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Highway Concrete Guardrail Lifting Scheme and Safety Performance Verification

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Abstract

In order to achieve the old fence of reuse, improve the safety performance of guardrail, barrier structure does not meet the requirements, make full use of the old concrete guardrail on the basis of heightening, through computer simulation experiment were analyzed, and optimization design, through the real car collision test, make the concrete guardrail after heightening structure satisfies the requirement of the safety performance of current specification. The results show that the protective performance of the two guardrail schemes meets the requirements of the current guardrail evaluation standards through the computer simulation experiment. Through the optimized design of scheme 1, the actual car crash test proves that the enhanced structure of Minhua TYPE II concrete guardrail can meet the requirements of safety performance evaluation. The research results provide an important basis for the transformation of the guardrail and the revision of the current design of expressway in China.

Keywords

Concrete Guardrail, Scheme Optimization, Simulation, Real Vehicle Collision, Safety Performance

1. Introduction

As a passive safety facility, highway guardrails play an important role in reducing the severity of the consequences of traffic accidents and improving the level of highway traffic safety protection.

Regarding the installation of highway guardrails, the research on guardrail structure has been started very early in European countries and a complete set of experimental facilities and corresponding test procedures have been established

[1] [2]. Japan has formulated an outline for guardrail installation in consideration of the applicable conditions and performance requirements of the guardrail [3]. Stolle, Coty S. has developed a short radius guardrail system to improve the safety of crossroads. For some intersecting road positions, a bending system with a radius greater than 10 m is required. Nonlinear finite factor simulation is performed using LS-DYNA to study large radius bending guardrail systems with various heights. The calibration finite simulation model of the short radius guardrail system has been improved [4]. In early 1994, the Ministry of Communications issued the first industry standard for highway guardrails, "Expressway Traffic Safety Facilities Design and Construction Technical Code (JTJ074-94)" [5]. Jian, Y. proposes a new removable mid-position guardrail that systematically evaluates its energy absorption capacity, vehicle acceleration, post-impact trajectory of the impact vehicle, and the behavior of the guardrail when it hits using LS-DYNA's 3D computer simulation. Use concrete and W-beam guardrails to compare the performance of removable middle guardrails. The performance of the proposed removable middle guardrail is better than that of traditional concrete and W-beam guardrails, the collision performance is higher, and the collision vehicle is more stable after the collision [6]. By building a model, Li, N. uses different methods to compare the severity of collisions between roads with and without guardrails. Research has found that the guardrail system can reduce the incidence of fatal and serious injury accidents [7]. The Ministry of Transport promulgated and implemented the latest "Highway Guardrail Safety Performance Evaluation Standard" on December 1, 2013. In the new standard, the guardrail protection grade is divided into 8 grades. At the same time, the central partition opening movable guardrail, anti-collision pad, Collision conditions and evaluation criteria of structures such as ends and transition sections [8]. The United States began to conduct research on the reuse of highway guardrails in the 1990s, and some progress has been made in some areas, such as the reuse of wooden posts for safety guardrails. In the 2011 edition of the "American Association of State Highway and Transportation Officials (AASHTO). Roadside Design Guide", the "guardrail upgrade system" was discussed in detail, and it was proposed to consider old guardrails as part of new or rebuilt highway projects [9]. Japan has determined the protective performance of a wire rope protective fence with buffering function through a crash test and has passed relevant standards, verifying the feasibility of using it as a central separation facility [10]. Yuan, D.J. and others set up a model of limited metadata of a metal beam column guardrail for vehicle collision, and through numerical simulation, analyzed the sensitivity of the maximum dynamic deformation of anti-collision guardrail to the change of vehicle mass, impact speed and impact angle. In the process of analysis, the average sensitivity coefficient is used as the criterion for evaluating sensitivity. The simulation results show that the impact speed is the most sensitive factor affecting the maximum dynamic deformation of the anti-collision guardrail [11]. In view of the problems existing in the road-side guardrail, a road-side high-protection grade beam column concrete guardrail structure was

developed, craft test and computer simulation method, through the research of guardrail protection performance, buffer performance, construction technology, landscape modeling, snow removal convenience, etc. The guardrail wall and basic strength were verified by the troer test, each evaluation index met the five-level (SA) protection level requirements [12].

