Collision simulation and design optimization of rear underrun protection device of lorry

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Abstract. Since most of the heavy-duty lorry rear underrun protective device does not have sufficient blocking capacity to prevent drilling collisions, the casualty rate of small passenger vehicle colliding with heavy trucks is high. Based on the actual participation in road traffic accident identification work, the authors investigated the current installation status and common problems of the rear underrun protective device of heavy-duty lorry. According to the requirements of GB 11567-2017, the authors used LS-DYNA simulation software for a brand of heavy-duty warehouse-type semi-trailers. The mechanical performance model of the rear underrun protective device is studied to provide safety for road traffic and to avoid or reduce the casualties caused by a vicious rear-end collision.

1.Preface

Small passenger car rear-end collision heavy-duty lorry are a common type of accident collision. According to the survey, the number of casualties caused by such accidents accounts for about 3/5 of the total number of casualties in traffic accidents[1]. Studies have shown that the rear underrun protection device with effective buffering energy can reduce the mortality rate of the passengers to 10% in the rear-end collision accident[2]. Therefore, the improvement and optimization of the rear underrun protection device of heavy goods vehicles is of great significance for improving the passive safety of vehicles and the promotion of road traffic safety.

Experts and scholars at domestic and abroad mainly use computer simulation soft to study the collision safety performance of the rear underrun protection device. Balta et al. optimized the finite element model by changing its structure, and chose the best solution from many aspects[3]. Based on the actual vehicle crash test, Ruecker et al. pointed out that the current standard requires the height of the lower edge of the cross member of the rear underrun protection device to be grounded. It cannot effectively absorb the energy absorption and prevent the drilling collision of small passenger cars, and proposes some amendments to current regulations[4]. Xichan Zhu, et al. constructed a mobile deformable barrier and analyzed the influence of the height of the rear underrun protection device and the material stiffness on the prevention of drilling[5]. Yan Yin and others scholars found some shortcomings of China's standards by comparing the standards of China and the United States, and put forward appropriate suggestions[6]. At present, experts and scholars study based on the height from ground of the rear underrrun protection device and pay attention to the scope of protection while ignoring the problem of structure and material selection of the protective device. Therefore, this paper takes a brand of heavy-duty warehouse-type semi-trailer rear underrun protection device as the modeling basis, and selects the 120mm required for the O_4 vehicle in GB 11567-2017 and the 140mm section height commonly used in the current O_4 vehicles as the construction protection device. The LS-DYNA simulation software is used to simulate and analyze the collision process, and the simulation results are used to verify whether it meets the relevant provisions of GB 11567-2017. According to the simulation results and the actual situation of the rear-end collision accident, the rear underrrun protection device of the brand heavy-duty warehouse-type semi-trailer is optimized.

2.Requirements for rear underrun protection of vehicles and trailers

2.1.Rear underrun protection device

The rear underrun protection refers to a special rear underrun protection device or a vehicle body, frame member or other components of a vehicle capable of having all or part of therear underrun protection device function by its own shape and characteristics; the rear underrun protection device is composed of cross members and connections. The structure consists of devices that are fixed to chassis components or other structures on the vehicle [7].

2.2.Test conditions for rear underrun guard

In September 2017, the General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China promulgated the Motor Vehicle and Trailers-lateral and Rear Underrun Protection Requirements (GB 11567-2017), The requirements for the rear lower protection of the four types of vehicles(O_3、O_4、N_3、N_4)were clearly defined, and the test requirements for the performance of the two types of detection and protection devices, static loading and rear-end collision, are introduced in Appendix B and C.Among them, the mobile wall barrier rear-end crash test uses a mobile wall barrier to hit the rear underrun protection device of the heavy truck to check its blocking and buffering energy absorption capabilities.

The national standard specifies the quality, surface strength and dimensional parameters of the mobile wall barrier, and the collision surface of the mobile wall barrier should be covered with 20mm thick high-quality plywood. The instantaneous speed of collision should be in the range of $30km\cdot h^{-1}$~$32km\cdot h^{-1}$. If the experiment is conducted at a higher speed and the rear underrun protection device meets the requirements, the test is also considered to be acceptable. The experimental results meet the following requirements and are considered as technically qualified:

(1) The protection device can be deformed and cracked but it cannot be break off entirely.

