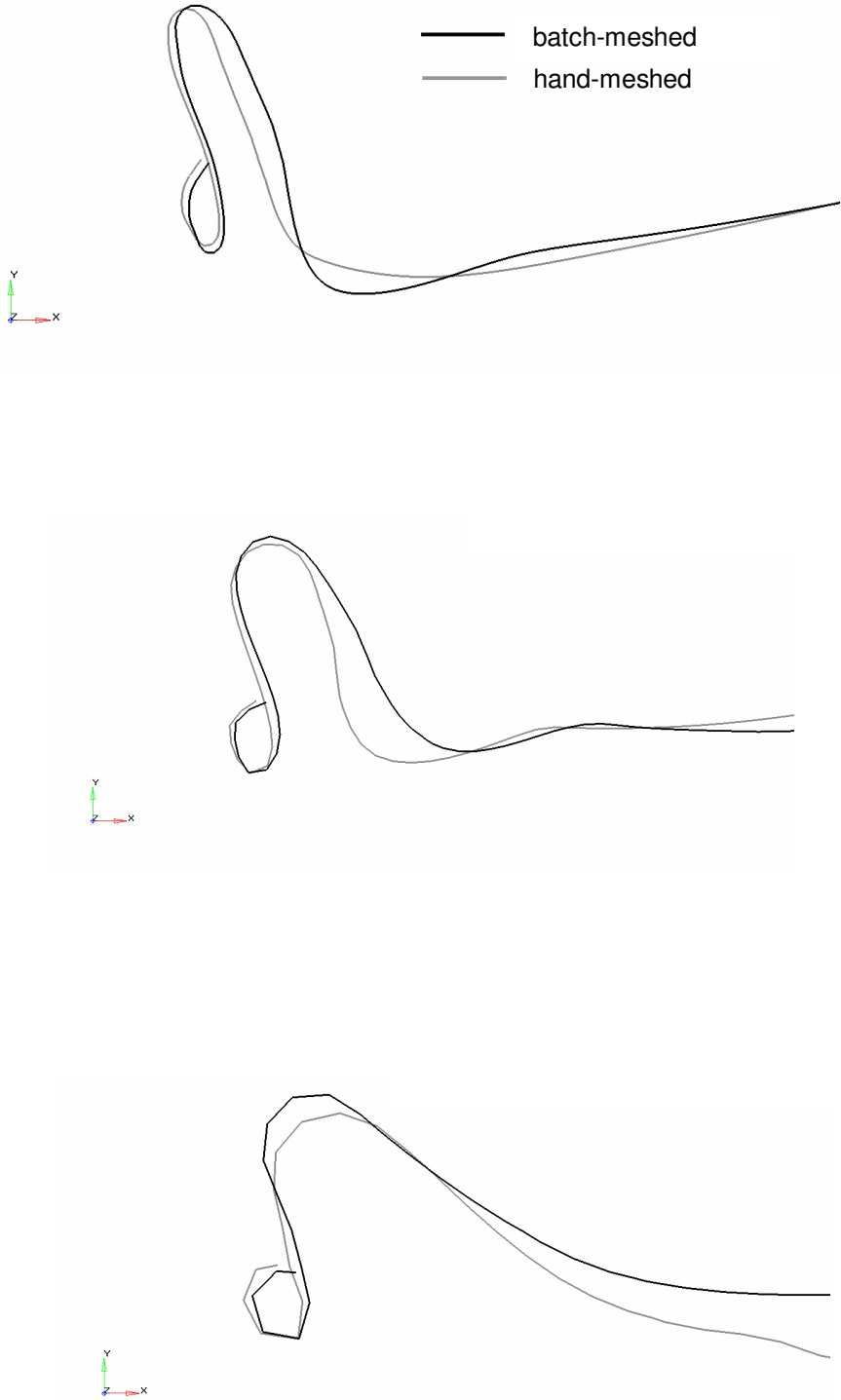
Fig.5: Buckling of the hand-meshed (hm) and the batch-meshed (bm) part P2 for 2mm (top), 5mm (middle) and 10mm (bottom) discretization, section view

Fig.4 shows the buckling behaviour of part P3 for the hand-meshed and the batch-meshed models with different discretizations. The top part compares the buckling modes for the 2mm, the middle part for the 5mm and the bottom part for the 10mm meshed models. Both model types show, for all three discretizations, two folds which are represented roughly for the two 10mm models and smoothly for the two 2mm models. The x locations of the two folds are in all cases approximately the same and differ maximal by the corresponding element length.

The buckling behaviour between the hand-meshed and the batch-meshed models differs more for the 10mm models than for the 2mm models. For all three disretizations, the two model types show more similarity for the first fold than for the second fold or for the undeformed section of part P3. This can be due to the fact that perturbations spread differently on meshes with different characteristics. As a result, more similarity is observed near the vehicle-wall contact point but less similarity in locations further away.

Fig.5 shows the deformation of part P2 for different discretizations. Again, the top part compares the fine models whereas the bottom part shows the results of the coarse models.

As a result of the front crash, the original flange on the front side of the part turns into a circular structure. Due to more flexibility of the 2mm meshes, the deformation might tend to be oval for the finer meshes. The peak points of the fold have approximately the same x position for all models but the extension of the fold differs. For the two 10mm meshed models, the fold has a wider extension than for the 2mm meshed models. This might be due to the fact that models with a 10mm discretization act stiffer than models with a finer discretization and therefore show less flexibility. As a result, the fold might get wider for a coarse model.

As for part P3 in Fig.4, the buckling behaviour of part P2 of the hand-meshed and the batch-meshed models become more similar as the discretization becomes finer.

4   Summary

In this paper, the effects of element size and meshing strategy on crash simulation results were investigated. The chassis of a commercial vehicle in a front crash with LS-Dyna was used as a test case. The rear part was manually meshed by an expert as well as automatically meshed by the Altair BatchMesher with an element size of 10mm. As a variation, the front part was discretized with 10mm, 5mm and 2mm, resulting in three manually meshed models as well as three automatically meshed models. The results of the different models for internal energy, for max. section force, for part length and for buckling modes were compared after the rebound.

For the max. section force and part length, the hand-meshed as well as the batch-meshed models converged monotonously. The hand-meshed models showed a non-monotonous convergence for the internal energy, whereas the batch-meshed models converged in a monotonous manner.

With regard to the buckling modes, all models showed a similar behaviour. The peak points of the folds were approximately at the same x-location and varied maximal by the corresponding element length. In one case, the fold showed a wider extension for the two 10mm meshed models than for the 2mm meshed models. This might have been due to a stiffer behaviour of the coarse model compared to the fine model.

In the majority of cases, the results of the two model types, namely hand-meshed and batch-meshed, were more similar for the 2mm discretization than for the 10mm discretization.

For this example, the automatically meshed models, built up with the Altair BatchMesher, behaved similar to the hand-meshed models regarding internal energy, max. section force, buckling mode and part length after the rebound.

References

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