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Long-term monitoring and analysis of hanger vibration of a high-speed railway steel truss arch bridge

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ABSTRACT

A steel truss arch bridge, i.e. Dashenguan Yangtse River Bridge, is selected as the research object of this work. The hanger's vibration velocity responses when the high-speed train passes were long-term monitored using the structural health monitoring system; then the long-term dynamic displacement responses were further obtained through the integration of velocity responses. With these long-term monitoring data, the probability statistics of a hanger's dynamic displacement amplitudes and the relationship of dynamic displacement amplitudes of the hanger and the main girder are discussed in detail. The analysis results indicate that: (i) the hanger's displacement amplitudes are much larger in the transverse direction than the longitudinal direction. And the generalized extreme value distribution model can be used to describe the probability characteristics of a hanger's longitudinal and transverse displacement amplitudes; (ii) there exits significant correlation between the hanger's longitudinal displacement amplitudes and the main girder's transverse displacement amplitudes. Therefore, the coupling effect of the main girder's transverse vibration caused by the high-speed train must be considered in the hanger's longitudinal vibration analysis. This work lays a foundation for hanger vibration analysis and control in the high-speed railway bridges.

1. INTRODUCTION

Structural health monitoring system has been set up in many engineering structures in the past decades. Many structural health monitoring system has collected

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plenty of monitoring data. It is an important topic that how to use these data for structural analysis and maintenance. This topic draws recently more and more attention. Ni et al (2012, 2013) proposed an approach for condition assessment of bridge deck and apply it to the Tsing Ma Bridge based on the long-term strain monitoring data. Liu et al (2014) recommended a method to calculate the localized reliability around an embedded sensor based on a long-term SHIM system.

The hangers' considerable vibration caused by high-speed trains may result in their fatigue failure (Roeder 2000; Pellegrino 2010; Li 2012). Therefore, research efforts should be focused on the vibration monitoring of the hangers so as to collect the reliable information that can be used in vibration analysis and control of the hanger (Malm 2006; Ni 2012).

In this study, a high-speed railway steel truss arch bridge is selected as the research object to study its hanger vibration by the long-term monitoring data from the structural health monitoring system. The probability statistics of a hanger's dynamic displacement amplitudes and the relationship of displacement amplitudes of the hanger and the main girder are discussed in detail. Some conclusions are summarized.

2. THE RESEARCH OBJECT

As shown in Fig. 1, the Dashenguan Yangtse River Bridge is selected as the research object of this work. It serves as the shared corridor crossing Yangtze River for both Beijing-Shanghai high-speed railway and Shanghai-Wuhan-Chengdu railway, and it is the first 6-track high-speed railway bridge with the longest span all over the world. It is a steel truss arch bridge with the span arrangement of 108+192+2×336+192+108 m (Fig. 2). Its 336m main span and 6-track railways rank itself the largest bridge with heaviest design loading among the high-speed railway bridges so far. Moreover, the design speed of 300km/h of the bridge is on the advanced level in the world. Due to these remarkable characteristics including long span of the main girder, heavy design loading and high speed of trains, the considerable vibration of the bridge caused by high-speed trains may threaten the structural safety of the bridge. To realize the vibration monitoring of the bridge, a structural health monitoring system for the Dashenguan Yangtse River Bridge has been established with modern techniques in sensing, testing, computing and network communication (Ye 2013; Watanabe 2014).

