Study on Effect of Warping to the Accuracy of Crash Simulation

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Abstract: When warping happens, the accuracy of hourglass control technique of Belytschko-Tsay element will not be as good as expected. Two examples of automobile components are used to investigate the effect of warping to crash simulation. It is observed that during collapse with large deformation, warping usually occurs in the corner area formed by stamping. In general, the hourglass energy and the ratio of hourglass energy over the internal energy are larger in this area than the other area. When mesh is refined, these values decrease and the uncertainty due to the hour glass control algorithm is reduced.

Keyword: crash simulation, explicit finite element method, hourglass control, warping, B-T shell element

1 Introduction

CAE applications in vehicle crash safety design have become an important part of the product development process. The accuracy of vehicle crash simulation is therefore one of the topics of practical interest. Due to the complexity of impact problem of the large deformation transient dynamics, many approximations and idealizations are made in the numerical simulation. To investigate the effects of these factors to the crash simulation, Wu [1,2] analysed the effects of meshing in the corner area formed by sheet metal stamping, Wu et al [3,4] analysed the effect by using different shell elements in the simulation. Wu et al [5] reported the effect of hourglass control method to the component impact analysis. Here we further investigate the effect of warping to the hourglass control method, which affects the vehicle crash simulation.

The 4-node Belytschko-Tsay (B-T) shell element, based on Reissner-Mindlin theory, is the element commonly used in crash simulation. It uses a one-point reduced integration scheme to avoid shear locking. But the hourglass control technique coming with the reduced integration does not completely compensate the missing part of stiffness and strain energy due to the one-point integration. Particularly, when warping exists in the element geometry the hourglass control scheme is not as effective as theoretically expected. Therefore it is necessary to analyse and evaluate the effect of hourglass to the numerical simulation, in particular, the effect of warping.

2 Hourglassing and warping

Crash simulation basically uses explicit finite element method. Most likely the 4-node shell elements are used to model the thin-walled structure. These elements use bilinear interpolation. When meshing the components with complex geometry, it is hard for the 4-node elements to keep the ideal co-plane configuration. It then results in warping, i.e., the four nodes of an element do not lie in the same plane. B-T element uses one-point reduced integration to eliminate shear locking. However, B-T element does not handle the geometrical warping effect very well. When the warped elements experience rigid body rotation, the hourglass control method generates artificial force and hence affects the computational accuracy. Even in the best situation, the initial mesh consists of flat 4-node elements only, there is no such loss due to warping, it will not be easy to keep them being flat without warping during large deformation. Particularly, at the corner line area of a tubular column, once collapsed by impact, the neighbouring surfaces fold in a progressive buckling mode. The materials at their inter boundaries, the corner line, inevitably excites warping. Although the finite element computation is able to simulate such kind of deformation, due to warping and hourglass control discussed earlier, the numerical results contain a part of error or uncertainty hard to be quantified. By the authors' knowledge, there is lack of sophisticated theory to support in depth analysis.

We use examples of automobile components to investigate the effect of hourglass control technique to crash simulation when warping exists.

3 Example 1 – axial collapse of a crash can for energy absorption

A steel crash can with cross section of 100 mm x 60 mm, as shown in Fig. 1, impacts a rigid wall with speed of 15 m/s and an attached mass of 500 kg. To investigate the hourglass effect, the corner line area is defined by different Part ID in the finite element model. Fig. 2a presents the deformation after 4 ms. It is observed that there is relatively large warping in the corner line area, whereas most of the material in the other areas experience smooth bending deformation without warping. Fig. 2b is a zoomed picture, clearly showing the deformation mechanism of warping. Fig. 3a shows the time histories of energy absorbed by the materials in several areas, whose locations are marked in Fig. 1. Fig. 3b presents the calculated hourglass energy of these parts. It is found that the material in the corner area has relatively high strain energy as well as the hourglass energy. In fact, the corner area occupies only a narrow band with small volume. Hence the energy absorption and hourglass energy per unit mass is higher in the corner area. This relatively higher hourglass energy contains a kind of uncertainty and therefore brings in a question regarding the reliability of numerical results.

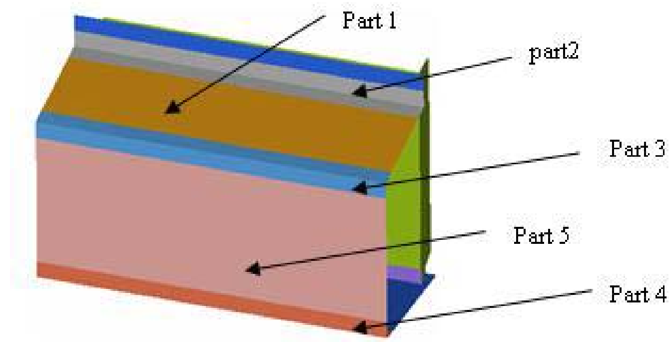
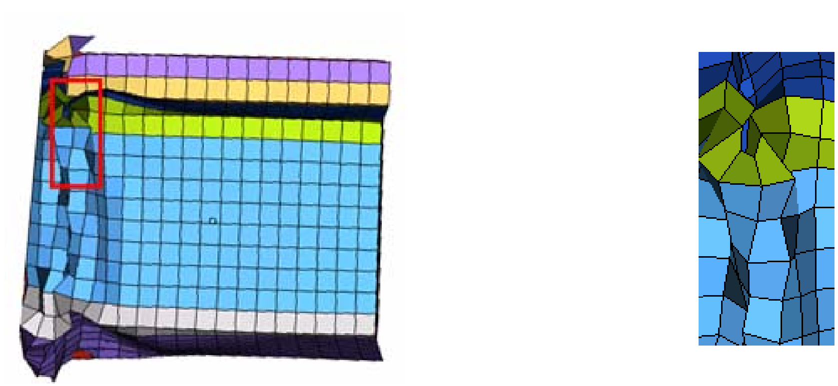


