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Simulation Analysis of Static Strength of Three W-Beam Guardrail Structures

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ABSTRACT. *In this paper, we calculated and analyzed the stress distribution, and static performance of three W-beam guardrail under impact using the finite element analysis method with CATIA as the modeling software, ANSA Beta CAE as the meshing software, ANSYS as the analysis platform. This study can provide an important reference for the design and development of the W-beam guardrail.*

KEYWORDS: *W-beam guardrail, static strength, stress, deformation.*

1. Introduction

The expressway has become an important bridge between cities and regions, and played a leading role in the economic development in China by driving the development of regional economy. The expressway has the characteristics of large traffic capacity and high traffic speed. However, those characteristics bring some hidden troubles to traffic safety as well. According to the statistics, the single-vehicle collisions with the roadside account for one-third of fatal accidents in China each year, and the crash rate is increasing year by year [1]. To ensure the traffic safety and to avoid the high possibility of traffic crashes, the guardrail has been widely used as the basic safety facility. Guardrail is a kind of longitudinal impact energy-absorbing structure, which absorbs destructive impact energy through its deformation. It can reduce injuries to the crew member by changing the driving direction of the cars and preventing vehicles from going out on the road or into opposite lanes. However, although many researchers worldwide have done a lot of work on the guardrail, the anti-collision ability and anti-collision effect of guardrail still need to be optimized.

Since the 1920s, some European and American countries have started to study the anti-collision guardrail and formulated relevant usage standards, which include the guardrail structure design, the guardrail form selection, as well as the guardrail manufacturing, transportation, and maintenance [2]. Japan's research on guardrails began in the 1950s. Through in-depth researches and experiments, it only took them a decade to develop a variety of guardrail styles, stipulate the structural design requirements, and clarify the installation details of guardrail [2]. The research of guardrail in China started late. However, after more than 20 years of unremitting efforts, considerable progress has been made in theory and practice in China. Based on the Lagrangian method and Euler method, Liu et al. [3] built the car-guardrail collision model and analyzed the internal forces and deformation of the guardrail under impact loading. This research provides the enlightenment and direction for the follow-up researches on the guardrail. After that, Yao et al. [4] established a mechanical model for the continuous system of reinforced concrete anti-collision guardrail, wherein the combined influence of the property of automobile and guardrail deformation is considered. Based on the proposed model, they determined the dynamic equation of the system, and gave the calculation expression of the impact force of the anti-collision guardrail. This study provides an important theoretical basis for the design of reinforced concrete crash guardrails. Zhang et al. [5] adopted the computer simulation technology to analyze the impact of curb placement distance, vehicle collision angle, and speed on driving safety. This study provides a basis for the subsequent formulation of relevant specifications.

With the increased systematic researches, Chinese researchers finally designed a kind of highway crash guardrail —— W-beam guardrail, which is more suitable for the real situation in China. Many researchers studied the guardrail components parameters, guardrail structure, guardrail material, and other aspects to constantly improve the performance of the guardrail and reduce the shortcomings of the W-beam guardrail. For instance, Yu et al. [6] used the finite element model of guardrail established in 2007 to analyze the anti-collision capability of BHI three-wave guardrail in the collision process. It shows that BHI three-wave guardrail’s anti-collision capability is better. On the one hand, it can orient the accident vehicle in the correct direction; on the other hand, it can absorb the energy of the collision to ensure the safety of the vehicle crew. The result also indicates that the structure of the block and the thickness of the column of the guardrail have a great influence on the performance of the guardrail. In 2011, Tang et al. [7] proposed a new type of guardrail —— double semi-rigid guardrail based on the analysis of collision mechanism between cars and guardrail. By studying the dynamic response, the superior protection ability of this kind of guardrail was confirmed. Subsequently, Yan [8] carried out systematic analysis and research on several new types of guardrail by using full-size crash test and finite element simulation analysis. The results show that the performance indexes of truss type, steel tube prestressed cable type, and chain concrete movable guardrail can meet the appraisal requirements. Recently, Xing [9] studied the difference in the anti-collision energy between medium manganese steel guardrail and Q235 ordinary carbon steel guardrail under different vehicle types, collision speeds, and collision positions for the common A-class W-beam guardrail using modeling and simulation methods. Owing to the in-depth researches conducted by many researchers, the performance of guardrail has been improved. However, there is still a great threat to the safety of vehicle crew in the event of collision accidents. Therefore, it is necessary to constantly strengthen the research on the guardrail to improve its protection performance, to reduce the accident rate, and to ensure driving safety.

