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Current Situation and Trend Analysis of Health Monitoring System for Continuous Rigid Frame Bridges

Jing xian SHI^{1,a}, Xun LIU¹ and Yuan YUE²

¹Oxbridge College, Kunming University of Science and Technology, Kunming, Yunnan, 650106, China

²Southeast University, Nanjing, Jiangsu, 211189, China

^asara_shivip@163.com

Abstract. Continuous rigid frame bridges almost dominate in the span of 100 m to 300 m. Firstly, this paper summarizes the application status of bridge health monitoring system on various bridges at home and abroad in recent years, and analyses the main research directions and existing problems. It is found that there are not too many technical obstacles in the hardware aspect of bridge health monitoring system with medium span at present. But how to reasonably use the data collected by the system to evaluate the bridge structure is the next task to be focused on. Finally, some opinions on the research trend of continuous rigid frame bridge health monitoring system are put forward.

1. Introduction

Continuous rigid frame bridge is composed of continuous girder and thin-walled pier. The structure not only keeps the advantages of continuous beam without expansion joint and smooth running, but also keeps the advantages of T-type rigid frame without support and convenient construction. Therefore, although it started late, it has developed rapidly in recent decades, and gradually occupies a dominant position in the span of 100 m to 300 m.

However, it is very difficult to fully grasp and predict the mechanical behavior of the bridge at the design stage because of its structural characteristics and specific environment. The theoretical analysis of structures is often based on the idealized finite element discrete model, and the analysis often takes many assumptions as the premise, which are inconsistent with the real conditions. Therefore, it is of great significance to verify the theoretical model and calculation hypothesis of the bridge through the dynamic and static behavior of the actual structure obtained from the bridge health monitoring.

The continuous rigid frame bridge shows the main beam deflection and main beam cracking in the operation process. Although the information of cracks and deflections can be obtained in detail by manual periodic inspection, it is not enough to judge the mechanical characteristics of structures. Later structural load test can reflect the mechanical characteristics of the structure under vehicle load, but it is difficult to reflect the internal force state under dead load. Therefore, it is necessary to establish a reliable health monitoring system combined with the bridge construction monitoring process, and at the same time combined with manual detection. The two systems complement each other and provide a strong basis for the later stage state evaluation of bridge structures.



2. Application of Long-term Monitoring System for Continuous Rigid Frame Bridge

Overseas research on bridge health monitoring began in the 1970s, and in the mid and late 1980s, some bridges were installed and equipped with operation period monitoring system. Since 1990s, structural health monitoring systems have been established on some large and important bridges in China.

(1) Dongying Yellow River Highway Bridge(Figure1), Two-way 4-lane Expressway bridge, 2743.1m in length, the design load is Vehicle-over 20 ton load, Trailer-123 ton load. The main bridge is $(116 + 200 + 220 + 200 + 116)$ m prestressed concrete rigid frame continuous composite beam. The design and application of engineering monitoring system were carried out in 2008.



Figure1 Dongying Yellow River Rigid Frame Bridge

(2) The Wulong River Bridge(Figure2) on National Highway 324 was built in September 1971. The structure of the bridge is a prestressed concrete T-shaped rigid frame: $58\text{m}+3\times 144\text{m}+58\text{m}$. It is the first bridge across the South Port of Minjiang River constructed in Fuzhou. The health monitoring system was installed in 2012 to monitor the real-time safety of bridges, and the health monitoring system was upgraded in March 2018.

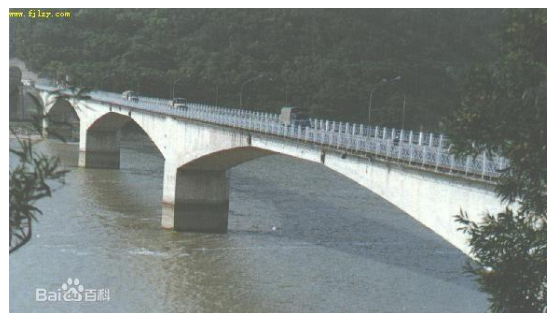


Figure 2 Wulong River Bridge

(3) The Xiaogou Bridge in Shanxi Province is composed of main bridge $(55+5\times 100+55)\text{m}$ +approach bridge $(7\times 30\text{m})$. The main bridge adopts continuous rigid frame composite system. The bridge established a relatively complete health monitoring system in 2013, which consists of three subsystems: sensor subsystem, data acquisition and transmission subsystem and remote analysis center subsystem, and constitutes an organic whole.

(4) Chongqing Yuao Light Rail Bridge(Figure3), with three spans of $96+160+96\text{m}$, is a fully prestressed concrete continuous rigid frame bridge. The bridge is equipped with a complete monitoring system. Data acquisition, data processing and analysis system mainly aims at the management and control work of data preprocessing, secondary processing, data storage, data display and so on.



Figure 3 Yuao Light Rail Bridge

3. Summary of research directions

3.1 Data analysis

In the aspect of data analysis, Mr. Xiang Yiqiang^[1] specifically pointed out the determination method of early warning threshold based on finite element analysis, the process of data processing and the method of damage identification. Most of the research on system data processing is based on statistical methods. For example, Mr. Han Zhijiang^[2] in the data analysis based on the health monitoring system of Xiaogou Bridge in Shanxi Province, both pre-processing and secondary processing are statistical methods.

