COLLISION SIMULATION AND PERFORMANCE IMPROVEMENT EVALUATION OF ROAD GUARDRAILS BY FEA

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Abstract - The impact resistance performance of road guardrail is an important factor that affects vehicle collision safety. Improving the structure of road guardrail and adding damping materials is a common way to improve the performance of guardrail. Taking the model of the F800 van as the research object in the finite element simulation software, the Ls-Dyna solver is adopted to conduct a comparative study on the energy absorption effects of the protective fences before and after the improvement. By adding anti-collision blocks and rubber pads to the protective fence structure specified in the national standards, the effects before and after the improvement are evaluated with the displacement and energy absorption status of the protective fence as the indicators. The results show that the protection performance of guardrail can be improved significantly by adding rubber pads or obstruction blocks. Both of them can reduce the maximum displacement of the guardrail column in the impact process, at the same time, the two structures can significantly increase the absorption effect of the road guardrail on the impact energy, especially the increase of the block structure on the road guardrail performance is more obvious. The research process is of great significance for enhancing the performance of road guardrails.

Keywords: Road guardrail, Rubber pad, Obstruction block, Vehicle collision.

1. Introduction

Among all kinds of road traffic accidents, the number of human deaths is the highest. According to statistics, the number of deaths accounts for 80%[1]. The installation of road traffic guardrail is an important way to avoid casualties caused by accidents. In China, the forms of road traffic guardrail are mainly rigid, semi-rigid and flexible three, their representative forms are concrete wall type, metal beam and column type and cable type. Among them, the metal beam-column guardrail is widely used in road traffic safety because of its combination of rigid and flexible properties. Therefore, it is meaningful to study the influence of metal beam-column guardrail on road traffic safety.

There are many factors affecting the performance of road protective guardrail. Wang Junjie et al.[2] studied the performance of side beam guardrail under different size parameters and vehicle speed conditions based on the orthogonal test method. Song Shiming[3] studied the prefabricated guardrail and gave suggestions for the optimization of guardrail with different materials and assembly forms. Sun Shengjiang[4] conducted impact and collision simulation analysis on the basalt fiber composite guardrail and improved the research on guardrail materials. However, there are various forms of guardrail, and a large number of studies have been carried out on hook parts [5], materials [6], cushioning and vibration absorption [7] of guardrail, providing a good reference value for the impact test of real vehicles. Although China issued the "Highway Guardrail Safety Performance Evaluation Standards" [8] in 2013, the form and load-bearing performance of road traffic guardrail are specified in more detail. However, optimizing the structure of guardrail and improving the metal side beam road guardrail is still a hot research issue.

The research methods of road guardrail mainly include three methods: real vehicle crash test, computer numerical simulation and model test [9]. Finite element method is a common method to analyze the collision mechanism between guardrail

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and vehicle. Through modelling and optimization and high-quality nonlinear calculation methods, the optimization work related to materials, structural dimensions and displacement parameters of guardrail can be limited [10, 11].

The application of the finite element method to conduct collision simulation research on improved guardrail structures has emerged as a pivotal technical approach for enhancing guardrail protection performance in the current context. Marzougui et al. [12] conducted collision simulation tests on existing guardrail structures under the condition of vehicles traveling at a speed of 100 km/h. The results indicate that, under high - speed collision scenarios, there is a significant risk of vehicles overturning, which seriously endangers the safety of drivers and passengers. James [13] systematically explored the influence mechanisms of key parameters, such as vehicle impact speed and road curve radius, on the collision performance of guardrails. Dai Jingang et al. [14] innovatively developed a flexible guardrail system. By optimizing the vehicle collision path guidance strategy, this system significantly reduces vehicle damage during collisions. Cheng Rui et al. [15] carried out a combined simulation analysis using Hyper-mesh and LS-DYNA software, comparing the response characteristics of small passenger cars and F800 medium-sized trucks during collisions. Their research points out that the protective performance of existing guardrails has limitations, and it is necessary to implement speed limits and height restrictions to enhance road traffic safety. Zhang Meiyi et al. [16] designed and developed a new-type guardrail with outstanding anti-collision performance, short construction cycles, and convenient installation features. Through a combination of experimental verification and numerical simulation, they confirmed the improved performance of this guardrail in terms of anti-collision, guidance, and buffering. Similarly, Wang Jia et al. [17] systematically evaluated the protective effectiveness of improved concrete guardrails using the finite element analysis method.

