Strain Data Analysis of Small and Medium Bridge Structures Based on Finite Element

Mao Lin1,2, Lin Xu3, Dai Li1
1. Jiangxi Transportation Institute, Nanchang China
2. Research and Development Center on Technologies and Equipment of Long-span Bridge Construction Ministry of Transport, PRC, China Jiangxi Nanchang
3. Nanchang Highway Administration Bureau, Nanchang, China
Corresponding author: 584419998@qq.com

Abstract. Structural health monitoring technology is increasingly used in the operation and management of small and medium span bridge structures, which also brings the problem that it is difficult to fully interpret and utilize the mass monitoring data. In this paper, the Sanyang Bridge is used as the engineering background, based on the strain monitoring data, combined with the finite element calculation software MIDAS/civil, to evaluate and analyze the operating state of the bridge structure. The results show that the overall operation status of Sanyang Bridge is good, the evaluation method combining finite element calculation and monitoring data is reasonable, this method can be applied to data processing and condition assessment of small and medium span bridges.

1. Introduction
As of 2019, there were 805,300 highway bridges in China, small and medium span bridges account for 90%. Due to construction quality, on-site inspection, maintenance and other reasons, the safety factor of medium and small span bridges is lower than that of large bridges. In addition, the phenomenon of focusing on construction and ignoring management in the field of bridges in China has also caused a large number of small and medium-span bridge structures to have varying degrees of safety hazards.

In order to reasonably save the cost of bridge maintenance and understand the actual status of in-service bridges, people began to build a long-term health monitoring system on the small and medium span bridge structures. For example, Professor Xiao Rucheng installed monitoring systems for more than 200 small and medium span bridges. The bridge health monitoring data can truly reflect the specific state of the bridge structure during the service period, and realize functions such as assessment and early warning. During the monitoring phase, the bridge long-term monitoring system will generate massive data, including stress (strain), overall vibration characteristics, deflection, and cracks of the bridge structure. The current difficulty of long-term bridge monitoring is to efficiently process massive monitoring data. Cloud storage technology has provided new ideas for solving the above problems in recent years, but its data utilization rate is low and the cost of data management is high.

To solve the above problem, this paper relies on the Sanyang Bridge equipped with a long-term monitoring system, based on the finite element software MIDAS/civil, combined with the bridge structure stress (strain) monitoring data, evaluate the technical status of the bridge to achieve the goal of early warning for small and medium-span bridges, and also provide example analysis for future technical assessment of small and medium-span bridges.
2. Project Overview
Sanyang Bridge is located on Changwan Highway, crossing Poyang Lake and Qinglan Lake from west to east. The upper structure of the bridge is a prestressed concrete simply supported box girder, which is composed of 4 small box girder horizontally, the box girder is 2.1m high, and the beam spacing is 3m; the bridge span arrangement is: 4×40m+4×40m+4+40m+5×40m+5×40m+5×40m+5×40m+5×40m. The cross-sectional schematic diagram of the mid-span section is shown in Figure 1.

![Figure 1. Cross-sectional view of the mid-span section of Sanyang Bridge](image1)

3. Overview of monitoring system
Stress (strain) monitoring is a key indicator to reflect the local stress and failure status of bridge components under load, by monitoring the critical stress section, directly understand the stress state of each measuring point, and provide a basis for the assessment and calculation of the bearing capacity, operating state and endurance capacity of the bridge. The upper structure of Sanyang Bridge is a prestressed concrete simply supported box girder, therefore, the cross section of each span is selected as the monitoring section and strain sensors are installed. Among them, 2 points are selected for safety monitoring per span, YBxx01 and YBxx02 are selected for odd spans, YBxx03 and YBxx04 (xx indicates the bridge span number) are selected for even spans, and the sensor layout for mid-span is shown in Figure 2, and the top view of sensor layout is shown in Figure 2.

![Figure 2. Sensor layout of the cross-section of Sanyang Bridge](image2)

4. Numerical simulation analysis
Based on the bridge finite element calculation software MIDAS/Civil, this paper conducts a full bridge finite element analysis of the Sanyang Bridge. According to the actual size and material, establish the bridge finite element model. The design load is car-super 20, tow-120, and pedestrian load-3.5kN/m². The full bridge finite element model is shown in Figure 3.

![Figure 3. Finite element model of Sanyang Bridge](image3)

In this paper, the calculation results mainly focus on the following three indicators:
(1) The maximum tensile stress (strain) on the lower edge of the mid-span section under the design load $\sigma_{\text{cont}}(\varepsilon_{\text{cont}})$.
(2) Under decompressed state of mid-span section, tensile stress (strain) of the lower edge of the mid-span section under the load of an automobile \( \sigma_{\text{con2}} \) \( (\varepsilon_{\text{con2}}) \);

(3) Under critical condition of box beam cracking, tensile stress (strain) of the lower edge of the mid-span section under the load of an automobile \( \sigma_{\text{con3}} \) \( (\varepsilon_{\text{con3}}) \).