Fig. 1 View of the Dashenguan Yangtse River Bridge

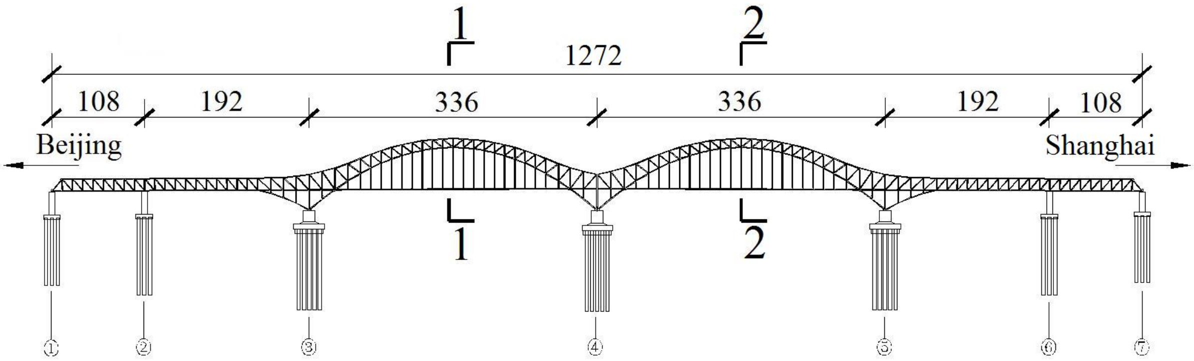


Fig. 2 The side elevation drawing of the bridge (Unit: m)

3. DYNAMIC DISPLACEMENT MONITORING OF HANGER

3.1 Dynamic displacing monitoring system

The length of the longest hanger in Dashenguan Yangtse River Bridge is close to 60 m. In order to monitor the hanger vibration, two velocity sensors are installed on the longest hanger at the 1-1 cross-section in the middle of the first main span of the bridge (Fig. 2 and Fig. 3). The two velocity sensors ZD-11-06 and ZD-11-05 are employed to collect the transverse and longitudinal velocity responses caused by the traveling high-speed trains. The sampling frequency is 200 Hz. The long-term dynamic displacement responses are further obtained through the integration of velocity responses.

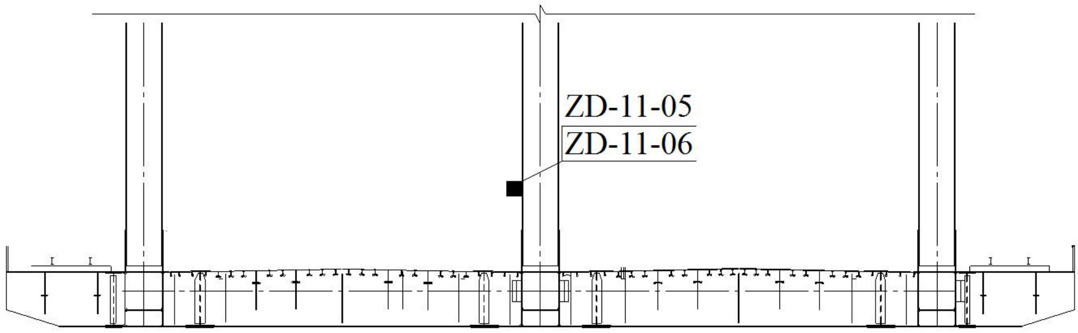
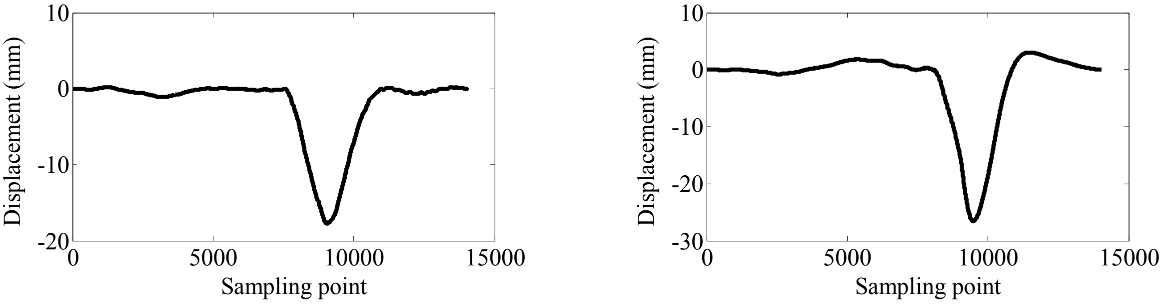


Fig. 3 Layout of two velocity sensors on the measured hanger

3.2 Dynamic displacement monitoring results

Fig. 4 shows the time-history responses of longitudinal and transverse dynamic displacements when a typical high-speed train passes through the bridge. It can be seen that the dynamic displacement monitoring results present the obvious single peak style during the pass of the train. As shown in Fig. 4, the dynamic displacement amplitudes in the two directions are 18.01 mm and 29.22 mm, respectively; it can be seen that the hanger’s displacement amplitudes are much larger in the transverse direction than the longitudinal direction when a train passes.



