Numerical simulations and full-scale impact testing to develop appropriate crash barriers

Z. Ying, B. Shufeng, T. Wenjie & Z. Shaoli
Beijing Shenhuada Traffic Engineering Technological Co., Ltd,
P. R. China

Abstract

Impacts with barriers represent a significant subset of vehicular collisions. The accidents, in which vehicles crush the median barriers and impact with subtend vehicles, are rising steadily in China. This paper is the first step, using computer simulation, to study the hardware of steel beam barriers to improve the intension of barriers and limit the injury to the occupants of vehicles during a lateral impact. Then, assembling hardware and reusing computer simulation, a series of initial new crash barriers have been developed. Finally, these new crash barriers have been validated by full-scale impact testing. Some of these new crash barriers have now been applied in expressways in China. It is demonstrated that, in the study process, the models of computer simulation have been corrected by the results of full-scale impact testing, and, using the corrected model, the appropriate median barriers have been developed. So this approach not only reduces the cost and time, but also enhances the precision of computer simulation.

Keywords: traffic engineering, barriers, finite element, computer simulation, full-scale impact testing.

1 Introduction

In China, expressways are developing rapidly now. The first expressways were built in 1989, and now there is more than 25,200 kilometres of expressways [1]. At the same time, the problem of traffic safety has been paid more attention by citizens. Figure 1 shows that the number of accidents, deaths, and injuries has increased sharply. More than 100,000 people are being killed annually in motor vehicle crashes [2]. Of this total most are the result of single vehicle, run-off-the-road crashes [3]. Therefore, improvements in roadside safety design have contributed significantly to the death rate decreases.
For reason of economy, the crashworthy level of median barriers is low in China now. The accidents, in which vehicles override the median barriers and impact with subtend vehicles, are rising steadily in China (figure2). So it is important to research and develop the cost effective crashworthy median barriers [4].

This paper introduces the research and development of appropriate steel beam median barriers. In the process of research, not only have the barriers been checked by full-scale testing, but also a nonlinear, dynamic, three-dimensional finite-element code PAM-CRASH is used in the calculation. Moreover, the security of new crash barriers has been validated in practice.

2 Numerical simulation

2.1 FEM models

Figure 3 shows the FEM model of a bus used in this research. The weight of the bus is 10 ton. The impact speed is 60km/h. And the impact angle is 20º. Figure 4 shows the FEM model of a saloon car used in this research. The weight of car is 1.5 ton. The impact speed is 100km/h. And the impact angle is 20º.
In the numerical simulation, the CPU time and the correct parameter are crucial. Firstly, both the calculation time and precision of result have been considered in dimension of element. The adaptive mesh has been used in the FEM model of the barrier. Then, the friction coefficient in contacting vehicle with the barrier has been corrected by the result of full-scale impact testing. Finally, the results of numerical simulation are compared with those of full-scale impact testing.

2.2 Research and development new appropriate crash barriers

2.2.1 Post analysis
The post plays a support role in the barriers. The H-post has a cross section shaped like an "H" as shown in Figure 5. The idea behind this geometry is to provide a non-isotropic section with large inertia around the axis parallel to the rail and small inertia around the perpendicular axis. In Figure 6, when the front of the bus first touches the barrier, the load acts in large inertia and the barrier holds up the bus. Then, the bus direction of movement is changed and the load acts in small inertia. At this time, the barrier redirects the bus and the H-post collapses. Based on the simulation analysis, the H-post barrier is capable of both holding up and redirecting the bus. So the H-post is selected in the new appropriate crash barrier.
2.2.2 Bumper analysis
The bumper can reduce the force of impact and change the deformation of a beam in the process of a crash. Occupant risk can be decreased when the force of impact is reduced and the movement track of vehicle can be improved by the appropriate deformation of the beam. Figure 7 shows that the saloon car model was used to design the bumper. The wedge-shape bumper has been chosen in research (Figure 8).

The result of numerical simulation, the occupant ridedown acceleration is 16.8g in longitudinal direction and 4.2g in lateral direction. These values are less than 20g/10ms which is the evolution criteria [5]. The barrier redirects the saloon car reasonably (Figure 9). The wedge-shape bumper satisfies the safety evolution criteria.