(2) The protection device shall be able to absorb the energy generated by the collision and mitigate the impact; and the maximum deceleration of the mobile wall barrier shall not be greater than 40g, and the rebound speed shall not be greater than $2m\cdot s^{-1}$.

(3) The longitudinal horizontal distance between the rear part of the protection device and the rearmost end of the vehicle after collision shall not exceed 400 mm.

3.Rear underrun protection device simulation model construction

3.1.Geometric Model Construction

In accordance with GB 11567-2017, using SolidWorks software to establish the geometric model of the rear underrun protection device, and the cross-section height of the cross-member was defined as 120mm and 140mm, respectively. The geometric model consists of a fixed barrier, a rear part of the semi-trailer frame, a rear underrun protection device and a mobile wall barrier, and the front impact surface of the mobile wall barrier collision is rigid and is covered with a layer of 20mm thick high-quality plywood at the front end. Since only the front end of the mobile wall barrier and the cross member of the rear underrun protection device collide with each other during the collision contact, the connection between the frames can be ignored and the establishment of some holes and other components can be omitted.

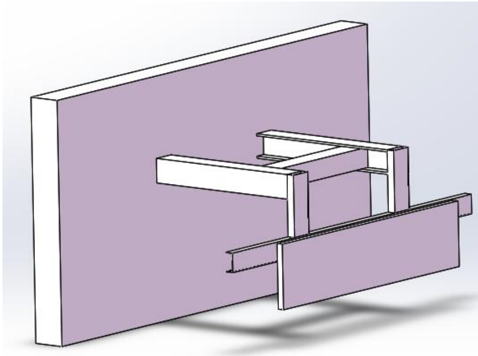

Figure 1. Geometry model of RUPD.

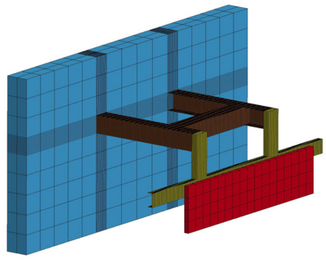

Figure 2. Finite element model of RUPD.

3.2.Finite Element Model

Two different cross-section heights of the cross-member geometry model were processed by finite element method. The fixed barriers, rear parts of the frame, guards and moving barriers were meshed. There were 26726 and 27196 nodes respectively, with 247267 and 25196 shell elements, and 2000 solid elements.

4.Analysis of collision performance of rear underrun protection device

According to the requirements of the national standard, the height of the lower edge of the rear underrun protection device is set to 500 mm, and the mobile wall barrier is 240 mm from the ground clearance. The mobile wall barrier moves in the -*y* direction and does not set a motion deviation in either direction. The movement speed is -32 $km \cdot h^{-1}$ (-8888.89 $mm \cdot s^{-1}$). So, after the collision contact, only the velocity of bounce in the *y* direction of the mobile wall barrier, the acceleration of the collision, and the deformation of the fixed barrier are calculated. It can be seen from the simulation results that during the collision process, the deformation of both sides of the cross member is the most serious, so the node is selected as the maximum displacement reference point of the rear underrun protection device (see Figure 3).

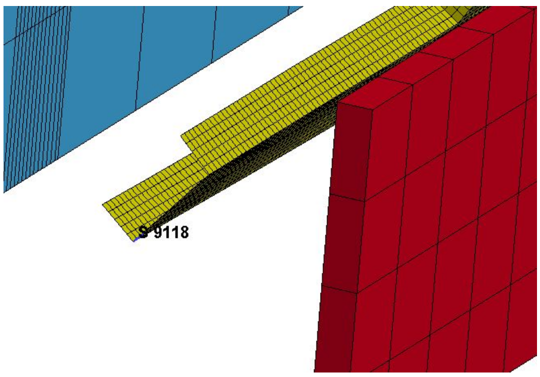

Figure 3. Max displacement point during the collision.