In China, due to the rapid growth of expressway traffic and the large proportion of large vehicles, the incompatibility of the original guardrail's anti-collision ability and the changes in the working conditions of the guardrail due to increased pavement have attracted the attention of the industry. And carried out related research and achieved some results. However, these results and methods are generally only remedial measures. The current guardrail renovation plan is only developed for individual cases. The investigation of the prerequisites for improving the collision avoidance level is unclear and imperfect. Therefore, the scope of application of the existing results is limited. It is difficult to get up. Secondly, even if the height and strength of the old guardrail meet the requirements of relevant specifications through some transformation measures, it is only for the transformation of the guardrail in a certain situation, and it is not universal, and it is easy to cause a waste of resources. Based on the Minhua II concrete guardrail in use, the guardrail heightening scheme is proposed. The computer simulation analysis method was used to compare and optimize the schemes, and finally a scheme with safe performance and good maintainability was selected to carry out a full-scale crash test on a real car, so that the modified guardrail could meet the requirements of the current code for the guardrail crashworthiness level.

2. Minhua II Type Guardrail Heightening Plan

The Minhua Type II guardrail is a built-in foundation. The two-piece guardrail is provided with a mutual support structure, and the bottom of the guardrail is equipped with a leveling layer or corbel, as shown in **Figure 1** and **Figure 2**.

In view of the vehicle rollover problem caused by the insufficient height of the central partition, considering the existing central partition, the green plants are currently growing luxuriantly. In order to avoid damaging the existing central partition, the height of the concrete guardrail was increased for the Minhua II barrier. And the heightened part has sufficient rigidity and strength, the following two schemes are proposed:

Option 1: Use section steel to heighten the guardrail. A rectangular section of steel is installed on the upper part of the guardrail by planting bars. The height of the section steel is 10 cm, the width is 140 cm, and the thickness is 8 cm. The prefabricated concrete guardrail blocks are connected at intervals of 1 meter. The section steels are connected by bushings.

Option 2: Use prefabricated reinforced concrete beams to heighten the guardrail. A prefabricated reinforced concrete beam is installed on the upper part of the guardrail by planting bars, and the beams are connected together by steel plates.

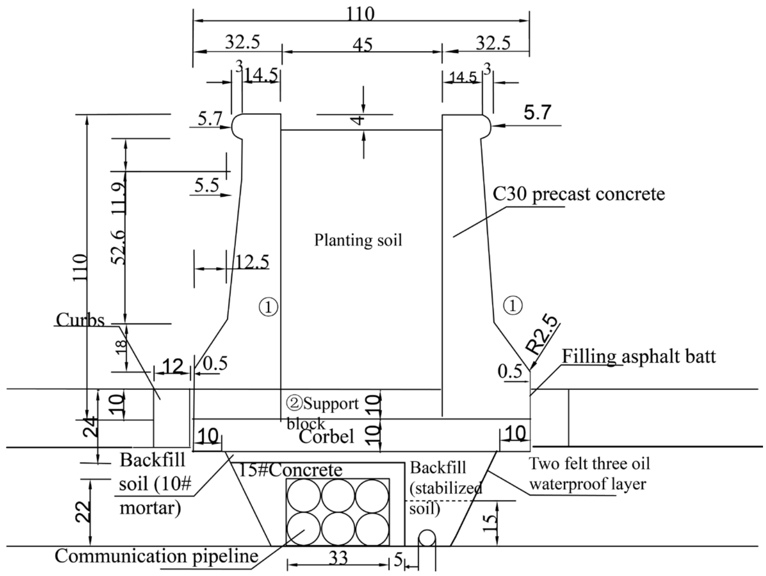


Figure 1. Sectional view of the guardrail of the Minhua II central divider belt.

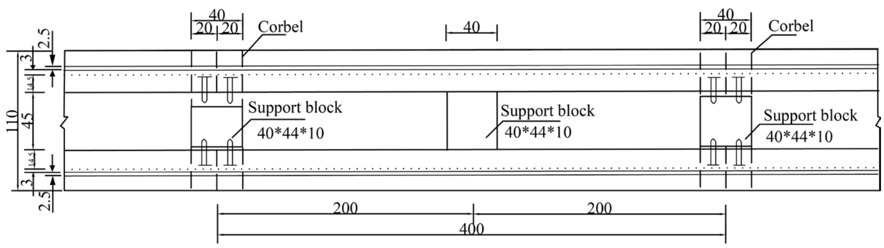


Figure 2. Plan view of Minhua II central divider guardrail.

