

# Innovative Application of Construction Technology and Structural Health Monitoring System for Half-through Concrete-filled Steel Tube Arch Bridges

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## Abstract

This article focuses on the half-through Concrete-filled Steel Tube (CFST) arch bridge, focusing on the innovative application of its construction technology and structural health monitoring system. In view of the important position of this type of arch bridge in modern bridge engineering and the limitations of the existing technology, through the combination of theoretical analysis, numerical simulation and practical engineering cases, the construction technologies such as fabrication and installation of steel tube arch ribs, concrete pouring and suspender tension are innovated and improved. Furthermore, a comprehensive structural health monitoring system is constructed, including sensor arrangement, data acquisition and transmission, data processing and analysis based on wavelet analysis and finite element model updating algorithm. The experimental results show that the new construction technology significantly improves the quality of steel tube arch rib and the efficiency of concrete pouring, and the data of structural health monitoring system is reliable, and the algorithm can accurately assess the structural state. Thus, the innovative application of this article can effectively improve the quality of bridge construction and structural safety, and provide useful reference for the technical development in the field of bridge engineering.

## Keywords

Half-through CFST Arch Bridge; Construction Technology; Structural Health Monitoring System; Innovative Application; Bridge Engineering.

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## 1. Introduction

In the field of modern bridge engineering, half-through CFST arch bridge is widely used in projects across rivers, valleys and other complex terrain because of its unique structural form, beautiful shape and good mechanical properties [1]. This kind of arch bridge perfectly combines the tensile performance of steel pipe with the compressive performance of concrete, which not only reduces the weight of the structure, but also improves the bearing capacity and span capacity of the structure [2]. However, the construction process of half-through CFST arch bridge is complex, involving many key technical links, such as the fabrication and installation of steel tubular arch ribs, concrete pouring, suspender tension and so on. Problems in any link may affect the overall quality and safety of the bridge [3]. Therefore, it is very important to explore and innovate construction technology continuously to ensure the smooth progress of the project and improve the quality of bridge construction.

With the increase of bridge service time and traffic flow, bridge structures are facing more uncertainties and potential risks [4]. As an effective means of real-time and dynamic assessment of the safety status of bridge structures, structural health monitoring system can find structural damage

and potential safety hazards in time and provide scientific basis for the maintenance, repair and management of bridges [5]. At present, although some achievements have been made in the construction technology and structural health monitoring system of half-through CFST arch bridge in the world, there are still some problems to be solved urgently [6]. This article focuses on the innovative application of construction technology and structural health monitoring system of half-through CFST arch bridge. The purpose of this article is to put forward innovative solutions through in-depth analysis of the advantages and disadvantages of existing technologies, and verify their effectiveness with practical engineering cases, so as to provide useful reference for promoting the technical progress and development in the field of bridge engineering.

## **2. Construction Technology of Half-through CFST Arch Bridge**

The steel tube arch rib is made of YEATION material and processed according to the precise design size. Steel cutting should ensure smooth incision, control deformation during welding, and adopt nondestructive testing to ensure weld quality. Cable hoisting method is commonly used in installation, which uses cable system to hoist arch rib segments to designated positions for splicing [7]. First, install the arch foot segment, fix it after positioning, adjusting verticality and elevation, then splice the subsequent segments in turn, and accurately measure and monitor during the process to ensure the linear accuracy of the arch rib.

Concrete pouring is the key process. Concrete with good self-compacting performance should be used to ensure uniform filling in the steel pipe. Before pouring, clean the inner wall of steel pipe, and set exhaust holes and grouting holes. It can be pumped and poured from the arch foot to the vault, and filled by concrete gravity and pressure flow [8]. Control the speed and height during pouring to avoid concrete segregation. Furthermore, check the compactness by tapping the steel pipe and ultrasonic testing, and handle the defects in time.

