Research on real time monitoring of prestressed concrete beam bridge

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Abstract: In order to ensure the safe operation of the bridge, it is very necessary to establish real-time monitoring system on some extraordinary large-scale bridges. In this paper, the prestressed concrete continuous beam bridge is taken as the research object. Firstly, ANSYS is used to establish the initial finite element model according to the design data of the bridge, and then update the calculation model to conform to the actual state of the structure. After that, the analysis of mechanical performance under design load is carried out to provide a theoretical basis for the optimal placement of sensors. Finally, the bridge real-time monitoring system is set up and the collected monitoring data (displacement, strain, acceleration, etc.) is taken a statistical analysis, for the purpose of making a preliminary judgement on the actual operation of the bridge, and being considered as the theoretical basis and database of real-time monitoring system for follow-up study.

1. Introduction
In recent years, the safety accidents of bridges have occurred from time to time. In order to ensure the safe operation of bridges, it is very necessary to establish real-time monitoring system on some key special large bridges. The function of the bridge real-time monitoring system is to monitor the behavior of the bridge structural in real time, to make judgements on whether the structural is damaged and to make clear the location and the severity of the damage, so as to evaluate the durability and reliability of the bridge, and provide the basis for the maintenance and management decision of the bridge[1].

2. Engineering Background
The length of the main bridge of a prestressed concrete continuous beam bridge is 500.9m, including 8 spans(40.45+6×70+40.45m). The width of bridge deck is 25.80m, the level of design load is automobile-over 20, trailer-120(General code for design of highway bridges and culverts) (JTJ_021- 89 ). The layout of the bridge elevation is as shown in Figure 1.

3. The establishment and correction of the model
The initial finite element model is established and corrected to conform to the actual structure according
to the design data and the static and dynamic load test data of the bridge. In addition, the finite element theory is used to calculate the effect of the design load and analyse the mechanical properties, which provides a theoretical basis for the optimal layout of the sensor for the real-time monitoring system of the bridge [2,3].

3.1. The establishment of the finite element model
The three-dimensional finite element model of the bridge is established by ANSYS, as shown in Figure 2.

3.2. Finite element model correction
In this paper, the correction of finite element model is based on dynamic and combined Parameter modification method[4]. Several parameters are chosen to modify the model, such as the mass density and elastic modulus of concrete, the flange thickness of box girder and the spring stiffness coefficient of lateral and longitudinal of supports.[5] The revised results are shown in Table 1, and the revised parameters are shown in Table 2.

| Content                      | Measured frequency | Before correction | After correction |
|------------------------------|--------------------|-------------------|------------------|
|                             | Modal order        | Measured frequency | Error (%) | MAC            | Measured frequency | Error (%) | MAC            |
| Lateral nature vibration    | 1                   | 1.17              | 1.02          | 13.1          | 71.4              | 1.25        | -7.2          | 87.8            |
|                             | 2                   | 1.66              | 1.15          | 30.7          | 70.3              | 1.42        | 14.6          | 87.4            |
|                             | 3                   | 2.05              | 1.57          | 23.4          | 74.7              | 1.90        | 7.4           | 84.5            |
| Vertical nature vibration   | 1                   | 1.27              | 1.08          | 15.1          | 90.4              | 1.26        | 0.7           | 98.1            |
|                             | 2                   | 1.47              | 1.32          | 10.1          | 91.5              | 1.51        | -2.6          | 94.2            |
|                             | 3                   | 1.86              | 1.65          | 11.1          | 89.1              | 1.85        | 0.4           | 98.6            |
|                             | 4                   | 2.35              | 2.04          | 13.3          | 88.1              | 2.26        | 3.9           | 97.4            |
|                             | 5                   | 2.74              | 2.22          | 19.1          | 85.2              | 2.70        | 1.5           | 91.3            |
6 3.13 2.46 21.4 84.5 3.16 -1.1 92.5

Table 2. changes in parameters before and after correction.

| Parameter | Elastic modulus of concrete (3.5×10^4 MPa) | Mass density of concrete (kg/m^3) | Roof thickness (m) | Transverse spring stiffness (10^7 N/m) | Longitudinal Spring stiffness (10^8 N/m) |
|-----------|------------------------------------------|----------------------------------|-------------------|---------------------------------------|----------------------------------------|
| Before correction | 1.000 | 2550 | 0.250 | 2.000 | 0.800 |
| After correction  | 1.188 | 2423 | 0.294 | 2.618 | 1.092 |
| Parameter changes | 18.8% | -5.0% | 17.6% | 30.9% | 36.5% |

It is concluded that the calculated values of the dynamic characteristics are more consistent with the measured values, indicating that the modified model can accurately reflect the actual situation of the bridge. This model is used to calculate and analyze the load of bridge design, and obtain the maximum load effect, which is used as the theoretical threshold of the real-time monitoring data of the bridge.

