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A model test for acquiring input excitations from dynamic response of pier under collision force

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Abstract. A model test is executed to verify a reverse derivation method for acquiring input excitations from dynamic responses of pier under collision loads, upon the train-bridge system test platform. A dynamic strain is measured at the bottom of pier under collision, and then the corresponding collision forces are reversely calculated from the tested strain, which match well with those directly obtained by the force sensor. Based on the results, a method of acquiring collision force time history is proposed as the excitation input for the research of train-bridge coupling system subjected to collision loads.

Introduction

By the end of 2015, high-speed railway had been more than 19,000 km in the total national railway of 120,000 km in China. As the high-speed railway adopts fully enclosed traffic mode and more bridge structure are adopted instead of embankment, train-bridge coupling vibration becomes very important. There have been many researches[1~3] on coupling vibrations of train-bridge on the high-speed railway, and those under wind loads or earthquake actions, while very few have been done on those subjected to impact loads . Xia et al. [3] applied the impact force to the bridge nodes in the form of nodal force histories, and a further study was carried on the dynamic response of the bridge and the safety of train operation under impact load.

On train-bridge coupled vibration analysis subjected to collision load, the input impulse load excitation is required. Due to the complexity of collision force time history, it is difficult to measure directly with the sensor, especially in the actual project, the direct acquisition of that is inefficient [5]. In this paper, a method to determine the impact load for the train-bridge coupling system is proposed, by using the dynamic response of piers to reversely derive the input excitation load. From the model train-bridge coupling test platform, the dynamic strain of the control point is tested by the rigid model truck colliding with the bridge pier, and the force time history from force sensor is compared with that reversely derived from the measured strain, with the purpose of validating the feasibility of using dynamic response to acquire the collision force time history.

Test Overview

According to the Wheatstone electric bridge [4] technology, the quarter-bridge, half-bridge and full-bridge circuits are commonly used to measure the bending strain.

Based on the measures of offsetting environmental factors, and by optimizing the bridge circuit and measuring points, the test results are ensured close to the true value. Considering the impact duration of collision is extremely short, the influence of temperature variation on the measured dynamic strain can be ignored, so the quarter-bridge Wheatstone bridge circuit is selected, as shown in Fig. 1.

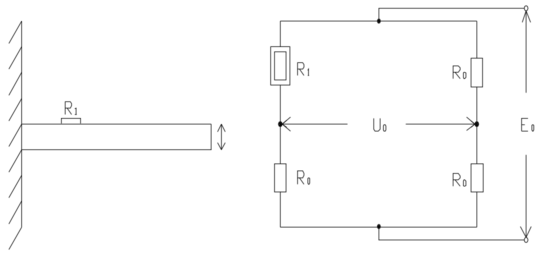

Fig. 1 The quarter-bridge Wheatstone bridge circuit for strain measurement

The experiment was carried out on the vehicle-bridge coupling platform. A through-type railway steel truss arch bridge model is established in the laboratory, as shown in Fig. 2. The main span of the arch is 8 m and the height is 1.5 m; the arch rib is made of 50 mm × 50 mm square steel tube with wall thickness of 4 mm and arch intercostal cross-linked; in the main arch on both sides of every 0.5 m sets a suspender with diameter of 1.5 cm. The bridge is supported by two piers at the ends. The pier is made of circular steel pipe with an outer diameter of 32.5 cm and a wall thickness of 0.6 cm. The pier bottom is fixed on the ground.

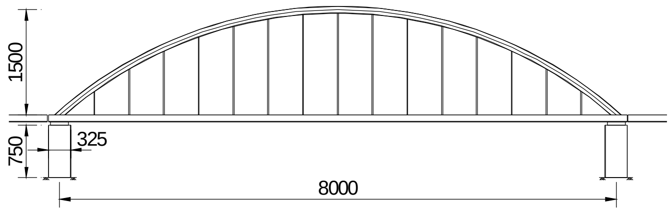

Fig. 2 Layout drawing of model arch bridge

A simple track is set up on the side of one pier, as shown in Fig. 3, from which the rigid model truck slides dawn along the track and collides with the pier, meanwhile the impact force time history is recorded by the sensor on the INV DFC-2 type high elasticity energy-gathering hammer.

