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Influence of temperature on transverse dynamic displacement amplitude of a hanger in a railway arch bridge under high-speed trains

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ABSTRACT

The excessive vibration of arch bridge hangers may be a potential threat for the driving safety of high-speed trains. Therefore, it is important to study the dynamic characteristics of hanger vibration under moving train loads and ambient excitations. This paper presents an analysis for the influence of temperature on high-speed railway arch bridge hangers' transverse vibration responses using long-term field monitoring data. Firstly, the train-induced hanger's transverse dynamic displacement amplitude is obtained through the integration of velocity, which is collected from the structure health monitoring system installed on Nanjing Dashengguan Yangtze River Bridge. Then, eight train load cases are classified, and the factors of train speed and ambient wind are excluded. Finally, the relationship of temperature and the hanger's transverse dynamic displacement amplitude is obtained. The conclusion shows that the hanger's transverse dynamic displacement amplitude is negative associated with the temperature. Therefore, the driving safety of high-speed trains should be paid more attention in winter.

1. Introduction

For the purpose of infrastructure construction and economy development (An et al. 2015), many long-span bridges have been built in China. Structural health monitoring (SHM) systems have been installed in many bridges for structural damage diagnosis (An and Ou 2013; An et al. 2016a), performance assessment, safety warning and data collection for scientific research (An et al. 2016b; Zhang et al. 2015). However, there is too much data collected from SHM system, so the useful information might be difficult to be obtained. Recently, a lot of researchers have paid more and more attention on studies of long-term monitoring data analysis. For example, Li et al. (2015) diagnosed

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structural damage using streamlined data collected from an integrated SHM system.

Served as the main connecting members and subjected to many kinds of dynamic loads, such as train loads and ambient excitations, hangers play an essential role in the arch bridge and the suspension bridge; as a result, the performance, especially the dynamic performance of hangers should be paid attention. Many studies based on the vibration characteristics analysis of hangers under vehicle loads or ambient excitations have been conducted. Ding et al. (2016) analyzed various vibration characteristics of hangers influenced by different railway load cases in a long-span high-speed railway steel truss arch bridge. With the help of numerical analysis and wind tunnel experiment, Bai and Liu (2012) studied the vortex-induced vibration responses of hangers in a steel arch bridge, and influence of different section types of hangers on their vibration response has been investigated. Considering the effect of vehicle-bridge interaction, Yang and Li (2010) studied the hangers' dynamic characteristics, and the possible failure mechanism for hangers of a tied-arch bridge was given. In a conclusion, there are many excellent studies on hanger's dynamic performance base on the experiment and simulation; however, there has been little research about vibration characteristics analysis of hangers utilizing the field monitoring data. As a result, it is necessary to further investigate the influence of vehicle loads and ambient excitation on hanger's dynamic performance utilizing field monitoring data collected from the SHM system.

Dashengguan Yangtze River Bridge, a high-speed railway truss arch bridge whose total length (1615m) ranks first among similar bridges in the world, is selected as the research object in this paper. This bridge has two main spans of 336m and six tracks, and the design speed of Jinghu high-speed railway in the bridge is 300 km/h. The remainder of this paper is organized as follows. Section 2 shows the research object and sensor layout in the SHM system; section 3 provides analysis of the temperature influence on train-induced hanger's transverse dynamic displacement amplitude (DDA); and finally section 4 gives the conclusions.

2. RESEARCH OBJECT AND SENSOR LAYOUT IN THE SHM SYSTEM

The Dashengguan Yangtze River Bridge is shown in Fig. 1. When a train passes through the bridge, the train-induced hanger's transverse DDA is directly defined as the maximum absolute value of transverse vibration displacement of a hanger when the influence of ambient wind can be ignored. Generally, a hanger's abnormal DDA is supposed to be a warning for the possible structural damage and measures should be taken to ensure the safety of train driving; therefore, it is necessary to obtain the hanger's accurate DDA. After preliminarily analyzing the field monitoring data collected from Dashengguan Bridge, transverse DDA in a hanger increases obviously when a high-speed train passes across the bridge. Besides, the temperature and wind may have influence on the hanger's transverse DDA. This paper discusses the influence of temperature on train-induced hanger's transverse DDA. There are 21 hangers on each side of the bridge in a main span, and the 11# hanger (the middle one in the left main span shown in Fig. 1) is selected as the research object. Fig. 2 shows the sensors installed in sections 11(1)# and 11(2)#. Some different types of sensors used in this bridge are introduced in detail in Table 1.

