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# Analysis of common diseases, monitoring, and maintenance of cable-stayed bridges

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**Abstract.** The tide of bridge building has passed. Nowadays, the monitoring and maintenance of bridges is very important for their safety, durability, and applicability, and it is the focus of the world's attention and research. This paper analyzes the common diseases and maintenance strategies of common cable-stayed bridges and cable-stayed bridges in coastal areas. This paper includes system composition, sensor layout, sensor types, monitoring objects, structural health status evaluation, and daily maintenance, as well as Sutong Bridge, Changmen Grand Bridge, and Ganjiang Grand Bridge of Changgan Passenger Transport in Ganzhou and other concrete examples. The modules and functions of structural health status assessment and the application of the bridge health monitoring system, such as early warning and assessment in the daily monitoring of cable-stayed bridges, are introduced. And Changmen Grand Bridge, Ganjiang Grand Bridge of Changgan Passenger Transport in Ganzhou, and Sutong Bridge are compared and analyzed according to the arrangement of measuring points, monitoring objects, and corresponding sensors. Finally, this paper briefly discusses the basic methods of preventive maintenance, BIM, and other related intelligent monitoring methods.

**Keywords:** cable-stayed bridge, bridge diseases, health monitoring, BIM, intelligent monitoring.

## 1. Introduction

As an important transportation infrastructure, bridges have been widely used all over the world, bringing convenience to human travel. With the continuous application and development of bridges and the increase in demand, a large number of bridges have been put into use. However, due to the complex structure of bridges, imperfect design and construction, untimely maintenance, and other reasons, a large number of bridges suffer from diseases to varying degrees during operation, which poses a threat to the durability and safety of bridges. With the increase in bridge age, the bridge's health condition deteriorates gradually. A set of health monitoring systems with excellent performance, comprehensive functions, and economic rationality is very important for the maintenance, design, construction, and management of bridges.

In this paper, the common diseases and maintenance strategies of cable-stayed bridges in different areas are analyzed. The health monitoring system is analyzed with specific examples, and the preventive maintenance measures of bridges are forecasted.

## 2. Common diseases and their conservation strategies

This chapter first analyzes the common diseases of cable-stayed bridges and discusses the corresponding protective strategies.

*2.1. Diseases and causes of cable stayed system of common cable -stayed bridge*

The main defects of common cable-stayed bridges are the cable, the anchorage system, and the cable tower. The main problems of the cable are cable retraction, cable force degradation, cable corrosion, cable vibration, and fatigue caused by improper anchoring system structure, construction error, temperature influence, etc. The cable will degrade to different degrees due to the decrease in steel wire strength caused by corrosion fatigue and the uneven deformation caused by breaking temperature. The structure of a long-span cable-stayed bridge will have wind sliding or large deformation under the action of the wind, resulting in wind induced oscillation failure of the cable-stayed bridge.

The main defects of the anchoring system are fatigue of the anchoring device and corrosion of the anchor head.

The damage of a reinforced concrete cable tower under various loads mainly manifests as local cracks in the cable anchorage area and cracks in the tower root due to the influence of a basic load and temperature. In addition, beam cracks may occur in pylons with a lower beam structure [1, 2].

*2.2. Maintenance policy*

In view of the common diseases of cable-stayed bridges, we can adopt the following maintenance countermeasures: First of all, strengthen the daily inspection and maintenance. Second, the protection's shape, such as the smooth surface of the protective casing into a rectangular bump or V-shaped groove. To keep stay cables from corroding, industrial hot extruded high-density polyethylene (HDPE) protective sleeves were used. Finally, the anti-wind energy of the stay cable is increased, such as by installing dampers at the contact point between the stay cable and the main beam or tower column and adding damping cables in the plane of the stay cable [3].

*2.3. Differences between cable-stayed bridges and common cable-stayed bridges in cold coastal Areas*

Cold coastal areas have large temperature differences, high air humidity, lots of winter snow melt water, and a lot of use of snow remover. It is different from common areas, so it is necessary to study and analyze the diseases and prevention of this kind of special bridges [4].