The measuring points of the test include the strain measuring point A at the bottom of the pier; the impact point B, the transverse acceleration and displacement measuring points C and D at the pier top, respectively, as shown in Fig. 3. The pier responses are measured by the TG-GPA-type accelerometer and the LVDT differential transformer-type displacement meter, and the measured signals were collected and analyzed by the INV3020C dynamic data processing system, as shown in Fig. 4.

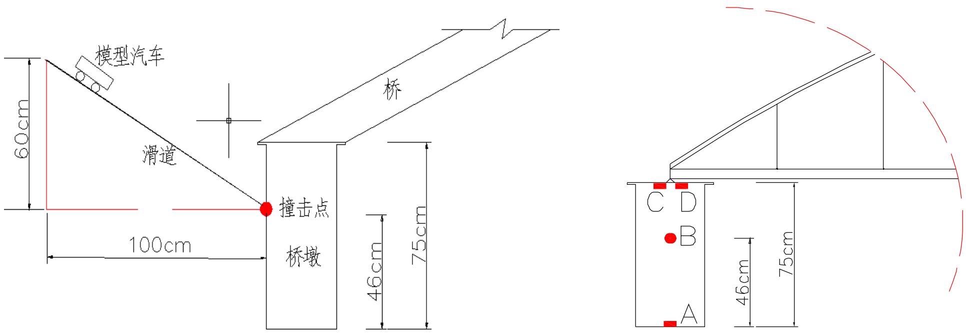

Fig. 3 Measuring points of model test

Fig. 4 Experimentations

Test Result and Analysis

From the dynamic data acquisition and analysis system, the impact force time history and the dynamic strain at the pier bottom of the model are acquired, as shown in Fig. 5. The peak value of the impact force is 9817 N and the peak value of the dynamic strain is 34.62με (17.96 ~ 17.98 s).

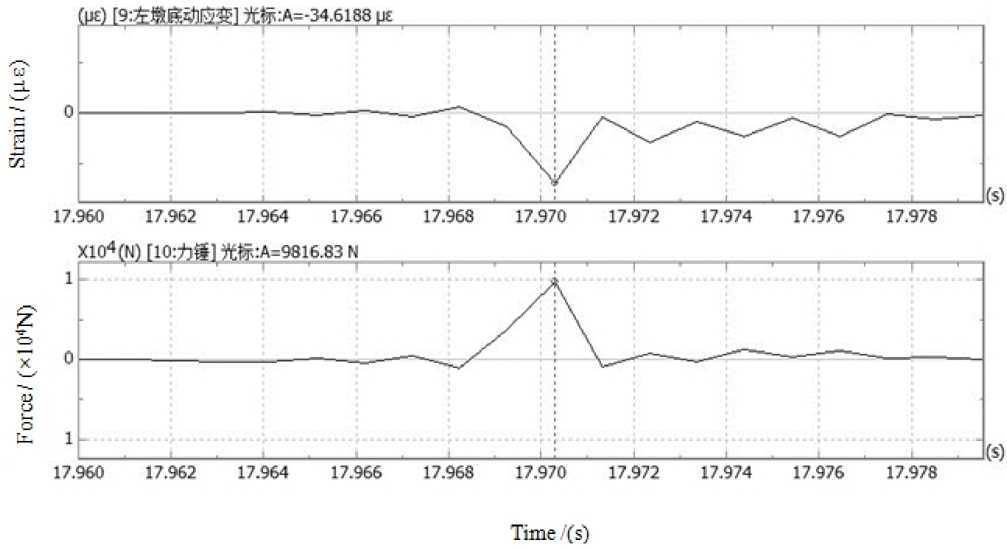

Fig. 5 The collision force time history and dynamic strain

It can be seen from Fig. 5, after the truck model hits the pier, there is little mechanical lag beteen the collision force time and the strain. The peak of the dynamic strain occurs at almost the same time with that of the impact force, and the waveforms of them agree well with each other, and the more fully the excitation, the better the experimental results.

