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Impact effect analysis for hangers of half-through arch bridge by vehicle-bridge coupling

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Abstract. Among the destruction instances of half-through arch bridges, the shorter hangers are more likely to be ruined. For a thorough investigation of the hanger system durability, we have studied vehicle impact effect on hangers with vehicle-bridge coupling method for a half-through concrete-filled-steel-tube arch bridge. A numerical method has been applied to simulate the variation of dynamic internal force (stress) in hangers under different vehicle speeds and road surface roughness. The characteristics and differences in impact effect among hangers with different length (position) are compared. The impact effect is further analyzed comprehensively based on the vehicle speed distribution model. Our results show that the dynamic internal force induced by moving vehicles inside the shorter hangers is significantly greater than that inside the longer ones. The largest difference of dynamic internal force among the hangers could be as high as 28%. Our results well explained a common phenomenon in several hanger damage accidents occurred in China. This work forms a basis for hanger system's fatigue analysis and service life evaluation. It also provides a reference to the design, management, maintenance, monitoring, and evaluation for this kind of bridge.

Keywords: half-through arch bridge; hanger; bridge surface roughness; vehicle-bridge coupling; impact effect

1. Introduction

Half-through arch bridge has been widely built in China in recent decades. The hanger system is one of the most important bearing members in this kind of bridge, and the safety of the bridge is directly related to the operation conditions of the system. However, the durability of hanger system is known to be the weakest in the bridge. In recent years, several damage accidents of half-through arch bridge have occurred in China, such as the Nanmen Bridge (Fig. 1) in Yibin, Sichuan (November 7, 2001), the Kongquehe Bridge (Fig. 2) in Korla, Xinjiang (April 12, 2011), the Gongguan Bridge (Fig. 3) in Wuyishan, Fujian (July 14, 2011), etc. These accidents are directly caused by the failure of the hanger system. As matter of fact, a detection test was conducted on the Kongquehe Bridge in 2008, and the conclusion is that "the total tension in hangers is less than the half of design value (3400 kN), the hanger system meets the strength requirement" (Jiang and Zainula 2008). However, the hanger fracture happened just three years later. So, the durability of hanger system has attracted more attention of scholars and engineers.

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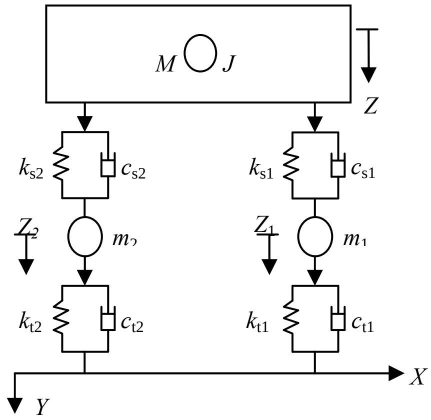


Fig. 5 Model of vehicle

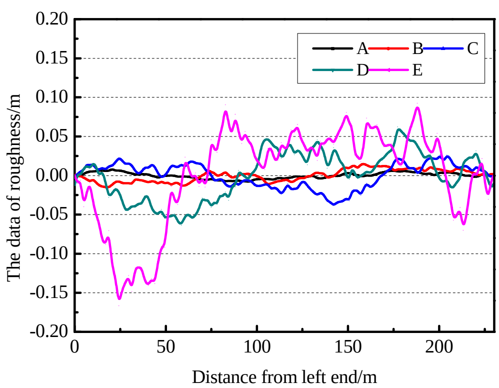


Fig. 6 Road surface roughness

in which, n is spatial frequency, the unit is m^{-1}, $n_0 = 0.1\mathrm{m}^{-1}$ is reference spatial frequency. $G_d(n_0)$ is the coefficient of road surface roughness depending on the roughness grade. $G_d(n)$ is the displacement power spectral density. ω is frequency index. A set of samples of the road roughness of levels A ~ E is shown in Fig. 6.

2.4 Vehicle-bridge coupling iteration method

First, the road roughness is applied to vehicle model as the displacement excitation. Assuming the wheels keep in contact with the bridge deck, vehicle wheel load at contact point is then calculated. The position of contact point changes with time based on the vehicle speed. Then, vehicle wheel load is applied to the corresponding position of bridge model to calculate vertical deflection of bridge deck. The next round of calculation can be started by adding the deflection to the roughness. The iteration is conducted by repeating the above process until two successive deflections meet the requirement of precision. The detailed process is shown in Fig. 7. This iterative algorithm has many advantages such as clear in concept, good in generality, and ease of programming.