The main purpose of the above two schemes is to increase the height of the concrete guardrail, and the heightened part should have sufficient rigidity and strength to prevent separation from the bottom concrete guardrail. The heightening scheme is mainly for the protection of large vehicles, so the simulation calculation only analyzes the large vehicles.

3. Simulation Analysis

3.1. Scheme 1 Simulation Analysis

Bus simulation

After the passenger car collides with the guardrail, the vehicle can be smoothly led out without overturning, crossing, or riding. The vehicle has been driving along the guardrail without driving out of the frame. The guardrail is partially damaged, especially the upper beam is damaged, but the vehicle is not affected. Guided, the maximum dynamic deformation of the guardrail is 155 mm, and the vehicle has a relatively obvious roll phenomenon (**Figures 3-5**).

Large truck simulation

According to the simulation results, after the guardrail is raised, although the vehicle roll is still serious, the vehicle does not roll over and the vehicle does not drive out of the frame. As shown in **Figures 6-8**, the maximum dynamic deformation of the guardrail is 43 mm, the beam deformation is small, and the connection with the lower concrete guardrail is firm, and the integrity is good.

Figure 3. Maximum dynamic deformation of the guardrail.

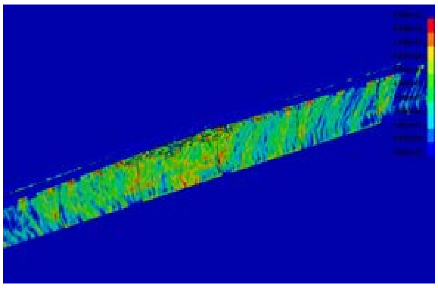


Figure 4. Cloud diagram of the force change of the guardrail.

Figure 5. The state of the vehicle driving out.

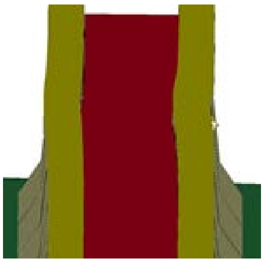


Figure 6. Deformation of the guardrail.

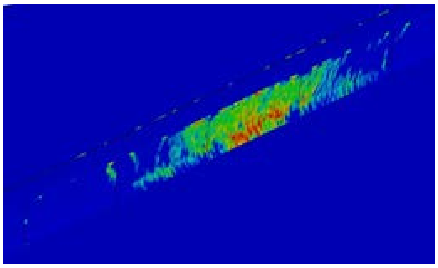


Figure 7. Partial force state of the guardrail concrete.

Figure 8. Vehicle trajectory.

3.2. Scheme 2 Simulation Analysis

Bus simulation

After the passenger car collides with the guardrail, the vehicle can be smoothly led out without overturning, crossing, or riding. The vehicle has been driving along the guardrail without driving out of the frame. The guardrail is partially damaged, especially the upper beam is damaged, but it does not affect the vehicle. Guided, the maximum dynamic deformation of the guardrail is 88 mm, and the vehicle has a relatively obvious roll phenomenon (**Figures 9-11**).

Large truck simulation

From the simulation results, after the guardrail is raised, although the vehicle roll is still serious, the vehicle does not roll over and the vehicle does not exit the frame. The maximum dynamic deformation of the guardrail is 58 mm, and the beam deformation is small. It is connected to the lower concrete guardrail. Strong and good integrity (**Figures 12-14**).

From the structural performance point of view, both options 1 and 2 may meet the requirements of protection level, but the form of the guardrail and vehicle of the first option is obviously better than that of the second option, and from the aspects of cost and construction difficulty, although the material cost of the first option is slightly higher As for option 2, but the construction of option two involves concrete pouring and curing, the construction is complex, and has a greater impact on road traffic. Therefore, it is recommended to adopt option one for the design of the transformation plan when the guardrail height is insufficient (under 30 cm). In the case that the height of the guardrail is seriously insufficient (more than 30 cm), it is recommended to adopt the second option, and its relative cost will be slightly better than that of the first option.

4. Program Optimization

In view of the excessive deformation in the collision process of Option 1, and the more serious damage to the guardrail, the optimal design of Option 1 is carried out, and lateral support is adopted, that is, the heightening beams on both sides of the guardrail are connected together so that they can receive the force in coordination and increase The overall anti-collision ability of the guardrail (**Figure 15**).