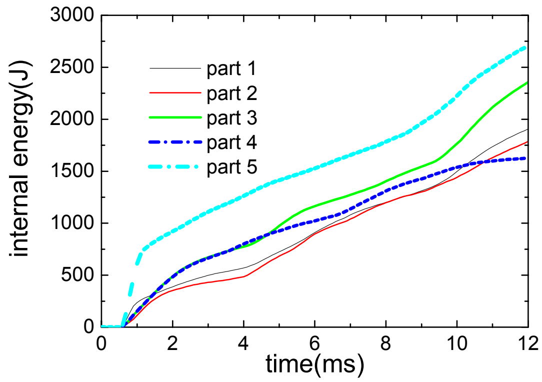
Fig. 1 The crash can



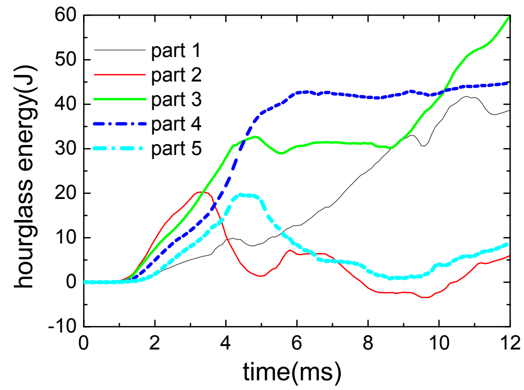
(a) (b)

Fig. 2 Deformation of crash can after 4 ms impact

(a) Deformation after 4 ms impact; (b) Zoomed local deformation



(a)



(b)

Fig. 3 Results for material at various locations

(a) Internal energy; (b) Hourglass energy

For further investigation, the mesh is uniformly refined. Fig. 4 presents the deformation at 4 ms calculated from the refined mesh. Fig. 5 is for the hourglass energy of various parts calculated from the refined mesh. Figs. 6 and 7 show the deformation and the hourglass energy of various parts calculated from the mesh after second refinement. Comparing Figs. 4 and 6 to Fig. 2, we find that the warping area in the refined meshes is smaller than that of the coarse mesh. From Figs. 5 and 7, we find that along with the refinement of mesh, the hourglass energy of various parts reduces gradually. This indicates that when mesh is refined, the area affected by warping shrinks, and the possibility of losing accuracy due to hourglass control technique reduces. However, it seems impossible to expect the hourglass energy in the corner area approaching zero. Because, warping is to happen certainly in this area and it must propagate to the material within a certain bandwidth. It deserves more in depth study to find the theoretical support for obtaining a convergent solution.

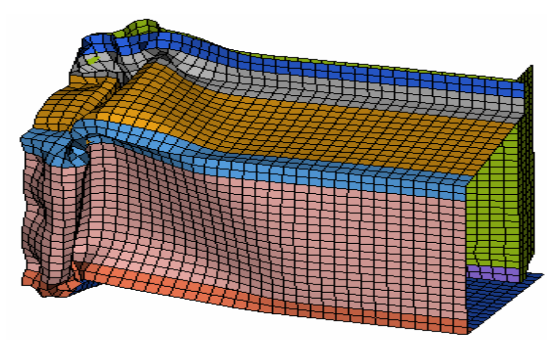


Fig. 4 Deformation at 4 ms, calculated from a refined mesh

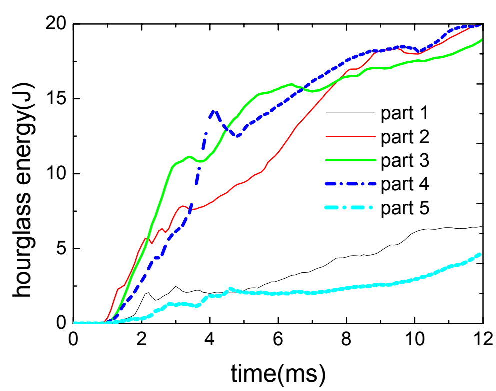


Fig. 5 Hourglass energy of material at various parts, calculated from a refined mesh