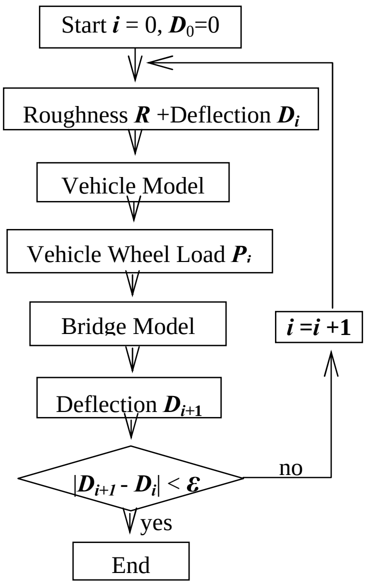
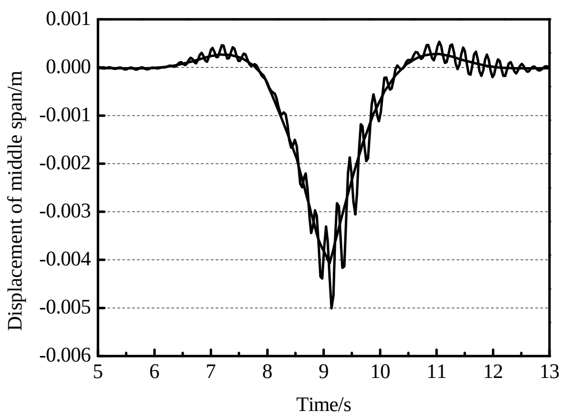


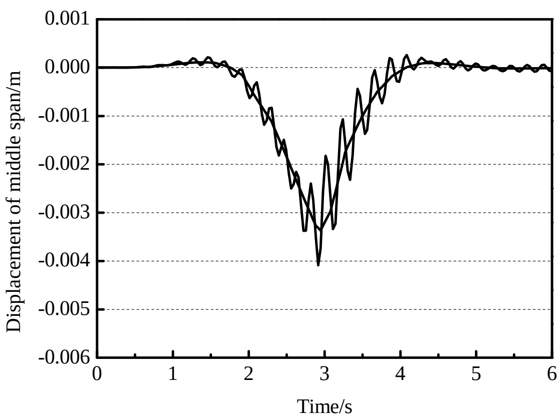
Fig. 7 The iterative process of vehicle-bridge coupling dynamics

2.5 Model modification and preanalysis

The vehicle (20000 kg) drives over the bridge at different speeds (10~60 km/h). The dynamic response of vehicle-bridge coupling is calculated at the road roughness of level C. Through comparing the response calculated from the experimental results, the bridge model is corrected and improved. The simulation results on modified model have a good match to the experiment results as listed in Table 1. The dynamic displacements of middle span are showed in Fig. 8.



(a) main span



(b) side span

Fig. 8 Dynamic displacements of middle span

Table1 Impact coefficient and frequency

	Impact coefficient		frequency /Hz	
Vehicle speed /km/h	calculation	experiment	calculation	experiment
10	1.231	1.148	4.4	4.1
20	1.379	1.349		
30	1.369	1.369		
40	1.330	1.354		

3. Impact effect analysis for hangers

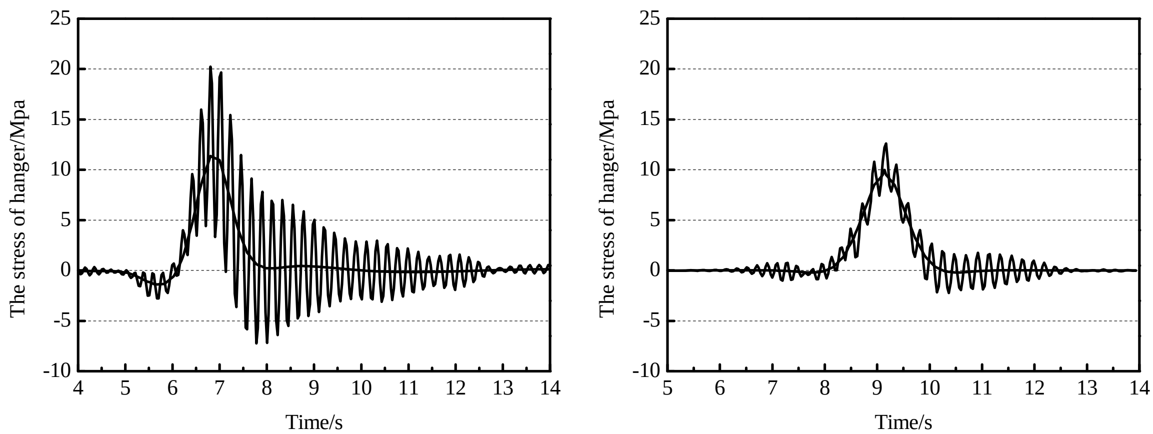
3.1 Impact effect

Usually, the impact coefficient $(1+\mu)$ is used to describe the magnitude of dynamic effect of the moving vehicle to the bridge. μ is defined as:

$$\mu = \frac{Y_{d\max}}{Y_{j\max}} - 1 \tag{5}$$

where, $Y_{j\max}$ is the maximum static displacement of the bridge, and $Y_{d\max}$ is the maximum dynamic displacement of the bridge.