Multiple software applications including CATIA, ANSA, ANSYS are utilized in this paper for the geometric modeling and finite element analysis. Under a certain loading, the stress distribution of the W-beam guardrail is studied by controlling the impact block material, which lays a foundation for the subsequent optimization work.

2 Model

2.1 Model review

In this paper, CATIA is used as the modeling platform to establish three kinds of W-beam guardrail models. All of them contain 3-span with a length of 12 m. The length of each span is 4000 mm. The thickness of the beam is 4 mm, and the thickness of each obstruction block and column is 4.5 mm. The height of the columns is 1450 mm. In the simulation, the elastic material model is employed, referring to Q235 ordinary carbon steel, whose elastic modulus is 2.1×105 MPa, and Poisson’s ratio is 0.3. In the simulation calculation process, the W-beam guardrail adopts the integral modeling method, and the guardrail and the beam are connected by the way of merging nodes so that the two parts will act a whole.

In this paper, the finite element software ANSYS was used to analyze the anti-collision performance of three different configurations of W-beam guardrail model under the condition that the cross-section length of guardrail board is unchanged. Here, the shell element 181 is used.

2.2 The geometric description of the model

2.2.1 Model 1

The schematic diagram of the W-beam guardrail section (Fig. 1), and model parameters of model 1 (Tab. 1), are as follows:

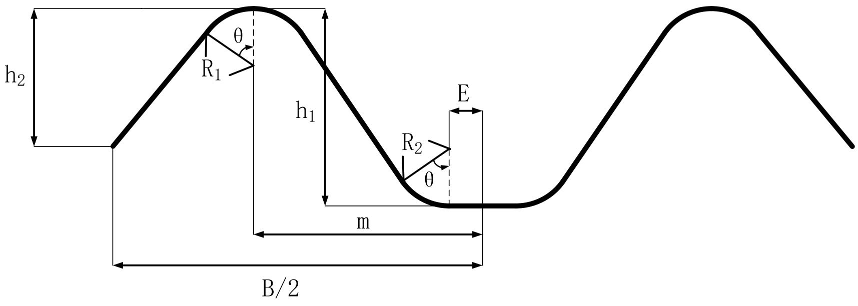

Figure 1 Schematic diagram of guardrail board used in Model 1

Table 1 Parameters of guardrail board used in Model 1

Parameters	$B/2$	m	h_1	h_2	R_1	R_2	E	θ
Values(mm)	310	96	83	39	24	24	14	55°

2.2.2 Model 2&Model 3

The schematic diagram of the W-beam guardrail section (Fig. 2), and model parameters of model 2 and 3 listed in Table 2 and Table 3, respectively, are as follows:

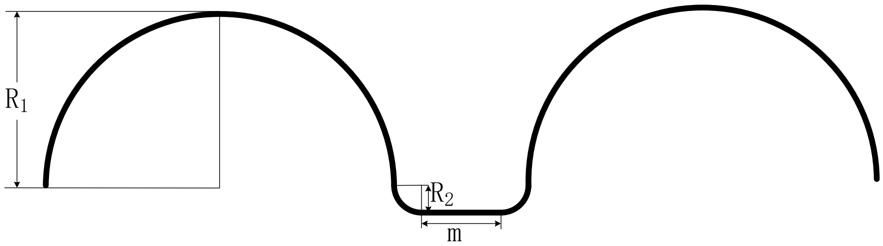

Figure 2 Schematic diagram of geometric topology of Model 2 and Model 3

Table 2 Parameters of the beam adopted in Model 2

Parameters	R_1	R_2	m
Values (mm)	63.124	10	14

Table 3 Parameters of the beam adopted in Model 3

Parameters	R_1	R_2	m
Values (mm)	58.15	20	14

2.3 Structural mesh and mesh quality check

2.3.1 Model 1

As illustrated in Fig. 3, Model 1 consists of 195712 quadrilateral structural elements. Through the mesh quality test, the maximum aspect ratio of all meshes is less than 4.0, and the maximum aspect ratio of most of the meshes is less than 2.0.