Large temperature difference may cause damage to the cable sheath and deterioration of the paint layer, including transverse and longitudinal cracking and scratches. Due to the high humidity in the air, the use of snow melt and a large amount of snow remover in winter will lead to steel beam corrosion damage and bridge deck pavement layer disease. The extensive use of snow remover containing chloride ions will cause further corrosion of deck paving. The influence of the damage of short-pylon cable-stayed bridge over time in an erosion environment is shown in Figure 1 below [5]:

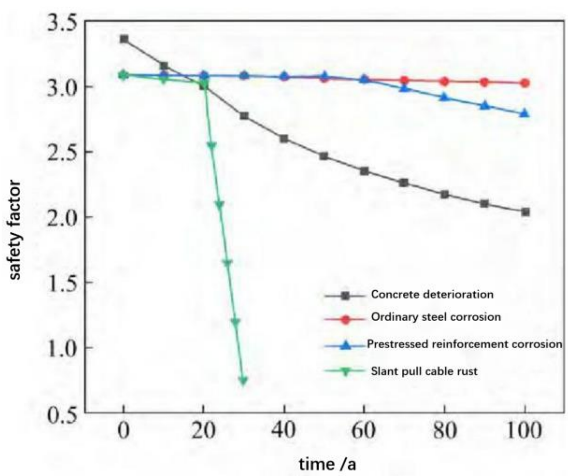


**Figure 1.** The influence of time on the damage of short pylon cable-stayed bridges in an erosion environment.

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### *2.4. Maintenance Strategy of Inclined Bridges in Cold Coastal Areas*

First of all, we should pay attention to the maintenance and repair of the stay cable. The interior of the bridge body is dehumidified. The bridge surface is coated with antirust grease. For the exposed part of the anchor, coat the surface of the cable wire with antirust grease and set up a stainless steel waterproof shield. We also need to use special packing material to seal the inside of the cable conduit to isolate the contact between the water, air, corrosive media, and the anchor. For the weak part of the seal, there are the internal polyurethane foaming agent, the sealing ring, the addition of a rain cover, and other measures to strengthen protection. Secondly, a viscoelastic high-damping material damping block is set at the interface parts of both ends of the cable. If necessary, a separation cable clip can also be set between the cables to achieve the effect of cable vibration reduction. Finally, it is necessary to improve the quality of the anticorrosive coating, actively prevent corrosion of steel, do a good job of anticorrosion of the joint of the anchor cable and cable body, regularly test the stay cable, and strengthen the development and application of new materials [4, 6].

## 3. Introduction of bridge health monitoring systems

Based on current research, most cable-stayed bridge health monitoring systems have similar principles. This paper will take Sutong Bridge as an example and compare and analyze Changmen Grand Bridge, and Ganjiang Grand Bridge of Changgan Passenger Transport in Ganzhou so as to elaborate on health monitoring systems of cable-stayed bridges.

### *3.1. Case study of sutong bridge*

System composition: Sutong Bridge health monitoring system is composed of a sensor subsystem, a data acquisition and transmission subsystem, a data management and control subsystem, and a structural health evaluation subsystem, for a total of four parts [7].

Sensor layout: Based on the analysis of bridge structural parameters and mechanical properties as the starting point, taking into account the bridge site environment, cost constraints, and other factors on the premise of meeting the needs of structural health assessment, the following sensor layout is obtained after careful analysis. [7]