The stresses in hangers are calculated based on the modified model at the road roughness of level C. The stress time history of the shortest (No.1) and the longest (No.7) hangers of main span are shown in Fig. 9. The figures show that the dynamic effects are significant and different between two hangers.



(a) hanger No.1 (b) hanger No.7

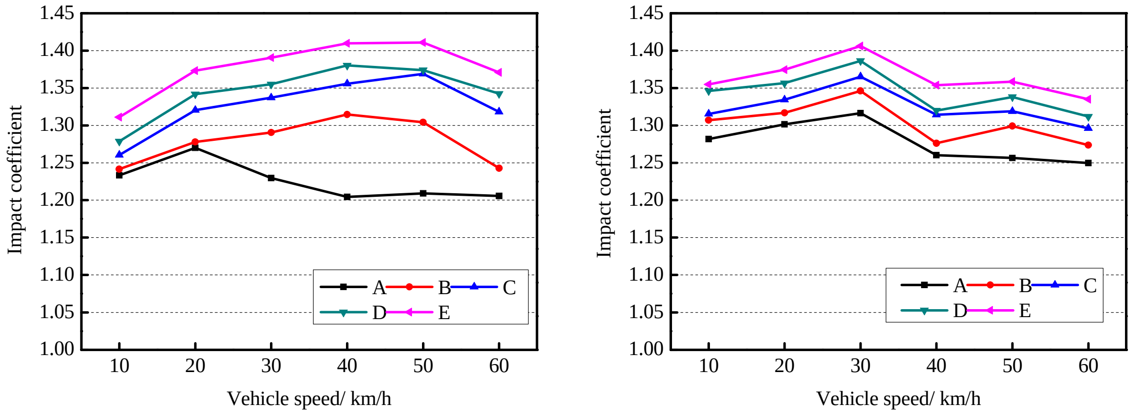
Fig. 9 Hanger stress of main span

3.2 Effect of road roughness

The impact coefficients of hanger internal force are calculated for 6 settings of vehicle speeds and 5 levels of roughness respectively. Fig. 10 shows the impact coefficients of the shortest hanger stresses of main and side span. The level of bridge roughness shows an obvious influence on the hanger stress impact coefficient. The impact coefficient increases with the decreasing of road surface roughness level.

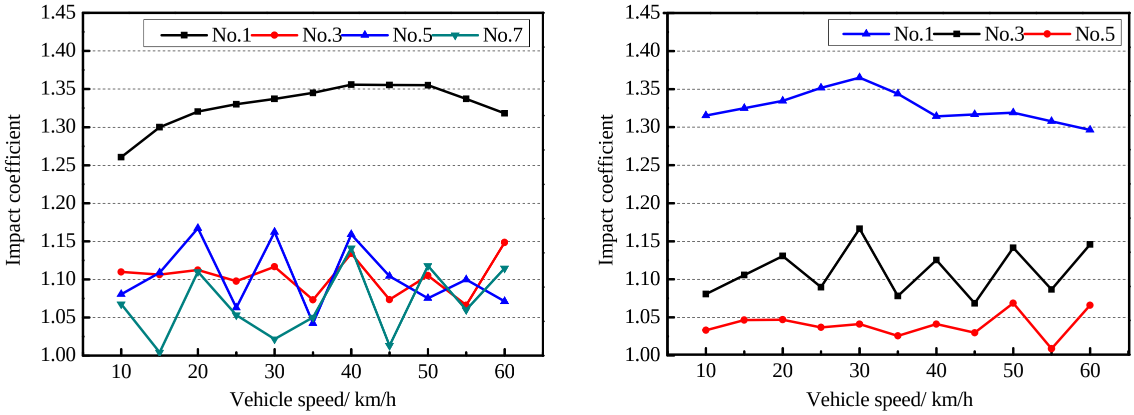
3.3 Effect of hanger length

Adopting C level of road roughness, the dynamic responses of bridge are calculated for the driving speed of 10 to 60 km/h. Fig. 11 shows the stress impact effect of hangers with different lengths.



