Research on Energy Absorption Characteristics of Protective Devices with Different Wall Thickness Structures

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Abstract: As square tube type protective device as the object, selected on the basis of the results of the simulation test, design the crossbar and arm structure plan of the six groups of different wall thickness. Through bus rear-ended dangerous goods transport vehicle simulation test way, analyzes the deformation and energy absorption about the bus and six groups of protective device which has different wall thickness. Research results show that the main energy absorption part of square tube type protective device is the arm structure. The optimal design scheme is when the wall thickness of the arm is 4 mm and the wall thickness of the crossbar is 3 mm.

1. Introduction
Based on the performance test and analysis of square tube type protective device, which could verify the correctness of bus rear-ended dangerous goods transport vehicle model, this paper improved the structure design of square tube type protective device on the basis of finite element analysis model, and further studied the energy absorption characteristics of protective devices with different wall thickness by using the improved finite element model. The results can be used as a reference for accuracy degree of improved design to enhance the protective performance of rear protective devices.

2. Improvement scheme design of different wall thickness structures
In the research of collision of bus-protective device-tank vehicles system, the simulation results of bus rear-end dangerous goods vehicle system are verified by experiments. When the wall thickness of the crossbar of the square tube type protective device is 3 mm and the wall thickness of the arm is 6 mm, the protective device is relatively "hard" for the rear-end collision of a 10-ton bus with 40 km/h. For the rear protective device of square tube type protective device, this section improves the wall thickness of its arm and crossbar, optimizes the quality distribution of protective device, and improves its energy absorption performance without changing its cross-section form. This paper has designed six groups of test schemes, namely scheme A, scheme B, scheme C, scheme D, scheme E and scheme F. specific design schemes for different wall thicknesses are shown in Table 1.

Table 1. Design Scheme of Different Wall Thickness.

| Scheme | SchemeB | SchemeC | SchemeD | SchemeE | SchemeF |
|--------|--------|--------|--------|--------|--------|
| Wall Thickness of Crossbar (mm) | 3 | 3 | 4 | 4 | 5 |
| arm wall thickness(mm) | 5 | 4 | 3 | 4 | 3 | 3 |
3. Analysis of simulation results of energy absorption of different wall thickness protective devices

The effect of energy absorption is an important index for evaluating protective devices. Deformation of protective device refers to the distance change between the end of protective device and the end of vehicle during collision. Through the simulation analysis and real vehicle test of the previous chapter, in the simulation process, at 20ms, the maximum stress nephogram position of the square tube type protective device (N1:112025) is selected to represent the terminal of the protective device, and the node (N2:130462) is selected to represent the terminal of the vehicle at the inner end of the protective device installation slot, as shown in Figure 1.

![Stress nephogram of protective device at 20ms](image1.png)

Figure 1. Stress nephogram of protective device at 20ms

The K file is imported into Hypermesh, according to the design scheme in Table 1, the wall thickness of the crossbar and the arm is set in turn, export K file, use LS-DYNA equation solver to solve K file, and use LS-Prepost to read the calculation results. After the simulation analysis of the six schemes, the change of the internal energy of the crossbar of the protective device is shown in Figure 2. Among them, the energy absorption process of the crossbar of the protective device in scheme A and B is stable, and the energy absorption is the largest.

![Changes of internal energy of crossbar in different simulation analysis](image2.png)

Figure 2. Changes of internal energy of crossbar in different simulation analysis
In Figure 2., curve A represents the scheme A internal energy of crossbar, and so on. After the simulation and analysis of different schemes, the change of internal energy of arm of protective device is shown in Figure 3. Among them, the energy absorption of arm is almost the same when the thickness of arm is identical, the thickness of crossbar is changed and other collision conditions are the same. The energy absorption effect of arm is related to its own thickness. With the increase of arm thickness, the energy absorption effect decreases progressively.

