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SHM-based condition assessment of expansion Joints in suspension Bridges

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ABASTRACT

In order to diagnose damage of expansion joints in suspension bridges, measurements from Structural Health Monitoring System are analyzed. Correlation between effective girder temperature and cumulative girder-end longitudinal displacement is found. Excessive cumulative longitudinal displacement and collision by passing vehicles are shown to be main reasons for damage of expansion joints in suspension bridges. Based on the study, specific countermeasures are proposed, which include using high wear-resistant slider, additional displacement-constraint device and longitudinal damper. The proposed countermeasures have been applied to Jiangyin Yangtze River Bridge and Runyang Yangtze River Bridge, and they prove to be effective.
Keywords: Expansion joints; Suspension bridges; Cable-stayed bridges; Structural health monitoring; Condition assessment; effective girder temperature; cumulative longitudinal displacement; countermeasures

1. INTRODUCTION

Bridge expansion joints, which connect different spans, are important members of a bridge. They are able to accommodate displacement from temperature variation, wind and other external loads on the bridge. But as expansion joints directly withstand the impacts of traffic loads, they are exposed to harsh environmental condition. It is susceptible to potential damages and difficult to be repaired. Statistics indicates that average service life of expansion joints is between 15 to 20 years, which is much shorter than that of bridges (Dexter et.al 2002). For instance, within the first 8 year operation period of the Tokyo-Nagoya Expressway in Japan, the average repair frequency is 1.6 times per joint (Pen et.al 2006). Damage of expansion joints increases the impact load from vehicles, hence affects performance of bridges. There have been studies on fatigue problem of expansion joints (Roeder 1998; Crocetti and Edlund 2003; Chaallal et.al 2006), and some researchers also investigated dynamic impact of vehicle on expansion joints (Steenbergen 2006).

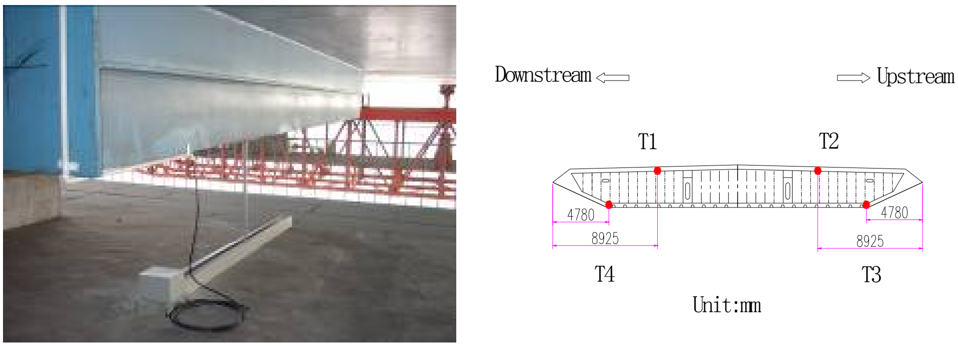
Jiangyin Yangtze River Highway Bridge (main span 1385m) was a suspension bridge which opened to traffic in 1999. Bearing damages first occurred in 2003, which accentuated gradually and resulted in total replacement in 2007 (Fig.1). Runyang Yangtze River Highway Bridge (main span 1490m), as another suspension bridge in Jiangsu, China, was opened to traffic in 2005. It experienced similar damages, and countermeasures were taken at an early stage to replace some parts. Based on SHMS (structure health monitoring system) data of these two bridges, this paper analyzes the main reason for the expansion joints damage, and proposes failure alarming method.

(a) Damage of expansion joints (b) Replacement of expansion joints
Fig.1 Damage and replacement of expansion joints for Jiangyin bridge

2. GENERAL PRINCIPLE FOR EVALUATION OF EXPANSION JOINTS

In recent years, SHM is widely used in long-span bridges to monitor its performance. Displacement is an important indicator of bridge behavior, in which longitudinal displacement at girder end is often used for assessment of expansion joints.

Taking Jiangyin Bridge for example, two displacement sensors are installed at both girder ends (Fig. 2 (a)). Temperature sensors are also equipped at nine cross-sections along the girder. For each section, layout of temperature sensor location is shown in Fig. 2 (b).



a) Displacement sensor photo at the girder end b) Temperature sensor layout
Fig. 2 Temperature sensor and displacement sensor layout of the Jiangyin bridge

In practice, evaluation method for expansion joints is shown in Fig. 3, and the process is illustrated as follows.

