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Safety Assessment of Steel Arch Bridges: Methods for Detection, Diagnosis, and Structural Evaluation

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Abstract: ***The systematic implementation of inspection and evaluation for steel arch bridges enables the timely identification of existing defects and the formulation of targeted remedial strategies, thereby preventing the further propagation of damage, establishing a foundation for the safe and stable operation of such bridges, and advancing the overall development of the bridge engineering sector. To this end, this paper first reviews several non-destructive evaluation techniques applicable to steel arch bridges, including acoustic testing, magnetic inspection, and optoelectronic detection. Subsequently, it analyzes bridge appearance inspection protocols, static load test procedures, and corresponding results. Finally, the study discusses reinforcement measures for steel arch bridges, focusing on the rational application of strengthening technologies, the use of bonded steel plates for arch crown reinforcement, and the enhancement of personnel competency. Collectively, these discussions aim to provide actionable references for relevant construction authorities.***

Keywords: Steel frame arch bridge, Inspection, Evaluation.

1. Introduction

During the operation of steel frame arch bridges, they will be affected by environmental factors, such as the influence of rainwater and atmospheric corrosion. In addition, with the continuous increase of traffic loads in recent years, the load and usage frequency of steel frame arch bridges have gradually increased, the service life of steel frame arch bridges has been greatly shortened, and the driving safety has also been threatened to a certain extent. As the use time increases, different types of disease problems will appear in steel frame arch bridges. In the face of this problem, it is necessary to do a good job in the inspection and evaluation of steel frame arch bridges, accurately judge the disease types and degrees of steel frame arch bridges, and take effective treatment measures and reinforcement countermeasures according to the specific situation to ensure the structural safety of steel frame arch bridges, improve the bearing capacity of steel frame arch bridges, reduce disease problems, extend the service life of steel frame arch bridges, and promote the better development of China's bridge industry.

2. Non-destructive Inspection and Evaluation Technology of Steel Frame Arch Bridges

1) Acoustic detection technology. The application principle of acoustic detection technology is to distinguish and judge the damaged parts of the bridge according to the sound propagation characteristics. It is a non-destructive detection technology often used in the current detection of steel arch bridges. This technology is easily affected by external sound waves during use. Usually, the mixed external sounds will affect the detection accuracy. Therefore, the main difficulty of acoustic detection technology lies in how to discard the sounds propagated by non-structures and use the sound properties propagated by the structure to accurately judge the damage location of the steel arch bridge [1]. Ultrasonic non-destructive detection technology and impact echo wave emission detection technology are two commonly used acoustic detection technologies. For example, the specific principle of shock wave echo detection technology in application is that shock waves will propagate in the bridge detection structure, and the damage location of the bridge can be judged by combining the actual change of the sound wave frequency. Applying the impact echo non-destructive detection technology to the detection of steel arch bridges can accurately reflect the bridge structure strength and position defect conditions.

2) Magnetic detection technology. In application, magnetic detection technology can be classified into magnetic powder detection method, magnetic flux leakage detection method, eddy current detection method, etc. according to its different principles, and electromagnetic induction method and potential detection technology can also be used. Generally, magnetic detection technology is applied in the detection of bridge damage parts, bridge fracture positions, and bridge corrosion degrees. Eddy current induction magnetic detection non-destructive detection technology can accurately judge the surface disease problems of the bridge. To give full play to the advantages of this technology, the staff can lay a conductor coil on the bridge surface before detection. The conductor coil will form an alternating magnetic field, and the induced current in the magnetic field will form a circular vortex on the surface of the component.

3) Optical and electrical detection technology. In the past, during the detection of steel arch bridges, the electrical detection method was used. This method requires sticking strain gauges on the bridge structure to achieve scientific monitoring and measurement of bridge deformation [2]. The actual working principle is to calculate the change of the electric quantity by using the deformation of the strain gauge, and detect the bridge deformation problem according to the relationship between the strain change and the resistance change of the strain gauge. The optical detection technology method mainly uses light to convert physical quantities into signals. It should be noted that the propagation of light in optical fibers will be affected by external factors to varying degrees.

4) Other types of detection technologies. In the continuous development of China's highway bridge industry, non-destructive testing technologies have been improved and optimized, and many new non-destructive testing technologies have been widely used in bridge detection. For example, nuclear magnetic resonance testing technology, acoustic vibration testing technology, laser image testing technology, etc. With the continuous progress of artificial intelligence, intelligent recognition technology, unmanned aerial vehicle aerial photography testing technology, etc. have also been applied to the detection of steel frame arch bridges [3]. Discover the diseases and other problems existing in the steel frame arch bridge in a timely manner, and give targeted adjustment measures to ensure the structural safety of the steel frame arch bridge and achieve the sustainable development of the highway bridge industry.