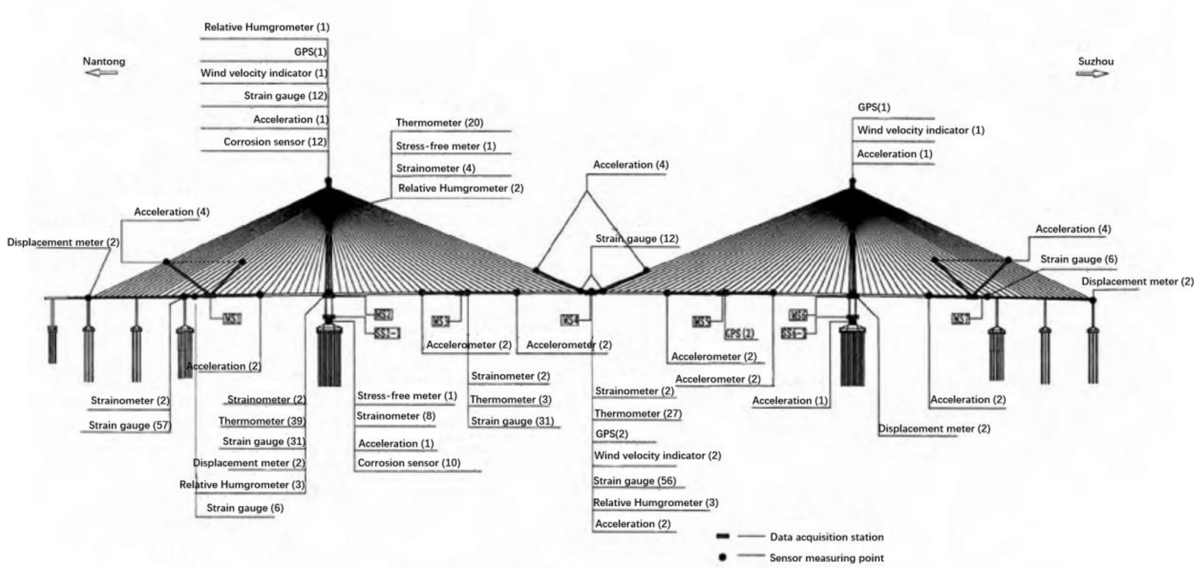


**Figure 2.** Schematic diagram of the connection between the sensor and the data acquisition station of the main cable-stayed bridge.

Sensor types and monitoring objects: Sensor monitoring objects can be divided into load monitoring and structural response monitoring. Table 1 below shows the monitoring items and corresponding sensor types of Sutong Bridge structural health monitoring and safety evaluation system [8].

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**Table 1.** Structural health monitoring items and corresponding sensor types of Sutong Bridge

| | Monitoring objects | Sensor types | | Monitoring objects | Sensor types |
|---|---|---|---|---|---|
| Load monitoring | Wind load | Three-way ultrasonic anemometer | Structural response monitoring | Global displacement | global positioning system (GPS) |
| | Temperature of steel member | temperature sensor | | Pylon, pier tilt | Bidirectional inclinometer |
| | Temperature of concrete member | temperature sensor | | support displacement | displacement sensor |
| | pavement temperature | temperature sensor | | Earthquake, ship pier and other acceleration | Three-way acceleration sensor |
| | Air temperature and relative humidity | Air temperature hygrometer | | | Bidirectional acceleration sensor |
| | Cable temperature | fibre optic temperature sensor | | strain | resistance strain gage |
| | transportation | Axle speedometer system | | | vibrating wire extensometer |
| | Corrosion of reinforced concrete members | Corrosion sensor | | cable force | Magnetic induction dynamometer |
| | | | | | Bidirectional acceleration sensor |
| | | | | | Portable acceleration sensor |

Structural health evaluation and daily maintenance: The health monitoring system of bridges is inseparable from daily maintenance. The health monitoring system guides the daily maintenance, which helps to improve the accuracy and scientificity of the evaluation of the health monitoring system. The two complement each other in order to achieve faster, better, and more comprehensive detection of structural defects and timely stop losses. Structural health evaluation and daily maintenance management are as follows:

