Experimental Research on Concrete Guardrail with Anchorage Rebar for Low Degree Highway

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Keywords: Low degree highway, Roadside, Anchorage rebar foundation, Concrete guardrail, Finite element simulation, Full-scale Impact Test.

Abstract. Until the end of 2017, there are 4151.3 thousands kilometers highway below degree three in our country, which accounting for 86.97% of the country's total mileage. Because of the lack of funds for construction and maintenance, the safety protection facilities on low degree highway are seriously insufficient, which affects the safety level badly.

For the purpose of reducing costs, satisfying the roadside safety requirements for low degree highway, the methods of finite element simulation analysis and real vehicle impact tests are used to develop a kind of anchor bar type concrete guardrail. By setting anchor bar in highway shoulder, the foundation of guardrail is tied tightly with shoulder, which makes them bearing external force jointly, accordingly, the protection ability and foundation stability of concrete guardrail is enhanced.

According to the full-scale impact test results, the anchor bar type concrete guardrail can reach C level (40kJ), the whole guardrail structure did not damage impacted by vehicles, which helps to decrease the maintenance workload after crash. The guardrail can reduce the accident rate and severity on low degree highway.

Introduction

As an important supplement of freeway and the national trunk road network, low-degree highway (degree of three and below) is the basic road network connecting the towns and villages and realizing the function of highway traffic service. According to the national highway statistics in 2017, there are 4151.3 thousands kilometers highway below degree three in our country, which accounting for 86.97% of the country's total highway mileage. Due to the restriction of natural conditions and other factors, there are general characteristics of sharp curve, steep slope, closing cliff or river, poor range of visibility on low degree highway [1].

Affected by the lack of funds for construction and maintenance, the safety protection facilities of low degree highway are seriously insufficient, thus influencing the traffic safety level badly. According to statistics, from 2011 to 2015, in the count of serious traffic accidents of highway which caused accidental death of more than 10 persons in one accident, 43.33% of the accidents occurred in the highway below degree three, the death toll accounted for 40.63% of the total deaths, the accident characteristics are mostly vehicles' falling from cliff or falling into river. With the rapid development of the economy in the township and rural areas, the traffic volume of low-degree highway has increased rapidly year by year, and the traffic safety problem has become increasingly prominent. Therefore, it is very necessary and urgent to improve the safety protection facilities and upgrade the traffic safety level of low-degree highway.

In the industry standard “Standard for Safety Performance Evaluation of Highway Barriers (JTG B05-01—2013)” that promulgated in 2013, the C-level protection (kinetic energy 40kJ) has been added to setting for the protection requirements of low-degree highway, however, there is almost no safety facility structure to match the C-level protection.

Based on the National Key Technology Support Program” Research and integrated demonstration of key technologies for safety prevention and control of low degree highway “, the methods of finite element simulation analysis and real vehicle crash tests are used to develop a kind of concrete...
guardrail with C-level protection, which can realize the purpose of reducing construction costs and satisfying the protection requirements of low-degree highway.

**Guardrail Structure Design**

**Foundation and Structure Design of Guardrail**

According to the “Technical Standard of Highway Engineering (JTG B01—2014)”, the shoulder width requirements of degree four and degree three highway are shown in Table 1 [2].

| Highway Degree | Degree three, Degree four |
|----------------|--------------------------|
| Design velocity [km/h] | 40 | 30 | 20 |
| Shoulder width [m] | 0.75 | 0.50 | 0.25 (Double lanes) | 0.50 (Single lane) |

Limited by the terrain conditions, the phenomenon of narrow pavement and insufficient shoulder width is common in low-degree highway. According to the field investigation, the shoulder width of degree three or degree four highway is about in range of 40~50 cm. Some sections are dangerous in roadside, but there are not sufficient shoulder width applied to set protection facilities in accordance with the specifications, thus exist a big security risk.