In the calculation results of MIDAS/civil software, only the stress value of the beam element can be obtained, and the strain value of the beam element cannot be directly obtain. Therefore, this paper assumes that the bridge structure is in the state of elastic deformation. According to the stress-strain relationship, calculate the mid-span strain value of the main beam through the stress value of the bridge structure. The calculation results are shown in Table 1.

| Table 1. Stress and strain values at the lower edge of mid-span cross-section in various states |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | \( \sigma_{\text{con1}} \) (MPa) | \( \varepsilon_{\text{con1}} \) (\( \mu \varepsilon \)) | \( \sigma_{\text{con2}} \) (MPa) | \( \varepsilon_{\text{con2}} \) (\( \mu \varepsilon \)) | \( \sigma_{\text{con3}} \) (MPa) | \( \varepsilon_{\text{con3}} \) (\( \mu \varepsilon \)) |
| Numerical value | 6.4             | 197             | 6.2             | 191             | 7.85            | 242             |

5. Data analysis

Due to on-site power failure, data was not collected from January 10 to January 30, 2019, and the system returned to normal on January 30, 2019. In January, the normal number of sensors was 47, and the abnormal number was 27. In February, the normal number of sensors is 49 and the abnormal number is 25. In March, the normal number of sensors is 52 and the abnormal number is 22.

Statistical analysis of monitoring data, we can get a statistical chart of sensor strain data in the first quarter of 2019, and time history statistics of strain data, as shown in Figure 4 and Figure 5. In the Figure 4, the abscissa is the time, the ordinate is the strain value \( \varepsilon \). Simultaneously, in the Figure 5, the abscissa is the strain value \( \varepsilon \) and the ordinate is the Frequency of occurrence.

![Graphs of sensor strain time history](image1)

**Figure 4.** Summary graph of sensor strain time history in the first quarter of 2019
Figure 5. Summary graph of sensor strain data in the first quarter of 2019

Comparing the real-time monitoring data of Sanyang Bridge with the calculated warning threshold of the bridge structure, the results can be obtained in Figure 6, number of strain monitoring data and number of warning are shown in Table 2. First level warning of strain value is $197 \mu \varepsilon$, and cracking warning of strain value is $242 \mu \varepsilon$. 
Figure 6. Analysis chart of strain data in the first quarter of 2019

Table 2. Statistical Table of Strain Data of Sanyang Bridge

|            | Side beam | Center beam |
|------------|-----------|-------------|
|            | Strain    | First level warning | Cracking warning | Strain    | First level warning | Cracking warning |
| January    | 13740     | 0            | 0               | 12802     | 0            | 0               |
| February   | 21401     | 0            | 0               | 16659     | 0            | 0               |
| March      | 39424     | 0            | 2               | 32557     | 1            | 0               |

As shown in Figure 6 and Table 2, the strain data of Sanyang bridge in the first quarter is good. In March, there were two first level warnings and one cracking warning. It means that vehicles over the design load pass by on the bridge occasionally, causing the strain value of the bridge structure to exceed the warning value.

6. Conclusions
Through finite element calculation, the strain of Sanyang Bridge under design load is $197 \mu \varepsilon$, the corresponding strain in the decompressed state is $191 \mu \varepsilon$, and the corresponding strain value in the critical cracking state is $242 \mu \varepsilon$, the structure of Sanyang Bridge is in good condition. The finite element simulation method is convenient and fast, and can make full use of the massive monitoring data generated by the small and medium span monitoring system to realize the state assessment of the bridge structure.

Acknowledgments
This paper was supported by Science and technology project of Jiangxi Provincinal Department of Transportation(Grant No: 2018H0040). The authors also wish to thank the anonymous reviewers for valuable comments to earlier versions of this paper.

References
[1] Shi Yongxin. A preliminary study on the evaluation method of the technical status of small and medium-span beam bridges fused with long-term monitoring data [D]. Chongqing Jiaotong University, 2015.
[2] Meng Libo, Tang Guangwu. Study on the Architecture Scheme of Small and Medium-sized Bridge Monitoring System Based on Cloud Platform [J]. Highway Transportation Technology, 2013 (04): 106-109.
[3] Ren Yuan. Digital research on maintenance management system of long-span cable-stayed bridge [D]. Harbin Institute of Technology, 2008.
[4] Chen Shimin. Theory and application of massive data analysis in bridge monitoring system [D]. Chongqing University, 2011.
[5] Shi Deju. Research on structural condition monitoring system of small and medium-sized bridge group during operation period [D]. Chongqing Jiaotong University, 2015.