After the passenger car collides with the guardrail, the vehicle can be exported smoothly without overturning, crossing, or straddling. The vehicle has been driving along the guardrail without driving out of the frame. The guardrail is partially damaged, but it does not affect the vehicle guidance. 96 mm, the guardrail protection performance meets the SAm level protection requirements (**Figures 16-18**).

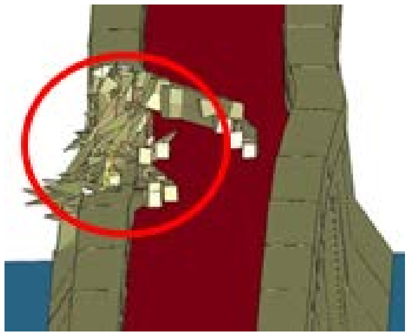


Figure 9. Maximum dynamic deformation of the guardrail.

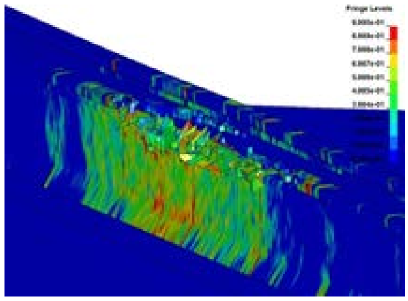


Figure 10. Cloud diagram of the force change of the guardrail.

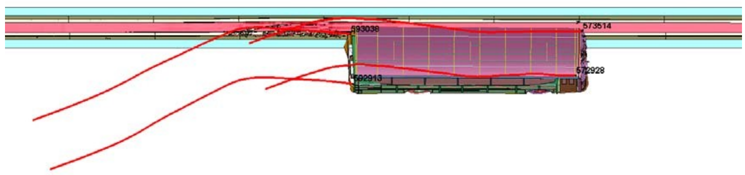


Figure 11. The state of the vehicle driving out.

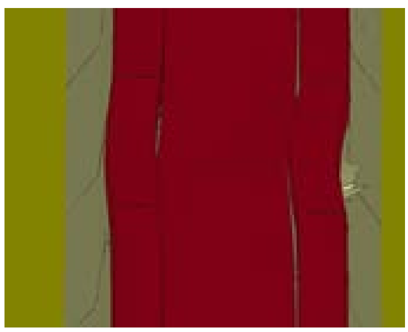


Figure 12. Deformation of guardrail.

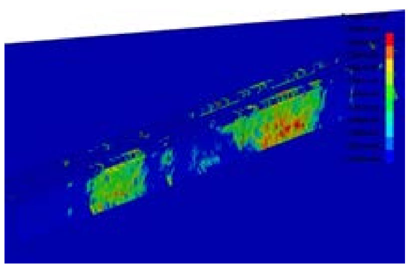


Figure 13. Partial force state of guardrail concrete.

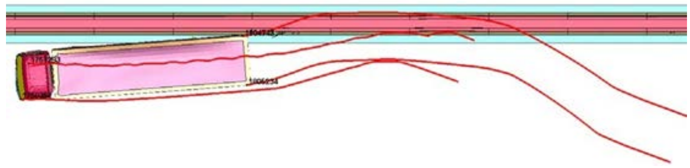


Figure 14. Vehicle trajectory.

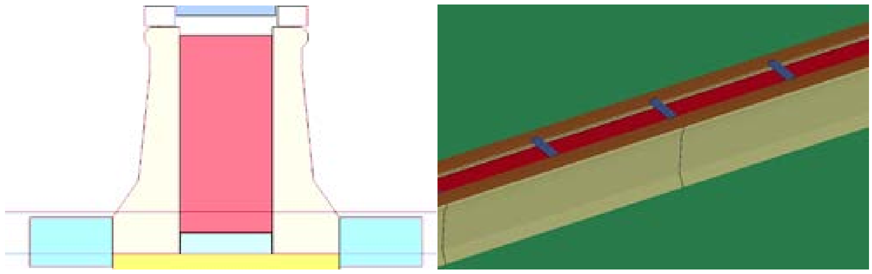


Figure 15. Guardrail heightening scheme.

