Simulation Study of Energy Absorbing Square Column for Vehicle Crash Test

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Abstract : The paper uses dynamic explicit finite element method to simulate the different section, number, length, thickness square column and tests to meet the standard of sled crash test absorbing device. Furthermore, the several factors are researched which affect crash simulation results heavily such as weld spots structure and size, mesh size and so on. And according to sled tests, the size and number combination of square column are founded, which make deceleration curve of sled reach the requirement. Based the model of sled crash test absorbing energy square column, we proposed different size and combination relate to different crash speed at 20 and 50km/h with better deceleration curves.

Keywords: Vehicle crash test, Square column, Energy absorbing device

1 Introduction

The energy absorbing buffer equipment of the auto simulation crash tests can be welded weld the different quantity and thickness energy absorbing square columns before sled car. When sled car crashed with rigid walls, the square columns produced transform and folded resistance, make the curve of deceleration of the sled with the whole vehicle crash test consistent or satisfy the request of crash test laws. In addition, in the vehicles fore-crash matters, more than 70% crash kinetic energy musts be bear by the vertical beam, so can guarantee the passenger-cab with small transform, so the ability of energy absorbing of vertical beam is key. And the thin square absorbing columns have stronger energy absorbing ability and simple structure. Therefore, the different structure the square columns are simulated and researched, not only has the important function for designing satisfy index sign vehilce crash test system, but also have the theories meaning and applied value for studying to the passive safety of vehicles.

2 Crash Absorbing Process Theories Calculation

Because the research of the absorbing ability of square column is more mature, and the structure is simple, absorbing ability is strong, so adopted the absorbing squares in sled crash test buffer's research. The sled deceleration curve is requested strictly in sled crash test, so must design the square column's quantity and structure size, then carry on simulating calculation by computer, and carry on the result by crash tests.

Under the condition of axis pressure, the thin column will cause the column appearing bending invalidation but not wrinkly sink which section ratio of breadth to length $(d/b)<0.67$. Contrary, if the ratio $d/b>0.67$, the column has the trend of wrinkly sink. So we should choose rectangle column which ratio is $(d/b)>0.67$. From the Flexible Stability Theory, it is known that the

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beam's ability of bearing compress and will descend when the length of the beam increased. When the ratio of beam's length and its section width is smaller than 15, the length's effect to the beam biggest loading of ability influence is little. The beam of vehicle's ratio length to the section width is smaller than 15 generally, so the rectangular beam's strength is decided mainly by the ratio thickness to width （t/b）and material characteristic. If $t/b < 0.016$, be called the not compact section, $t/b > 0.016$ be called the compact section, when we design the absorb beam we should choose the compact section generally.

During crash moment, square beam bears the biggest compress force $p_{\max}$ and the partial inflectional force p_1, the minimum bearing force p_3, and virtual average force $p_2 = (p_3 + p_1)/2$, they can be used to calculate the deceleration and displacement of vehicle.

$$p_{\max} = A\left\{\frac{k_p E(t/b)^2}{(1-u^2)\beta}\right\}^{0.43} \sigma_y^{0.57} \tag{1}$$

$$p_i = A\left\{\frac{k_i E(t/b)^2}{(1-u^2)\beta}\right\}^{0.43} \sigma_y^{0.57} \qquad i = 1,2,3 \tag{2}$$

where, b is the width of rectangular beam section, t is the thickness of the beam, σ_y is yield stress, u is Passion ratio, A is the sectional area of the beam, E is modulus of elasticity, k_p is inflectional coefficient, β is the function of t/b, k_i is the plank coefficient, the α is the function of the ratio of shorter side to longer side.