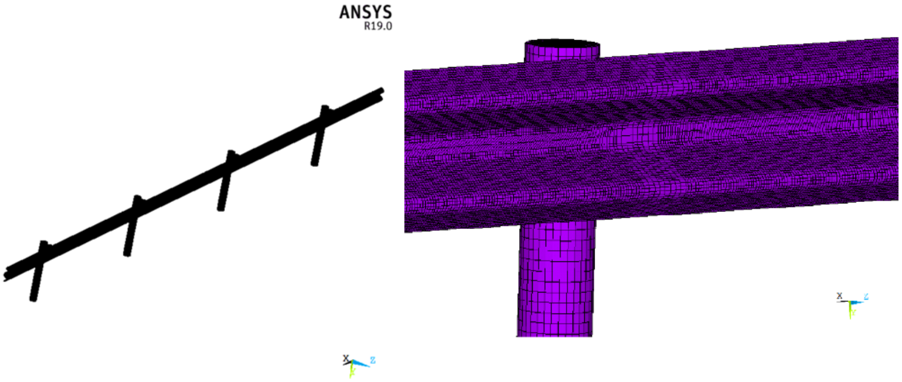

Figure 3 The mesh diagram of Model 1

2.3.2 Model 2

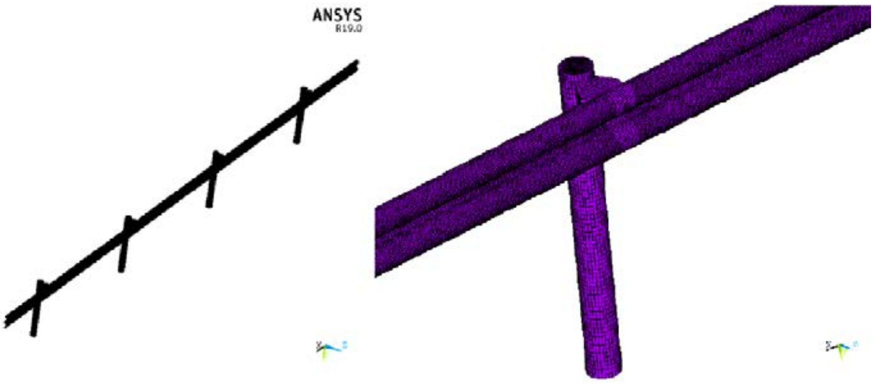

Figure 4 The mesh diagram of Model 2

As illustrated in Fig. 4, Model 2 consists of 141920 quadrilateral structural elements. Through mesh quality test, the maximum aspect ratio of all meshes is less than 4.2, and the maximum aspect ratio of most meshes is less than 2.0.

2.3.3 Model 3

As illustrated in Fig. 5, Model 3 consists of 116352 quadrilateral meshes. Through the mesh quality inspection, the maximum aspect ratio of all the meshes is less than 3.1, and the maximum aspect ratio of most of the grids is less than 1.5.