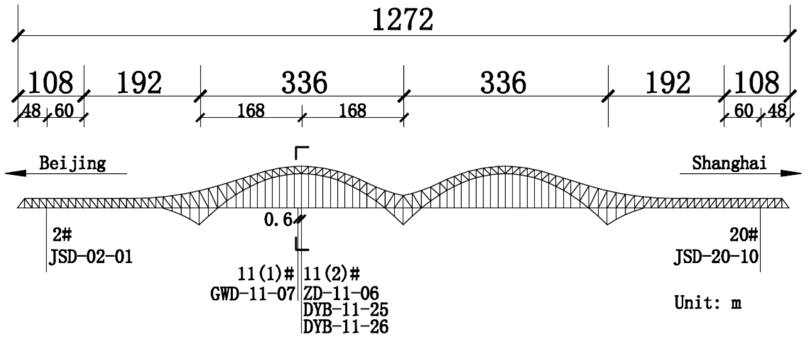

Fig. 1 Nanjing Dashengguan Yangtze River Bridge

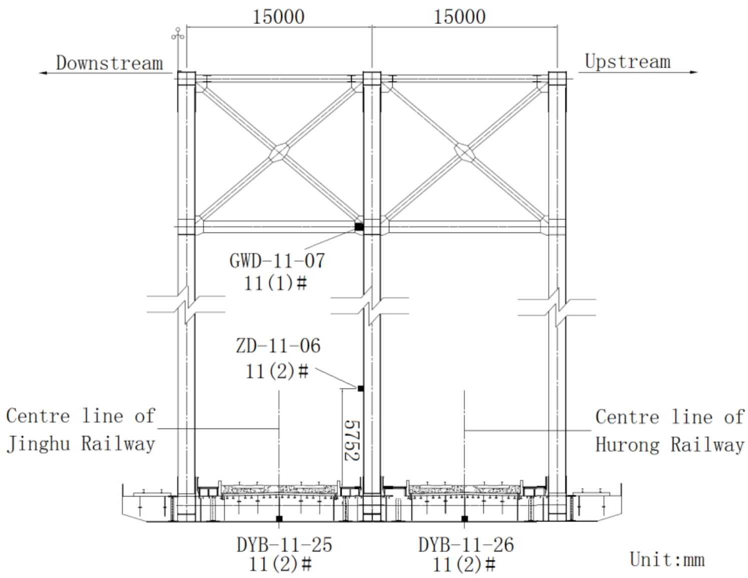

Fig. 2 Sensor Layout Diagram in 11# Section

Table 1 Sensor Type and Location

Sensor Name	Section Number	Description
ZD-11-06	11(2)	Hanger’s transverse vibration velocity collection
JSD-02-01	2	Deck’s vertical acceleration collection
JSD-20-10	20	Deck’s vertical acceleration collection
DYB-11-25	11(2)	Track’s steel dynamic stain collection
DYB-11-26	11(2)	Track’s steel dynamic stain collection
GWD-11-07	11(1)	Steel truss arch’s temperature collection

3. ANALYSIS OF INFLUENCE OF TEMPERATURE ON THE TRAIN-INDUCED HANGER'S TRANSVERSE DDA

As for the hanger vibration characteristics, it is generally considered that the hanger's transverse DDA are influenced by the following factors: the direction, speed, carriage number, the track of the train, the ambient wind, and the temperature. As a result, in order to study the influence of temperature on the train-induced hanger's transverse DDA, the influences of all the other factors should be excluded.

3.1 Extraction of Useful Characteristics from Field Monitoring Data

In order to exclude the interference factors and investigate the temperature influence on the train-induced hanger's transverse DDA, many kinds of data ought be obtained and analyzed. The hanger's transverse DDA and all the factors mentioned above are obtained from the field monitoring data according to the following steps.

Firstly, after the process of de-nosing using wavelet packets, filtering and integrating, the hanger's transverse DDA can be obtained by its transverse vibration velocity collected from sensor ZD-11-06.