According to the above design standard, the section size of the square column can adopt as Fig. 1. The square column's quantity, length and the thickness are variable. We can calculate the average force p_i with the formula (2), to same square column, $p_{\max}$ and p_i is r only elated to the coefficient k. In sled crash test, the mass of sled is 870k/g, if we choose different quantity square column and the thickness is 2mm, the section size 120mm ×120 mm, then the average force p_i can be calculated with the formula (2) . Where, $k_p = 2$， $k_1 = 0.415$， $k_2 = 0.18$， $k_3 = 0.05$， $t/b = 2/120 = 0.01667$， $\beta = 1$. The results are shown as Table 1.

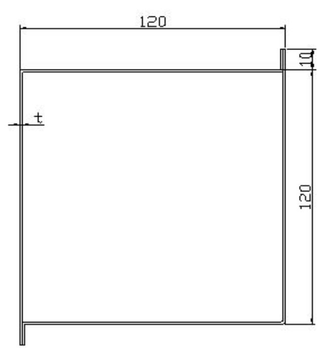


Fig.1 Structure of Square Column

Table 1 Different Number Square Columns Calculated Results

	3 square columns	4 square columns
p_{max}(N)	510727.3	680969.7
p_1(N)	259720.9	346294.5
p_2(N)	181348.3	241797.3
p_3(N)	104545.0	139393.3
a_{max}(m/s^2)	587.0	782.7
a_1(m/s^2)	298.5	398.0
a_2(m/s^2)	208.5	278.0
a_3(m/s^2)	120.2	160.2

From theory calculation, it is known that the deceleration of 3 square columns is smaller than the safety belt dynamic sled test standard request. Where $a_2 = 208.446 m/s^2$, so the deceleration of every column is 69.482 m/s^2. If 4 square columns are adopted, the deceleration is 277.928 m/s^2,so it satisfied the standard request of safety belt dynamic sled test.

3 Crash Simulation With Finite Element Method

A. *Affect Crash Simulation Factors*

Using the explicit dynamic finite element method research big transform, big turn over and big strain, many factors should consider which affect simulation results, mainly having two kinds of as follows.

The mesh density distributing and size :The mesh density distributing and size of the square column affect the collapse mode, speed, acceleration directly. The mesh size not only affected computing time, smaller mesh size longer computing time, but also affected " the sand leak" phenomenon, bigger mesh lead to " the sand leak" phenomenon hard to repress [1]. For the section size120×120mm square columns model, simulation results show that 20×20mm mesh can not imitate a smooth fold and collapse and producing sawtooth form. But 12×12mm mesh, the transform mode and displacement are fit crash tests well. So the mesh size should take the ratio of mesh size to the square section side length about 0.1.

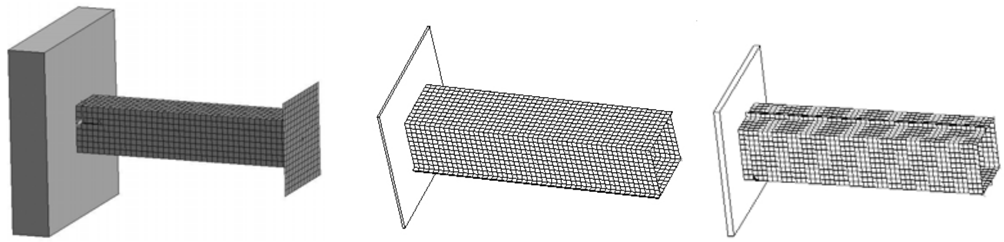
Weld spots design: During crash simulation, welding should imitate and very important for whole vehicle crash simulation. So welding simulating design is key to results. The mainly designing method have 3 kinds of[2]: Rigid pole conjunction method, Common node method, Common unit method. In the paper, the square column is welded by two steel plate as Fig.1, its rearward connected sled tightly, the rear welding will not take place the breakage generally during crash. It can be simulated by common unit method. If the two welding steel plates are not torn, it can be simulated by common node method. If the two plates are torn, they can be simulated by weld spots, and they should satisfy formula (3) .

$$\left(\frac{|f_n|}{S_n}\right)^a + \left(\frac{|f_s|}{S_s}\right)^b \geq 1 \qquad (3)$$

where, f_n is vertical force, f_s is tangential force, parameter a= b=2, breakage limit S_n =130000 S_s =100000.