3. Steel Frame Arch Bridge Detection and Evaluation

3.1 Project Overview

Taking a certain load-bearing steel frame arch bridge as an example, the total length of the bridge is 234 m, the width is 7.5 m, and there are 6 piers and 5 spans. Five arc-shaped steel frame arch beams are erected on the bridge. The load standards adopted by the bridge are that the lane load and the pedestrian load are Class −A and 3.5kN/m respectively. The motor vehicle lane is 7 m, and the crosswalk is 2 m.

3.2 Bridge Appearance Detection

The bridge appearance inspection work is simple and intuitive, which can accurately judge the bridge problems and the locations of diseases, and the overall analysis is more accurate. The implementation of the bridge appearance inspection work can provide a reference for analyzing the reasons for the internal stress loss of the bridge. The main purpose of the appearance inspection of steel structure bridges is to timely discover the disease problems existing in the bridge appearance, formulate targeted maintenance measures, promptly deal with the disease problems, and prevent the further expansion of the influence range of the diseases [4]. Appearance inspection is a key content in the daily maintenance of bridges. For this work, based on the bridge structure monitoring data, understand the actual situation of the bridge to ensure the subsequent bridge reinforcement. In the bridge appearance inspection, it is necessary to pay attention to investigating and collecting the basic data of the bridge; investigating the hydrological and geological conditions around the bridge, and at the same time understanding the changes in the surrounding structures and the factors that may affect the bridge. It is necessary to focus on understanding, observing and analyzing the situation at the scouring area of the bridge location, and clarify whether the debris flow cleaning work at such locations is in place and whether there are landslide problems [5]. In addition, check the deck pavement, waterproof and drainage conditions, etc. For the inspection of the upper structure of the bridge, check whether there are damages to the beam slab load-bearing members.

Regarding the inspection of bridge 附属 structures, staff should also pay more attention, especially to do a good job in the inspection and evaluation of the bridge deck system, the inspection and evaluation of the lower and upper structures of the bridge.

3.3 Static Load Test Content and Results

In this static load test, 4 working conditions can be loaded around. The layout method of the working conditions is as follows: Working condition 1, the live load loading standard of vehicle -20 level is adopted, with a total of 8 vehicles, and the loading section is arranged at 1/4 of the bridge span; Working condition 2, the live load loading standard of vehicle -20 level is used, with a total of 8 vehicles, and the loading section is arranged at 1/2 of the bridge span; Working condition 3, the live load loading standard of vehicle -20 level is used, with a total of 8 vehicles, in a 5-row and 3-column layout, and a single-span layout with eccentric load; Working condition 4 is the most unfavorable design load, with a total of 20 vehicles, in a 5-row and 3-column layout, and a single-span layout with full load. The bridge loading method of Working condition 1 is shown in Figure 1; the specific test content is shown in Table 1.

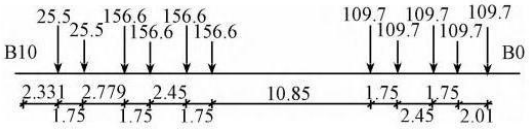

Figure 1: Bridge loading method of Working condition 1

Table 1: Test content

Loading conditions	Number of cycles	Load grading	Test content
1	3	3	1. Stress and strain of each section (Section I, Section II, Section III); 2. Displacement of measuring points arranged on the beam; 3. Upward arch deformation displacement
2	3	3	1. Stress and strain of each section (Section I, Section II, Section III); 2. Displacement of measuring points arranged on the beam; 3. Upward arch deformation displacement
3	3	1	1. Stress and strain of each section (Section I, Section II, Section III); 2. Displacement of measuring points arranged on the beam; 3. Upward arch deformation displacement
4	1	2	1. Stress and strain of each section (Section I, Section II, Section III); 2. Displacement of measuring points arranged on the beam; 3. Upward arch deformation displacement

Through the static load test, the staff can accurately judge the bearing capacity of the bridge and clarify whether its bearing capacity meets the safety operation standards. By comparing with the original bearing design, the consumption of the bearing capacity of the bridge in the use stage can be grasped. Through the analysis of data information, scientifically judge the reinforcement effect of the bridge and ensure that the bridge reinforcement meets the bearing capacity requirements of the bridge in use [6]. Then compare the measured deflection value and the measured stress value of the static load test with the theoretical design value of the bridge to master the difference between the two. The difference between the measured value and the theoretical value of this bridge is small, indicating that the bridge has a good load-bearing structure. The deflection value is less than the theoretical value, indicating that the main body of the bridge

structure has a large stiffness.

