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Internet of Things based Construction and Health Monitoring of High-pier Long-span Continuous Rigid Frame Bridge

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***Abstract*—This paper studies the network system framework of construction and health monitoring for high-pier long-span continuous steel bridges based on the Internet of Things. First, use midas/civil to establish a finite element analysis model, perform construction simulation calculations, study the changes in the stress and deflection of the main beam during the maximum cantilever state, mid-span closing, and ten-year shrinkage and creep, and determine the key control The cross-section and control parameters provide a theoretical basis for the framework of the health monitoring network system; secondly, combining the theoretical analysis results of the Wen tang Bridge, the construction monitoring status and integrating it into the health monitoring system, the integration of sensor distribution, software equipment, and information technology is proposed Designed and established a complete network system framework for construction and health monitoring of high-pier and large-span continuous steel bridges. The application of Internet of Things technology to bridge monitoring (control) realizes the effectiveness and intelligence of bridge monitoring (control) information, and ensures the safety and reliability of the bridge structure.**

Keywords—*Internet of Things; rigid frame bridge; construction monitoring; bridge health monitoring.*

Introduction

The high-pier large-span rigid frame bridge is a special bridge type, which is difficult to construct. In the construction process of high-pier large-span continuous rigid frame bridge, bridge construction monitoring is a very important step. The key to construction monitoring is to control the stress and deflection of the main beam to ensure that the bridge reaches the linearity and stress state required by the design. Construction monitoring is to find the key control section during the bridge construction process, analyze the structural internal forces and deformation parameters in each construction stage in real time, and compare with the finite element modeling data to make corrections. Bridge construction monitoring system includes real-time measurement system, data acquisition system, data processing system, data storage system, linear and stress early warning system, etc. [1.2].

Bridge health monitoring uses modern sensing technology, communication technology and calculation and analysis technology to monitor the external load, natural environment and structural response of the bridge, so as to obtain the working state of the bridge in real time. Through data collection, analysis, processing and analysis of the structural status make judgments and make timely warnings of the potential risks of the bridge [3-5]. The information needed for construction and health monitoring, including bridge load information, geometric information, stress information, environmental status information, etc., is mediated by Internet or communication network, through two-way transmission and query of network information, summarized in real time in bridge monitoring (control) Cloud platform, through intelligent calculation analysis and intelligent, real-time evaluation strategy, to achieve high precision, high intelligence and high efficiency of bridge monitoring [6]. Based on Wen Tang Super Bridge, this article studies the integration of bridge construction monitoring system and health monitoring system. The integrated intelligent bridge monitoring method based on Internet of things is the combination of traditional bridge construction monitoring method and health monitoring theory and practical experience. Comprehensive use of bridge engineering, modern wireless sensors, big data analysis, Internet of things technology, computer technology, damage identification and structural safety assessment and other modern technologies and equipment, to facilitate the design and implementation of the system [7-10].

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I. ANALYSIS OF CONSTRUCTION MONITORING DATA

A. Project Overview

The main bridge of Wen Tang Bridge is (95+180+95) continuous rigid frame main beam adopts prestressed concrete variable cross-section cantilever box girder, box girder is left and right split single box single room cross section, the upper structure box girder uses C55 concrete The height of the main beam and the bottom plate are changed by 1.8 times of parabola. The height of the root beam of the fulcrum in the box beam is 1160cm, and the height of the beam in the mid-span and side-span is 350cm. The superstructure of the main bridge adopts longitudinal, horizontal and vertical prestressed systems. The main bridge pier adopts C50 concrete, and the main pier No. 4 and 5 adopt double-limb thin-wall pier, and the foundation adopts pile cap foundation.

B. Finite element modeling

This paper uses Midas/Civil to perform finite element analysis on Wen Tang Bridge, and the model is shown in Figure.1. The finite element model can simulate various construction stages, and can fully consider the influence of the shrinkage and creep of the main beam and the loss of prestress on the internal force according to the characteristics of the continuous rigid frame bridge.

The simulated construction stage of the bridge can be divided into 52 stages, and most of the stress stages from the completion of the pier to the 10 years after the completion of the bridge girder are summarized .The software defines the assumed various factors and basic structures as structural groups, load groups, and boundary groups, and simulates the entire construction through activation and passivation among the three groups.

The specific data are as follows: (1) Structure group: main pier, main beam 22 segments, side span cast-in-place section, side middle span helong section, block 0#; (2) boundary group: main side pier permanent support, 0# block cast-in-place, side span cast-in-place, main side pier rigid connection, main pier temporary wind rigid connection, side pier temporary rigid connection; (3) load group: hanging basket, wet weight, prestress, weight, second Period load.

