Impact Performance Study of Easy-open Movable Guardrail for Expressway

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Abstract: Accidents often occur when vehicles collide with the movable guardrail of center median divider, and the traffic safety has become an important issue in the field of traffic. Based on easy-open movable guardrail, a finite element simulation model had been established. Full-scale collision simulation between vehicle with and movable rail was calculated using the LS DYNA software, and the results showed that the subject structure of the movable guardrail had enough strength and design capacity, which were fully meet the relevant inspection standards.

1. Introduction

Since 1920, the researches and applications of guardrails in the United States have been carried out earlier and deeper [1, 2]. There were many large vehicle crash test sites with advanced testing instruments and equipment. The rapid development of highway has brought rapid development to highway transportation in China. At the same time, with the emergence of various traffic accidents, it has caused considerable economic losses to individual and countries at different levels. The central partition belt movable guardrail can ensure the normal operation of the expressway. The movable guardrail at the opening plays a vital role in traffic accident rescue and vehicle guidance. Movable guardrail must have high safety performance. The so-called safety performance of guardrail refers to a comprehensive performance of correctly guiding vehicles and ensuring the safety of passengers in collision vehicles through the overall protection of guardrail when a collision accident occurs. Specifically speaking, in order to prevent passengers from being injured in collision accidents, the guardrail has buffering, collision avoidance, guidance and other aspects. Comprehensive performance. Model experiment, full-scale experiment and computer simulation experiment are mostly used on guardrails performance, which are complement and verify each other. Because of the superiority of computer simulation experiment, the simulation calculation method with computer simulation experiment as the main means has developed rapidly since the last century [3]. The impact process between automobile and guardrail is very complicated [4, 5, 6]. During the collision process, the contact between automobile and guardrail will occur, and the position and area of contact will change with the continuous running of automobile.

2. Methods and Model

When a impact occurs between objects, the velocity in the vertical direction of the contact surface is instantaneous discontinuous, and the response in the contact-collision problem is not smooth, which brings great difficulties to the time integration of the discrete equation. Therefore, the correctness of selection equation and algorithm is directly related to the success of numerical analysis. In Figure 1. , it shows a simplified model circle for object deformation. In Cartesian coordinate system, when any point on object B moves to a point, the deformation of object can be expressed by its coordinates and time t by Lagrange formula. When solving the collision problem between automobile and corrugated beam guardrail, the algorithm is generally based on the following equations:

Kinematic equation
$$x_i = x_i(X_\alpha, t) \qquad i = 1,2,3 \tag{1}$$

Mass conservation equation
$$\rho(X,t)J(X,t) = \rho_0(X) \tag{2}$$

Momentum conservation equation
$$\frac{\partial \rho_{ij}}{\partial x_j} + \rho b_i = \rho a_i \tag{3}$$

Energy conservation equation
$$\rho \dot{w}^{int} = D_{ji}\sigma_{ij} \tag{4}$$

Deformation rate equation
$$D_{ij} = \frac{1}{2}\left(\frac{\partial v_i}{\partial x_i} + \frac{\partial v_j}{\partial x_j}\right) \tag{5}$$

Constitutive equation
$$\hat{\sigma} = \hat{\sigma}(D_{ij}, \sigma_{ij}, \ldots) \tag{6}$$

Where, $\rho(X,t)$ is current mass density; $J(X,t)$ is Jacobin determinant; $\rho_0(X)$ is initial mass density; $\frac{\partial \rho_{ij}}{\partial x_j}$ is Cauchy stress; b_i is unit mass volume force; a_i is acceleration; w^{int} is internal energy per unit mass; D_{ij} is deformation rate tensor; $\frac{\partial v_i}{\partial x_i}, \frac{\partial v_j}{\partial x_j}$ is velocity gradient tensor; $\hat{\sigma}$ is stress rate.

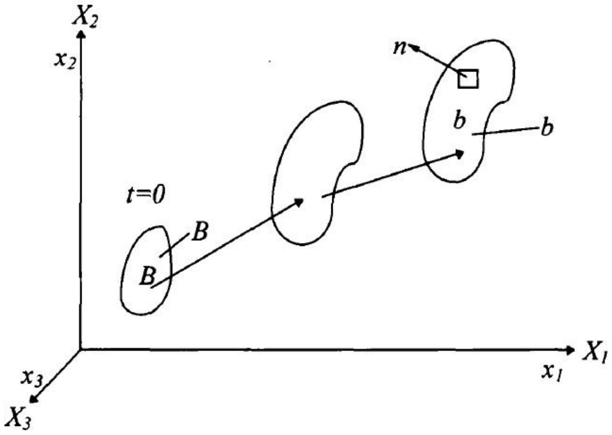

Figure 1: Simplified model of object deformation in Cartesian coordinate system.

