Sensitivity Analysis of Barriers Test Parameters Based on Deformation Index

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Abstract. 7(HB) grade combined bridge barriers was taken as the analysis object, and the simulation collision analysis model was established. After full-scale impact test with real vehicle and energy balance analysis method were used to verify the effectiveness of the model, the sensitivity level of the maximum dynamic lateral deflection of highway barriers to the collision test parameters was quantitatively analyzed by single factor sensitivity analysis technique. The results show that the finite element simulation is consistent with the full-scale impact test with real vehicle results, and the energy curve is reasonable, which verifies the reliability of the computer simulation. The sensitivity coefficients of the maximum dynamic lateral deflection index of highway barriers to vehicle mass, impact velocity and impact angle are 0.625, 1.64 and 1.635, respectively. Impact velocity and impact angle are relatively sensitive factors affecting the maximum dynamic lateral deflection of highway barriers. The research results can provide reference for the fault tolerance of test parameters in formulating standard for safety performance evaluation of highway barriers.

Keywords: Traffic facilities; Safety evaluation; Collision test; Sensitivity analysis; Computer simulation; Finite element method; error.

1. Introduction

Setting barriers with safety protection performance meeting the requirements on the road can effectively reduce accident mortality [1]. The protective function of barriers is evaluated through the full-scale impact test with real vehicle, in which the maximum dynamic lateral deflection of highway barriers is the concrete embodiment of the protective performance of barriers structure [2]. Parameters of full-scale impact test with real vehicle include test vehicle mass, impact velocity and impact angle [2-4]. In the process of organizing and implementing impact tests, error of test parameters is inevitable. Therefore, it is necessary to analyze the sensitivity of maximum dynamic lateral deflection of highway barriers to test parameters, so as to provide a basis for developing reasonable fault tolerance test parameters.

After establishing the computer simulation model, organizing and implementing the full-scale impact test with real vehicle to verify the reliability of the simulation collision model, the sensitivity level of the maximum dynamic lateral deflection index of highway barriers to the test parameters was analyzed.

2. Single Factor Sensitivity Analysis

From the perspective of quantitative analysis, sensitivity analysis is an uncertain analysis method for the influence level of a single or a group of important indicators after a change of relevant factors. Its essence is to use the method of changing the relevant variables one by one to illustrate the law of the degree of a certain key indicator influenced by the changes of these factors.

Single factor sensitivity analysis method is used to analyze the sensitivity of the maximum dynamic lateral deflection index of highway barriers to test parameters [3-4]. The sensitivity coefficient is the ratio of the change percentage of the maximum dynamic lateral deflection index of highway barriers to the change percentage of test parameters. The high sensitivity coefficient
indicates that the maximum dynamic lateral deflection index of highway barriers has a high sensitivity level to the test parameters, and its calculation formula is as follows:

\[ E = \frac{\Delta A / A}{\Delta I / I} \]  

(1)

Where: E is the sensitivity coefficient of the maximum dynamic lateral deflection index of highway barriers A to test parameter I; \( \Delta I / I \) is the change rate of test parameter I; \( \Delta A / A \) is the corresponding change rate of the maximum dynamic deformation index A of the highway barriers when the change \( \Delta I \) of test parameter I is generated. E>0, indicates that the maximum dynamic deformation index of barriers changes in the same direction as the test parameter; E<0, represents the change of maximum dynamic deformation index and test parameter in the opposite direction; If E absolute value is larger, it indicates that the maximum dynamic deformation index of barriers is sensitive to this test parameter.

Single factor sensitivity analysis by calculating the sensitivity coefficient to find the sensitive factor, to provide data support for reasonable determination of the allowable error range of test parameters.

3. Test Parameters And Dynamic Deformation Index

3.1 Test Parameters

Fig.1 shows the impact test conditions. In the full-scale impact test with real vehicle, effectively controlling the accuracy of several major impact test conditions, such as vehicle mass, impact velocity and impact angle, is an important work of test organization, but also an important symbol to judge whether the test organization is successful. Therefore, vehicle mass, impact velocity and impact angle are used as the test parameters affecting the maximum dynamic lateral deflection index of highway barriers.

![Fig. 1 Schematic diagram of collision conditions](image)

3.2 Dynamic Deformation Index

The maximum dynamic lateral deflection of highway barriers is an important index of safety protection performance of barriers [5-6]. When the maximum dynamic lateral deflection of highway barriers is too large, compared with the roadside barriers, the vehicle may cross the edge line of the roadbed and drive out or collide with the roadside obstacles. In the case of the barriers of the central separation belt, vehicles may endanger the safety of the sign gantry column in the central separation belt, piers and other structures.

