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Effects of Crash Trigger on Behavior of Thin-walled Straight Beam in Frontal Impact

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Abstract: Crashworthiness of thin-walled members plays an important role in the vehicle safety. Few researches on the effects of crash trigger on behavior of thin-walled straight beam had been conducted in frontal impact, which restrict the design of thin-walled straight beam significantly. The objective of the present work is to investigate the effect of crash trigger design on longitudinal beam crash performance based on a longitudinal beam frontal impact simulation. The square walled straight beam finite element model was established. LS-DYNA software was used for collision simulation. The effect of derivational groove numbers and spacing on the crash performance of thin-walled beams was investigated through deformation of the stringers, energy absorption and impact force. Simulation results showed that the derivational groove numbers had little effect on energy absorption, but its increase can reduce the peak force of the collision in some extent. The derivational groove spacing had significant effect on both energy absorption and collision force, which decreased with derivational groove spacing for the thin-walled beam. This study provides guidance for optimization of the vehicle energy absorption.

Key words: Thin-walled column, crash trigger, interval, crash capability

INTRODUCTION

In the field of automotive engineering, safety, energy conservation, environmental protection is considered to be the three main themes for the future of automotive industry development. With the increase of vehicle volume, more and more attention has been put on traffic safety, and the vehicle collision accidents are inevitable in the current scientific level. Furthermore, with the increasingly fierce competition in the national automobile makers, traffic safety has become a focus for many research institutes (Zhang *et al.*, 2000).

Most of the automobile frames are nowadays commonly designed with thin-walled structure, which can absorb energy through deformation in the collision process. The front longitudinal beam is not only the main energy absorption structure of vehicle front longitudinal collision, but also is the main device in the distribution of car collision energy. Previous research showed that, a well designed front longitudinal beam absorbed more than 50% of the total absorption energy in frontal impact. Therefore, the crashworthiness of thin-walled members plays an important role in the safety of the vehicle (McNay, 1988).

At present, most of the analysis on the thin-wall straight beam is from the thickness, material, cross-section shape and so on (Peng *et al.*, 2011; Liu *et al.*, 2006). The research on the effects of crash trigger on behavior of thin-walled straight beam is less. This study established the finite element beam model using HyperMesh software, using explicit finite element software LS-DYNA to evaluate this effect. The influence of the number and space of crush trigger on the deformation of thin-walled beam was illustrated in this study.

MODEL

Model establishment: Analysis model is shown in Fig. 1 The length of the side of square straight beam a = 80 mm, radius of fillet r = 8 mm, thickness is 1.6 mm; length of straight beam is 500 mm. A rigid wall set at the front of thin-walled beam, and set a mass of 500kg at the end, which instead of the mass of car. The thin-walled beam hit the rigid wall at the speed of 25 km h^{-1}. the material used for the base model is B340LA, and the strain rate can be calculated by formula of the cowper-symonds (Zhu and Zhong, 2000):

$$\sigma_y = \sigma_0 (1 + \frac{\varepsilon}{C})^{1/P} \quad (1)$$

Where σy is the dynamic yield stress, σ0 is the static yield stress. The variables of C and P are 40 and 5. Its mechanical properties, Young's modulus E = 210 Mpa,

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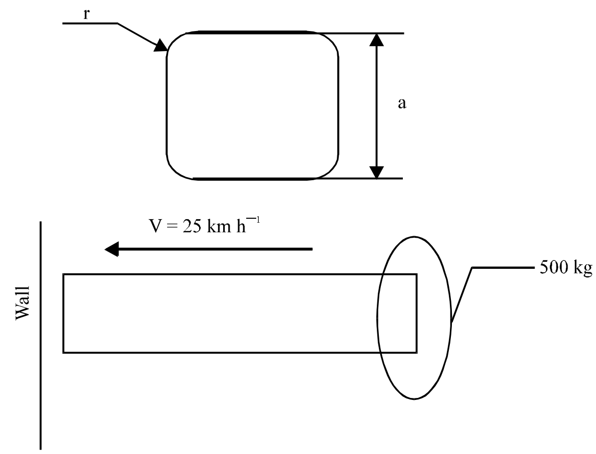

