Research on the impact coefficient of vehicle wheel load on bridge expansion joint by scale model experiment

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Abstract—The wheel load of the vehicle acting on the bridge expansion joint is a kind of dynamic load, and its impact coefficient needs to be determined, so as to provide basic design parameters for the bridge expansion joint. In this paper, the scale model of the bridge and the vehicle is designed and constructed, and the experimental study of vehicle model passing through bridge model is carried out. In the experiment, the wheel impact load of the vehicle on the bridge expansion joint is measured, and the impact coefficient of the wheel load is calculated. The measured results show that the greater the vehicle speed, the greater the impact load of the wheel on the expansion joint, that is, the greater the impact coefficient. The larger the width of the gap in the expansion joint, the greater the impact load and impact coefficient of the wheel on the expansion joint. The greater the mass of the vehicle, the longer the contact length between the wheel and the road surface, which reduces the impact effect and the impact coefficient of the wheel load on the expansion joint. The maximum impact coefficient of wheel load is greater than the design value in the Chinese bridge code, i.e. 0.45, even greater than that in the American bridge code, i.e. 0.75.

1. Introduction
The long-term repeated action of moving vehicles on the bridge may lead to fatigue and damage of the bridge structure. In particular, the phenomenon of jumping when vehicles pass across the bridge expansion joint will produce a large local impact load on the bridge structure, leading to the damage of the expansion joint and deck at the bridge head, which requires regular maintenance and replacement [1-3].

Steenbergen [4] studied the dynamic characteristics of the expansion joint and established a mathematical model. Combined with the test results, it is considered that the impact coefficient of wheel load was within the range of 0.1~0.5. Xie et al. [5] measured the dynamic response generated by vehicles passing through the bridge at different speeds, it is found that the impact response of vehicles on the expansion joint is greater than that on the mid-span of the bridge. Ding et al. [6] proposed a distributed spring-damping element to reflect the contact between the wheel and the bridge deck when passing across the bridge expansion joint. Liang [7] did a vertical and horizontal modal analysis of the expansion joint, and found that the maximum impact coefficient generated by vehicle passing across the modular expansion joint of bridge is very close to the Chinese standards. Zhang et al. [8] proposed a vertical dynamics model of the coupling system of heavy-vehicles and the expansion joints, and found that the maximum impact coefficient generated by heavy vehicle passing across the long-displacement expansion joint of bridge exceeded the current Chinese standards.

In this paper, the method of scale model experiment is adopted to analysis the impact load of the vehicle on the bridge. The vehicle model consists of elastic wheels and rigid body. The bridge model is
made of grooved aluminum alloy. The vehicle model is pulled by the stepping motor control system to pass through the bridge model. The local impact load of moving vehicles passing across the bridge expansion joint is tested. The effects of vehicle speed, vehicle mass and expansion joint width on impact effect are analyzed.

2. Scale model test system of vehicle and expansion joint

2.1. Bridge and expansion joint model
The scale experimental model of the bridge and the expansion joint are established. The bridge model is a three-span simply supported beam with a scale of 1:30, in which the first and third spans are approach bridges, and the midspan is the main bridge. The model is made of aluminum alloy and shown in Fig.1. One end of the support in midspan is simply supported by a rolling bearing (Fig.2), and the other end is simply supported by two vertical dynamic force sensors at the same height. In order to reduce the influence of external vibration and noise on the bridge, the bridge support is fixed on heavy section steel support. As shown in Fig.3, the expansion joint is set between the approach bridge and the main bridge, and a gap with a certain width is reserved to simulate the actual expansion joint.

![Model sketch](image1.png) ![Model photo](image2.png)

Fig.1 Model of Scale Experiment

![Rolling bearing](image3.png) ![Bridge expansion joint](image4.png)

Fig.2 Rolling bearing of main ridge Fig.3 Model of bridge expansion joint

The relevant parameters of the bridge are shown in Table 1.

| Parameter | value | Parameter | value |
|-----------|-------|-----------|-------|
| \(l/(m)\) | 3.8   | \(l_0/(m)\) | 3.77  |
| \(E/(GPa)\) | 70    | \(\xi\) | 0.047 |
| \(m_{total}/(kg)\) | 3.64  | \(E/(GPa)\) | 70    |
| \(m/(kg)\) | 0.95824 | \(f/(Hz)\) | 9.16  |
| \(A/(cm^2)\) | 3.62   | \(I/(cm^4)\) | 9.4046 |

The meaning of each parameter in the above table is as follows: \(l\) is the beam length, \(l_0\) is the calculation span, \(m_{total}\) is the total mass of the beam, \(m\) is the mass per meter, \(\xi\) is the damping ratio of aluminum alloy beam, \(E\) is the elastic modulus of aluminum alloy beam, \(f\) is the natural frequency, \(A\) is the section area and \(I\) is the moment of inertia of the section.