The maximum dynamic lateral deflection of highway barriers is taken as an important index and the influence of the change of impact test parameters on the index is studied.
4. Test and Model

4.1 Test Barriers

The design anti-collision grade of a bridge barriers is HB 640kJ. The lower part is made of concrete wall and the upper part is made of metal beam and column combined structure. The total height of barriers is 1.4m, of which the upper double rectangular tube beam metal beam column structure is 0.55m high, the lower concrete wall is 0.85m high. The upper double-beam metal beam-column structure consists of a diagonal H-shaped column with 2m spacing wing plates and 10mm thick web plates, and two rectangular steel beams with a section of 160mm long ×120mm wide ×10mm thick are arranged side by side and 10mm thick bracket. The longitudinal direction of beam adopts the way of casing joint. The lower concrete wall adopts "F" type slope, the vertical reinforcement of the wall adopts φ18mm II grade reinforcement with 150mm spacing, the longitudinal reinforcement adopts φ12mm II grade reinforcement as structural reinforcement, and the connecting reinforcement of the wall and flange plate is φ20mm II grade reinforcement with 150mm spacing. The upper metal beam-column structure and the lower concrete wall structure are connected by foundation bolts, and foundation bolts are arranged in the front 5 and the back 4.

Fig. 2 shows the combined bridge barriers used in the test.

Fig. 2 A combined bridge barriers

4.2 Test Vehicle

There are two kinds of vehicles used for vehicle collision barriers test: small vehicles and large vehicles. Large vehicles have larger impact force on barriers due to the total mass of the collision, and the dynamic lateral deflection of highway barriers is larger in the impact. Therefore, the maximum dynamic lateral deflection of highway barriers is mainly measured by the collision of large vehicles.

The maximum dynamic lateral deflection index of the combined bridge barriers was measured by the collision analysis between the barriers and the 33-ton 4-axle heavy truck with the speed of 65 km/h at 20° angle.

Fig.3 shows the test vehicle.
4.3 Simulation Model

In previous studies, simulation models of barriers and vehicle collision system were established according to test parameters, and the simulation results were compared with the test results to verify the reliability of the "vehicle-barriers" model from the perspective of the plastic deformation of barriers structure [7-10].

Fig. 4 shows the established finite element simulation model of vehicle and barriers.

![Simulation model](image)

(a) Barriers simulation model  (b) Vehicle simulation model
(c) Barriers test deformation  (d) Barriers simulation deformation

Fig. 4 Model and results

Fig. 5 is the energy change curve of the system extracted from the simulation calculation results. In the process of collision, the kinetic energy of the system gradually decreases, and the deformation energy and friction energy gradually increase. In the process of collision, due to the tilt and climb of the car, the gravity does work, and the total energy fluctuates slightly, which conforms to the law of conservation of energy. The pseudo deformation energy based on the single point Gaussian integration is less than 10% of the total energy, which makes the simulation results meet the accuracy requirements.
Fig. 5 Energy change curve

Through the analysis of the collision results, the simulation energy time curve is reasonable, the structural deformation and occupant acceleration simulation results are consistent with the test results, which verifies the reliability of the "vehicle-barriers" model, and lays a foundation for the application of simulation method to analyze the sensitivity parameters of the maximum dynamic lateral deflection index of highway barriers.

5. Sensitivity Analysis

5.1 Sensitivity Analysis Parameters

Based on the test parameter of 40 tons integral truck with impact velocity of 60 km/h and impact angle of 20° setting model, the sensitivity level of the maximum dynamic lateral deflection index of highway barriers to these parameters was investigated by changing the test parameters such as vehicle mass, impact velocity and impact angle.

The adjustment range of test parameters is set as 10% of the standard value. Table 1 shows the test parameters used for sensitivity analysis.

<table>
<thead>
<tr>
<th>Test parameter</th>
<th>Vehicle mass(ton)</th>
<th>Impact angel (°)</th>
<th>Impact velocity(Km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard value</td>
<td>40</td>
<td>20</td>
<td>60</td>
</tr>
<tr>
<td>The standard value is increase by 10%</td>
<td>44</td>
<td>22</td>
<td>66</td>
</tr>
<tr>
<td>The standard value is reduced by 10%</td>
<td>36</td>
<td>18</td>
<td>54</td>
</tr>
</tbody>
</table>

5.2 Sensitivity Analysis

For barriers that the vehicle can steer out smoothly, its dynamic deformation displacement time history curve often has two peaks. The first peak generally appears when the front of the vehicle collides with barriers, and the second peak appears when the rear of the vehicle collides with barriers collision surface. Sensitivity analysis is performed only for the large dynamic deformation in the two peaks.

Fig.6 shows the displacement time history curve of the maximum dynamic lateral deflection point of highway barriers when vehicles with different mass hit barriers. As can be seen from the figure, when the vehicle mass is 36 tons, 40 tons and 44 tons respectively, the maximum dynamic lateral deflection of highway barriers is 287.7mm, 311.8mm and 328.0mm, indicating that the greater the vehicle mass, the greater the maximum dynamic lateral deflection of highway barriers during the impact process, and vice versa.
Fig. 6 Displacement time history curve of the maximum dynamic lateral deflection point of highway barriers under different vehicle masses

Table 2 shows the sensitivity analysis of the maximum dynamic lateral deflection of highway barriers under different vehicle masses. When the vehicle mass increases by 10%, the maximum dynamic lateral deflection of highway barriers increases by 5.20%, and the sensitivity coefficient is 0.520. When the vehicle mass decreased by 10%, the maximum dynamic lateral deflection of highway barriers decreased by 7.29%, and the sensitivity coefficient was 0.729. The average value of sensitivity coefficient of the maximum dynamic lateral deflection of highway barriers to vehicle mass is 0.625.