According to the requirements of Appendix C of the China Standard, combined with the simulation results, the comparison were as followed:

Table 1. Max displacement point during the collision.

	Max horizontal deformation of the RUPD/mm	Mobile wall barrier bounce speed/ （mm·s^{-1}）	Max deceleration of mobile wall barrier/ （mm·s^{-2}）
China Standard required	≦400	≦400	≦400
120 mm component	280	-6.14	13.4
140 mm component	316	1.96	31.7
Comparative Results	Qualified/Qualified	Unqualified/Qualified	Qualified/Qualified

It can be seen from the speed-time curve of the mobile wall barrier that the protective device built by the 120mm cross member cannot block the drilling of the mobile wall barrier; The 140mm cross member increases the effective contact area with the mobile wall barrier and the material stiffness of the cross member itself. At 0.044 s, the cross member rebounds to remove the mobile wall barrier from the rear under of the large truck frame. It can be stated that the rear underrun protection device of the structure can meet the requirements of the China standard when the cross-sectional height of the cross member is larger than 140 mm, and has sufficient buffering energy to prevent the drilling from colliding.

5.Improvement of rear lower guard for 120mm cross member

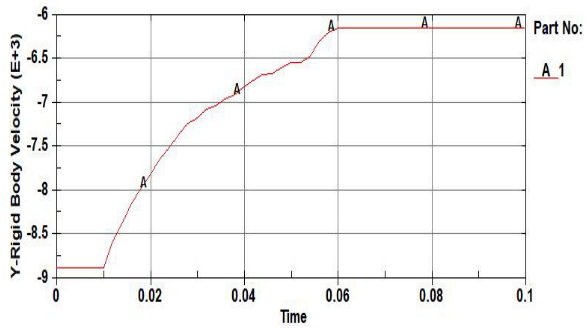

Figure 4. Movement velocity curve of mobile wall barrier crash with 120mm cross member.

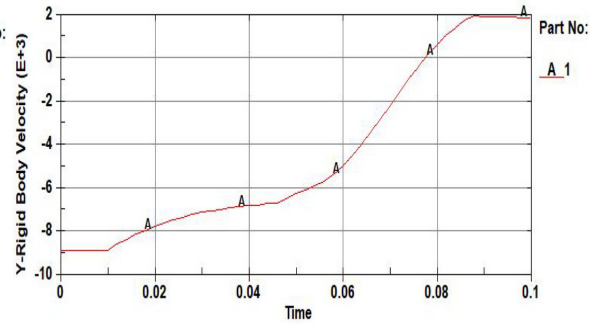

Figure 5. Movement velocity curve of mobile wall barrier crash with 140mm cross member.

5.1.Mode improvement

During the collision process, the vertical members of the rear underrun protection device assumed the main effect of mitigating impact and absorbing energy, and a large deformation occurred during the collision. Optimizing the structural form of the protective device or adding the oblique support member can effectively enhance the buffering energy absorption and blocking effect. Therefore, a diagonal support is added to the cross member of the 120 mm section height, the lower end of the oblique support is connected with the junction of the horizontal and vertical members, the extension line of the center line of the vertical member, and the upper end is connected with the lower part of the frame; the upper end of the member has a width of 150.0 mm, and the lower end is consistent with the cross-sectional height dimension of the cross member, and the longitudinal horizontal distance between the foremost portion of the upper end and the vertical member is 200.0 mm, and the wall thickness is 2 mm. In order to ensure that the component has sufficient barrier and energy absorption effect, after referring to the front and rear impact beams of the domestic automobile manufacturing industry, the magnesium alloy 6061T is selected as the oblique support member of the protection device. The alloy material has good formability, weldability and machinability, and is widely used in car body structural materials of automobiles, subway vehicles, railway passenger vehicles and high-speed passenger cars. The improved structure is shown in Figure 6.