A multitude of research findings demonstrate that various guardrail improvement technologies are of great significance for enhancing road traffic safety. However, due to the complexity and diversity of actual road conditions, a unified optimization scheme applicable to all scenarios has not yet been established [18-20]. Therefore, research on the safety performance of guardrails remains a core direction for improving the safety guarantee capabilities of road traffic.

2. Finite Element Modelling

In this paper, the vehicle model with specific data set is selected and the structural parameters are optimized for collision simulation test. After the collision, the impact model can be judged according to the proportion of hourglass energy. Then, the three-dimensional structure form of the guardrail is established through the three-dimensional modelling software, and the relevant parameters of the collision are defined after grid division and other processes in the finite element analysis software. According to the simulation results, the connection type and material type of the guardrail are optimized, and the anti-collision property of the guardrail can be further studied to observe the optimization effect. The vehicle body mainly uses MATL1 sheet metal material, MATL20 rigid material and MATL24 elastoplastic material as its material models.

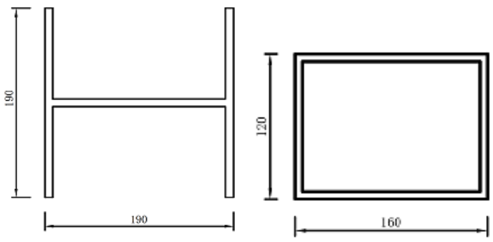
2.1 Vehicle Finite Element Model

In this paper, The Ford F800 van of The National Crash Analysis Center (NCAC) of the United States was selected as the vehicle model, and its vehicle weight was 8.037 tons. In order to calculate efficiency, the interior of this model is simplified, and the model has a total of 36,568 units and 38,973 nodes. The main material models used for the vehicle body are MATL1 sheet metal material, MATL20 rigid material, and MATL24 elastoplastic material.

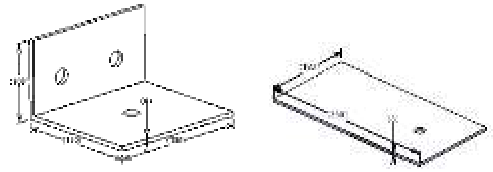
Figure 1: Vehicle finite element model of Ford F800

2.2 Guardrail Finite Element Model

A guardrail type with a safety rating of SS is established in the 3D modeling software. The guardrail consists of columns, beams and connectors connected by high-strength bolts. The structural parameters of the guardrail column, beam and connector are shown in Fig.2 below. In the FEA, RIGID elements are used to simulate the connection relationships between beams, and BEAM elements are used to simulate the form of the guardrail and output the stress. Meanwhile, the segmented elastoplastic material No. MAT24 is used to simulate the performance of the guardrail.



(a) Column section (b) Beam section



(c) Central connector (d) Top connector

Figure 2: Geometric parameters of the column (a), beam (b) and connector structure (c, d) of the guardrail (unit: mm)

Among them, Fig. 2(d)is the connection piece at the top of the protective fence, and the c is the middle connection piece of the column and the guardrail. The column thickness is 8mm and the beam wall thickness is 6mm. By connecting each structure, the obtained guardrail 3D model and its finite element model are shown in Fig. 3 and Fig. 4 respectively.