4. Bridge real time monitoring system

4.1. system composition

The bridge real-time monitoring system is composed by 4 systems including sensor subsystem, data acquisition and transmission subsystem, data signal processing and control subsystem and structure early warning state evaluation subsystem [6].

4.2. Sensor system

Sensor system is an important part of bridge real-time monitoring system. In terms of technology, the keypoints of bridge real-time monitoring are the optimization of the sensor layout and the efficient transmission of information [7].

The control cross section of the main girder is determined according to the mechanical analysis results of the bridge, and then the optimal layout scheme of the sensor is determined. The South half bridge is chosen as the main research object of the real-time monitoring of this bridge. The layout scheme of the sensor is shown in Figure 3, and the scene sensor layout is shown in Figure 4.
5. Analysis of real-time monitoring data of bridge
The preliminary statistical analysis of the monitoring data of the bridge is carried out to know the actual state of the bridge and provide a theoretical basis for the future structural state evaluation, so as to provide guidance for the maintenance of the bridge and provide a scientific basis for the safety early warning of the bridge[8].

5.1 Analysis of displacement monitoring data
The deflection of each measuring point within a week is shown in Figure 5.
5.2. Analysis of stress monitoring data
The stress changes within ten days of the bridge are shown in Figure 6.

5.3. Analysis of acceleration monitoring data
The acceleration response of the bridge during one day is shown in Figure 7.

5.4. Comparison of the monitoring displacement and stress and theoretical threshold
By comparison of the displacement and stress extremes of each monitoring section obtained from the bridge monitoring with the theoretical calculation threshold, the state of bearing capacity of the bridge is preliminarily judged. The ratio of measured value to theoretical threshold is shown in Table 5 and 6 respectively.
Table 5. Ratio of measured values of displacement to theoretical threshold of each monitoring section of bridge (unit: mm).

| Section              | First span midspan | Second span midspan | Third span midspan | Fourth span 1/4 cross section | Fourth span midspan |
|----------------------|--------------------|---------------------|--------------------|------------------------------|---------------------|
| Theoretical threshold| -10.82             | -19.63              | -17.02             | -8.39                        | -20.37              |
| Measured value       | -1.58              | -12.67              | -8.34              | -5.01                        | -8.71               |
| Ratio                | 0.15               | 0.65                | 0.49               | 0.60                         | 0.43                |

Table 6. Section stress extremes of bridge monitoring points (unit: MPa)

| Section              | Fourth span midspan | Fourth span right support |
|----------------------|---------------------|---------------------------|
|                      | Theoretical threshold | Measured value | Ratio | Theoretical threshold | Measured value | Ratio |
| Roof                 | -3.38               | -0.84                    | 0.25  | 0.78                | 0.53           | 0.68  |
| Floor                | 6.63                | 1.76                     | 0.27  | -1.11              | -0.63          | 0.56  |

As a result, the bridge can meet the requirements of structural stiffness and bearing capacity in the aspect of both deformation and stress. The measured value is less than the threshold value of the theoretical calculation because the load of the bridge does not reach the maximum value under the design condition during the monitoring.

6. Conclusion

- According to the theoretical calculation and analysis method of this paper, the structural response of the prestressed concrete continuous girder bridge under various loads is obtained, and the mechanical characteristics of the structure can be grasped, which can provide the theoretical basis for the optimization of the sensor layout of the real-time monitoring system.
- The real-time monitoring data of the bridge can be analysed by the method of statistical mode, and combining the calculation results under the effect of the design load, the actual operation status of the bridge can be judged preliminarily. The bridge has a good structure at the present stage and meets the design requirements.
- Through the subsequent long-term structural monitoring of the bridge, it can provide historical data for the damage identification and bearing capacity assessment of the bridge in the future, and can gradually realize the safety early warning of the bridge.

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