In order to meet the setting requirements of the protection facilities on narrow shoulder sections of low-degree highway, the structure of the guardrail is designed with concrete construction and anchor rebar foundation. The protection level of anchor bar type concrete guardrail is designed for C-level, vehicle impact test conditions are shown in Table 2 [3].

| Vehicle Type | Vehicle Mass [t] | Impact Speed [km/h] | Impact Angle [°] | Kinetic Energy [kJ] |
|--------------|-----------------|---------------------|-----------------|-------------------|
| Car          | 1.5             | 50                  | 20              | -                 |
| Bus          | 6               | 40                  | 20              | 40                |
| Truck        | 6               | 40                  | 20              | 40                |

The anchor bar type concrete guardrail consists of reinforced concrete wall, guardrail foundation and anchorage steel bar. The width of the bottom of the guardrail is 30 cm and the top width is 17.2 cm, which satisfies the setting conditions of narrow shoulder section. The depth of guardrail below ground is 5 cm, the height of guardrail up ground is 81 cm.

For the retaining wall shoulder condition, guardrail and hard shoulder connected by anchorage bars implanted in shoulder, for the soil shoulder section, guardrail is fixed with concrete foundation setting in soil shoulder by anchorage bars. In this way, the guardrail can work with shoulder as a whole to resisting the impact force, then, the safety performance and stability of concrete guardrail foundation are improved accordingly. The diameter of anchorage bar is 12 mm, the distance of adjacent bar is 600 mm and the depth of bar below the ground is 400 mm. Figure 1 shows the structure of the anchor bar type concrete guardrail.
Reinforcement Design of Guardrail

When the guardrail is crashed by vehicle, the reinforcement of the collision surface is affected mainly by the tension force, the non-collision surface suffer less force [4]. In order to meet the requirements of the strength and economy of the guardrail, asymmetric reinforcement design method is adopted considering the stress characteristics of the guardrail structure. In the collision surface, φ10mm steel bar with spacing of 300mm is laid in vertical direction, 5 φ8mm steel is laid in horizontal direction, in the non-collision surface, φ8mm steel bar with spacing of 600mm is laid in vertical direction, 3 φ8mm steel is laid in horizontal direction. The asymmetric reinforcement design decreases the number of reinforcement in the non-collision surface and reduces the diameter of the reinforcement. Compared with the traditional reinforcement design method, the construction cost of the guardrail can be reduced in proportion of 40%, under the premise of ensuring the strength of the guardrail structure.

Finite Element Simulation and Analysis of Guardrail Structure

Finite Element Model Establishment

Through the finite element simulation method, the safety performance of C-level anchor bar type concrete guardrail structure is verified preliminary. The finite element model of concrete guardrail and vehicle are established on the actual size through pretreatment software in LS-DYNA. The simulation parameters of the concrete guardrail are defined by physical unit and the Mat159 elastomeric material. The steel bar is defined by beam element and Mat24 elastic material [5,6]. According to the actual size, the finite element model of vehicle is built with shell unit. Tire pressure parameters of vehicle are determined by tests, tire pressure of car is 0.3Mpa, tire pressure of medium bus and truck is 0.8Mpa.

Simulation Analysis Results

Simulation Analysis Results of Car. After the collision of car to guardrail, the vehicle did not cross guardrail or ride guardrail, the vehicle traveled out smoothly without turning over, the simulation collision process is shown in Figure 2. When the vehicle passes through the redirective exit box (A=4.6m, B=10m), the maximum distance of tire track is 3.6m, which does not exceed the exit box and meets the boundary requirements. During the collision of the vehicle, the components of guardrail did not fall off or invade the vehicle cabin, the guardrail was almost no deformation. The OIV (occupant impact velocity) and ORA (occupant ride down acceleration) did not exceed the limit.
Simulation Analysis Results of Bus. After the collision of bus to guardrail, the vehicle traveled out smoothly, did not cross guardrail or ride guardrail, the simulation collision process is shown in Figure 3. When the vehicle passes through the redirective exit box (A=8.0m, B=20m), the maximum distance of tire track is 6.0m, which does not exceed the exit box and meets the boundary requirements. During the collision process, the guardrail has a slight crack and broken, there is no components invading the vehicle cabin, and the maximum dynamic lateral deflection of the guardrail is 32mm.