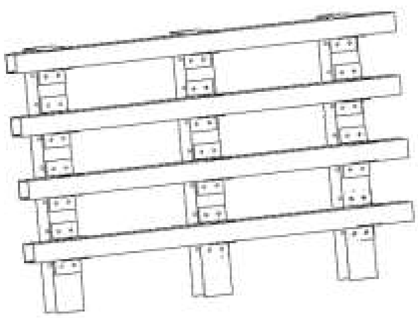


Figure 3: The 3D model of the guardrail

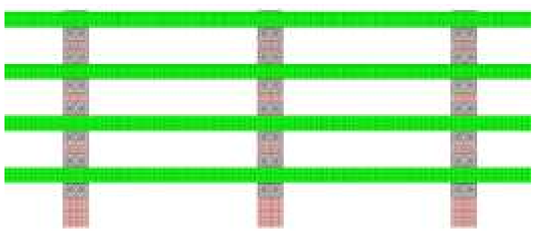


Figure 4: Finite element mesh model of guardrail

2.3 Vehicle-Guardrail Collision Finite Element Model

According to the guardrail collision standard requirements, the guardrail - vehicle collision model established is shown in Fig.5 below. Among them, the collision Angle between the guardrail and the vehicle is selected as 20°, the collision speed is defined as 80km/h, the length of the guardrail is 39m, and the simulation time is 1s.

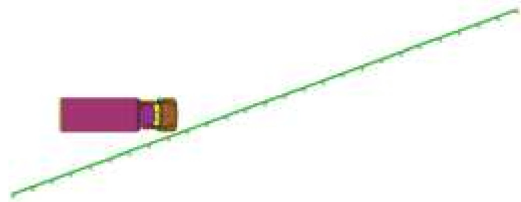


Figure 5: Finite element model of vehicle-guardrail collision

2.4 Analysis of Collision Finite Element Results

In the collision simulation, the SURFACE-SURFACE contact algorithm is adopted to define the contact relationships among various components of the vehicle during the collision. The *CONTACT_AUTOMATIC_SINGLE_SURFACE is set to define the contact characteristics of the guardrail, and the *CONCACT_AUTOMATIC_SURFACE_TO_SURFACE is set to define the face to face contact between the vehicle model and the corrugated guardrail. For the contact between the vehicle and the ground, a rigid wall is set by defining the keyword *CONTROL_RIGIDWALL to simulate the contact effect of the ground.

After a 1s simulation of the collision process, the displacement result of the guardrail as shown in Fig. 6 is obtained.

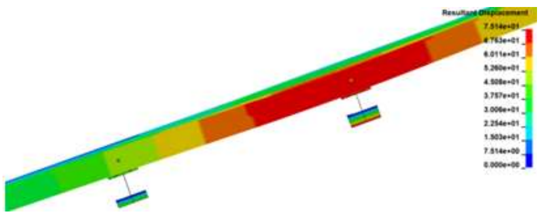


Figure 6: Deformation cloud map of guardrail specified by national standard

It can be seen from Figure 6 that the maximum deformation of the guardrail is close to 90mm, and the guardrail beam and column have a large deformation in the collision process. The guardrail energy absorption curve and the column deformation curve are analyzed, and the change process is shown in Fig. 7 below.

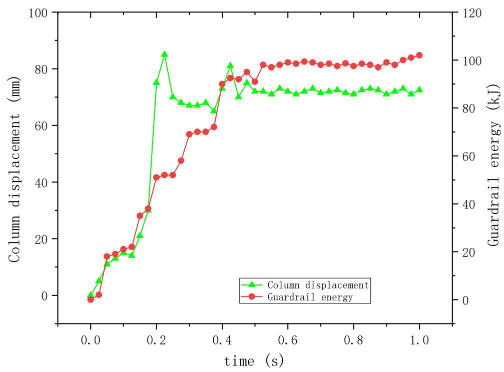


Figure 7: Displacement of the column and guardrail energy change curve

According to the changes in the diagram 7, the energy of the guardrail gradually increases from 0, indicating that after the collision, the guardrail can gradually absorb the impact energy generated by the vehicle collision and reduce the occupant injury. In this process, the diagram showed three impact changes before 0.4s, indicating that after three impact collisions between the vehicle and the guardrail, the vehicle remained stable and the guardrail energy absorption reached saturation. This result indicates that the numerical simulation can simulate the process of energy absorption and change more accurately.