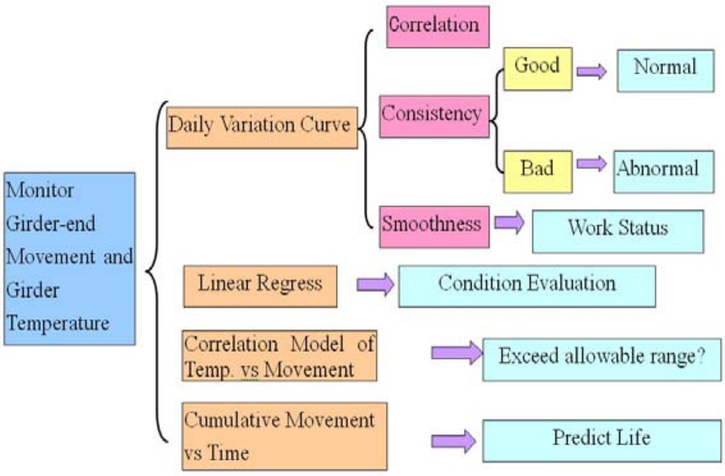


Fig. 3 Procedure for evaluation of large displacement expansion joint

(1) Effective temperature (T) is calculated using measurements of temperature sensor; average longitudinal displacement (D) is obtained from displacement measurements at both girder ends;
(2) Hourly average of displacement measurements is calculated to check the correlation with variation of effective temperature of the girder. (Effects from wind and vehicle impact are eliminated in the average, as their effects are mainly at short periods.) If there is no good consistency, specific analysis is required to investigate possible factors affecting movement of expansion joint;
(3) Linear regression method is used to establish a correlation model between girder temperature (T) and joint movement. By using movement - temperature correlation model, we can analyze the extreme value of joint movement. It is analyzed whether the joint movement exceeded the allowable maximum movement. The slope of the curve is used for evaluation of expansion joints.
(4) Relation between cumulative movement of expansion joints and time is established, which can be used to forecast the remaining service life of the expansion joint.

3. CONDITION ASSESSMENT FOR EXPANSION JOINTS OF SUSPENSION BRIDGE

Utilizing the proposed method, condition assessment for expansion joint of Jiangyin Yangtze River Highway Bridge is conducted. Using the 813 hours' measured data from January to April in 2006 of Jiangyin Bridge, correlation between expansion joint movement and girder temperature is established with linear regression method as shown in Fig. 4. It shows that they are in good correlation, and the regression equation can be expressed as Eq. (1).

$$D = 10.859T - 250.325 \quad (1)$$

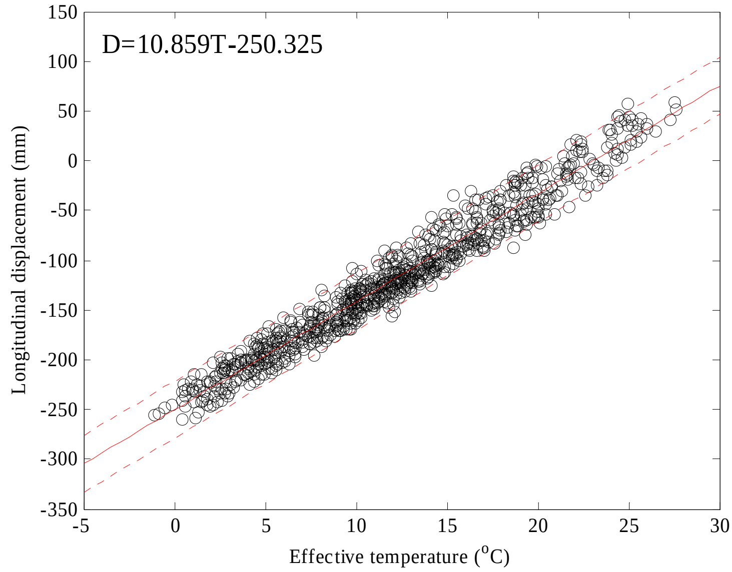


Fig. 4 Linear correlation model on average longitudinal displacement and effective temperature

Based on the bridge site meteorological data of Jiangyin Bridge, the movement range of steel box girder expansion joints are calculated as -404mm ~ 249mm, which is obviously far less than designed value of ± 1m. However, there is premature failure of expansion joints even the maximum movement is within the allowed range.