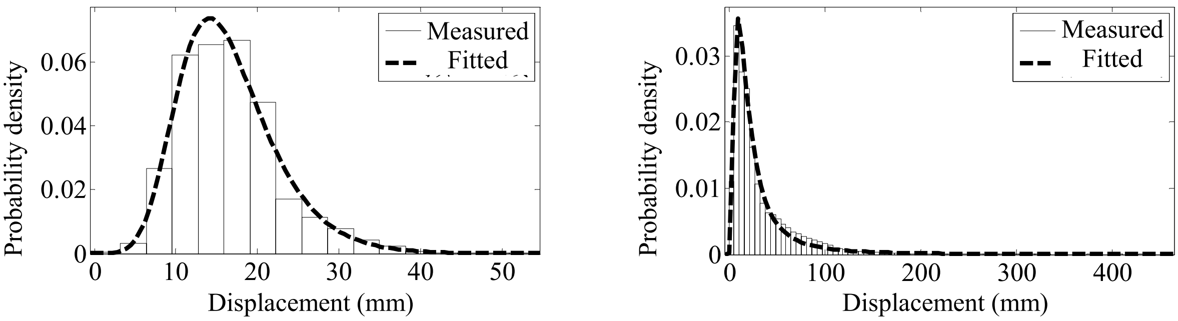
(a) (b)

Fig. 4 Dynamic displacement monitoring results during the pass of typical train: (a) the longitudinal displacement; (b) the transverse displacement

4. LONG-TERM ANALYSIS OF DYNAMIC DISPLACEMENT AMPLITUDES

4.1 Probability statistical analysis

Statistical analysis based on the monitoring data of the year 2014 is performed to obtain the most suitable probability distributions for longitudinal and transverse dynamic displacement amplitudes. A generalized extreme value distribution model is adopted for modeling the random variables of dynamic displacement amplitudes (Xia 2012). Fig. 5 shows the probability distributions of the longitudinal and transverse dynamic displacement amplitudes; at the same time, the estimated generalized extreme value distribution models are also shown in Fig. 5 for comparison. A good agreement between the estimated values and the measurement results is illustrated.

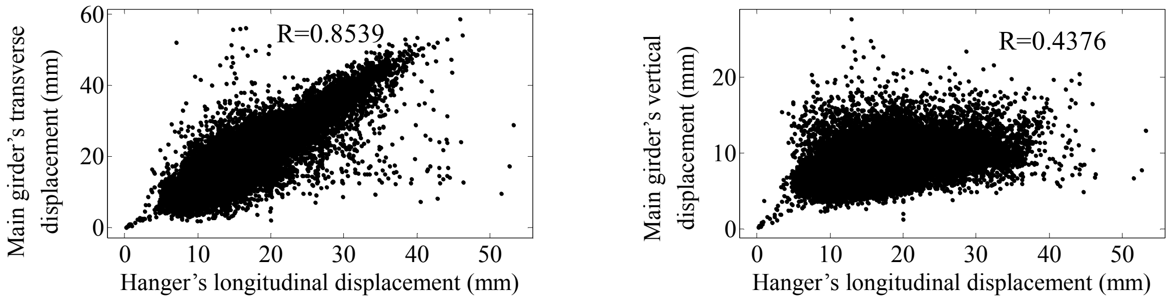


(a) (b)

Fig. 5 Generalized extreme value distribution models for: (a) the longitudinal displacements; (b) the transverse displacements

4.2 Correlation analysis between the hanger's longitudinal displacement amplitudes and the main girder's transverse displacement amplitudes

In order to investigate the effects of the main girder's vibration on the hanger's vibration when a high-speed train passes, the correlation analysis between the hanger's displacement amplitudes and the main girder's displacement amplitudes is shown in Fig. 6. The main girder's displacement amplitudes are obtained using the velocity sensors installed on the main girder at the 1-1 cross-section in the middle of the first main span of the bridge. As shown in Fig. 6(a), the correlation coefficient is 0.8539; it can be seen that there exits significant correlation between the hanger's longitudinal displacement amplitudes and the main girder's transverse displacement amplitudes. However as shown in Fig. 6(a), the correlation coefficient is only 0.4376; the correlation between the hanger's longitudinal displacement amplitudes and the main girder's vertical displacement amplitudes is weak. Therefore, the coupling effect of the main girder's transverse vibration caused by the high-speed train must be considered in the hanger's longitudinal vibration analysis.