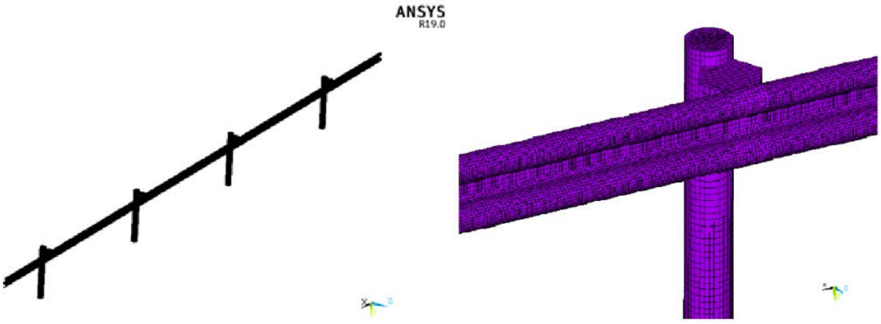

Figure 5 The mesh diagram of Model 3

3. Load Description

Since elastic materials are adopted in this paper, to ensure that the maximum stress of the material is less than its yield strength, and to fully reflect the stress characteristics, a load of 6000N will be applied to the W-beam guardrail along the beam-slab normal direction(-z) during the simulation process. To simulate the situation of a car collision, the applied loading will be evenly distributed to the nodes at the two peaks in the center of the guardrail board of the two middle spans of the beam guardrail.

4. Calculation Result

4.1 Model 1

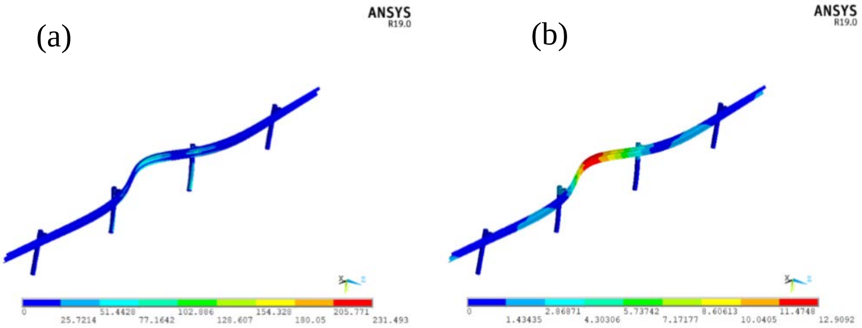

Figure 6 Von Mises node stress diagram (a) and nodal displacement diagram (b) for Model 1

According to the von Mises node stress diagram and nodal displacement diagram for Model 1 shown in Fig. 6, it shows that the maximum stress in this model is 51.4428 MPa. The stress is mainly concentrated in the middle of the two main peaks of the guardrail, and the main peak can maintain its mechanical structure and effectively prevent the accident vehicle. The maximum nodal displacement of the model is 12.9092 cm. The deformation is large, and it may not be able to effectively prevent the vehicle from rushing to the opposite lane and may cause a secondary accident.

4.2 Model 2

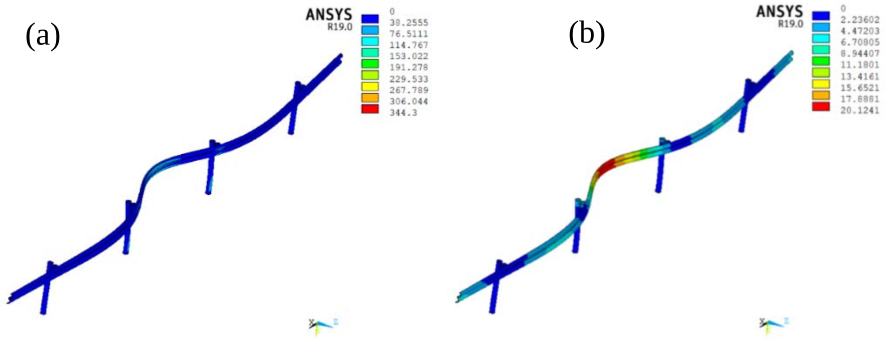

Figure 7 Von Mises node stress diagram (a) and nodal displacement diagram (b) for Model 2

According to the von Mises node stress diagram and nodal displacement diagram for Model 2 shown in Fig. 7, the calculation results show that the maximum stress in this model is 191.278 MPa. The stress is mainly concentrated in the middle of the two main peaks of the guardrail, and the main peak can maintain its mechanical structure and effectively prevent the accident vehicle. The maximum nodal displacement of the model is 20.1241 cm. The deformation is large, and it may not be able to effectively prevent the vehicle from rushing to the opposite lane, and may cause a secondary accident.