![Figure 7: Numerical model.](image1)

![Figure 8: Wedge-shape bumper.](image2)

![Figure 9: The result of Numerical simulation.](image3)

2.2.3 Beam design and new crash barriers design
To prevent bus from overriding, the height of barrier must be increased. So corrugated steel three beam was designed in new crash barriers. The 4 mm thick of three beam is used popularly around the world, but the cost of barrier will be increased remarkably. Generally, the width of median is more than 2 m. According to the width of median, the evaluation criteria of lateral deflection of barrier can be adjusted. Therefore, 3 mm thick of three beam is designed in new crash barriers.

From figure 10, it can be seen that the new crash barriers are assembled by H-shape post, wedge-shape bumper and 3mm thick corrugated steel three beam. The bus cannot override the barrier as shown in figure 11.
3 Full-scale impact testing and comparative analysis

3.1 Test vehicle

The test vehicles are corresponding to the numerical simulation model. The weight of bus is 10 ton, the impact speed is 60km/h, and the impact angle is 20º and the weight of saloon car is 1.5 ton, the impact speed is 100km/h, and the impact angle is 20º.

3.2 Full-scale impact testing for bus

Figure 12 shows the comparison of the bus deformation of the barrier from full-scale testing and the numerical simulation. The results of the deformation of the barrier are very close. When the front of the bus first touches the barrier, the H-posts support the barrier and the barrier hold up the bus, and then the bus changes direction and moves along the barrier. At this time, the H-posts separate from the beam and collapse. In the proceeding moments of impact, the beam deformed and sunk into the notch of the wedge-shape bumper. At the same time, three beams keep upright. These practices improve crashworthiness of the barrier.

Figure 13 shows the comparison of bus movement track from full-scale testing and the numerical simulation. The front of bus first impacts the barrier and the bus redirects. Then the bus moves along the barrier. Finally, the bus shifts the movement direction and leaves the barrier. The results of numerical simulation are similar to the result of full-scale testing.

However, the numerical simulation model is an ideal model. The fix bounding has no displacement absolutely and the three-beam slice has no connection. In fact, there is no ideal barrier in engineering. Hence, there are differences between numerical simulation and full-scale impact testing. Table 1 shows the maximal displacement in lateral direction. The maximal displacement of barrier in numerical simulation is less than that of full-scale impact testing.

<table>
<thead>
<tr>
<th>Item</th>
<th>Numerical simulation</th>
<th>Full-scale testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>The displacement</td>
<td>90cm</td>
<td>136cm</td>
</tr>
</tbody>
</table>
Figure 12: The deformation of the barrier.

Figure 13: The bus behaviour.
3.3 Full-scale impact testing for saloon car

To ensure that new crash barriers produce an overall balanced resistance to the whole population of vehicles, a saloon car has been chosen to check occupant risk and movement track.

Figure 14 shows the saloon car movement track of it during the collusion process. The barrier holds up the saloon car and makes it come back to the road way. The occupant ridedown maximal acceleration is 17.5g which less than 20g/10ms. The full-scale testing of saloon car satisfies the safety evolution criteria.

![Figure 14: The saloon car movement track.](image)

4 The practice

The new crash barrier has been applied on the expressway in China (Figure 15). On 3rd Oct 2003, there is an error saloon car crash into the new median barrier, but no one is hurt in this accident. Moreover, the deformation of the barrier in the accident is very close to that of the full-scale impact testing (Figure 16). These validate the security of new median barrier further.

![Figure 15: The view of new median barrier.](image)
5 Conclusion

In this research, the numerical simulation and full-scale impact testing have been used in research and development of the new crash barriers and the following conclusions can be drawn:

1) By numerical simulation, the approach, which hardware of barrier is first studied, and then which hardware is assembled to become the barrier, is effective.
2) In the specified impact condition, the new crash barrier with H-shape post, wedge-shape bumper and 3mm thick corrugated steel three-beam is safe.
3) The method of numerical simulation should be improved by comparing with the result of full-scale impact testing.

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References