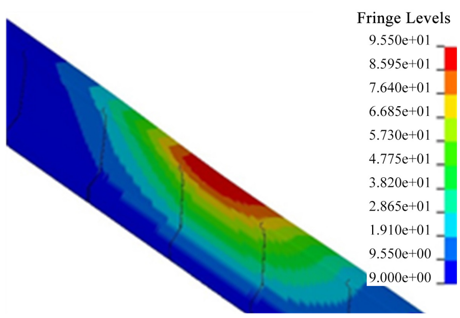


Figure 16. Maximum dynamic deformation of the guardrail.

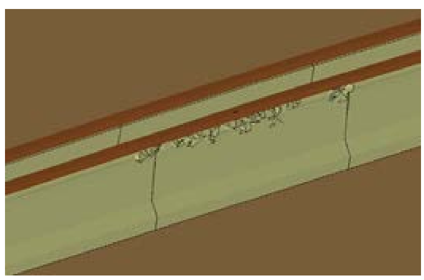


Figure 17. Partial deformation of the guardrail.

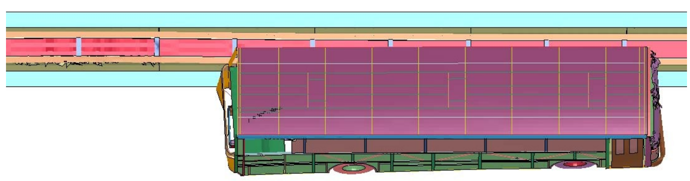


Figure 18. Vehicle driving out.

5. Heightening Scheme Real Car Crash Test

The standard section of the guardrail is composed of a concrete guardrail wall with a central separation zone on both sides, planting soil, upper supporting beam, heightening beam and casing. The upper supporting beam is 770 × 120 ×

61 (mm), the heightening beam is 150 × 100 × 6 × 3980 (mm), and the splicing casing size is 120 × 80 × 6 × 300 (mm). The height of the concrete guardrail is 0.9 m, the height of the raised beam is 0.10 m, and the overall height of the installation is 1.0 m. A total of 10 sections of the guardrail are installed, the length of a single section is 4.0 m, the total installation length is 40.0 m, and the concrete strength grade is C30; the heightening beam is anchored to the top of the concrete guardrail through chemical anchoring bolt planting bars (**Figure 19**).

5.1. Car Collision

The driving posture of the vehicle is normal, and the maximum dynamic deformation of the guardrail is 0.0 m. After the collision, there is no visible residual deformation of the guardrail; the scraping length between the vehicle and the guardrail is 3.20 m (**Figure 20**).

After the vehicle collided with the guardrail, the front bumper was damaged and fell off, the headlight of the vehicle was damaged and fell off; the front left side of the vehicle was scratched and damaged (**Figures 21-25**).

5.2. Coach Collision

When the vehicle is running normally, the maximum lateral dynamic deformation value of the guardrail is 0.25 m; the maximum lateral dynamic displacement extension value of the guardrail is 1.15 m; the maximum dynamic camber value of the vehicle is 0.85 m; the maximum dynamic camber equivalent value of the vehicle is 1.05 m (**Figure 26**).

After the collision, from the starting end of the guardrail, the 14.00 m - 18.00 m guardrail heightening beam deformed; the 13.26 m concrete was damaged and cracked; the maximum residual deformation of the guardrail was 0.08 m; the scratch length between the vehicle and the guardrail was 6.20 m (**Figure 27**).

After the vehicle collided with the guardrail, the front bumper was damaged; the left front headlight of the vehicle was damaged; the left side body of the vehicle was scratched and damaged.

5.3. Large Truck Collision

The driving attitude of the vehicle is normal, the maximum lateral dynamic deformation value of the guardrail is 0.15 m; the maximum lateral dynamic displacement extension value of the guardrail is 1.00 m; the maximum dynamic camber value of the vehicle is 1.00 m; the maximum dynamic camber equivalent value of the vehicle is 1.40 m (**Figure 28**).

After the collision, from the starting end of the guardrail, the heightening beam of the 13.70 m - 16.00 m guardrail is deformed; the surface of the 13.70 m - 19.90 m concrete guardrail wall is damaged; the 14.70 m concrete is damaged and cracked; the maximum residual deformation of the guardrail is 0.07 m; the scratch length between the vehicle and the guardrail is 10.00 m (**Figure 29**).

After the vehicle collided with the guardrail, the front bumper was damaged; the left front headlight of the vehicle was damaged.