(a) main span (b) side span

Fig. 10 The effect of roughness on hangers' impact coefficient



(a) main span (b) side span

Fig. 11 Stress impact coefficient of hangers

The stress impact coefficient of the short hanger is significantly greater than the others. This means that the short hangers have to withstand greater impact than longer ones. So the short hangers are easier to be damaged. From the above results, the hangers with different lengths (or at different position) will have a different service life. The stress impact coefficients for each hangers of main span are shown in Fig. 12.

As a preliminary study and evaluation to the hanger impact effects under operation conditions, stress impact coefficient is also analyzed comprehensively based on the vehicle speed distribution model (Shi 2004) shown in Fig. 13. The impact coefficient of speed weighted is calculated. The comprehensive impact coefficients of the hangers of main and side spans are shown in Fig. 14. The comprehensive impact coefficient varies obviously and regularly with the change of the hanger length. Therefore, under the operation conditions, the dynamic stresses in shorter hangers are significantly larger than the longer one.

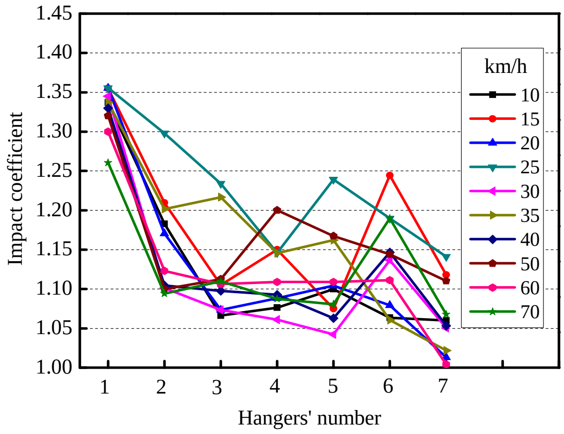


Fig. 12 Stress impact coefficient of hangers with different length

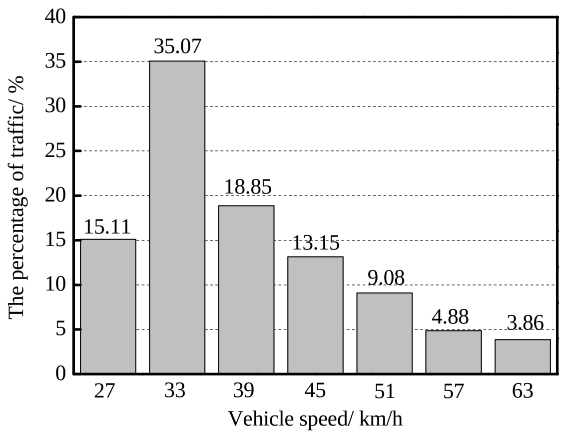


Fig. 13 Vehicle speed distribution model

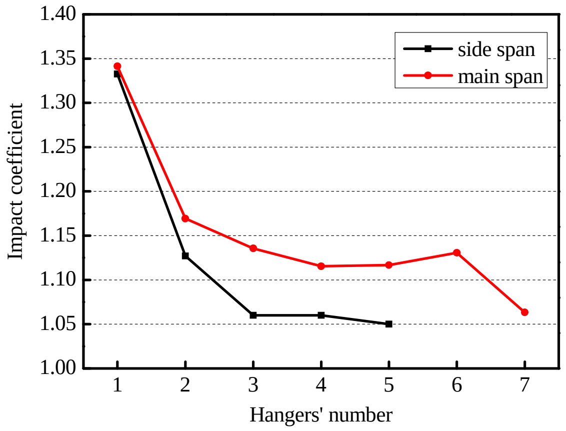


Fig. 14 Vehicle-speed-weighted impact effect of hangers

4. Conclusions

The impact effect of hangers is obviously magnified by the road surface roughness. Keeping road surface in a good condition is very important for the hangers' durability.

The dynamic internal force induced by moving vehicles in the shorter hanger is significantly greater than that in the longer ones. The largest difference of dynamic internal force among hangers is as high as 28%. The hangers with different length (or at different position) will have a different service life. Our results well explained a common phenomenon in several hanger damage accidents occurred in China.

The differences in impact effect between short and long hangers are mainly caused by differences in vertical stiffness. These differences can be diminished by the means of design so as to improve the service life of the bridge.

This work forms a basis for hanger system's fatigue analysis and service life evaluation. It also provides a reference to the design, management, maintenance, monitoring, and evaluation for this kind of bridge.

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