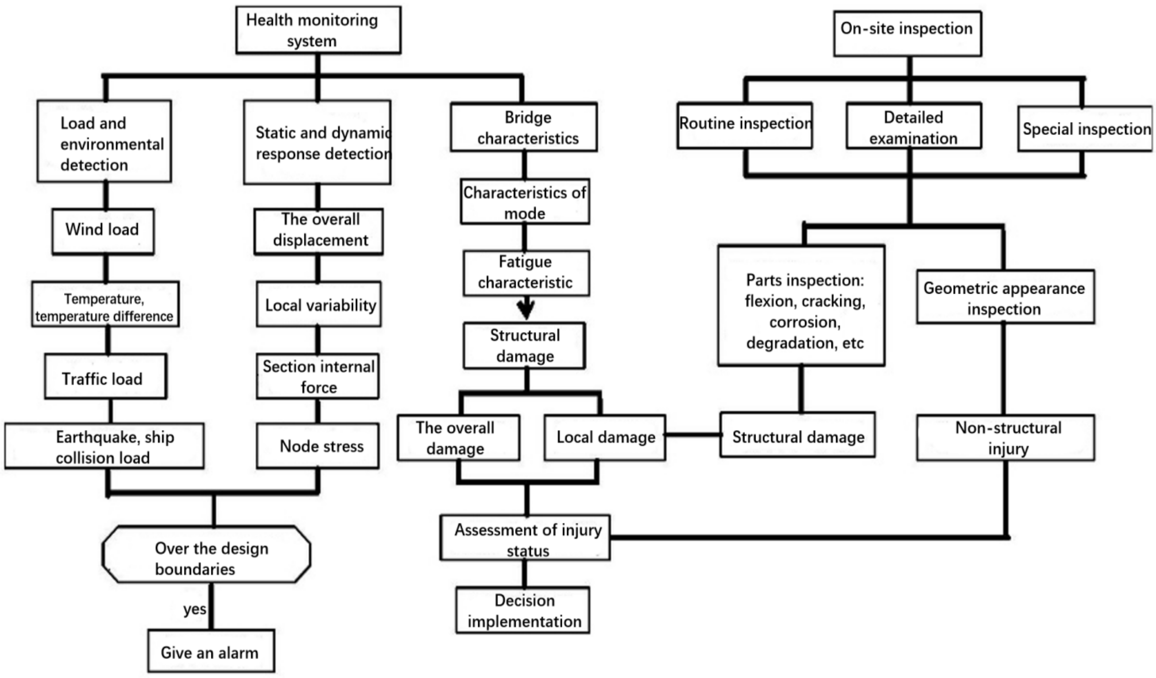


**Figure 3.** Evaluation of structure health status and daily maintenance management.

Component modules and functions of structural health assessment: The composition of Sutong Bridge structural health assessment system can be seen in Figure 4, and the functions of some modules are described as follows:

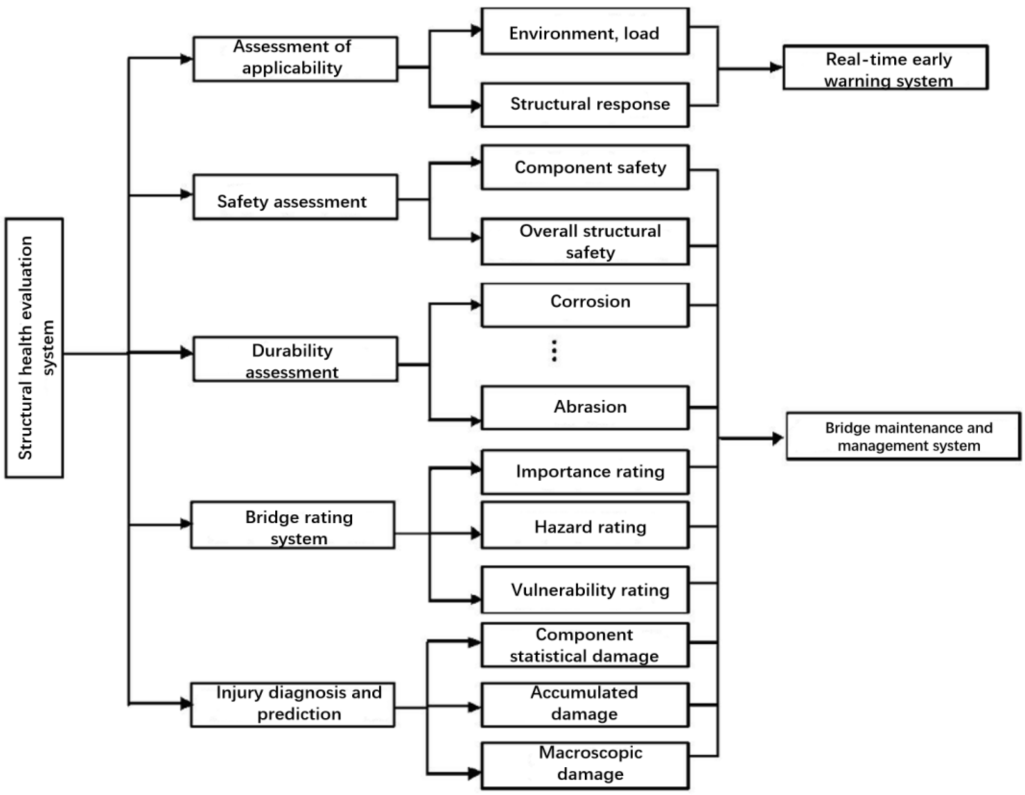


**Figure 4.** Sutong Bridge’s structure health evaluation system [8].

The main purpose of the applicability assessment is to ensure the serviceability of the bridge during its service life, control the degradation rate of the bridge and its components, and ensure the safety of

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driving. The main purpose of the bridge rating system is to provide a basis and guidance for the inspection and maintenance of bridge components. Component rating includes component importance classification, component risk classification, and component vulnerability classification, which are carried out in the way of score rating. The damage diagnosis and prediction module consist of three parts: statistical damage recognition of components, fatigue damage diagnosis and prediction of components or joints, and overall damage recognition [8].