In summary, the actual vehicle crash test verifies that the Minhua II concrete guardrail lifting structure can meet the safety performance evaluation requirements.

Figure 19. The split belt guardrail.

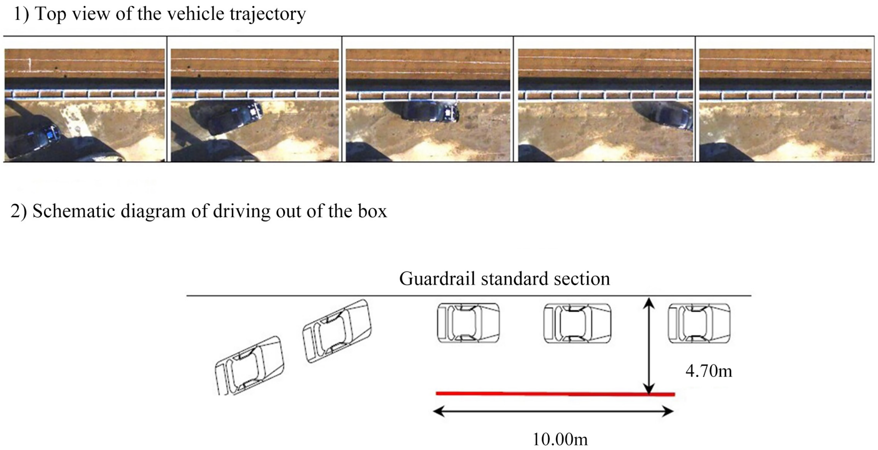


Figure 20. Vehicle trajectory.

Figure 21. The situation after the barrier collision.

Figure 22. The damage of the vehicle.

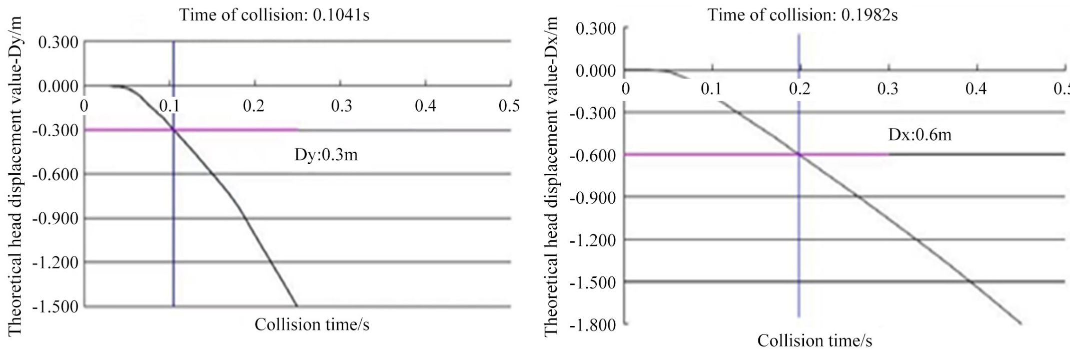


Figure 23. Theoretical head displacement value.

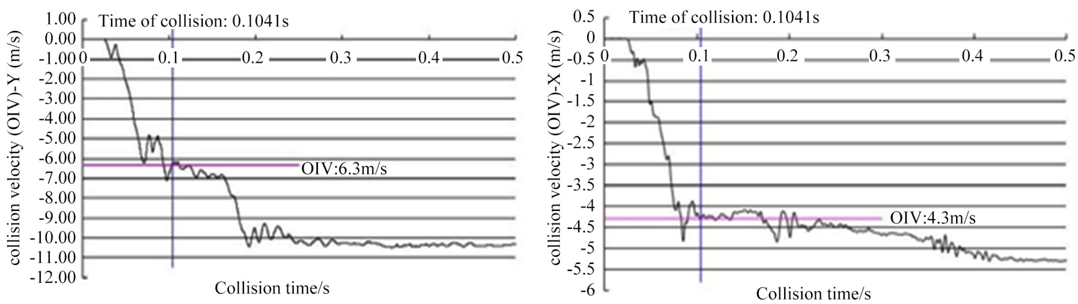


Figure 24. Collision speed.