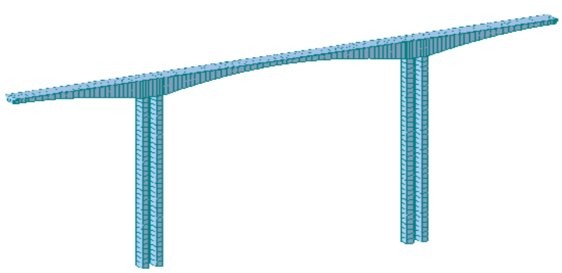

Fig. 1. Finite element modeling.

C. Analysis of calculation results

Using Midas/Civil to analyze the displacement and stress of the continuous beam during the construction process, the theoretical displacement value is the basis of the linear control of the bridge, and the theoretical stress value is the basis of the bridge stress control. According to the software, the pre-camber value of each section of the construction process is calculated, the deformation value of the hanging basket is obtained according to the pre-compression test, and the design elevation is added to calculate the vertical form elevation of each stage. The finite element analysis software was used to study the changes of the stress and deflection of the main beam during the process of maximum cantilever state, mid-span closing, and ten-year contraction and creep. Figure.2. Distribution map of maximum cantilever state, mid-span closing, ten-year contraction and creep stress， and Fig.3. Distribution of maximum cantilever state, mid-span closing, ten-year contraction and creep deflection.

During the maximum cantilever state during construction, the cumulative deflection of the side span reaches a maximum of -44.76mm; the cumulative deflection of the middle span reaches a maximum of -41.15mm; the maximum point of compressive stress appears in the side span with a value of 10.90 MPa; the maximum compressive stress of the mid span occurs At 1/4 section, the value is 10.82 MPa.

In the closed state of the mid-span, the accumulated deflection of the side span is up to -40.74mm; the accumulated deflection of the middle span is up to -38.47mm; the maximum point of the compressive stress of the side span appears in the middle of the span, the value is 11.15MPa; the maximum compressive stress of the middle span appears in the span In the middle, the value is 13.66 MPa.

Ten years of shrinkage and creep, the cumulative deflection of the side span reaches a maximum of -49.05mm; the cumulative deflection of the mid span reaches a maximum of -43.50mm; the maximum point of the compressive stress of the side span appears in the middle of the span, the value is 10.84 MPa; the maximum compressive stress of the middle span appears at At mid-span, the value is 10.15MPa.

D. Parameter sensitivity analysis

During the construction process, different design parameters have different effects on the structural state. The change of parameters directly affects the deformation and internal force of the structure, and the design parameters that affect the state of the bridge structure (force and deformation) mainly include: ① structural geometry parameters; ② material characteristic parameters; ③ section characteristic parameters; ④ load parameters; ⑤ and Time-related parameters, such as shrinkage and creep [11]. This article mainly takes the deflection of the main beam (side span and middle span) after the ten-year contraction and creep of the completed bridge as the control target, mainly analyzes the parameter sensitivity of the concrete bulk density and concrete elastic modulus, and the pipeline friction coefficient and pipeline deviation coefficient . These data have little effect on deflection, so this paper does not analyze the deflection [12]. Each parameter changes by 10% to see its effect on structural deformation. The main design parameters of sensitivity analysis are shown in Table Ⅰ, and the influence of deflection is shown in Figure .4. ~ Figure. 5.

TABLE I. SENSITIVITY ANALYSIS OF MAIN DESIGN PARAMETERS

Analysis parameters	Parameter value		
	Design value	***10% increase***	***10% reduction***
Bulk density(KN/m³)	26	28.6	23.4
Modulus of elasticity(MPa)	35500	39050	31950

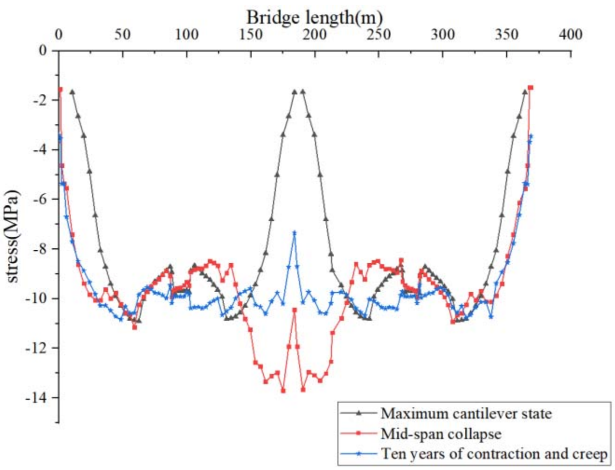

Figure. 2. Distribution map of maximum cantilever state, mid-span closing, ten-year contraction and creep stress.