2.2 The vehicle model
The vehicle model is a two-axle model with the scale of 1:30, which is shown in Fig.4. The suspension system of the vehicle is composed of elastic rubber wheels and body springs, which can reflect the
vibration characteristics of the real vehicle. In the experiment, the vehicle is driven by the traction system. The power is generated by the stepping motor at the end of the bridge, and the vehicle is pulled by the thin steel cable. The movement path includes a three-section bridge model, so the bump when the vehicle passes across the expansion joint can be simulated.

![Fig.4 Vehicle and bridge model](image)

![Fig.5 The mechanical model of vehicle](image)

The mechanical model of the vehicle is shown in Fig.5, and the relevant parameters are shown in Table 2.

| Parameter | Value | Parameter | Value |
|-----------|-------|-----------|-------|
| $k_1$/(N/mm) | 64.05 | $m_1$/(kg) | 4.35 |
| $k_2$/(N/mm) | 64.05 | $m_2$/(kg) | 0.125 |
| $c_1$/(N·s/mm) | 61.39 | $m_3$/(kg) | 0.125 |
| $c_2$/(N·s/mm) | 61.39 | $l_1$/(cm) | 10 |
| $J_{x1}$/(kg·cm²) | 78.67 | $h_1$/(cm) | 1.30 |
| $J_{z2}$/(kg·cm²) | 47.01 | $h_2$/(cm) | 5.40 |

In Table 2, $J_{x1}$ and $J_{z2}$ are the moments of inertia of the vehicle body on side and forward direction, respectively.

3. Analysis of experimental results

The experiment uses a vehicle with a total weight of 4.6kg. The test is carried out by adjusting the width of the expansion joint and the speed of the vehicle. During the experiment, the impact force was measured by the sensor at the bottom of the bridge. The impact force sensors are only 0.5cm away from the bridge end. Therefore, the dynamic reaction from the sensors and the wheel load is nearly same. The measured force of the two sensors can be approximately equal to the dynamic wheel load of two front wheels. And the result is shown in Fig.7.

![Fig.6 Measured force from two impact force sensor](image)

The impact coefficient is used to evaluate the impact of vehicles on the bridge, and it is defined as follows:

$$ m = \left( \frac{R_{d \text{max}} - R_s}{R_s} \right) R_s \tag{1} $$
where $R_{d\text{max}}$ is the maximum impact force under moving load, and $R_s$ is the static load.

In the case of four different width of expansion joints, the relationship between the impact coefficient and vehicle speed is plotted in Fig.10. It indicates that the impact coefficient of the vehicle load increases with the vehicle speed regardless of the width of the expansion joint. In the case of five different vehicle speed, the relationship between the impact coefficient of the vehicle load and the width of the expansion joint is shown in Fig.11. It indicates that the impact coefficient of vehicle load increases with the width of the expansion joint at different vehicle speed. When the vehicle speed is 0.9m/s and the expansion joint width is 3mm, the maximum impact coefficient can be up to 0.85.

![Fig.7 Impact coefficient of vehicle load at different expansion joint width](image)

The effect of the vehicle weight on the impact coefficient is also studied. Fig. 12 shows the relationship between the mass of the vehicle and the impact coefficient of the vehicle wheel load when the vehicle speed is 0.5 m/s. It can be seen that the impact coefficient decreases when the vehicle mass increases. This is because the contact area between the wheel and the bridge deck increases as the mass of the vehicle increases, which reduces the impact force and the impact coefficient of the vehicle load on the expansion joint.

![Fig.9 The relationship between the impact coefficient of wheel load and the vehicle mass](image)

4. Conclusion

In this paper, the scale model of the bridge expansion joint and the vehicle is constructed, and the local impact loads of the vehicle passing across the expansion joint are measured. The results are shown as follows.

1. The larger the width of the gap in the expansion joint, the greater the impact load and impact coefficient of the wheel load on the expansion joint.

2. The greater the vehicle speed, the greater the impact coefficient of the wheel load on the
expansion joint.

(3) The greater the mass of the vehicle, the longer the contact length between the wheel and the bridge deck, which reduces the impact effect and the impact coefficient of the wheel load on the expansion joint.

(4) The maximum impact coefficient of wheel load is greater than the design value in the Chinese bridge code, i.e. 0.45, even greater than that in the American bridge code, i.e. 0.75.

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