Fig.1: Thin-walled beam model establishment

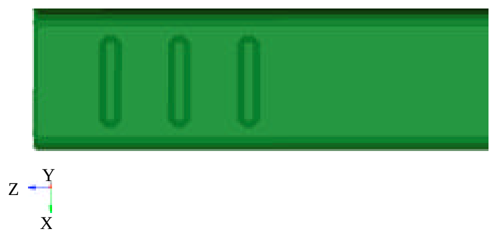

Fig.2: Position of the crush trigger

initial yield stress 380Mpa, the density ρ=7830 kg m^{-3} and Poisson's ratio v = 0.3. According to the literature (Weirzbicki and Abramowicz, 1988), the folding radius of thin-walled beam can be expressed as:

$$R = 0.72a^{1/3}t^{2/3} \quad (2)$$

In which a is the breadth of section, t is the thickness of thin-walled beam. In order to accurately describe the straight beam deformation in the collision process, the grid size should be less than L = 0.5 πR. According to the model thickness value and cross section in this study, the value of L is 6.67 mm. So, in this study, size of mesh opening is 5×5 mm. Simulation time is 80 m sec.

Preference of the crash trigger: The setting of crash trigger as show in Fig. 2. The crash trigger is arranged in two relative to the plane of the straight beam.

Crash trigger is a ladder type structure. One edge is 15 mm, the other edge is 5 mm and the depth is 2 mm. The left of trigger have 40 mm from the forepart of the beam. When considering the relationship between the number and impact properties of the groove, the center of each groove is 45 mm. The total simulation is five groups,

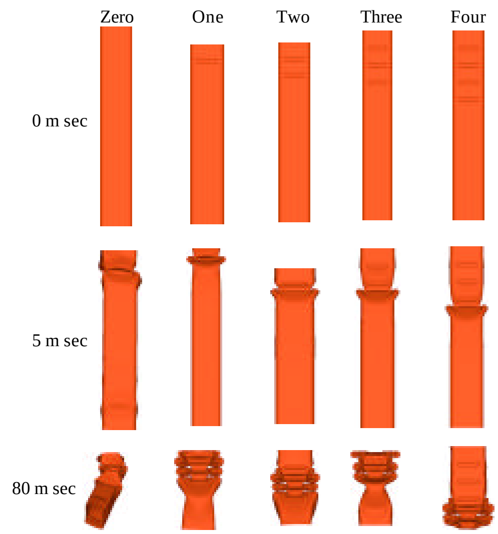

Fig.3: Collision deformation results of straight beam

which is the number of groove from zero to four. When considering the relationship between the distance and impact properties of the groove, defining the number of groove is two. The total simulation also is five groups, that is the distance of each groove, respectively is 45, 55, 65, 75 and 85 mm.

MODEL ANALYSES

Influence of materials on the thin-wall beam energy absorption: When impacting a rigid wall, the thin-wall beam, had a compressive deformation. Fig. 3 showed the deformation of thin-walled beam with different numbers of crash trigger.

It can be seen from Fig.3, when the thin-walled straight beams without crash trigger, the bending phenomenon had engendered in the process of collision. So, this type was unable to provide a stable crushing force in the axial direction. After setting the groove, all beams can generate a folding collapse deformation in the axial direction, and the folding sequence was same in each model.

According to the literature (Gao and Li, 2010), in the process of collision simulation, the hourglass energy had little effect on the results of deformation calculation when hourglass energy and internal energy ratio is in the range of 10%. In this study, the simulation results of the hourglass energy and internal energy ratio was less than 10%, so that the grid density was appropriate, and the simulation calculation results were reliable.

Table 1: Parameters from each specimen

No.	Total energ (kJ)	Specific energy absorption (kJ kg^{-1})	Forc peak (kN)	Averagforce (kN)
0 (A)	10.09	5.27	204.16	39.86
1 (B)	11.81	6.17	170.41	39.00
2 (C)	11.80	6.16	161.91	39.26
3 (D)	11.67	6.09	158.11	37.18
4 (E)	11.79	6.16	152.60	39.94