Simulation Analysis Results of Truck. After the collision of truck to guardrail, the vehicle traveled out smoothly, did not cross guardrail or ride guardrail, the simulation collision process is shown in Figure 4. When the vehicle passes through the redirective exit box (A=7.9m, B=20m), the maximum distance of tire track is 7.5m, which does not exceed the exit box and meets the boundary requirements. During the collision process, there is no components invading the vehicle cabin, and the maximum dynamic lateral deflection of the guardrail is 10mm.

The simulation results show that the safety performance of the guardrail structure can meet the requirements of the evaluation standard for C-level. Real vehicle impact tests will be adopted further to verify the safety performance of the guardrail.

Safety Performance Verify of Guardrail

Vehicle and Guardrail for Tests

According to the evaluation standard, the safety performance of the guardrail must be evaluated by method of real vehicle impact tests. In accordance with the proportion of 1:1, C-level anchor bar type concrete guardrail is built in the collision test field, as shown in Figure 5.
The car, bus and truck for impact tests are shown in Figure 6.

Full-Scale Impact Tests

Impact Test Results of Car to Guardrail. The test results show that the guardrail has good containment performance, buffering performance and redirective performance to protect car. After the impact of car to guardrail, the vehicle did not cross or ride guardrail, traveled out smoothly without turning over, the impact process is shown in Figure 7. When the vehicle passes through the redirective exit box (A=4.8m, B=10m), the maximum distance of tire track is 4.5m, which does not exceed the exit box and satisfies the evaluation standards. During the impact of the vehicle, the components of guardrail did not fall off or invade the vehicle cabin.

The acceleration-time curve of the vehicle's barycenter is shown in Figure 8. The OIV (occupant impact velocity) and ORA (occupant ride down acceleration) did not exceed the limit.

The guardrail has no deflection after impacted, there is a small amount of scratches on the surface of the guardrail. The situation of car and guardrail after impacted is shown in Figure 9.
Impact Test Results of Bus to Guardrail. The test results show that the guardrail has good containment performance and redirective performance to protect bus. After the impact of bus to guardrail, the vehicle did not cross or ride guardrail, traveled out smoothly, the impact process is shown in Figure 10. When the vehicle passes through the redirective exit box \((A=7.4m, B=20m)\), the maximum distance of tire track is 2.1m, which does not exceed the exit box and satisfies the evaluation standards.

The guardrail has no damage or deflection after impacted, the situation of bus and guardrail is shown in Figure 11.

Impact Test Results of Truck to Guardrail. The test results show that the guardrail has good containment performance and redirective performance to protect truck. After the impact of truck to guardrail, the vehicle did not cross or ride guardrail and traveled out smoothly, the impact process is shown in Figure 12. When the vehicle passes through the redirective exit box \((A=7.6m, B=20m)\), the maximum distance of tire track is 2.2m, which does not exceed the exit box and satisfies the evaluation standards.

The guardrail has no deflection after impacted, there are a short number of small cracks on the guardrail, the structure of guardrail is not damaged. The situation of truck and guardrail after impacted is shown in Figure 13.
Conclusion on Safety Performance Evaluation

The conclusion on the safety performance evaluation of the guardrail is shown in Table 3 obtained from the real vehicle full-scale impact tests.