Secondly, the direction and speed of the train can be determined by the deck's vertical accelerations collected from accelerometers JSD-02-01 and JSD-20-10 installed on sections 2# and 20# considering the distance between the two sensors is known.

Thirdly, the carriage number and the track of the train can be determined by the number of extreme stains and the relationship of stain maximums obtained from sensors DYB-11-25 and DYB-11-26.

Finally, the temperature is directly determined by the steel truss arch's temperature collected from sensor GWD-11-07. Unfortunately, the collection of ambient wind speed data is failed in the SHM system of this bridge at present due to the anemoscope malfunction; the factor of ambient wind will be further discussed in section 3.2.

3.2 Exclusion of the Interference Factors

Three kinds of factors which may have influence on the hanger's transverse DDA are listed as follows: the running train (including the direction, speed, carriage number, and the track), the ambient wind, and the temperature. If the first two factors keep the same or approximately the same, the interference factors will be excluded and the influence of temperature on the train-induced hanger's transverse DDA can be obtained.

Firstly, eight load cases are defined in Fig. 3 (Ding et al. 2016). In a load case, the running direction, carriage number and the track are the same. In the train load case 1 (Fig. 3), a 8-carriage train runs from Shanghai to Beijing in downstream side. Data from different cases are analyzed respectively to exclude all the factors except the train speed caused by running train. Regarding the train speed, only the cases in which the train speed ranges from 230~250 km/h are used in the calculation.

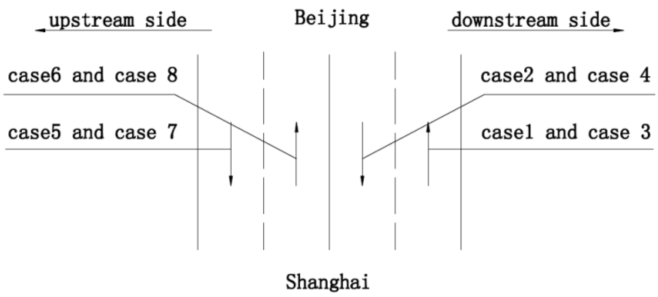

Fig. 3 The eight train load cases

Then, in order to exclude the influence of ambient wind, the ratios of a hanger's transverse DDA induced by ambient wind and the train to the hanger's transverse DDA induced by ambient wind should be calculated. The ambient wind-induced hanger's transverse DDA is related to the ambient wind strength, so the effect of ambient wind can be ignored when the ratios are large enough. In this paper, only those sets of data with ratios larger than 10 are selected to exclude the effect of ambient wind.

3.3 Analysis Results of Temperature Influence on Train-induced Hanger's Transverse DDA

After excluding all the other interference factors, the influence of temperature on the train-induced hanger's transverse DDA can be obtained. For example, analyzing data collected from train load case 1 with the train speed in range of 230~250 km/h and the ratio large than 10, the influence of temperature on the train-induced hanger's transverse DDA is shown in Fig. 4.

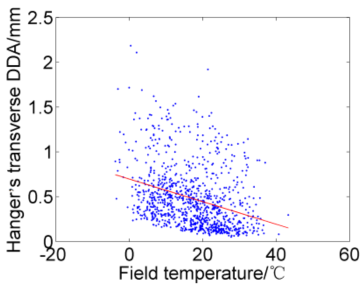

Fig. 4 Relationship between temperature and the train-induced hanger's transverse DDA for train load case 1

From Fig. 4 it can be seen that the train-induced 11# hanger's transverse DDA is negative associated with the temperature, which means the train-induced hanger's transverse DDA is greater with lower temperature. Because the transverse DDA is bad for high-speed train which runs on a fixed track, the driving safety of the train should be paid more attention in winter.

4. CONCLUSIONS

This paper analyzed the field monitoring data collected from the SHM system installed in a high-speed railway arch bridge. A conclusion about the influence of temperature on the train-induced hanger's transverse DDA is drawn as follows. There is negative correlation between temperature and the train-induced hanger's transverse DDA when a high-speed train passes, which means the train-induced hanger's transverse DDA is greater with lower temperature; therefore, the driving safety of high-speed trains should be paid more attention in winter, such as train speed limitation.

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