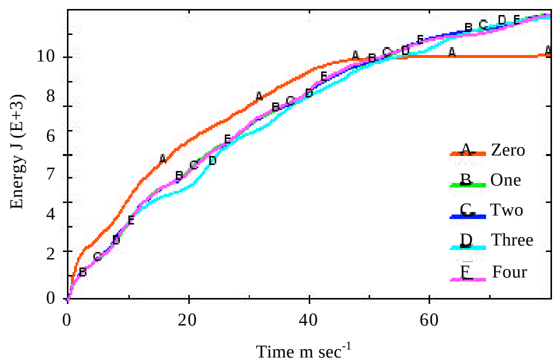

Fig. 4: Energy-time curve under different crush trigger number

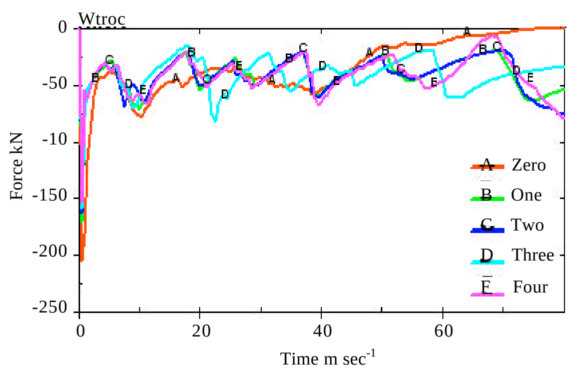

Fig. 5: Collision force-time curve under different crush trigger number

Energy-time curve and collision force-time curve under different crush trigger number were shown in Fig. 4 and 5.

In order to quantitative analysis the relationship between the number of crush triggers and beam crash performance, relevant parameters from analysis results was shown in Table 1.

From Fig. 4 and Table 1, the total energy absorption for the thin-wall beam without crush trigger was low in the late time, due to bending deformation. Conversely, the absorption increase obviously and more gently after add the crush trigger. The maximum energy absorption was only 12% more than the minimum. Therefore, the number of crush trigger on the total energy absorption was not affected. Shown in Fig. 5 and Table 1, the peak value of collision force decreased with the increase of the number of grooves. The maximum peak of all specimen appeared at about 0.5 m sec and the average collision force had little change. Thus, groove can reduce the impact force peak at the initial time effectively in the case of not affecting the energy absorption. Therefore, the increase in the number of grooves was conducive to the protection of occupant. Therefore, setting up multiple crush trigger can reduce the maximum impact force usefully when designing the vehicle front longitudinal beam. But with the increase of groove number, the crushing sequence of beam becomes difficult to ensure, which may have certain effect on the absorption process and the average impact force.

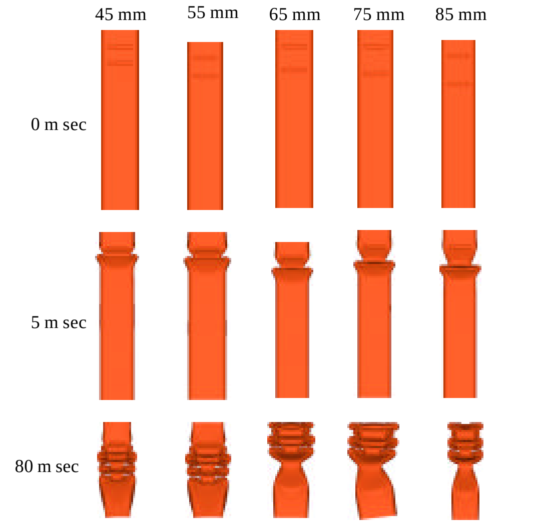

Fig. 6: Collision deformation results of straight beam

The analysis of influence of space on the thin-wall beam energy absorption two grooves were selected in this simulation. The deformation process of each specimen was shown in Fig. 6.

At the beginning of collision, deformation was observed firstly in the groove far from the front end. At the end of collision, four fold were produced in each thin-walled beam, with similar final deformation. Mild bending was observed for the thin-walled beam in 75 mm gap, due to the insufficient friction in the later stage of rigid wall impacting. Besides, the forepart has no deformation at the later stage of impacting, due to the lower stiffness between two grooves than the forepart, with 45 and 55 mm gaps. It was unfavorable for energy absorption by the length of the thin-walled beam. Therefore, in the car front longitudinal design, the gradient of front longitudinal stiffness should be guaranteed to obtain proper crush sequence.