Fig. 6 Deformation at 4 ms calculated from a mesh after second refinement

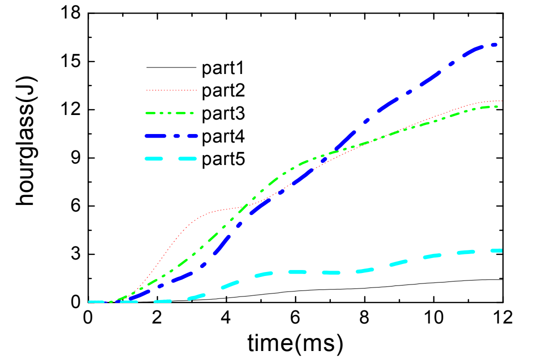


Fig. 7 Hourglass energy of various parts calculated from the mesh after second refinement

4 Example 2 – Bumper beam impacts a rigid center pole

The second example is a steel bumper beam impacting a rigid center pole. The bumper beam moves with a speed of 6 m/s, with an attached mass of 1000 kg, to impact the rigid pole, depicted in Fig. 8. To investigate the hourglass effect, the material at corner line area is defined by different Part ID. Figs. 9 present the hourglass energy of various parts calculated from three meshes with refined element sizes. Like the first example, the hourglass energy in the corner area is relatively higher. When the mesh is refined, the area affected by warping shrinks. The hourglass energy of various parts also reduces gradually. It is more evident in the corner area.

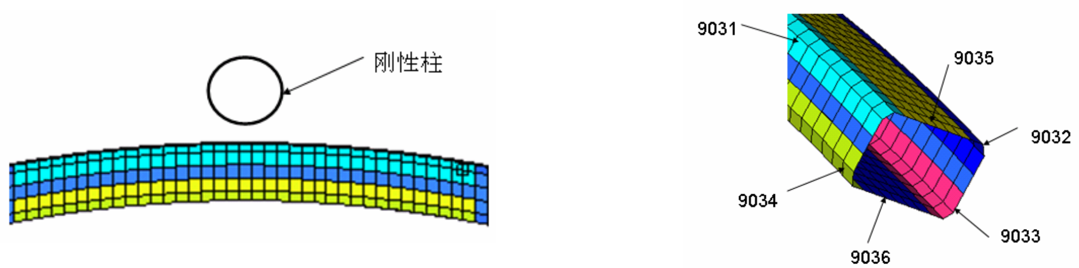
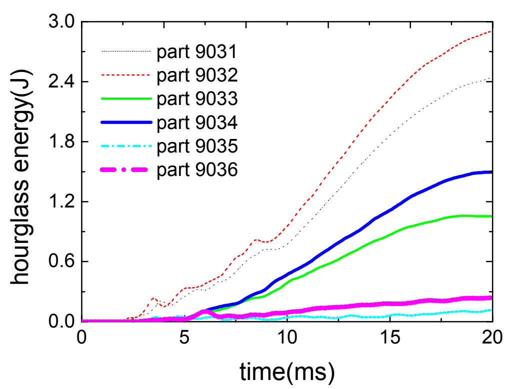
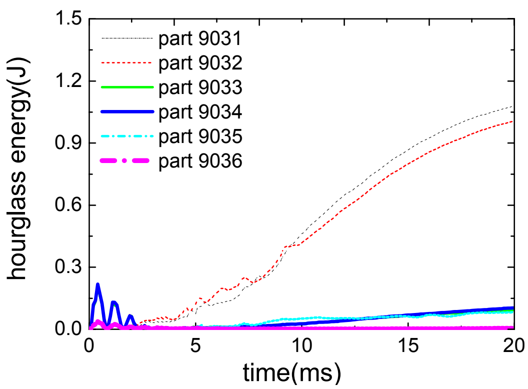


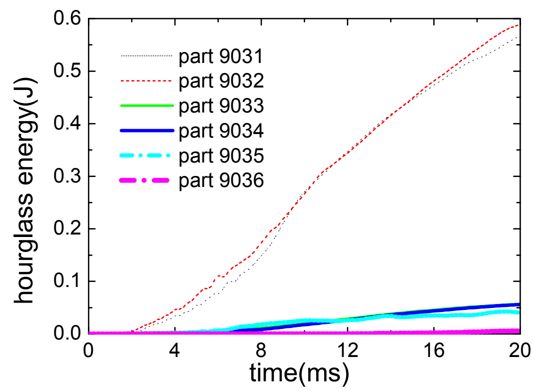
Fig. 8 Bumper beam impacts a rigid pole



(a)



(b)



(c)

Fig. 9 Hourglass energy of various parts:

(a) the first mesh; (b) the second mesh after a refinement; (c) the third mesh after twice refinement.

4 Summary

The large deformation of structural components by impact could not avoid exciting warping in local area. Crash simulation for two vehicle components were performed by using B-T shell elements. It was observed that warping occurred mainly in area near the corner line. When mesh was refined, the warping zone shrinks gradually and approaches a narrow band in the corner line area. Meanwhile the hourglass energy reduced gradually with the refined meshes. It was hence concluded that appropriate mesh refinement could help to enhance reliability of hourglass control method.

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