The momentum conservation equation in the previous section is required to be satisfied everywhere in the solution domain. It is almost impossible to solve the equation directly. Starting from the weak form of differential equation, only the momentum equation is required to satisfy in the sense of its inner product, and then the virtual displacement equation is deduced. Taking the velocity as the weighted coefficient and using the weighted residual method, the weak form of momentum equation can be written:

$$\int_V \delta v_j \left(\frac{\partial \sigma_{ij}}{\partial x_j} + \rho b_i - \rho a_i\right) dV = 0 \tag{6}$$

Where,$\delta v_j \in R_0$, $R_0 = \{\delta v_j | \delta v_j \in C^0, \delta v_j | A_V = 0\}$ is virtual velocity.

It is consistent with the finite element method of elasticity to solve the virtual displacement equation. The numerical solution of this equation is to discretize the space between the car and the guardrail structure. As follows:

$$\mathrm{x_i(X,t) = N_I x_{iI}(t)} \tag{7}$$

Where, $\mathrm{N_I}$ is shape function of node I. The displacement of any point in the element can be obtained as follows:

$$\mathrm{u_i(X,t) = x_i(X,t) - X_i = N_I(X) u_{iI}(t)} \tag{8}$$

Similarly, the velocity, acceleration, deformation rate and virtual velocity at any point in the element can be expressed as:

$$\dot{u}_i(X,t) = N_I(X)\dot{u}_{iI}(t) \tag{9}$$

$$\ddot{u}_i(X,t) = N_I(X)\ddot{u}_{iI}(t) \tag{10}$$

$$D_{ij} = \frac{1}{2}\left(\frac{\partial \dot{u}_i}{\partial x_j} + \frac{\partial \dot{u}_j}{\partial x_j}\right) = \frac{1}{2}\left(\dot{u}_{iI}\frac{\partial N_I}{\partial x_j} + \dot{u}_{jI}\frac{\partial N_I}{\partial x_i}\right) = B_I u_I \tag{11}$$

$$\delta v_j(x) = N_I(X)\delta v_{iI} \tag{12}$$

Establishing an accurate and reliable finite element calculation model for vehicles is a very important work, which directly affects the correctness of the calculation results. In this paper, the prototype is small car, medium bus and medium truck. The vehicle weight is 1.5 tons, 10 tons and 10 tons respectively. The vehicle model is established according to the actual size of the vehicle. Because the body structure is mainly thin-walled metal parts, the main element type is quadrilateral single-point integral shell element which is good at deformation. In order to obtain good elements, the warpage of quadrilateral elements is less than 15, the aspect ratio is less than 4, the maximum angle is less than 135 degrees, the minimum angle is more than 45 degrees, the number of triangular elements is less than 5%, and the minimum characteristic length is about 5 mm. Each part of the body is mainly connected by spot welding, and the door and the body are connected by the hinge joint unit. The material properties of the vehicle are obtained through experiments, and the Cowper-Symons model is used to consider the strain rate effect of the material. The tire pressure is measured by test. The tire pressure of small wheel is 0.3Mpa and that of large car is 0.8Mpa. Automatic single surface contact type based on penalty function method is used to solve boundary nonlinearity problem. According to the contact between the vehicle and the guardrail, different element feature lengths are used to divide the grids in different parts of the vehicle, which improves the calculation efficiency on the premise of ensuring the accuracy. The collision model of small car, medium bus, medium truck and movable guardrail is shown in Figure 2.

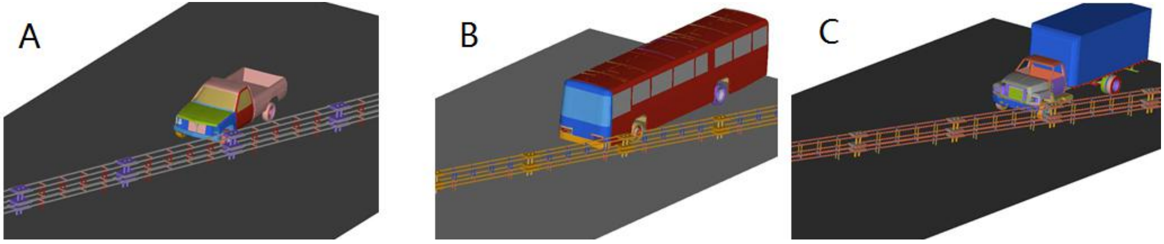

Figure 2: Three numerical impact models of elastomeric vehicle: (A) small car impact model; (B) medium bus impact model; (C) Medium truck impact model.

In the simulation, the pavement is treated with full rigidity, and the deformation is neglected. The main parameters of vehicle-barrier collision are shown in Table 1, which gives the mass, impact speed and angle of each impact vehicle.

Steel is the main structural material of guardrail. The simulation accuracy of guardrail is verified by research.

Vehicle crash barrier is a physical process of dynamic impact, and impact hardening of materials should be considered. Figure 2 is the stress-strain curve obtained from static tensile test of Q345 steel, which is used as the material simulation parameter without considering strain rate.

Table 1: Main parameters of vehicle-guardrail.