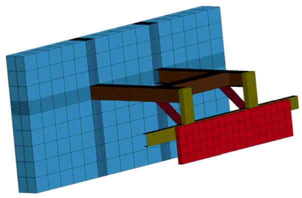

Figure 6. RUPD after adding diagonal support.

5.2.Optimized guard device simulation analysis

5.2.1.Maximum displacement analysis of moving barriers. The optimized maximum displacement node selection of the guard device is consistent with that before optimization, as shown in Figure 8.

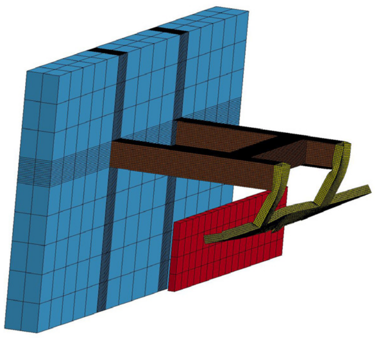

Figure 7. Drilling collision of the original device

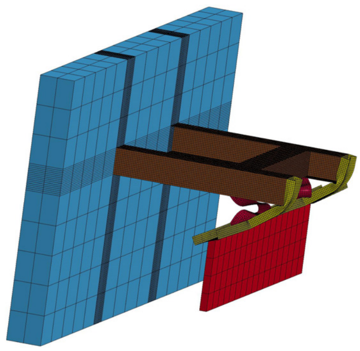

Figure 8. Maximum displacement after improvement.

From the displacement-time curve of the node, it can be known that the mobile wall barrier before the collision is in a relatively static state, and the displacement curve moves in the negative direction y-axis at 0.10 s, indicating that the collision occurs at 0.10 s. The original scheme mobile wall barrier to a maximum displacement of 289 mm at 0.046 s, then the curve fluctuates in the positive direction of the y-axis, and the vertical member rebounds under the influence of the elastic deformation, but, at this time, the mobile wall barrier has passed through the guard and a drilling collision occurs; the optimized guard device reached a maximum displacement of 338 mm at 0.094 s, after which the curve was accompanied by a slight rise in gentle fluctuations, the oblique support member and the vertical member drive the plastic member to spring rebound, prevents further penetration of moving barriers. It can be seen from the displacement-time curve that the longitudinal maximum displacement of the two does not exceed 400 mm; the original scheme has a maximum displacement of 289 mm and the optimized maximum collision displacement of 338 mm.

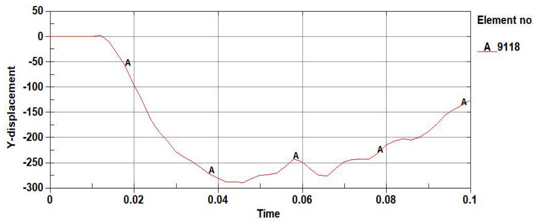

Figure 9. Original solution displacement time curve.

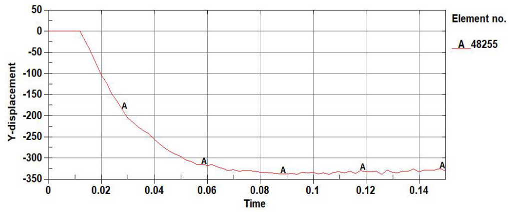

Figure 10. Displacement time curve after optimization scheme .

Compared with the original solution, the optimized scheme collision displacement is closer to the 400mm required by the China Standard, moreover, the time to reach the collision displacement also increased from 0.046 s to 0.094 s. It shows that the diagonal support member plays a sufficient role in mitigating impact and absorbing energy.

5.2.2.Analysis of the rebound speed and acceleration of mobile wall barrier after optimization. Figures 4 and 11 show the rebound velocity-time curve of the mobile wall barrier before and after optimization of the guard device.

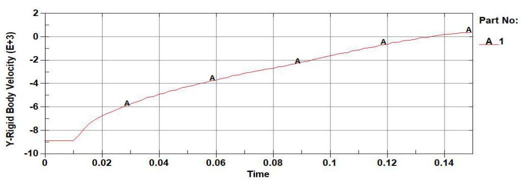

Figure 11. Bounce speed-time curve after optimization.