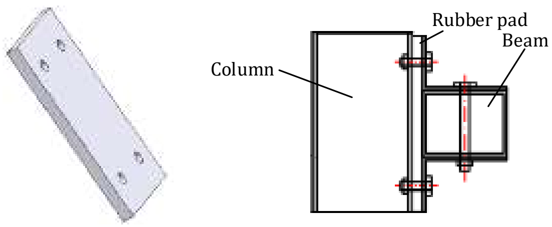
3. Optimization Design of Guardrail

In order to further optimize the energy absorption performance of guardrail, it is necessary to improve and optimize the guardrail structure. The common form of structural improvement is to increase the elastic buffer material, this method has low cost and obvious effect, and is a common form of improvement for road guardrail.

- ***Analysis of Adding Rubber Pads***

In order to ease the impact process, rubber pads are added between the guardrail post and the beam. The rubber material has good wear resistance and drag reduction performance, which can alleviate the transient impact generated in the process of vehicle collision and protect the safety of vehicles and occupants.

In this structure, the type of connection between the beam and the column is changed. The structure of the added rubber pad is shown in Fig. 8(a), where the thickness of the rubber pad is 18mm, and the guardrail structure unit is shown in Fig. 8(b).



(a)Rubber pad (b) The guardrail structure unit
Figure 8: Rubber pad(Left)and the guardrail unit structure

- ***Analysis Of Simulation Results***

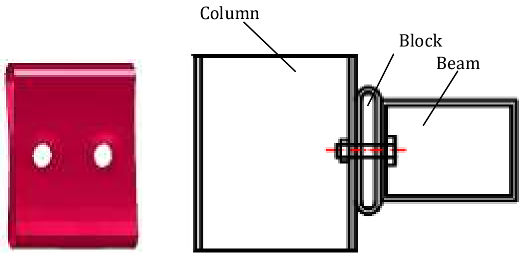
With other conditions unchanged, the collision process of the vehicle under this working condition is simulated again. Through simulation analysis, it is found that the deformation of the guardrail is shown in Fig.9 below.

Figure 9: Top view of guardrail

As can be seen from Fig. 9, the maximum deformation of the guardrail is about 80mm, and the shape variables of the guardrail beam and column are reduced compared with the collision situation without adding the rubber pad, and the rubber pad has a significant impact on the deformation distribution of the guardrail and beam.

- ***Simulation Analysis of Adding Obstruction Block***

The obstruction block structure is often used to improve the energy absorption performance of guardrail. As shown in Fig. 10(a), the obstruction block structure as shown below is used instead of the rubber pad to carry out vehicle collision simulation under the mentioned working conditions. The structure of the added block unit is shown in the below. Its thickness is 6mm, the outer diameter of the top rounded corner is 30mm, and the overall length is 120mm. The form of the guardrail structure unit is shown in Figure 10(b) below.



(a) Obstruction block (b) Guardrail structure unit
Figure 10: Obstruction block and the guardrail unit structure adding Obstruction block

Through the collision simulation of the guardrail with the addition of the anti-resistance block, the working condition of the maximum stress and displacement of the guardrail beam is obtained, as shown in Fig. 11 below.

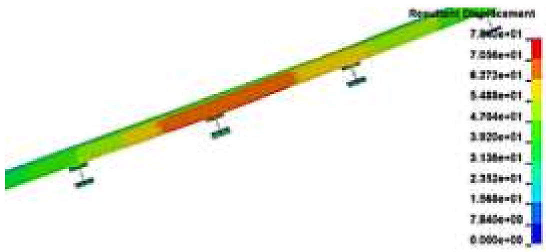


Figure 11: deformation nephogram of the guardrail after adding obstruction block

As can be seen from Fig. 11, the maximum deformation of the guardrail after the addition of the barrier block is about 78mm, and the maximum shape variable decreases compared with the non-improved guardrail form. At the same time, the deformation structure of the guardrail is mainly reflected in the guardrail beam, and the deformation of the column is significantly reduced.

- ***Comparison and Analysis of Optimization Results***

In order to further compare the improvement degree of the protective performance of the guardrail by adding the rubber pad and the obstruction block structure, the displacement of the column and the energy distribution of the guardrail are compared.