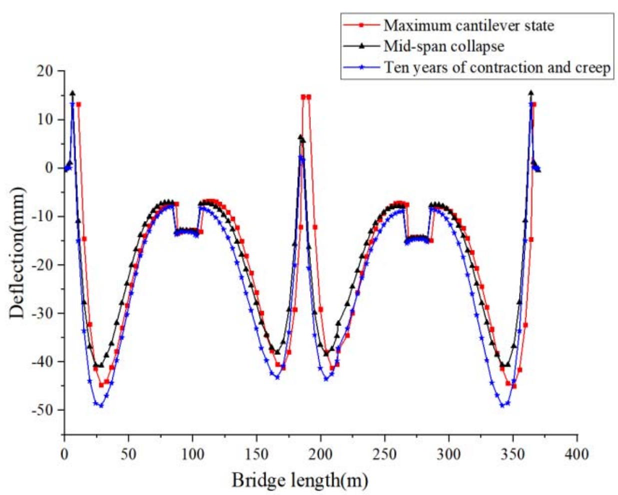

Fig.3. Distribution of maximum cantilever state, mid-span closing, ten-year contraction and creep deflection

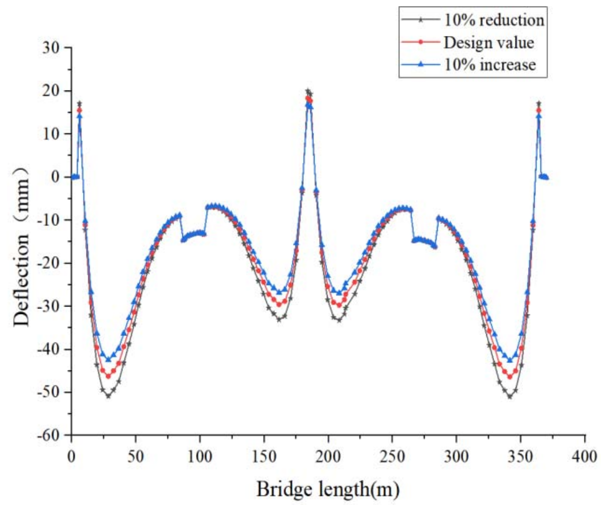

Figure.4. The influence of concrete elastic modulus on deflection

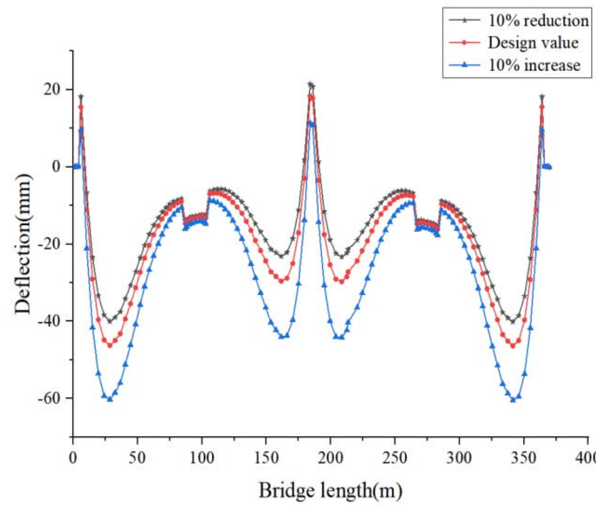

Figure 5 Effect of concrete bulk density on deflection

The results show that the influence range of concrete elastic modulus on deflection is within 10%, and the maximum influence range of concrete bulk density on deflection can reach 34%. It can be concluded from the data,oncrete elastic modulus and bulk density are the key factors that need to be controlled during the bridge formation process. The pipeline friction coefficient and pipeline deviation coefficient not studied in this paper need not be considered.

II. INTEGRATED RESEARCH ON CONSTRUCTION AND HEALTH MONITORING

With regard to the characteristics of the high-pier large-span of Wen Tang Super Bridge, the integrated design of the bridge's construction monitoring system and long-term health monitoring system is established based on the theoretical analysis results of Wen Tang Super Bridge. The design includes the following points. 1) For the characteristics of the bridge at different construction stages and after the bridge is completed, design sensors are integrated for distribution, reasonable control section is set, test equipment is optimally arranged and pre-buried in advance. 2) The integrated design of software equipment adopts supporting software products with mature technology and high cost performance to ensure the stability and accuracy of the system and the reliability of the system, and meet the needs of system improvement, improvement and update. 3) The integrated design of information technology, the use of Internet of Things, cloud computing, big data and other information technologies to establish a complete set of bridge monitoring (control) system to make the bridge safer and more reliable, step into a new informatization, technology and Technological era.