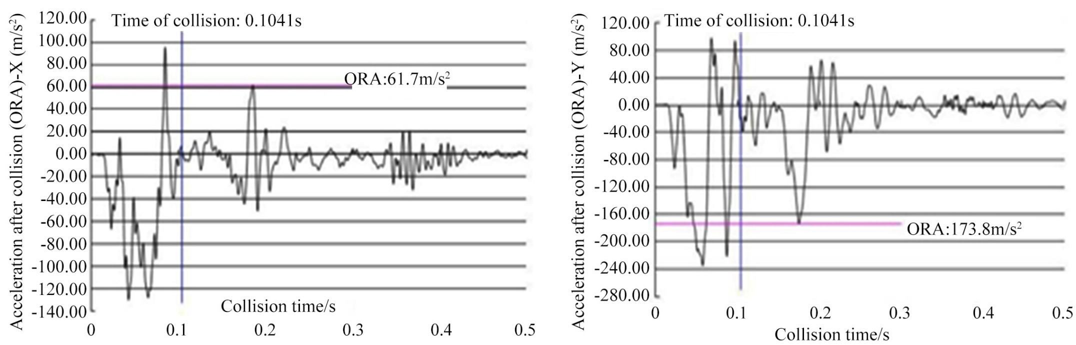


Figure 25. Collision acceleration.

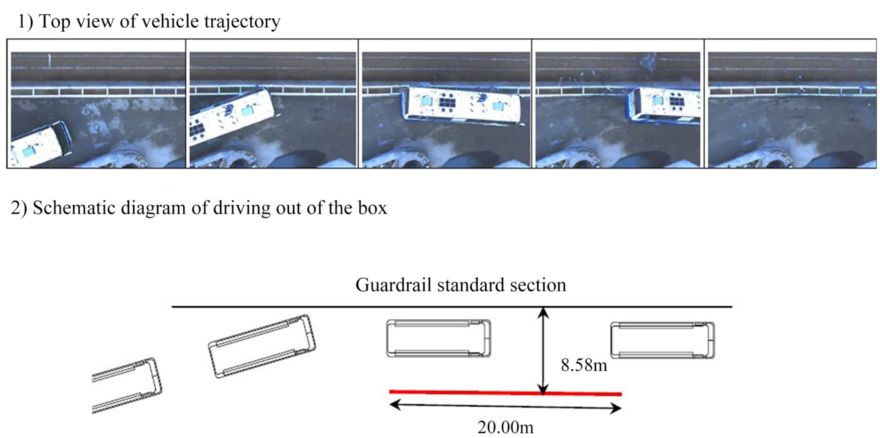
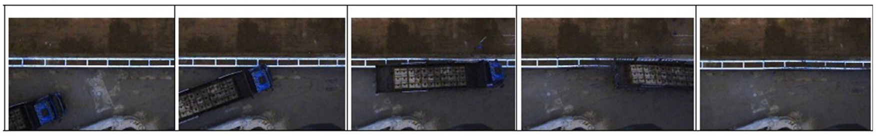


Figure 26. Vehicle driving out process.

Figure 27. Deformation of guardrail.

1) Top view of the vehicle trajectory



2) Schematic diagram of driving out of the box

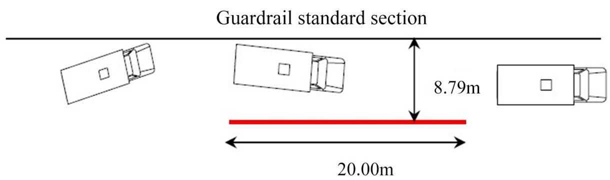


Figure 28. The process of driving out of the vehicle.

Figure 29. Deformation of guardrail.

6. Conclusion

In view of the vehicle overturning problem caused by insufficient height of the central partition, considering the existing central partition, in order to avoid destroying the existing central partition as much as possible, two guardrail heightening schemes are proposed by simulating large passenger cars and large trucks and guardrails. During the collision process, the damage and deformation of the guardrail and the vehicle after the collision were discussed. The test results verified the feasibility of the guardrail heightening scheme and optimized analysis, and finally verified by the actual vehicle collision experiment. 1) Through computer simulation experiments, the two proposed schemes were tested by simulation tests, and the results showed that the protective performance of the two guardrail schemes met the requirements of the current guardrail evaluation standards; 2) Through the optimization design of Option 1, and the actual vehicle crash test verification, the Minhua II concrete guardrail lifting structure can meet the safety performance evaluation requirements.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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