The selection of suspenders shall be determined according to the bridge load and structural stress, and its quality and performance shall be checked before installation. When installing, install anchorage at the position corresponding to the arch rib and the bridge deck system, penetrate the suspender and fix it. Tension follows the principle of symmetry and classification, and prestress is gradually applied according to the design cable force. During the tensioning process, the pressure sensor and the displacement meter are used for double control, so as to ensure the uniform stress of the suspenders, meet the design requirements and ensure the overall stability of the bridge. The foundation construction in arch support should ensure the bearing capacity of the foundation, select appropriate foundation forms according to the geological conditions, such as expanding the foundation or pile foundation, and control the quality of concrete pouring during the construction [9]. The construction of bridge deck system includes the laying of bridge deck, the construction of waterproof layer and pavement layer, etc. All links are closely connected to ensure the smoothness and durability of bridge deck and lay the foundation for the safe operation of bridge.

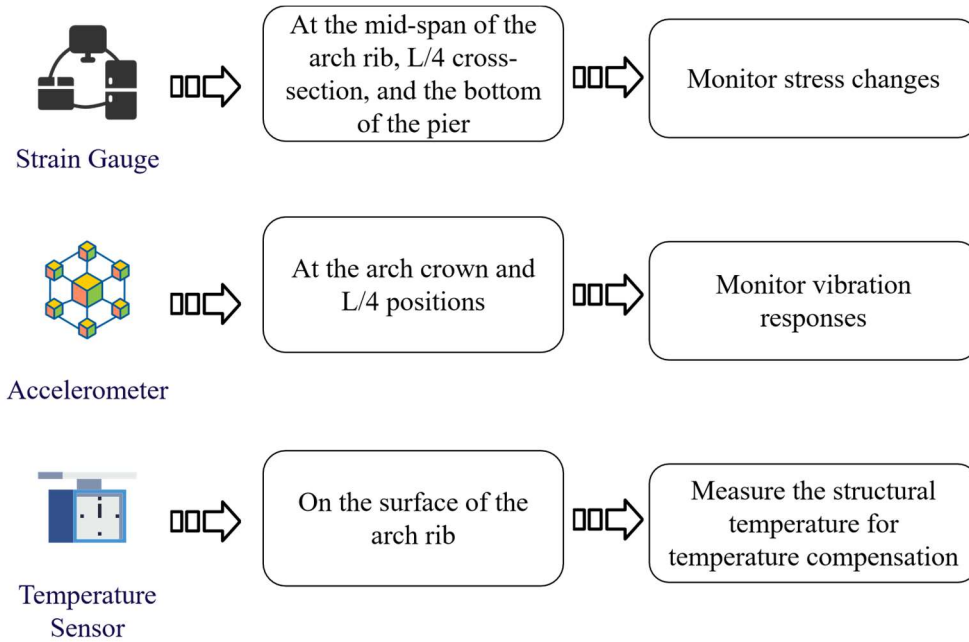
## **3. Half-through CFST Arch Bridge Structure Health Monitoring System**

The structural health monitoring system of half-through CFST arch bridge includes sensor arrangement, data acquisition and transmission, data processing and analysis, early warning and decision-making and other subsystems. Sensors are like the "tentacles" of the system, which are distributed in key parts of the bridge to collect information; The data acquisition and transmission subsystem is responsible for accurately collecting and transmitting data in time; The data processing and analysis subsystem deeply digs massive data and extracts key features; The early warning decision subsystem judges the structural safety state according to the analysis result and issues an alarm.

### **(1) Sensor selection and layout**

According to the structural characteristics and monitoring requirements of arch bridges, strain gauges are used to monitor the stress changes of key sections of arch ribs and piers. Accelerometers are

arranged at the vault, L/4 and other positions to monitor the vibration response of the bridge. Figure 1 shows in detail the specific arrangement position and function of different types of sensors on the bridge body.