4.3 Model 3

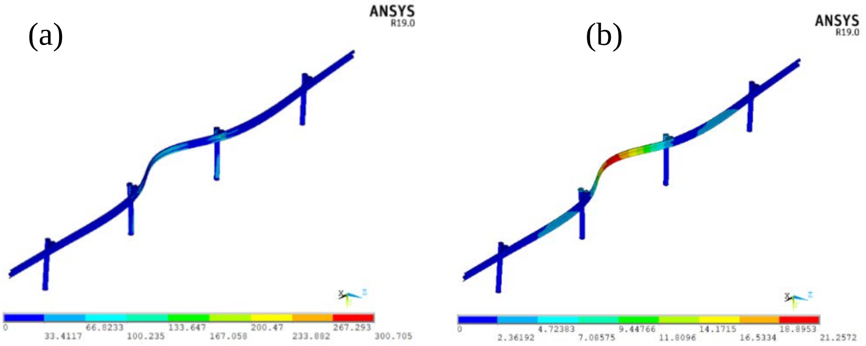

Figure 8 Von Mises node stress diagram (a) and nodal displacement diagram (b) for Model 3

As shown in Fig. 8, the calculation results show that the maximum stress of Model 3 is 133.647 MPa, the overall stress of the W-beam guardrail structure is relatively uniform, and the maximum nodal displacement of Model 3 is 21.2572 cm. Compared with Model 1 and Model 2, its nodal displacement is the largest, which may not prevent the vehicle from rushing out of the road and may cause secondary accidents.

5. Conclusion

In this paper, three kinds of W-beam guardrails are analyzed. In Model 1, the stress on the collision surface is relative uniform and guardrail can absorb energy effectively. Meanwhile, the maximum stress is minimum under the same loading. In Model 2, the high-stress area is smaller, but the deformation of guardrail is a little larger. In Model 3, the distribution of stress is more uniform. Taken together, the static strength performance of Model 2 is the best. Our study can provide a reference for future optimization design of guardrails.

References

[1] S.Peng, J.Zhou, H.Zhong, Z.Chen(2012.09). Analysis on the relationship between the reasonable height of the bridge body and the safe driving speed for the bridge [J]. HIGHWAY, p.127-129.
[2] Y.Zhou(2009). Simulation Experiment Study on Crashed W-beam Guardrail [D]. Chongqing Jiaotong University.
[3] L.Feng, Z.Liu, W.Xiong (1996.11). Study on Analogue of Moter-Fender Fence Collision Process [J]. Journal of Hubei Polytechnic University, p.8-13.
[4] Q.Yao, L.Sun, M.Li, L.Zhou (2002.04). A Study of Movement Response of

Vehicle Impacting on Safety Barrier [J]. Journal of Shenyang Arch. and Civ. Eng. Univ, p.250-253.

[5] H.Yang, S.Zhang, S.Yang (2008.02). Simulation test on collision of vehicles on guardrail of expressway median [J]. Journal of Chang’an University (Natural Science Edition), p.44-48.

[6] X.Yu, J.Mao, L.Liu (2009.03). Numerical Simulation and Analysis of W 3beam Semi-rigid Guardrail when Crashed with the Carriage [J]. Vehicles Technology, p.54-58.

[7] J.Liu, H.Tang (2012). Structure Design of Double-Bar Semirigid Guardrail of Freeway [J]. Journal of Chongqing Jiaotong University (Natural science), vol.31, no.01, p.68-71.

[8] S.YAN (2013). Impact Analysis of Crashworthiness Moveable Barriers [J] Journal of Wuhan University of Technology (Transportation Science& Engineering), vol.37, no.05, p.1046-1050.

[9] Y.Xing (2018). Simulation study on the crashworthiness of W-beam guardrail [D]. Dalian University of Technology.