Early warning and assessment: The threshold value of Sutong Bridge is studied by combining the traditional model and the numerical model. According to the red, orange, and yellow warning instructions, multi-level warnings of bridge health monitoring can be realized. The classification table of the warning threshold of the vertical deflection calibration coefficient of Sutong Bridge is shown in Table 2 below [9].

**Table 2.** Joint warning threshold classification table of the vertical deflection calibration coefficient of Sutong Bridge.

| Warning level | Safe state | Abnormal state | Hazardous condition |
|---|---|---|---|
| Range of threshold | $\zeta \leq 0.70$ | $0.70 < \zeta \leq 1.0$ | $\zeta > 1.0$ |

*3.2. Different Kinds of Cable-stayed Bridges and Sutong Bridge Health Detection System*

Design and layout of the monitoring points of Changmen Grand Bridge: The design and layout of the monitoring points of Changmen Grand Bridge are shown in Figure 5 below. Different from Sutong Bridge, Changmen Grand Bridge is equipped with two high-definition cameras on the north side of the main bridge. One HD camera will be installed on the south side of the main bridge and the lower part of the north tower. By means of video monitoring, the traffic vehicles and channel flow of the bridge during the operation period are monitored.

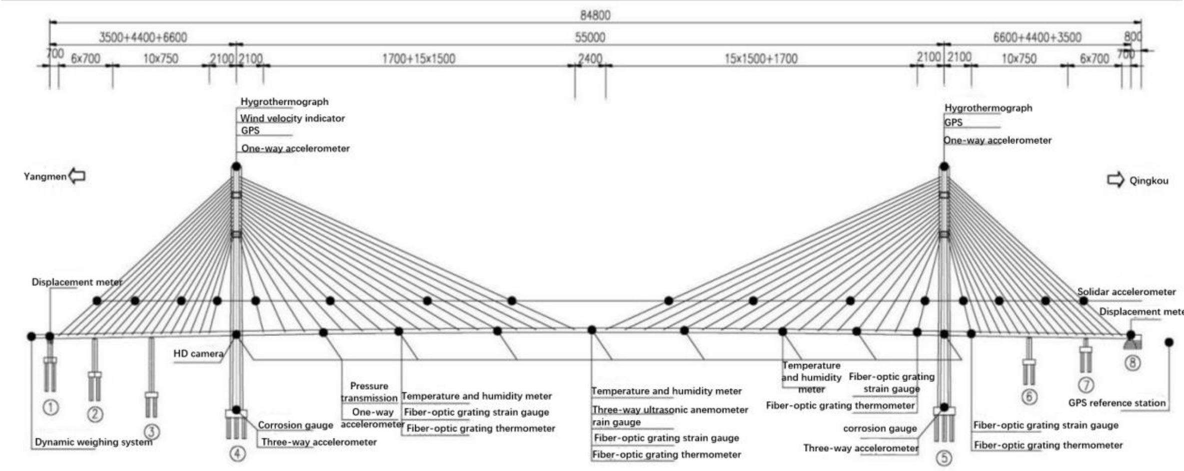


**Figure 5.** Layout of monitoring points on Changmen Grand Bridge.

Monitoring objects of Changmen Grand Bridge: Local response monitoring of the structure includes monitoring items such as section strain and temperature at key positions of main beams, concrete cracks, structural corrosion, and deformation of supports and expansion joints ,which are shown in Table 3 below [10].