(a) (b)

Fig. 6 Correlation between the hanger's displacement amplitudes and the main girder's displacement amplitudes: (a) correlation between the hanger's longitudinal displacement amplitudes and the main girder's transverse displacement amplitudes; (b) correlation between the hanger's longitudinal displacement amplitudes and the main girder's vertical displacement amplitudes

5. CONCLUSIONS

This work provides an initial analysis of hanger vibration in a high-speed railway steel truss arch bridge based on the long-term monitoring data. The conclusions can be summarized as follows:

(1) When a high-speed train passes, the hanger's displacement amplitudes are much larger in the transverse direction than the longitudinal direction.The generalized extreme value distribution model can be used to describe the probability characteristics of a hanger's longitudinal and transverse displacement amplitudes.

(2) There exits significant correlation between the hanger's longitudinal displacement amplitudes and the main girder's transverse displacement amplitudes. However, the correlation between the hanger's longitudinal displacement amplitudes and the main girder's vertical displacement amplitudes is weak. Therefore, the coupling effect of the main girder's transverse vibration caused by the high-speed train must be considered in the hanger's longitudinal vibration analysis.

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REFERENCES

Li, D.S., Zhou, Z., and Ou, J.P. (2012), “Dynamic behavior monitoring and damage evaluation for arch bridge suspender using GFRP optical fiber Bragg grating sensors,” *Optics and Laser Technology*, **44**(4), 1031-1038.

Liu, Z.J., Li, Y.H., Tang, L.Q., Liu, Y.P., Jiang, Z.Y., Fang, D.N. (2014), "Localized reliability analysis on a large-span rigid frame bridge based on monitored strains from the long-term SHM system", *Smart Structures and Systems*,**14**(2), 209-224.

Malm, R. and Andersson, A. (2006), “Field testing and simulation of dynamic properties of a tied arch railway bridge,” *Engineering Structures*, **28**(1), 130-143.

Ni, Y.Q. and Lin, K.C. (2013), Reliability-Based Condition Assessment of Bridge Deck using Long-Term Monitoring Data, *Structural Health Monitoring 2013*, 1-2, 2736-2743. 9th International Workshop on Structural Health Monitoring (IWSHM), Stanford Univ, Stanford, CA, SEP 10-12, 2013

Ni, Y.Q., Xia, H.W., Wong, K.Y. and Ko, J.M. (2012), “In-service condition assessment of bridge deck using long-term monitoring data of strain response,” *Journal of Bridge Engineering, ASCE*, **17**(6), 876-885.

Pellegrino, C., Cupani, G. and Modena, C. (2010), “The effect of fatigue on the arrangement of hangers in tied arch bridges,” *Engineering Structures*, **32**(4), 1140-1147.

Roeder, C.W., MacRae, G., Crocker, P., Arima, K. and Wong, S. (2000), “Dynamic response and fatigue of steel tied-arch bridge,” *Journal of Bridge Engineering*, *ASCE*, **5**(1), 14-21.

Watanabe, E., Furuta, H., Yamaguchi, T. and Kano, M. (2014), “On longevity and monitoring technologies of bridges: A survey study by the Japanese Society of Steel Construction,” *Structure and Infrastructure Engineering*, **10**(4), 471-491.

Xia, H.W., Ni, Y.Q., Wong, K. Y. and Ko, J.M. (2012), “Reliability-based condition assessment of in-service bridges using mixture distribution models,” *Computers & Structures*, **106**, 204-213

Ye, X.W., Ni, Y.Q. and Yin, J.H. (2013), “Safety Monitoring of Railway Tunnel Construction Using FBG Sensing Technology,” *Advances in Structural Engineerin*g, **16**(8), 1401-1409.