The original solution is insufficient to block the drilling collision of the mobile wall barrier due to the material rigidity and structural form of the vertical member of the guard device. After the speed of the mobile wall barrier is reduced slightly, it reaches -6.14m·s^{-1} at 0.06s. After that, it maintains a uniform motion and a drilling collision occurs. The rebound does not meet the requirements of the China Standard, so it does not meet the standard requirements. Figure 11 shows the optimized rebound velocity-time curve.After the collision occurred in 0.01s, the mobile wall barrier decelerated, and the speed was reduced to 0m·s^{-1} at 0.136s after the collision. Then, the rebound occurred and reached the maximum rebound speed of 0.15m·s^{-1} at the end of the simulation at 0.15s, Less than 2m·s^{-1} required by China Standards. Compared with the original scheme, the optimized scheme absorbs the energy generated by the collision and hinders the drilling of the mobile wall barrier. Therefore, it is considered that the project meets the requirements of China Standards.

Figures 12 and 13 show the acceleration-time curve of the mobile wall barrier before and after optimization of the guard device.

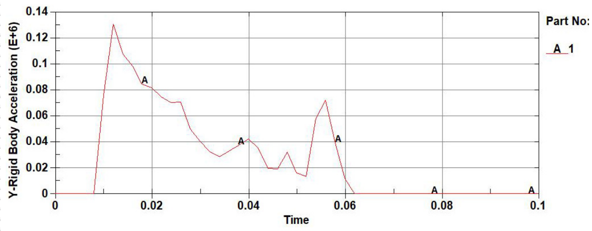

Figure 12. Original solution acceleration-time curve

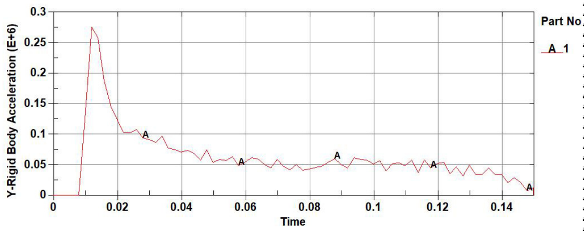

Figure 13. Acceleration-time curve after optimization .

As can be seen from Fig. 12, the acceleration of the mobile wall barrier quickly rises to 13.4 g after the collision occurs, and then the acceleration fluctuates and falls to 0 at 0.062 s. Explain that the collision of the mobile wall barrier and the protective device is over, and a drilling collision occurs, which does not meet the requirements of China Standards. Fig 13 is the acceleration-time curve of the mobile wall barrier after the optimization of the guard device. The acceleration of the mobile wall barrier reaches 28.2g at the peak point of 0.012s, which is less than 40g required by the China Standard.After that, the acceleration of the mobile wall barrier gradually decreases with time, indicating that the guard device has a good buffering energy absorption effect.

6.Conclusion

Modeling and finite element analysis of the rear lower guard of a brand of heavy-duty warehouse-type semi-trailer according to the requirements of GB 11567-2017 "*Motor Vehicles and Trailers-lateral and Rear Underrun Protection Requirements*" The 120mm section height specified by the China Standard and the 140mm section height of the semi-trailer are selected as the basis for modeling the cross members. After simulation, it is concluded that the rear underrun protection device with 120mm cross member cannot effectively block the drilling collision of the mobile wall barrier. On the basis of the 120mm cross member scheme, the diagonal support member connected between the lower flange of the rear end of the frame longitudinal beam and the guard is added. The finite element analysis of the improved model shows that the optimization result has sufficient buffer energy absorption. To prevent the impact of drilling barriers from moving barriers, it can meet the China Standards' requirement. Using computer simulation to analyze the car collision problem can improve the structure of the car body and safety components, and has strategic significance for improving the passive safety performance of the car, shortening the development cycle and reducing the expenditure. Subsequent work will further optimize the structural form of the improved rear underrun protection device, find a better alternative to the oblique support, and gradually apply the simulation model to the experiment and practice to further verify its authenticity and effectiveness.

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