B. Square Column FEM Model Building

The simplification of the model: Because of the square columns symmetry arranged, the mass of the sled can be distributed to every column equally. So the crash test simulation can be used only one square column. Built up three kinds of models: take no account of welding sides' influence entity model as Fig.2. (a), take no account of welding sides' influence entity model as Fig.2.(b) and the welding sides at middle of square column beam as Fig.2. (c).



(a) (b) (c)

Fig.2 Three Kinds of Different Designing Square Columns

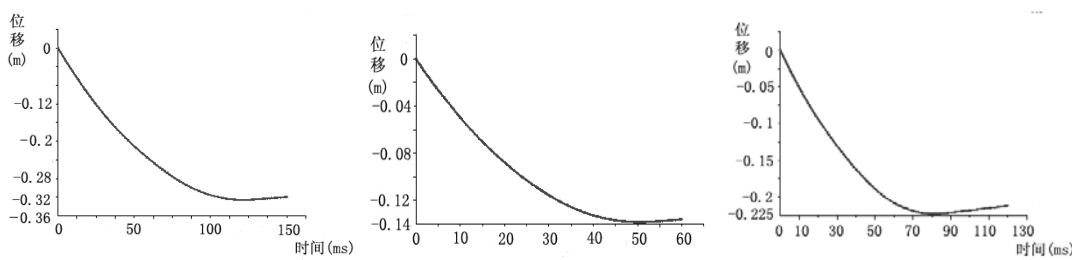
4 Simulation Results and Application

In order to get proper square column for sled crash test or whole vehicle safety designing, the different thickness and section area columns are simulated to research their absorbing abilities. And the different welding modes are simulated to get the proper welding structure. Then sled crash tests are carried on from simulated results, and get better effect.

A. *Square Column Absorbing Energy Simulation and Tests at 20km/h*

The plate thickness and section size affect absorbing energy ability. In simulation, the crash test initial velocity is $5.556\,m/s$ (km/h), uses two pieces square columns, the length is 450mm. Three simulations are carried for different thickness and section size. Fig.3. (a) is transform displacement curve of thickness 1.0mm and section area 120×120mm square column, (b) is transform displacement curve of thickness 1.5mm and section area 120×120mm square column, (c) is transform displacement curve of thickness 1.0mm and section area 180×180mm square column.

It is shown in Fig.3 that the biggest displacements are 0.32 m, 0.135m and 0.22m respectively. So if the plate thickness and section sizes increased at the same proportion, the thickness of square column affected absorbing energy ability more hardly than section size.



(a) (b) (c)

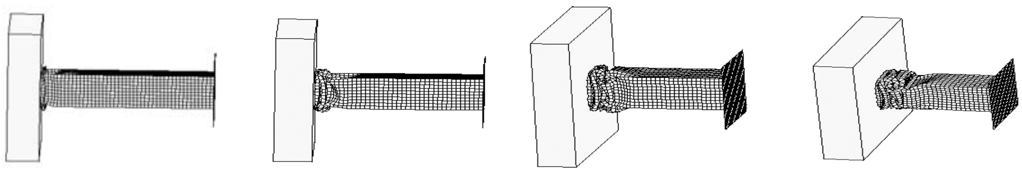
Fig.3 Transform Displacement Curves of Different Structure

Sled crash test. It is indicated from theory calculation and crash simulation that the thickness of square column affected absorbing energy ability more greatly than section size changing. In order to validate the absorbing ability with different thickness, sled crash tests were carried on for 1.0mm and 1.5mm thickness and section 120×120mm square columns respectively . Before crash test the length of square columns were 450mm. After crash, the thickness 1.0mm square columns were 110mm, the thickness 1.5mm are 330mm as shown Fig.4. So it is seen that thickness of square column affected absorbing ability greatly, and according with theory and simulation analysis. In simulation the 1.0mm square columns are 135mm after crash, 1.5mm thickness are 320mm, they accorded with tests approximately.