A. Integrated design of stress sensors for construction and health monitoring

When designing the bridge wireless stress sensor, the ZigBee wireless short-range data transmission function is used, and the low-power design supports multi-level sleep and wake-up modes to minimize power consumption. The communication distance is large, from the standard 75m to hundreds of meters, several kilometers, and supports unlimited expansion. The optimal layout of wireless stress sensors has also become a key point. Combining the monitoring of the construction stage and the health monitoring stress distribution under the ten-year contraction and creep state, the integrated design of construction and health monitoring stress sensor distribution is realized. 2 Analysis shows that the maximum stress points of the main span and side span are concentrated in the mid-span position, and the 1/4 section is relatively large. The monitoring section layout of the stress sensor of the main bridge is shown in Figure.6. There are a total of 11 test sections, including 1-1, 1-6 and 1-11 cross-sections, 1-3 and 1-9 cross-sections, and 1-4 and 1-8 cross-sections. Sections 1-5 and 1-7 are at 1/8 section. The optimized layout of the stress sensor can quickly and efficiently monitor the real-time stress state of the bridge and ensure the safety and reliability of the structure.

During the displacement monitoring of the bridge, under the action of wind load, vehicle load and brake load, the measurement points will produce lateral, longitudinal and vertical displacements. Thus,Long-term displacement monitoring in multiple directions is required. The distance measured by the old sensor system changes, and the value obtained does not meet the actual engineering needs, so the optical fiber ultrasonic three-dimensional displacement sensor is used in the bridge. The optical fiber ultrasonic three-dimensional displacement sensor system can not only ensure the accuracy of large displacement and small displacement in one direction of the measuring point, but also measure the three-dimensional displacement of the measuring point with high precision [13]. The optimal arrangement of displacement sensors, combined with the monitoring of the construction stage and the distribution of health monitoring deflection under the ten-year contraction and creep state, realizes the integrated design of the construction and health monitoring displacement sensor distribution, which can be obtained from the analysis of Figure 3 above: The cumulative maximum deflection in the span is at 1/4 section, while the cumulative maximum deflection in the middle is at 1/3 section. The monitoring section layout of the displacement sensor of the main bridge is shown in Figure.7. There are a total of 9 test sections, of which 2-4 sections are mid-span sections, 2-2, 2-6 sections are fulcrum sections, 2-1, 2-7 sections are 1/4 sections, 2-3, 2-5 sections At 1/3 section.

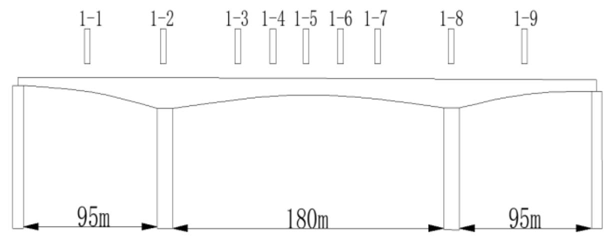

Figure. 6. Layout of the monitoring section of the main bridge stress sensor

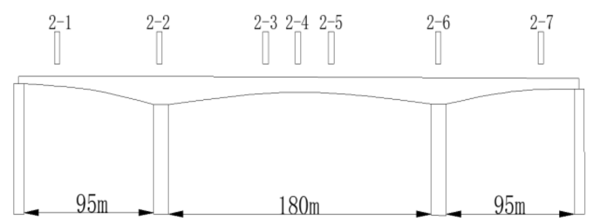

Figure.7. Layout of monitoring cross section of main bridge displacement sensor

B. Integrated design of construction and health monitoring software equipment

Software subsystem mainly includes data acquisition software subsystem, data processing software subsystem, database software subsystem, user interface software subsystem, mobile application software subsystem. In order to meet the simultaneous needs of construction and health monitoring, the integration of related software can be achieved. Due to the different goals of construction and health monitoring, the software has different functional requirements, and the software should be comprehensively designed to form the integration of construction and health monitoring software and equipment.

C. *Integrated design of construction and health monitoring information technology*

Based on the latest Internet of Things, cloud computing, big data and other information technologies, a new construction and health monitoring system is established. The Internet of Things, cloud computing and big data processing are the three important guarantees for the development of monitoring (control) systems, Supported by the powerful computing, storage and compatibility capabilities of the cloud platform, to achieve networked and intensive management [14]. The use of big data storage and management, intelligent mining and intelligent processing of massive data in the later period, to achieve the accuracy and effectiveness of bridge data. The design scheme of the system is mainly based on the wireless sensor network (WSN) [15], which can be adapted to both construction and health monitoring. Therefore, it is more suitable for the construction of bridge monitoring (control) systems. The system provides more comprehensive basic data, and uses real-time wireless transmission technology to transfer data to the bridge monitoring (control) cloud platform built. The integrated design scheme is shown in Figure.8.