3.2 Research on Evaluation Method

At present, the common assessment methods can be roughly divided into two categories, bearing capacity assessment and state assessment. State assessment is the main consideration in China. In the research of structural state assessment using health monitoring system, there are many evaluation methods related to the application of interdisciplinary disciplines, such as analytic hierarchy process, reliability theory, fuzzy theory and neural network.

Damage identification is the premise of safety assessment. The identification methods can be divided into model and non-model. The difference is whether the monitoring data are brought into the finite element model to identify structural damage. The former is mainly based on modal, while the latter is based on data analysis.

3.3 Research on Early Warning Mechanism

In 2009, Sun Jun^[3] analyzed the correlation between structural response and temperature, took the mean value as the upper and lower limit of the index to control, and warned the test value that was not within the limit. In 2010, Zheng Chun et al.^[4] gave the framework and process of early warning based on the two bridges of Zhoushan Sea-Crossing Bridge, and divided the early warning into online and offline two steps. In 2012, Zheng Gang^[22] analyzed the possible abnormal events in the structure, and gave the method to determine the early warning threshold of various abnormal events. In 2013, Hao Zhiqiang^[6] divided the existing monitoring data of the structure according to the period, and counted the probability distribution of the maximum value of the previous period. The statistical results were used as the warning threshold of the next cycle. In 2014, Wu Haijun^[7] put forward the idea of determine and early warning the operation state of bridge structure by taking the structural response under live load as an index.

At present, there are many research results on structural early warning. Liu Yongji^[8] takes the normative limit as the early warning value of monitoring results directly, and carries out early warning when it exceeds the scope. After early warning, the off-line evaluation of the structure is carried out, and the data processing method used is also a statistical method. Zong Zhouhong^[9] designed a hierarchical early warning model, which was divided into two levels: general level and safety limit level. he evaluation method adopted was a comprehensive evaluation method combined with periodic bridge inspection.

4. Problems in Current Research

At present, there will be many bridges to install health monitoring system, but most of them cannot really achieve early warning. At present, many bridges equipped with health monitoring system can measure the response under actual load state. However, the data are mixed in various noises, and the amount of data is large, but it is not effectively utilized. The goal of health monitoring system has not really been achieved. There are two main problems: firstly, it is difficult to distinguish abnormal data from structural response after a large number of data acquisition, not to mention the data accumulation caused by assessment and early warning; second, with the progress of technology, health monitoring equipment has become inexpensive, health monitoring system is more and more widely used, many construction units will be along the bridge health monitoring system data together to form a regional monitoring system.

The main problems are as follows:

(1) If the optimal sensor placement is not in place, the inappropriate location and number of sensors will easily miss the key data. The lifetime of the sensor and the length of the system design are not in conformity with each other, so the real operation period monitoring cannot be realized.

(2) The environmental noise and system noise in the test data are too large to affect the reliability of the data.

(3) Large amount of real-time data and imperfect on-line processing system are easy to cause accumulation and waste of data resources. Therefore, online real-time early warning cannot be realized.

(4) The bridge safety evaluation system is imperfect, and the monitoring data and final state evaluation are separated.

Although there are a lot of theoretical research results about health monitoring, it cannot be effectively applied to engineering practice. Because most of them are based on finite element models and damage identification methods to evaluate early warning, the identification process is difficult to carry out online, and even some can only set a threshold according to the calculated value of finite element model to carry out a single level early warning, which cannot really achieve the system objectives (online monitoring and early warning, off-line structural evaluation).

5. Trend analysis of monitoring system research

The health monitoring system of continuous rigid frame bridge will play a key role in the operation and maintenance of the bridge, and is the technical guarantee for the long-term health monitoring of the bridge. At present, with the progress of sensor technology, the cost of instrument is reduced, and the technology of transmission and acquisition is more and more advanced. Health monitoring is more and more installed in new bridges in our country, which not only makes progress in hardware, but also makes great progress in theoretical research. However, further research can be done in the following areas:

(1) Monitoring content is more comprehensive. The main monitoring contents of health monitoring system should include stress monitoring, environmental monitoring (temperature field monitoring of bridge components, etc.) and geometric monitoring.

(2) Hardware and software systems, data acquisition and transmission systems should be improved.

The Fiber Grating Sensor is commonly used in hardware monitoring system, which aims to provide users with later data analysis services. Software system should generally include: data acquisition, transmission settings and control module; data processing and analysis module; structural safety early warning module; structural state comprehensive evaluation module. The data acquisition and transmission system can only reliably and accurately transmit the field data signals, and only after the later data analysis and processing can the structural abnormalities be found and the structural state be correctly evaluated.

At present, there are not too many technical obstacles in the hardware of the medium-span bridge health monitoring system, mainly reflected in how to rationally use the collected data to evaluate the bridge structure. The health monitoring system of continuous rigid frame bridge is controlled by the

cost. The health monitoring system of continuous rigid frame bridges is controlled by the cost. It cannot arrange all kinds of sensors like cable-stayed bridges and suspension bridges, and the number of measuring points is limited. These problems lead to difficulties in structural damage identification and structural comprehensive assessment. The theoretical and technical problems caused by incomplete data are even more complex than those of long-span bridges, which deserve more in depth study.

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