Fig.4 The thickness 1.0mm and 1.5mm square column sled crash tests

B. *Safety Belt Dynamic Sled Crash simulations and tests*

Fig.2 (a) model: Four square columns were simulated in sled crash which thickness is 2mm and section size 120×120mm, the length 600mm. Fig.5 are square columns' transforming process during crash. Fig.6 are sled's deceleration and transform displacement during crash by simulation.



6ms 16ms 26ms 50ms

Fig.5. Simulation Transforming Process

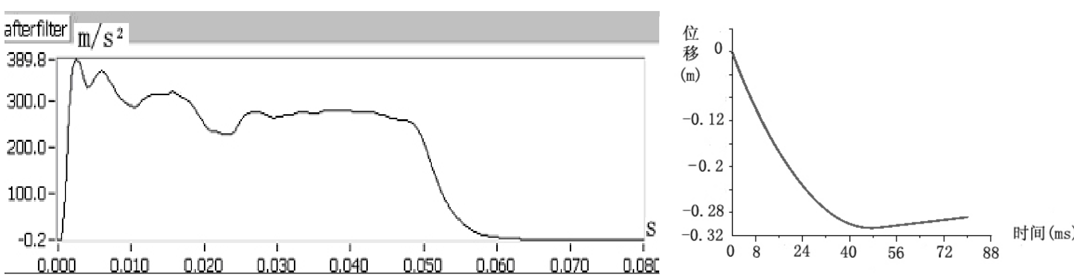


Fig.6 Deceleration and Transform Displacement During Crash

Fig.2 (b) model: Four square columns were simulated in sled crash which thickness is 2mm and section size 120×120mm, the length 600mm. The Fig.7 are their deceleration and transform displacement during crash.

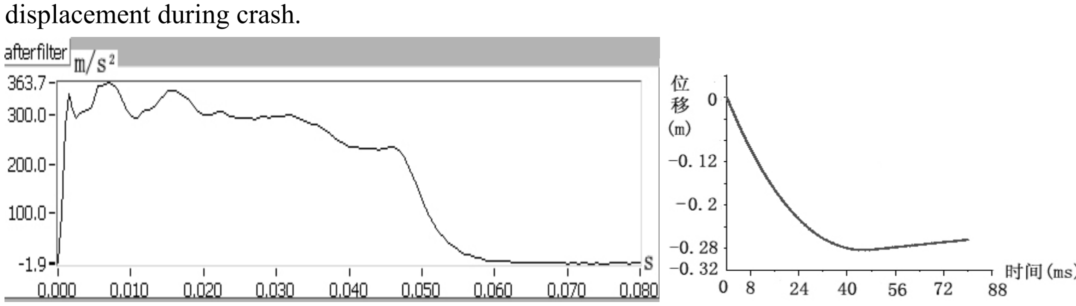


Fig.7 Deceleration and Transform Displacement During Crash

Fig.2 (c) model: Four square columns were simulated in sled crash which thickness is 2mm and section size 120×120mm, the length 600mm. The Fig.7 are their deceleration and transform displacement during crash.