	W (kg)	V(km/h)	A(°)
small car	1500	100	20
medium bus	10000	60	20
medium truck	10000	60	20

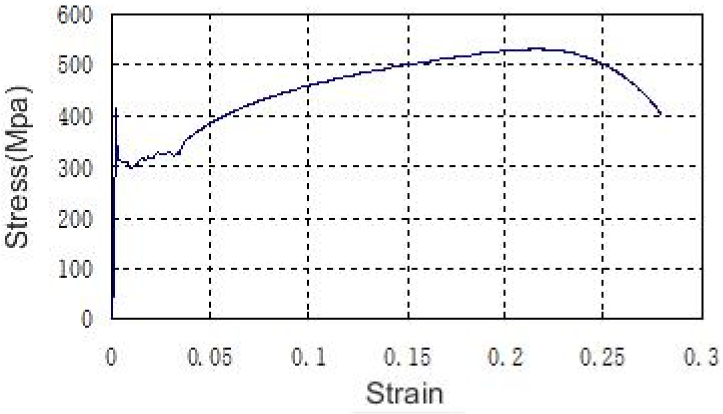

Figure 3: Strain curve of Q345 steel.

3. Results and Analysis

As shown in Figure 3, the impact numerical simulation were carried out among small car, medium bus medium truck and movable guardrail. After the impact, no phenomenon of passing, overturning or riding the movable guardrail occurs for a small car, a medium bus or a medium truck. The phenomenon of turning around and so on, still maintains the normal driving posture.

The trajectories of small car, medium bus and medium truck are shown in Fig. 3, respectively. Through the trajectory diagram of vehicles, it is found that the guardrail plays a role of interception and guidance for vehicles. The direction of the car body is basically parallel to the guardrail. After the collision, the vehicle does not rush out of the guardrail and enter the adjacent lane. The maximum displacement of the three types of guardrail is 1480 mm, 1890 mm and 1587 mm respectively, which indicates that the guardrail can effectively prevent the vehicle from entering the opposite lane. The deformation mainly occurs during the initial period of the collision when the car body climbs the guardrail, and there is no obvious deformation at the junction of the guardrail. Besides, the displacement and deformation of guardrails at both ends are basically zero except for those in contact with the car body. The acceleration at the center of the vehicle body is far less than 20g in the whole collision process, which can effectively protect the passengers on the vehicle.

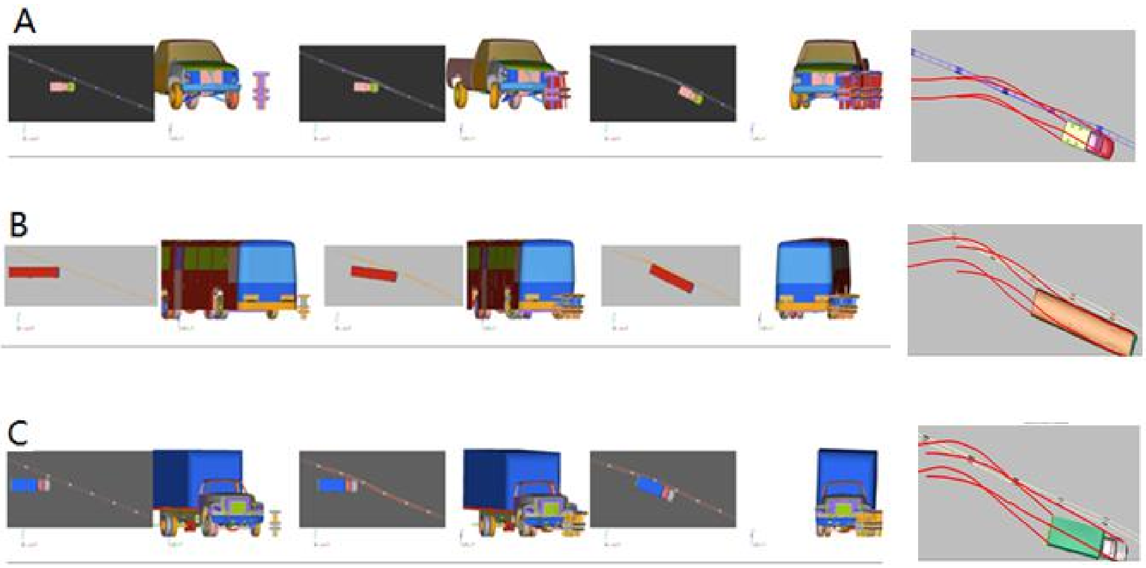

Figure 3: Impact process and trajectory of small car, medium bus and medium truck.

4. Conclusions

Aiming at the newly developed movable barrier, a reasonable numerical simulation collision model is established strictly according to the relevant dimensions and national standards. The deformation of the contact area between the barrier and the vehicle and the trajectory of the collision vehicle are analyzed emphatically. The results show that all performance indexes of the new movable barrier can meet the requirements of the evaluation criteria and can effectively prevent the collision vehicle from crossing. The design rationality of the new type movable guardrail is verified by its good guiding performance, which provides a theoretical basis for the further development of high performance movable guardrail.

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