Table 2.The parameters from each specimen

Distanc (mm)	Total energ (kJ)	Specific energy absorption (kJ kg^{-1})	Forc peak (kN)	Averagforce (kN)
45 (A)	11.80	6.16	161.91	39.68
55 (B)	11.65	6.08	163.79	36.47
65 (C)	11.64	6.08	162.30	41.38
75 (D)	11.65	6.08	165.63	42.86
85 (E)	11.58	6.05	167.56	38.96

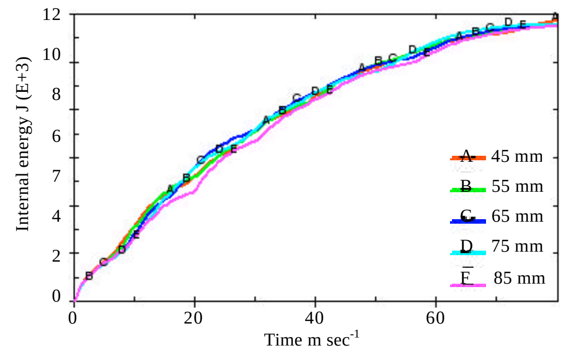

Fig. 7: Energy-time curve under different crush trigger distance

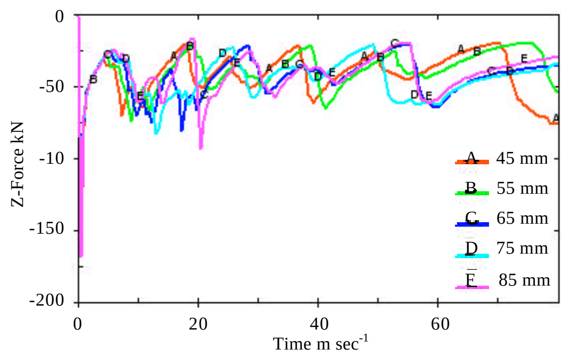

Fig. 8: Collision force-time curve under different crush trigger distances

Energy-time curve and collision force-time curve under different crush trigger distance were shown in Fig. 7 and 8.

It can be seen from Fig. 7 that A curve was more gentle than the other four curves in energy absorption. This avoided second injuries to passengers by the shock of repeated fluctuations. With the increasing of distance, curve fluctuations became fiercer. E curve had the biggest fluctuation. This phenomenon showed that the increase of distance will cause collapse instability. After the first collision force peak, the stable timing increased with the increase of distance for each curve, shown in Fig. 8. The second peak (68.6 kN) was observed at about 7.5 m sec for A curve. The second peak for the E curve occurred at about 20.5 m sec, which was 20% higher than that of A curve. Thus, the collision force became unstable along with the increase of distance, which resulted in higher fluctuation for the impact deceleration. This was not conducive to the design of the occupant restraint system.

Table 2 showed the relevant parameters from analysis results, to quantify the relationship between distance of crush triggers and beam crash performance.

In Table 2, from the top to bottom, the total energy absorption trend was from more to less, and, the impact force peak trend was from small to large. Although the average impact force of A curve was larger than B and E, the load ratio of A was more close to one than this two curves (Jing *et al*., 2009). Even the average impact force of B and E was relatively small but the maximum impact force was higher, which may generate dramatic acceleration changes for the thin-walled beam in the impacting process.

Therefore, the smaller the groove distance was, the smaller fold wavelength was, in certain extend. Thus, more energy would be absorbed, and lower peak impact force became, in the same length.

CONCLUSION

In this study, the crush trigger of thin-walled beam were analyzed and compared through nonlinear finite element software LS-DYNA. The influence of the number and space of crush trigger on the deformation of thin-walled beam was illustrated in this study. From the above simulation results, the following conclusions can be drawn:

- The number and spacing of crush trigger had positive effect on the deformation and collision force. In the automotive design stage, the effect of grooves on the impact performance of the front rails should be fully considered
- The number of grooves had little impact on the collision energy absorption, but increased groove can obtain smaller peak impact force. This may play an important role for passenger protection.
- The space of grooves had greater effect on the energy absorption and collision force. With the increase of space, energy absorption and peak force performance of thin-walled beams were getting worse, and the crushing process became unstable
- In order to make full use of the limited length of the thin-walled beams, the front longitudinal stiffness should be soft in the front and hard in the rear in the design process, to obtain beter crushing sequence

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