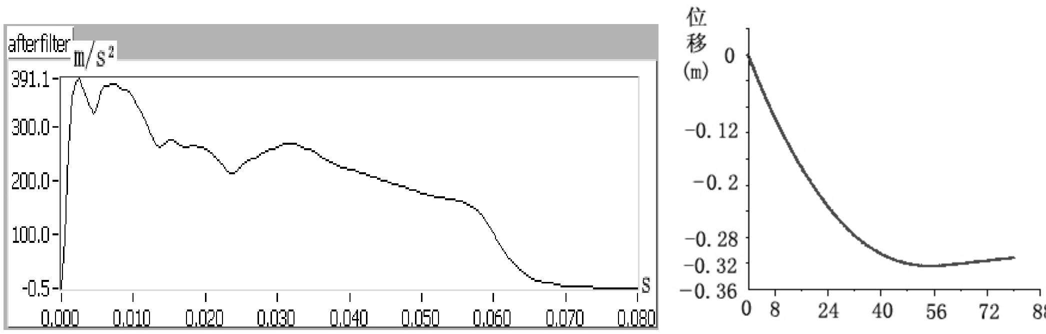
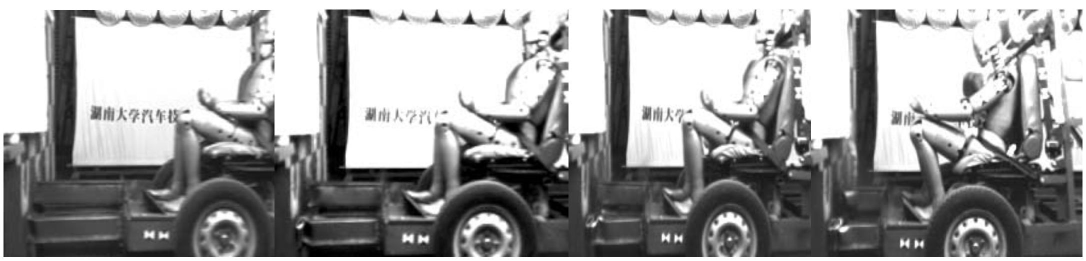


Fig.8 Deceleration and Transform Displacement During Crash

It is indicated from Fig.6, Fig.7 and Fig.8 that their maximum transform displacement are 0.3m, 0.28m, 0.32m respectively, their average decelerations are 28g, 28g and 23g respectively during crash. Therefore, the conclusion is got that model 1 and model 2 decelerations didn't change greatly, but model 3 displacement is the biggest and average deceleration smaller, so its absorbing ability smaller.



6ms 16ms 26ms 50ms

Fig.9 Square Columns Transform Process

According to simulating results, four square columns are adopted as sled crash test absorbing buffer. The thickness is 2mm, length is 600mm, section size 120×120mm. Sled crash tests were carried on for validated the results.Fig.9 are photos shot by high speed camera for transform process and Fig.10 is deceleration curve required from acceleration sensor.

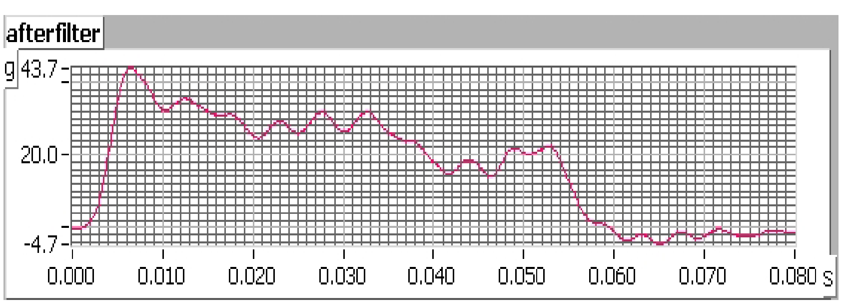


Fig.10 Deceleration of Sled During Crash Test

It can be seen from Fig.9 that the square columns are folded regularly during transforming. From Fig.10 compared with Fig.6 and Fig.7, the deceleration curve satisfied sled crash test standard.

5 Conclusion

This paper built up three kinds of square columns simulating model in ANSYS/ LS-DYNA software according to the request of sled crash test absorbing buffer. Different number, different length, different section size and different thickness square columns were analysed by theory calculation and crash simulation. And satisfied standard request curves were got by simulation and sled tests, provided the optimal sizes and combination of beam. Moreover, welding spots and mesh size and distributing were researched for their influencing crash simulating results.

6 References

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