The pier is the hollow steel pipe, ***D*** is the outer diameter, and ***d*** is the inner diameter, then the moment of inertia I of the section can be calculated as follows:

$$I = \frac{p(D^4 - d^4)}{64} \tag{1}$$

The stress σ is calculated as:

$$s = Ee = \frac{MD}{2I} = \frac{FhD}{2I} \tag{2}$$

where ***E*** is the modulus of elasticity of steel material, ε is the measured strain, ***M*** is the bending moment of the measuring point, ***F*** is the impact force, and ***h*** is the height of the impact point from the strain point.

From Formula (2), the available impact force ***F*** expression is:

$$F = \frac{2EIe}{Dh} \tag{3}$$

According to each measured value of the dynamic strain ε, the corresponding impact force ***F*** can be calculated separately, so as to obtain the impact force time history.

Shown in Fig. 6 are the distributions of peak forces calculated from dynamic strains measured in various impacts, where the upper and lower envelopes of 1.2 and 0.8 times of the measured peak values are also given.

It can be seen from Fig. 6 that when the excitation is not sufficient (for the peak values of the impact force from 2000 to 3000N), the calculated dynamic forces exceed 20% of the peak values from the force sensor. But in the other cases, the calculated peak values of dynamic forces basically lie within the upper envelope curve of the peak values.

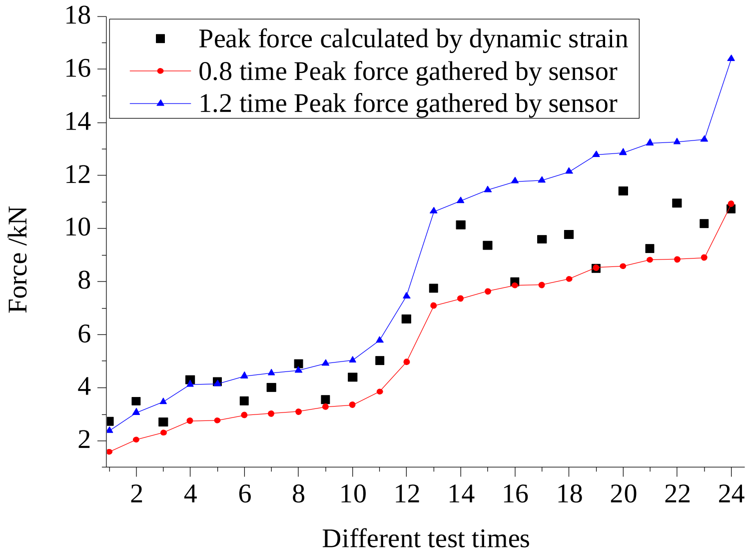

Fig.6 Envelope graph of peak forces calculated from dynamic strain

Conclusions

In this paper, through the model test, the dynamic strains at the bottom of the piers during the collision are obtained, and the collision force time histories are calculated, which match well with those gained from force sensor. A 1.2 times of the calculation of force time history is advised for the actual application of the collision force time history in train-bridge coupled vibration analysis.

It should be noted that in this analysis, the simplified rigid-body was adopted in the model truck, the deformation of the truck-body and the similarity of the materials were not taken into account, and the bottom of the pier was fixed on the ground thus the deformation of the foundation soil was not considered. Because the collision process is a complex problem with large deformation and nonlinearity, in the following research, the above factors should be considered in the field or a more detailed model experimental study will be carried out, and the collision force process in the frequency domain will be explored.

Acknowledgements

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