![Energy absorption curve](image1)

Figure 3. Changes of internal energy of arm in simulation analysis of different schemes

In Figure 3., curve A represents the scheme A internal energy of arm, and so on. The distance between the end of protective device and the end of rear of vehicle, that is, the initial distance between N1 and N2, is 525 mm. From the comparison of scheme A, scheme B, scheme C, scheme D and scheme E, we can see that: When the wall thickness of crossbar remains unchanged, the distance between N1 and N2 varies greatly with the change of arm wall thickness. As the wall thickness of arm decreases, the distance between N1 and N2 decreases sharply, the internal energy of crossbar changes little, and the internal energy of arm changes greatly. From the comparison of scheme B, scheme D and scheme C, scheme E and scheme F, we can see that: When the wall thickness of arm remains unchanged, the distance between N1 and N2 varies very little with the change of crossbar wall thickness, even negligible, the internal energy of crossbar changes slightly, and the internal energy of arm remains almost unchanged.

![Distance variation](image2)

Figure 4. Distance variation of nodes 130462 and 11225 in X direction in different schemes
Figure 5. Final deformation diagram of protective device in scheme A

Figure 6. Final deformation diagram of protective device in scheme B

Figure 7. Final deformation diagram of protective device in scheme C
As can be seen from Figures 7., 9. and 10., the final deformation of protective device in scheme C, E and F is basically the same, and all of them reach the maximum deformation value. Figure 4 shows that when the wall thickness of arm is 3 mm, changing the wall thickness of crossbar, the protective
device is crushed and deformed to the limit after the collision, so the energy absorption can not be effectively evaluated. When the arm wall thickness is 5 mm, through the analysis of energy absorption and the final deformation of protective device in the collision process, it can be seen that the protective device is too "hard" to absorb energy and can not play an effective buffer role. Figure 5 is the final deformation diagram of protective device of scheme A. The protective device has little deformation and less energy absorption.

From Figure 3, Figure 4, Figure 6 and Figure 8, it can be seen that scheme B and scheme D with arm wall thickness of 4 mm are compared, and the results are basically the same. The simulation results of six different wall thickness schemes are shown in Table 2.

Table 2. Calculations of simulation results for different wall thickness schemes

| Scheme  | Scheme A | Scheme B | Scheme C | Scheme D | Scheme E | Scheme F |
|---------|----------|----------|----------|----------|----------|----------|
| Longitudinal deformation (mm) | 432.0 | 237.6 | 83.5 | 261.5 | 86.2 | 104.1 |
| Crossbar energy absorption (kJ) | 45.5 | 64.8 | 53.6 | 44.8 | 47.7 | 41.0 |
| Arm energy absorption (kJ) | 22.1 | 133 | 187 | 135 | 187 | 189 |

In summary, the analysis results of six groups of test schemes show: scheme B, the protective device with 3 mm crossbar wall thickness and 4 mm arm wall thickness, has the best comprehensive energy absorption effect.

4. Conclusion
As square tube type protective device as the object, selected on the basis of the results of the simulation vehicle test, design the crossbar and arm structure plan of the six groups of different wall thickness. Through bus rear-ended dangerous goods transport vehicle simulation test way, analyzes the deformation and energy absorption about the bus and six groups of protective device which has different wall thickness. Research results show that the main energy absorption part of the "square tube type protective device" is the arm structure. The optimal design scheme is when the wall thickness of the arm is 4 mm and the wall thickness of the crossbar is 3 mm.

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References
[1] Cappello, F., Ingrassia, T., Nigrelli, V. (2008) Design of a New High Energy Rear Under-run Protective device. WIT Transactions on the Built Environment, 225-335.
[2] Kumar, Eriki, A. (2012) Crush Simulation of Car Using LSDYNA. Advanced Materials esearch, (433-440): 2326-2331.
[3] Atahan, AO. (2007) A Recommended Specification for Heavy Vehicle Rear Under-run Guard. Accident Analysis and Prevention, 39(4):696-707.
[4] Alexander, B., Michael, K., Lars, R., Ulrich, B. (2003) Passive Safety of Trucks in Frontal and Rear end Impacts with Cars. In:Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicles. Nagoya, Japan. 1102-1110.
[5] AlrikL, S., Vasanth, K.,Daniel, B.18ESV-000225_An Analysis ofHeavy Truck Occupant Protection Measures. pdf, pp. 225.
[6] Yucheng, L., Bin, Y., Kun, C. (2004) Study on collision compatibility of Automobile. Automobile science and technology, (1):15-18.