Table 2. Sensitivity analysis of maximum dynamic lateral deflection of highway barriers under different masses

<table>
<thead>
<tr>
<th>Test parameter (I)</th>
<th>Evaluation index (A)</th>
<th>Sensitivity coefficient (E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (ton)</td>
<td>Rate of change(%)</td>
<td>Maximum dynamic lateral</td>
</tr>
<tr>
<td></td>
<td></td>
<td>deflection value(mm)</td>
</tr>
<tr>
<td>40</td>
<td>-----</td>
<td>311.8</td>
</tr>
<tr>
<td>44</td>
<td>10</td>
<td>328.0</td>
</tr>
<tr>
<td>36</td>
<td>-10</td>
<td>287.7</td>
</tr>
</tbody>
</table>

Fig. 7 shows the displacement time history curve of the maximum dynamic lateral deformation point of highway barriers when vehicles with different impact velocity collide with barriers. As can be seen from the figure, the impact velocity of vehicles are 54 km/h, 60 km/h and 66 km/h respectively, and the maximum dynamic lateral deflection of highway barriers are 236.0mm, 311.8mm and 332.4mm respectively, indicating that the greater the vehicle impact velocity, the greater the maximum dynamic lateral deflection of highway barriers during the collision process, and vice versa.

Fig. 7 Displacement time history curve of the maximum dynamic lateral deformation point of highway barriers under different impact velocity
Table 3 is the sensitivity analysis table of the maximum dynamic deformation of highway barriers at different impact velocity. The velocity increases by 10%, the maximum dynamic deformation of highway barriers increases by 8.5%, and the sensitivity coefficient is 0.85. The impact velocity decreases by 10%, the maximum dynamic deformation of highway barriers decreases by 24.3%, and the sensitivity coefficient is 2.43. The average value of sensitivity coefficient of the maximum dynamic lateral deflection of highway barriers to impact velocity is 1.64.

Table 3. Sensitivity analysis of the maximum dynamic lateral deformation of highway barriers at different velocity

<table>
<thead>
<tr>
<th>Test parameter(I)</th>
<th>Evaluation index(A)</th>
<th>Sensitivity coefficient(E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity (km/h)</td>
<td>Rate of change(%)</td>
<td>Rate of change(mm)</td>
</tr>
<tr>
<td>60</td>
<td>-----</td>
<td>311.8</td>
</tr>
<tr>
<td>66</td>
<td>10</td>
<td>338.4</td>
</tr>
<tr>
<td>54</td>
<td>-10</td>
<td>236.0</td>
</tr>
</tbody>
</table>

Fig. 8 shows the displacement time history curve of the maximum dynamic lateral deformation point of highway barriers when vehicles with different impact angles collide with barriers. As shown in the figure, when the impact angles are respectively $18^\circ$, $20^\circ$ and $22^\circ$, the maximum dynamic lateral deflection of highway barriers are 265.5mm, 244.3mm and 223.6mm, indicating that the larger the impact angle, the larger the maximum dynamic lateral deflection of highway barriers during the impact process, and vice versa.

Table 4 shows sensitivity analysis of the maximum dynamic lateral deflection of highway barriers at different impact angles. It can be seen that the impact angle increases by 10%, the maximum dynamic lateral deflection of highway barriers increases by 11.2%, and the sensitivity coefficient is 1.12. When the impact angle decreases by 10%, the maximum dynamic lateral deflection of highway barriers decreases by -21.5%, and the sensitivity coefficient is 2.15. The average sensitivity coefficient of the maximum dynamic lateral deflection of highway barriers to the impact angle is 1.635.
Table 4. Sensitivity analysis of the maximum dynamic lateral deflection of highway barriers at different angles

<table>
<thead>
<tr>
<th>Angle (°)</th>
<th>Rate of change(%)</th>
<th>Maximum dynamic lateral deformation value(mm)</th>
<th>Rate of change(%)</th>
<th>Rate of change of A/rate of change of I</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>-----</td>
<td>311.8</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>22</td>
<td>10</td>
<td>346.7</td>
<td>11.2</td>
<td>0.867</td>
</tr>
<tr>
<td>18</td>
<td>-10</td>
<td>244.8</td>
<td>-21.5</td>
<td>0.847</td>
</tr>
</tbody>
</table>

6. Conclusion

The sensitivity level of the maximum dynamic lateral deflection of highway barriers to vehicle mass, impact angle and impact velocity was analyzed by computer simulation. The calculation results show that the errors of vehicle mass, impact angle and impact velocity all have a great influence on the maximum dynamic lateral deflection of highway barriers. According to the sensitivity level, the influencing factors are ranked as impact velocity, impact angle and vehicle mass. The research results have a certain guiding significance for formulating the permissible error range of full-scale impact test with real vehicle.

References