**Figure 1.** Sensor arrangement of half-through CFST arch bridge

## (2) Data acquisition and transmission

The frequency and accuracy of data acquisition should be ensured, and the frequency of stress and strain acquisition should be set at 100Hz to ensure that the instantaneous stress change of the structure can be captured; The frequency of vibration data acquisition is 50Hz, which meets the vibration characteristic analysis. The collected data is transmitted by wired or wireless means. Wired transmission is used in convenient places such as bridge towers and piers to ensure data stability; For areas with difficult wiring such as arch ribs, wireless transmission is used, which is flexible and convenient.

In the process of data acquisition, for the collection of stress and strain data, we usually consider the sensitivity  $S$  of the sensor, which is defined as the ratio of output variation  $\Delta y$  to input variation  $\Delta x$ , namely:

$$S = \frac{\Delta y}{\Delta x} \quad (1)$$

This formula is helpful to accurately assess the sensitivity of strain gauge to stress change and ensure that the collected data can truly reflect the stress state of the structure.

## (3) Data processing and analysis

Data preprocessing removes outliers and noise interference. Wavelet analysis algorithm is used to decompose and reconstruct vibration data and extract features of different frequency bands. Taking the vibration monitoring data of a half-through CFST arch bridge as an example, through wavelet analysis, the local vibration details of the structure are captured in high frequency band, and the overall vibration trend is reflected in low frequency band. The core of wavelet analysis is wavelet function  $\psi(t)$ , and the wavelet basis function  $\psi_{a,b}(t)$  is constructed by translating and scaling it. Its expression is:

$$\Psi_{a,b}(t) = \frac{1}{\sqrt{|a|}} \Psi\left(\frac{t-b}{a}\right) \quad (2)$$

Among them,  $a$  is a scale parameter, which controls the expansion and contraction of wavelet function;  $b$  is a translation parameter, which controls the position of wavelet function. By choosing appropriate  $a$  and  $b$ , the vibration data can be analyzed at different scales, and the structural vibration characteristics can be effectively extracted.

Structural state evaluation adopts finite element model updating algorithm. According to the measured data, the parameters of the finite element model are constantly adjusted to make the calculated results of the model consistent with the measured values. For example, by adjusting the parameters such as elastic modulus  $E$  and moment of inertia  $I$ , the response difference between the model and the actual structure can be narrowed, and the real state of the structure can be accurately assessed. In the process of finite element model updating, the commonly used objective function  $J$  can be expressed as:

$$J = \sum_{i=1}^n w_i (\hat{y}_i - y_i)^2 \quad (3)$$

Where  $\hat{y}_i$  is the calculated value of the finite element model,  $y_i$  is the measured value,  $w_i$  is the weight coefficient, and  $n$  is the number of data points. By minimizing the objective function  $J$ , the parameters of the finite element model are continuously optimized to make it closer to the actual structural response. Furthermore, combined with statistical analysis method, the probability distribution model of structural response index is established to judge whether the structure is in normal working state.

#### (4) Early warning decision-making

Establish an early warning index system based on monitoring data, covering stress, strain, vibration displacement and other indicators. Set the warning threshold. If the stress exceeds 80% of the design value, a yellow warning will be triggered, and if it exceeds 95%, a red warning will be issued. Formulate decision-making methods, strengthen monitoring frequency in yellow warning, and take traffic control measures immediately in red warning. Through scientific early warning decision-making, the potential safety hazards of the structure can be found in time to ensure the safe operation of the bridge.

## 4. Case Analysis of Innovative Application

In order to verify the validity of the proposed construction technology and structural health monitoring system of half-through CFST arch bridge, a half-through CFST arch bridge under construction is selected as the experimental object. The length of the main span of the bridge is 200 meters, the width of the bridge is 12 meters, and the design load level is highway-I.

In the process of making steel tube arch rib, new welding technology and quality control method are adopted. The weld quality parameters at different welding stages were recorded experimentally, including weld width, residual height and nondestructive testing defect rate. Table 1 shows some key data. As can be seen from the table, the new welding technology makes the deviation of weld width within a very small range, the average weld residual height meets the standard requirements, and the defect rate of nondestructive testing is significantly reduced to 1%, which is greatly improved compared with the traditional technology, indicating that this technology has effectively improved the production quality of steel pipe arch ribs.