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**Table 3.** Changmen Grand Bridge monitoring system monitoring objects.

| Monitoring item | Monitoring content |
|---|---|
| Load and environment | Wind speed and direction |
| | Earthquake |
| | Rainfall |
| | Ambient temperature and humidity |
| | Traffic load |
| Structural global response | Vibration and cable force monitoring of stay cables |
| | Bridge dynamic characteristics, vibration response monitoring |
| | Spatial displacement of tower and main beam |
| | Deflection of main beam |
| | Longitudinal displacement of main beam |
| Structure local response monitoring | Strain and temperature of key section of main beam |
| | Distress in concrete |
| | Structural corrosion |
| | Deformation of support and expansion joint |

Ganjiang Grand Bridge Health Monitoring System measuring point layout: Ganjiang Grand Bridge health monitoring system measuring point layout is shown in the figure below [11]. Similar to Changmen Bridge, Ganjiang Grand Bridge adopts five high-definition cameras for continuous monitoring of the beam end, four points of the main span, and the top of the tower. Through video monitoring, the bridge can grasp its apparent condition, traffic condition, and navigation condition in real time.

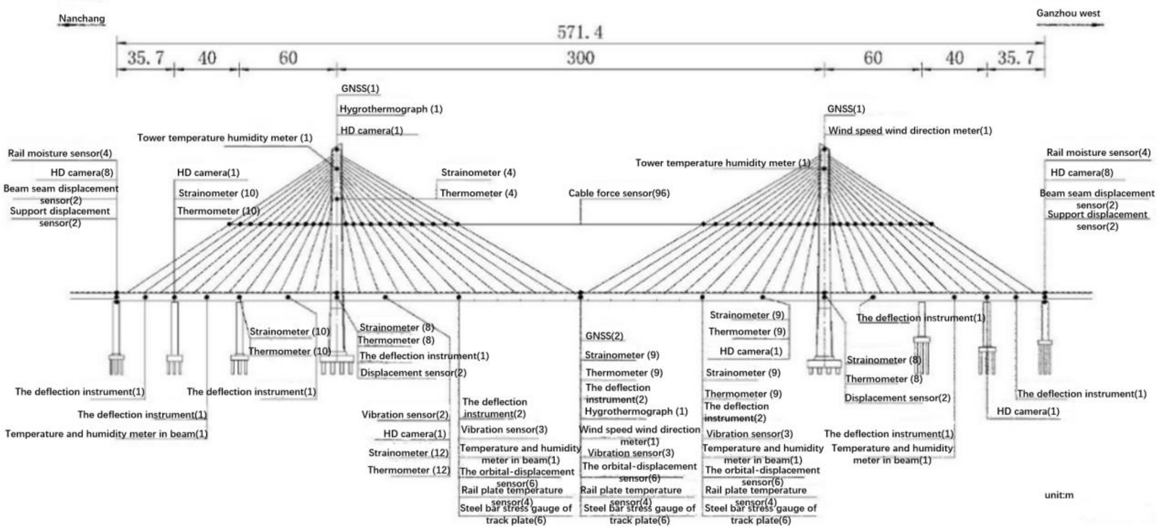


**Figure 6.** Layout of monitoring points on Ganjiang Grand Bridge.

Monitoring objects and corresponding sensors on Ganjiang Grand Bridge of Changgan Passenger Transport in Ganzhou: In addition to routine monitoring, special parts of the Ganjiang River Bridge in Ganzhou have also been monitored. Special position monitoring includes track plate stress and temperature, relative displacement of track structure, rail expansion regulator region displacement, support and expansion joint displacement, and other monitoring items ,which are shown in Table 4 below [11].

**Table 4.** Special parts monitoring project of Ganjiang Grand Bridge of Changgan Passenger Transport Health Monitoring system in Ganzhou

| | Monitoring objects | Sensor types | Number | Monitoring section | Frequency of sampling |
|---|---|---|---|---|---|
| Track structure | Rail temperature | Temperature sensor | 8 | The end of the beam | |
| | Track plate stress | Strain gauge | 18 | | |
| | Track plate temperature | Temperature sensor | 12 | Main span spans middle and four points | 1 time / 10 min |
| | Relative displacement of the orbital structures | Expansion joint state | 18 | | |
| Rail overlapping device | Sharp rail expansion and expansion displacement, basic rail expansion and expansion displacement, scissors fork deformation, support beam skew | HD camera | 12 | The end of the beam | 1 time / 10s |
| | Relative displacement of one rail rail and one rail sleeper | HD camera | 4 | Beam end and 100m range from the beam joint | |
| | Support state | Expansion joint state | 8 | Beam end and bridge tower support | |
| | Expansion joint state | Expansion joint state | 4 | The end of the beam | 1 time / 1min |

## 4. Intelligent Bridge Monitoring Application

Based on the background of the digital age of "Internet Plus," the integration of cloud technology and big data has gradually penetrated all walks of life, which is an important measure to build a powerful transportation country.