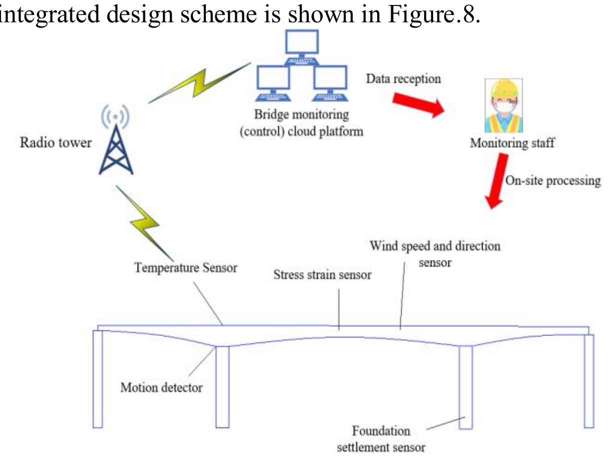

Figure .8. Integration of information technology

D. *Integrated design of construction and health monitoring system*

The integrated design of construction and health monitoring system during operation period, in the state of construction monitoring of Wen Tang Super Bridge, and the integration of structural health monitoring system, a brand new bridge monitoring (control) system was established. It integrates the traditional monitoring mode and uses modern brand-new wireless sensors, cloud platforms, big data processing, and Internet of Things technologies. As shown in Figure 9, the integrated design flow chart of bridge monitoring (control).

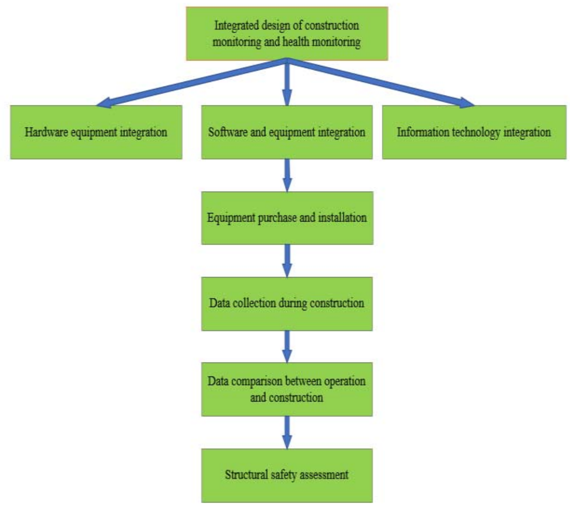

Figure. 9. Flowchart of integrated design of bridge monitoring (control)

The integration of the bridge monitoring (control) system fully considers the optimization of the construction of the new bridge itself and the layout of the health monitoring system during the operation period and the sharing of monitoring data, the consistency of later data processing and software operations, and reduces the system software base of a single project. Development and construction costs, while significantly improving project management, operation and maintenance efficiency. Considering the long-term interests of the country and locality, the concept of integrated design of construction and health monitoring system during operation period will contribute to the significant improvement of bridge construction and maintenance management.

III. IN CONCLUSION

(1) Taking the actual bridge under construction as the background, Due to the tensioning of the prestressed steel beam, the deflection decreases correspondingly, while the maximum compressive stress at the middle span section of the middle span is 13.66mpa. With the change of time, the deflection of side span and middle span increases correspondingly, and the maximum rate of change can reach 20.42%.

(2) The elastic modulus and bulk density of concrete are two key factors that need to be controlled in the process of bridge construction. The influence range of concrete elastic modulus on deflection is within 10%, while the maximum influence range of concrete bulk density is up to 34%.

(3) To establish a set of bridge construction monitoring system and health monitoring system based on sensor distribution, software and information technology integration design, the construction and health monitoring organic combination, can effectively reduce the cost. In addition, the

measured data of construction monitoring, the calculation model of construction monitoring and the calculation process of each stage are carried out cloud database, which is convenient for the bridge health monitoring data to be separated at any time The analysis of transfer and initial state is more conducive to the structural maintenance and construction operation period of the bridge.

(4) With the continuous progress of science and technology and the rapid development of the Internet of things, the relationship between bridge monitoring and Internet of things is deepening. In the future era, intelligent monitoring, intelligent sensors and big data analysis will emerge from bridge monitoring (control).

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