Table 3. Safety evaluation conclusion of impact tests.

| Test items                        | Technical requirement                                      | Test result | Test result  |
|----------------------------------|-----------------------------------------------------------|-------------|--------------|
|                                  |                                                           | Test value  | conclusion   |
| Containment performance          | Vehicle can not cross or ride guardrail.                  | car Meet    | Qualified    |
|                                  |                                                           | bus Meet    | Qualified    |
|                                  |                                                           | truck Meet  | Qualified    |
|                                  | Component of guardrail can not invade the vehicle cabin.  | car Meet    | Qualified    |
|                                  |                                                           | bus Meet    | Qualified    |
|                                  |                                                           | truck Meet  | Qualified    |
| Redirective performance          | Vehicle can not turn over after impact.                  | car Meet    | Qualified    |
|                                  |                                                           | bus Meet    | Qualified    |
|                                  |                                                           | truck Meet  | Qualified    |
|                                  | Tire track can not exceed redirective exit box.           | car Meet    | Qualified    |
|                                  |                                                           | bus Meet    | Qualified    |
|                                  |                                                           | truck Meet  | Qualified    |
| Buffering performance            | OIV $V_x \leq 12m/s$                                      | car 2.6     | Qualified    |
|                                  | OIV $V_y \leq 12m/s$                                      | car 3.7     | Qualified    |
|                                  | ORA $a_x \leq 200m/s^2$                                  | car 9.80    | Qualified    |
|                                  | ORA $a_y \leq 200m/s^2$                                  | car 48.02   | Qualified    |
| Maximum dynamic lateral deflection of guardrail $D$, m | car 0                                                   |             |
| Maximum dynamic widening distance of lateral deflection of guardrail $W$, m | car 0.35                                              |             |
| Maximum dynamic vehicle incline-out distance $VI$, m     | bus 0.22                                               |             |
|                                  | truck 0.09                                              |             |
| Normalized maximum dynamic vehicle incline-out distance $VI_n$, m | bus 0.44                                              |             |
|                                  | truck 0.47                                              |             |

Verified by full-scale vehicle impact tests, the containment performance, buffering performance and directive performance of the guardrail meet the requirements of safety performance evaluation standards, the anchor bar type concrete guardrail can reach C level (kinetic energy 40kJ). The evaluation conclusion provides condition and basis for the guardrail's engineering application.

Application Conditions of Guardrail

C-level anchor bar type concrete guardrail is applicable to the following conditions: High risk sections on roadside of low degree highway, soil shoulder width greater than 45cm, or retaining hard shoulder width greater than 40cm. Sections existing permanent waters in depth above 0.5m in the distance less than 3m to the shoulder edge line on highway roadside. Dangerous highway sections
with roadside height between 4m ~ 6m and slope more than 1:1 on the outside of small radius curve. Dangerous highway sections with height greater than 6m and slope more than 1:1 on roadside. Other dangerous sections on roadside of highway that have been identified as C-level security requirements.

**Conclusions**

1) For the purpose of reducing costs, satisfying the roadside safety requirements for narrow shoulder highway, the methods of finite element simulation analysis and real vehicle impact tests are used to develop a kind of anchor bar type concrete guardrail. Verified by full-scale vehicle impact tests, the guardrail can reach the protection level of C-level (40kJ), the containment performance, buffering performance and redirective performance of the guardrail meet the requirements of safety performance evaluation standards.

2) By setting anchor bar in highway shoulder, the foundation of guardrail is tied tightly with shoulder, which makes them bearing external force jointly, accordingly, the protection ability and foundation stability of concrete guardrail is enhanced. The bottom width of the guardrail is 30cm, which can enhance the application scope of the guardrail.

3) According to the stress characteristics of guardrail, asymmetric reinforcement design method is used to reduce the cost of construction in proportion of 40%. The whole guardrail structure did not damage impacted by vehicles, which helps to decrease the maintenance workload after impacted, thus reduce the maintenance cost in operation period.

4) The guardrail can reduce the accident rate and severity on low degree highway, prevent vehicle from falling down the cliff, falling into river or driving out of roadside.

**References**

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