Intelligent monitoring is to collect and transmit the monitoring results of cable-stayed bridge force, displacement and deformation of key parts, and crack development to the cloud management platform. In combination with various environmental monitoring data, finite element software, BIM technology, and system identification methods are used in the cloud background to form real-time judgment results of bridge health status so as to provide management suggestions for end users such as bridge users, maintenance units, and supervision units.

The fatigue life reliability of the cable is calculated based on the cable force detection data and fatigue damage accumulation theory. According to the development law of concrete creep and the material-related test results, the finite element software is used to calculate the time-history change law of the bridge line type, and the measured results of the key point displacement and deformation of the bridge are compared with the calculated results to judge the structure shape of the bridge. Finite element software was used to locate the crack position of the bridge structure under various working conditions, and a scanning device was used to detect the development of cracks [12].

### *4.1. BIM Technology and Health Monitoring*

BIM technology, with the help of computer technology and big data technology, builds a three-dimensional model that is intuitive and clear. It is not only an innovation in model construction but also an upgrade in management ideas, which has a broad application prospect.

The author uses Changtai Bridge as an example to give a brief overview of the BIM-based visual application of structural health monitoring for cable-stayed bridges. Figures 7 and 8 show the point elevation and sectional view of Changtai Bridge, respectively [13].

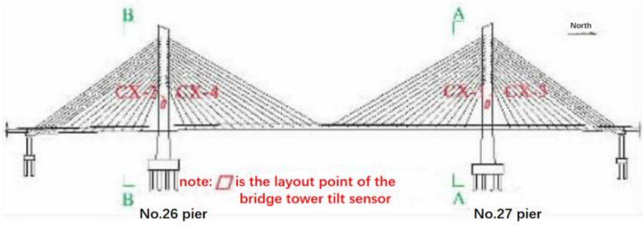


**Figure 7.** Elevation of point arrangement.

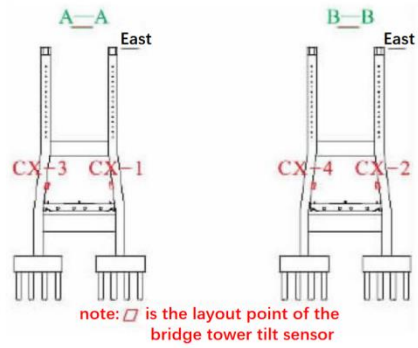


**Figure 8.** A-A and B-B sections in point arrangement.

Through the BIM three-dimensional model management system, the monitoring information can be associated with the model so as to facilitate the display of sensors, detection data, and other information. The monitoring curve obtained by the BIM model is shown in Figure 9. [13]

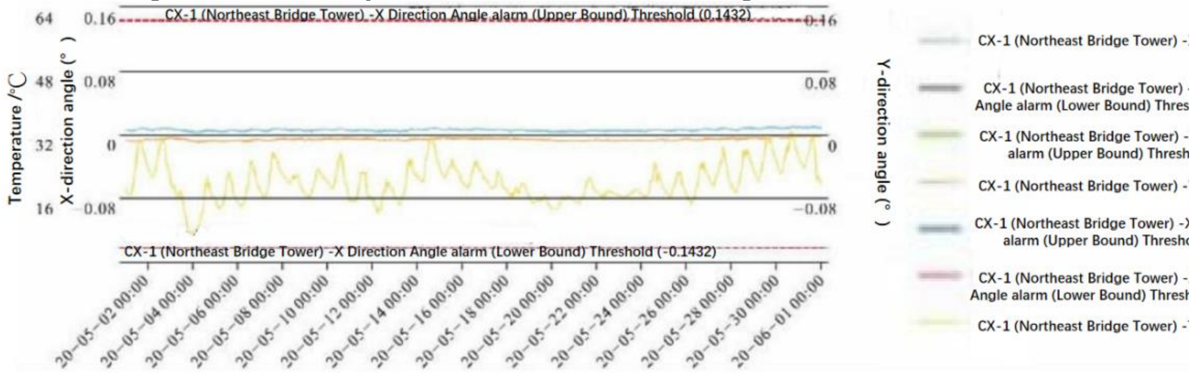


**Figure 9.** CX-1 tilt monitoring trend of Changtai Bridge’s northeast tower.

### *4.2. Finite Element and Health Monitoring*

In this paper, the application of finite elements in the structural health monitoring of cable-stayed bridges is briefly summarized by taking Chaoyanggou Bridge as an example.