Detailed investigation on daily data shows irregularity in the longitudinal displacement. For example, data of Feb. 14, 2006 is shown in Fig. 5. Obvious inconsistency is observed from 0:00 to 6:00 am, which indicates abnormal behavior of expansion joints. Regular inspection of expansion joints indicates severe friction of expansion joint bearing.

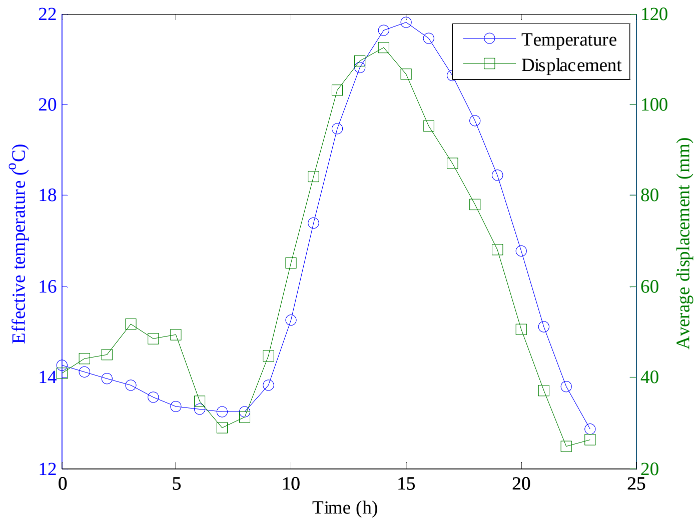


Fig. 5 Comparison between longitudinal displacement and girder temperature (Feb. 14, 2006)

4. COMPARATIVE ANALYSIS OF JOINT MOVEMENT BETWEEN SUSPENSION BRIDGE AND CABLE STAYED BRIDGE

As damage of expansion joints in suspension bridges (Jiangyin bridge and Runyang bridge) is more severe than cable stayed bridge (Sutong bridge), comparative study is conducted on behavior of expansion joints in two kinds of bridges.

Analysis shows that displacement of large displacement of expansion joints consists of two components, which are the main daily changes due to temperature variation and smaller displacement waves due to vehicle or wind loads. As shown in Fig. 6, components induced by vehicle and wind loads are quite small for Sutong bridge, as there is constraint effect from the stay cables. However, the components induced by vehicle and wind have a much larger amplitude in Jiangyin Bridge (Fig. 7).

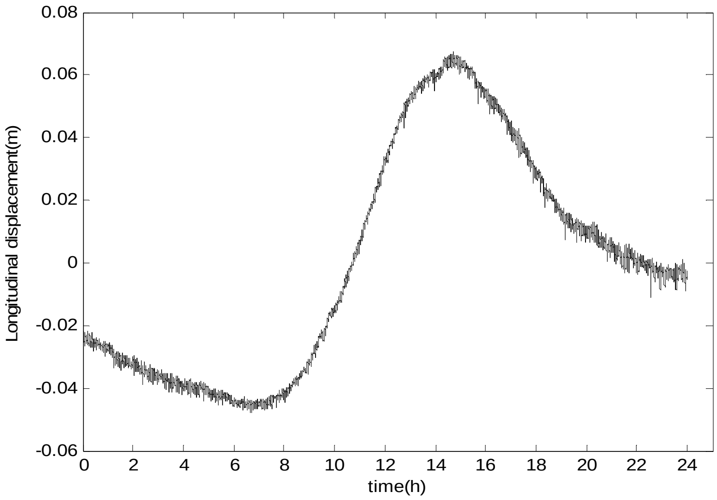


Fig.6 Girder-end longitudinal displacement for Sutong Bridge(Cable-stayed bridge)