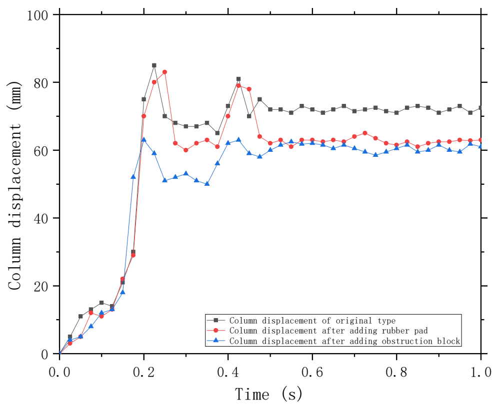


Figure 12: Three types of column displacement changes

As shown in Fig. 12, the overall displacement of the column in the collision process decreases after the addition of the rubber pad and the anti-block, which indicates that the beam of the guardrail has borne part of the impact energy during the collision, and the rubber pad and the anti-block can absorb part of the energy, so the impact energy is more dispersed in the guardrail and the displacement of the column decreases.

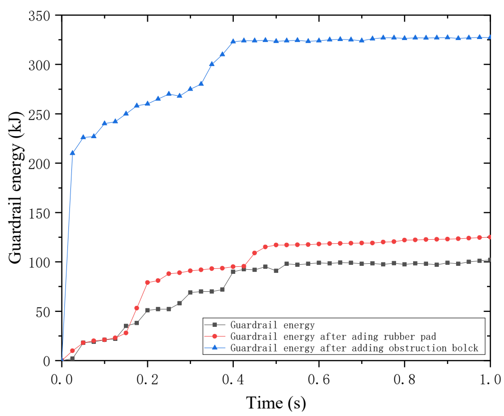


Figure 13: Energy distribution diagram of three forms of guardrails

The energy distribution of the guardrail is shown in Fig. 13. The analysis shows that the energy of the guardrail after the addition of the rubber pad is significantly increased compared with the original structure, which indicates that the guardrail after the addition of the rubber pad can better absorb the impact energy of the vehicle in the collision process, thus reducing the injury of vehicles and pedestrians caused by the collision. This effect is more obvious after the addition of the anti-blocking block structure.

The analysis shows that after the addition of rubber pads and anti-blocking blocks, the rigidity of the rigid bolt connection between the original guardrail column and the beam decreases, making the guardrail have a certain flexibility, which can alleviate the impact of the vehicle during the collision process and absorb the impact kinetic energy of the vehicle faster, delay the collision time, and play a better protective role.

4. Conclusions

Road guardrail structure is an important factor affecting vehicle crash safety. Finite element collision simulation is an effective method to study and improve the structural performance of protective guardrail.

The addition of rubber pads and anti-blocking blocks can significantly improve the energy distribution during vehicle collisions. In contrast, the increase of the block structure can better absorb the impact kinetic energy of the vehicle during the collision process, which can better achieve occupant protection, followed by rubber pads, but a reasonable size should be selected to obtain better optimization results.

In order to better protect the safety of vehicles and occupants, by appropriately increasing the time to reach the peak collision energy or adding structural components that can buffer vibration absorption is an effective measure to improve the guardrail, but should consider the relevant structure, the cost of materials, durability and so on.

References

[1] M. A. Jian, FENG Zhen, QIU Junling, et al. (2018). Transformations and inspirations of technology in Chinese road transportation industry over the past 40 years of Reform and Opening up. *Journal of Chang'an University,* 20(6):38-67. https://DOI: 10.3969/j.issn.1671-6248.2018.06.004.

[2] Wang Junjie, Guo Chao, Li Shouxin, et al. (2024). Simulation of wave beam barrier collisions and orthogonal test modifications. *International Journal of Mechatronics and Applied Mechanics*, 18(4):184-189. https://dx.doi.org/10.17683/ijomam/issue18.22

[3] SONG Xuming, PAN Pengyu, RONG Yawei, et al. (2021). Protection Performance of New Fabricated Guardrail Based on Collision Simulation. *Journal of South China University of Technology*, 49(10):41-49. https://DOI: 10.12141/j.issn.1000-565X.200710.

[4] SUN Shengjiang, ZHU Changhua, MEI Kuihua. (2019). Anti-collision performance of basalt fiber composite beam-column guardrails. *Journal of Vibration and Shock*, 38(21):265-270. https://DOI: 10.13465/j.cnki.jvs.2019.21.037.