By using ANSYS, we established the finite element model of the full bridge entity of the Chaoyanggou Bridge and laid the structural response monitoring site on the bridge. Through Midas/Civil finite element simulation analysis, the characteristic position of the bridge in the normal service limit state was obtained, as was the stress sensitivity of the top and bottom of the main beam.

As can be seen from Figure 10 [14], the normal stress of the top and bottom plates of the main beam of the Chaoyang Gou Bridge has obvious extreme normal stress at the mid-span of the main span, 1/4 span of the main span, and mid-span of the side span. This shows that the sections at these positions are more sensitive to the stress of the bridge, and the stress monitoring sites on the top and bottom of the main beam can reflect the change in law of the internal forces of the main beam more clearly.

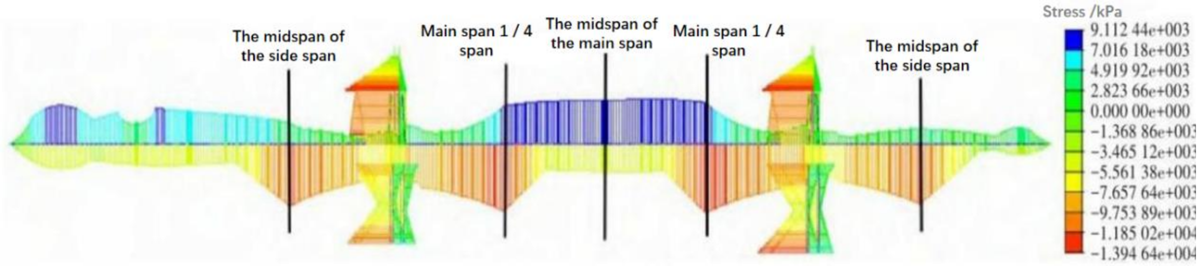


**Figure 10.** Nephogram of normal stress on top and bottom plate of main beam.

It can be seen from the shear stress nephogram of the corrugated steel web that the monitoring sites of the corrugated steel web at the anchorage surface of the outer cable and the steel-concrete joint section can better understand the shear stress status of the corrugated steel web of the whole bridge. It can be seen from the stress nephograph of the stay cable that selecting the outer cable (No. 1), middle cable (No. 7), inner cable (No. 13), and staggered cable (No. 2, No. 8, No. 12) on the outer cable surface as the stress monitoring sites of the stay cable and conducting staggered monitoring can more comprehensively reflect the overall stress situation of the stay cable of the whole bridge. As can be seen from the full-bridge displacement nephogram, displacement monitoring sites for the whole bridge structure should be arranged at the extremums of each span displacement [14].

## 5. Conclusion and Prospect

By analyzing and comparing common diseases and maintenance measures of common cable-stayed bridges and cable-stayed bridges in cold coastal areas and analyzing the health detection system of cable-stayed bridges with specific examples, we draw the following conclusions:

(1) The defects of common cable-stayed Bridges are mainly manifested in three aspects: cable, anchorage system, and cable tower. Cold coastal areas have large temperature differences, high air humidity, a lot of winter snow melt, and a lot of use of snow remover. The common areas of cable-stayed bridges also have certain differences.

(2) The general cable-stayed bridge health monitoring system includes six parts: system composition, sensor layout, sensor type, monitoring object, structural health status assessment and daily maintenance, component modules and functions of structural health status assessment, and early warning and assessment. Different types of cable-stayed bridges have slightly different point layouts and detection objects, but the principle of the health monitoring system of most cable-stayed bridges is similar.

(3) The bridge intelligent monitoring application, combined with BIM and finite elements, has a broad development prospect in the future. The penetration and application of cloud technology and big data provide new ideas for solving the problems faced by bridge monitoring technology.

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