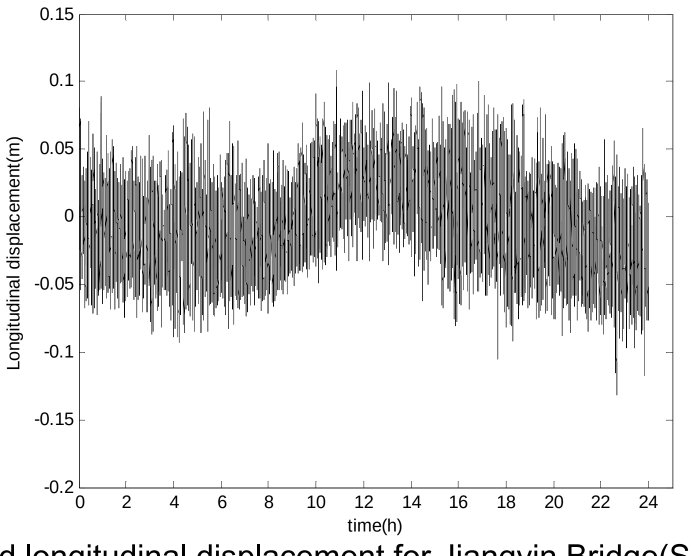


Fig. 7 Girder-end longitudinal displacement for Jiangyin Bridge(Suspension bridge)

The calculated cumulative displacement for Sutong Bridge (1088m), Ruanyang Bridge (1490m) and Jiangyin Bridge （1385m are 7.38m, 80.96m and 93.36m, respectively. Suspension bridge is more flexible, and it is similar to a free pendulum system. Due to the impact of vehicles and wind, suspension bridge has large cumulative displacement. Taking Runyang Bridge as an example, the accumulative displacement has reached 140km within four years after completion, while the design life of PTFE slider in the expansion joint is only about 20km. This causes premature damage of the joint slider material, hence overall damage of the expansion joint.

5. COUNTERMEASURES

Based on the above analysis, suggestions are given on countermeasures to prevent premature failure of expansion joints.

(1) Slider material with high wear-resistant property is installed. For example, high-performance slider material is used in repair of expansion joints in Runyang Bridge in 2009. (Fig. 8) Higher durability of expansion joints is achieved through replacement with new slider.

Fig. 8 High-performance slider material used in Runyang bridge

(2) Displacement constraint devices are added. For example, displacement constraint deivecs are added during repair of control spring in expansion joints in Runyang bridge, as shown in Fig. 9.

Fig. 9 Displacement constraints for expansion joints in Runyang bridge

(3) Damper is installed. During replacement of expansion joints in Jiangyin Bridge, fluid damper is installed for displacement dissipation in longitudinal direction as shown in Fig. 10.

Measurements show that daily cumulative displacement of expansion joints decreased from 93.36m to 64.15m after installation of the damper. Longitudinal speed and acceleration were reduced from 2.67mm/s and 24.2mm/s2 to 1.91mm/s and 17.36mm/s2 respectively. It indicates that dynamic vibration of the expansion joints is suppressed. Measurements also show that largest longitudinal displacement decreased from 34.8 mm to 12.5 mm. Therefore, the damper has played an important role for better performance of expansion joints.

Fig. 10 Longitudinal damper at the girder end of Jiangyin bridge

6. CONCLUSIONS

Expansion joints are important components in bridges, which are subject to various loads including wind, temperature and vehicle pounding impact. Based on measurements of SHM, investigation is conducted on damage mechanism of expansion joints in suspension bridges.

A procedure is proposed to evaluate health condition of expansion joints with girder temperature and girder-end longitudinal displacement measurements. Displacements between suspension bridges and cable-stayed bridges are compared. The result shows large discrepancy of cumulative girder-end longitudinal displacement in two types of bridges. Excessive cumulative longitudinal displacement and collision by passing vehicles are found to be main reasons for damage of expansion joints in suspension bridges.

Based on the study, specific countermeasures are proposed to improve the performance and extend the service life of large-displacement expansion joints, which include using high wear-resistant slider material in expansion joints, additional displacement-constraint device and fluid girder damper. The proposed countermeasures were applied to Jiangyin Yangtze River Highway Bridge and Runyang Yangtze River Highway Bridge. Measurements of longitudinal displacement show large decrease in both cumulative displacement and largest displacement under vehicle pounding impact.

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