[5] Davids William G., Botting Joshua K., Peterson Michael. (2006). Development and structural testing of a composite-reinforced timber highway guardrail. *Construction and Building Materials*, 20(9):733-743. https://DOI: 10.1016/j.conbuildmat.2005.01.060.

[6] Jian long Huang, Guang juan Jie, Zheng wei Liu. (2008). FEA of hyperelastic rubber material based on Mooney-Rivlin model and Yeoh model. *CHINA RUBBER INDUSTRY*, 55(8):467-471. https://DOI: 10.3969/j.issn.1000-890X.2008.08.004

[7] Heng zhi Li. (2022). Study on real vehicle crash test of new SA class bridge guardrail. *Highway*, 67(9):332-335.

[8] JTG B05-01-2013, Highway guardrail safety performance evaluation standard[S].

[9] Tangjian. (2024). Highway guardrail safety evaluation method and case analysis. *Road Traffic Management*, 5:34-37.

[10] Atahan Ali O.(2002). Finite Element Simulation of a Strong-Post W-Beam Guardrail System. *Simulation (San Diego, Calif.)*, 78(10):587-599. https:// DOI: 10.1177/0037549702078010001.

[11] Gutowski Matthew, Palta Emre, Fang Howie. (2017). Crash analysis and evaluation of vehicular impacts on W-beam guardrails placed behind curbs using finite element simulations. *Advances in Engineering Software*, ,114:85-97. https://DOI: 10.1016/j.advengsoft.2017.06.004.

[12] Marzoug R, Lakouari N, Ez-Zahraouy H, et al.(2022). Modeling and simulation of car accidents at a signalized intersection using cellular automata. *Physica A: Statistical Mechanics and its Applications*, ,589:126599. https://DOI:10.1016/j.physa.2021.126599.

[13] K J R. (2017). The Dangerous Curve and The Guardrail: Disease and Vaccination. *American journal of public health*. 107(1):15-17. https:// DOI:10.2105/AJPH.2016.303540.

[14] Dai Jin gang, Liu Jun, Gao Bo lin. (2015). Flexible device design and research on bend highway guardrail. *Mechanical & Electrical Engineering Magazine*, 32(12):1549-1554. https:// DOI:10.3969/j.issn.1001-4551.2015.12.005.

[15] Cheng Rui, Huang Yanwen, Gao Xu. (2025). Simulation of the Collision Characteristics of Curved Roadway Guardrails on Low-Grade Highways in Mountainous Areas. *Journal Of Jilin University Engineering And Technology Edition*, 1-10. https:// DOI: 10.13229/j.cnki.jdxbgxb.20241083.

[16] Meiyi Zhang, Haigu Nong, Cao Lü, et al. (2025) Research on the Protection Performance of Highway Outward-Extended Guardrails Based on Simulation. *TestsTransportation Science & Technology and Management*, 6(06):134-136.

[17] Wang Jia, Wu Ya Wei. (2025) Simulation Analysis on Collision Characteristics of New Guardrail. *Urban Roads Bridges & Flood Control*, (3):77-81. https:// DOI:10.16799/j.cnki.csdqyfh.240603.

[18] Noh M, Lee S. Construction tolerance effects of reinforced posts on crash performances of an open-type guardrail system[J]. Thin-walled structures, 2017,120:138-152. https://DOI:10.1016/j.tws.2017.08.028.

[19] Chen Zhen, Fu Jun, Li Guan Chao, et al. (2024) Performance Analysis of Assembled Crash Barrier Scheme and Vehicle Crash Simulation. *Journal of Wuhan University of Technology(Transportation Science & Engineering)*, 48(3):515-520. https:// DOI: 10.3963/j.issn.2095-3844.2024.03.019.

[20] Wu De Hua, Chen Zhi Qing, Ceng Jun Cheng, et al. (2024). Research on Simulation Optimization of Novel Highway Corrugated Beam Guardrail Structure. *Journal of Guizhou University (Natural Science)*, 41(6):91-98. https:// DOI:10.15958/j.cnki.gdxbzrb.2024.06.14.