**Table 1.** Quality Parameters Table for Welding of Steel Pipe Arch Ribs

Welding Stage	Average Weld Bead Width (mm)	Weld Bead Width Deviation (mm)	Average Weld Reinforcement Height (mm)	Non-destructive Testing Defect Rate (%)
Backing Weld	8.5±0.2	±0.2	1.5±0.1	0.5
Filling Weld	10.2±0.3	±0.3	2.0±0.2	0.3
Cosmetic Weld (Cover Pass)	11.0±0.4	±0.4	1.8±0.2	0.2
Overall	-	-	-	1%

In concrete pouring construction, the compactness and pouring time of concrete in steel pipe are monitored by comparing the traditional pouring technology with the improved technology. The experimental results show that the improved grouting technology not only improves the compactness of concrete to more than 98%, but also shortens the grouting time by about 20%. This achievement effectively improves the construction efficiency and ensures the quality of concrete pouring.

Real-time monitoring of bridges is carried out by using the constructed structural health monitoring system. In the process of bridge loading experiment, stress, strain and vibration data under different load conditions are collected. Using data processing and analysis algorithm, the collected data are processed and compared with the theoretical calculation value. Table 2 shows the comparison of stress and strain data of arch rib midspan section under typical load conditions.

**Table 2.** Comparison Between Measured and Theoretical Values of Structural Responses Under Different Load Conditions

Load Condition	Measured Stress at Mid-span Section of Arch Rib (MPa)	Theoretical Stress at Mid-span Section of Arch Rib (MPa)	Relative Stress Error (%)	Measured Strain at Mid-span Section of Arch Rib ( $\mu\epsilon$ )	Theoretical Strain at Mid-span Section of Arch Rib ( $\mu\epsilon$ )	Relative Strain Error (%)
Condition 1	55.2	58.0	-4.83	210	220	-4.55
Condition 2	78.5	82.0	-4.27	305	320	-4.69
Condition 3	92.0	96.0	-4.17	360	380	-5.26

As can be seen from Table 2, the relative errors between the measured values and the theoretical values of stress and strain are controlled at about 5%. This shows that the data collected by the structural health monitoring system is reliable, and the data processing and analysis algorithm adopted can accurately assess the actual working state of the structure. Furthermore, in the monitoring process, the early warning decision-making system can send out early warning signals in time according to the set threshold, which provides an effective guarantee for the safety of the bridge structure.

Based on the analysis of the above experimental results, the construction technology and structural health monitoring system of half-through CFST arch bridge proposed in this article have performed well in practical engineering applications, which can effectively improve the construction quality and structural safety of the bridge.

## 5. Conclusion

In this article, the construction technology and structural health monitoring system of half-through CFST arch bridge are studied and a series of results are obtained. In terms of construction technology, the innovative welding technology is used to make steel pipe arch ribs, which greatly improves the weld quality and reduces the defect rate of nondestructive testing to 1%. The improved concrete pouring technology makes the concrete compactness reach over 98%, and the pouring time is shortened by about 20%, which significantly improves the construction efficiency and quality.

The construction of structural health monitoring system has also achieved remarkable results. By reasonably arranging all kinds of sensors, the stress, strain and vibration data of the bridge can be accurately collected. Wavelet analysis and finite element model updating are used to process the analysis data, and the results show that the relative error between the measured and theoretical values of stress and strain is controlled at about 5%. This shows that the data of the system is reliable and the algorithm can accurately assess the actual working state of the structure. The early warning decision-making system can also give early warning according to the threshold value, and escort the safe operation of the bridge.

In the future, more advanced technologies, such as deep learning algorithm in artificial intelligence, can be considered to further improve the intelligent level of construction technology and structural health monitoring system of half-through CFST arch bridge, so as to better adapt to the complex and changeable engineering environment and promote the sustainable development of bridge engineering.

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