3.4 Notes on the Results of Bridge Inspection and Evaluation

1) During the operation of the steel truss of the bridge span, through the overall calculation of the bearing capacity, it can be clarified that the bearing effect of the bridge is good, but in many important parts, the members are severely corroded, and the actually measured bearing capacity is lower than the design [7]. In the face of this problem, for the components with less serious corrosion damage, the staff should scientifically remove rust and do anti-corrosion treatment at the same time. If the components are severely damaged and cannot be processed, new components should be replaced immediately.

2) Small steel plates and hot rivets of angle steel are important components of the bridge truss. The structural system of this bridge is light, but the connection positions of the steel frames are relatively numerous and complex. Some components are deformed after being stressed. Under the comprehensive influence of stress, some components are easily damaged, and the truss system adopts a statically simply supported system. The construction time of this bridge is relatively long, and it has been repaired and reinforced many times during operation, resulting in changes in the overall stress of the bridge.

3) In the specific measurement, it can be found that the measured values of the deflection detection measurement points of the bridge exceed the theoretical values. By comparing the structural check coefficient with the specified check coefficient, it can be determined that the actual measurement coefficient has exceeded the normal coefficient specified range. When the staff checks the appearance of the bridge, it is not difficult to find that there are slight cracks on the right side of the main girder, and these cracks show a gradually increasing trend. Some crack problems have extended to the web top plate position. The deformation margin of the measurement points is relatively large and the recovery elasticity is reduced, but it can meet the relevant requirements [8]. When analyzing the dynamic test results, the calculated frequency value of the actual frequency exceeds the frequency value of the theoretical calculation, which indicates that the overall performance of the bridge can meet the requirements of the theoretical calculation value. The large measured damping coefficient is because there are already damage conditions in the internal structure of the bridge.

On the basis of scientific analysis, different methods can be adopted for the reinforcement of this bridge. The staff should pay attention to the maintenance of the external structure of the bridge and implement the overall maintenance work of the bridge to ensure that the external characteristics of the bridge can be strengthened; pay attention to implementing the reinforcement work of the bridge cross beam, reinforce the main girder structure to ensure that the bearing capacity of the bridge can meet the specified standards; the reinforcement of the bridge pier is also a key work in the reinforcement of this bridge. Once the bearing capacity of the bridge pier does not meet the requirements, it will directly affect the normal operation of the bridge. Therefore, the staff should do a good job in the reinforcement and maintenance of the bridge pier in combination with the actual situation [9].

4. Steel Frame Arch Bridge Reinforcement Measures

4.1 Rational Use of Reinforcement Techniques

1) Bridge deck reinforcement. When demolishing the bridge deck pavement, manual chiseling can be adopted, and heavy mechanical equipment should be avoided during the specific chiseling process. For hoisting the micro-curved plate and bridge deck, symmetric chiseling should be adopted. C40 concrete can be used for the bridge deck pouring. When connecting the bridge deck and the arch rib, the planting bar connection method can be used. Anchor bolts can use 12 mm threaded steel bars or 16 mm threaded steel bars. The construction of planting bars should be implemented strictly in accordance with the regulations: the staff should carry out the lofting work in combination with the designed hole positions and mark the drilling locations; during the drilling process, the hole diameter is 20 mm, the depth of the planted bar should ensure that it is the same as the hole, and the planted bar hole should be straight; when cleaning the hole, tools and equipment such as brushes and air compressors should be reasonably utilized; pour the planting bar glue into the hole. When the planting bar glue reaches 2/3 of the hole depth, the self-made anchor bar can be inserted into it; before inserting the anchor bolt to the bottom of the hole, the staff should do a good job in removing the rust of the anchor bolt to ensure that there is no leakage at the bottom of the hole. For removing the planting bar glue, it should be cleaned in time. Before the planting bar glue solidifies, the anchor bolt should be prevented from being disturbed and water leakage is prohibited at the hole opening. To meet the quality requirements of the steel bar construction, the staff should implement the construction according to the design drawings and the concrete structure anchorage code. The staff should master the correct reinforcement process and implement the bridge deck reinforcement work according to the process, so as to make the bridge deck reinforcement achieve better results, ensure that the bridge deck reinforcement meets the specified requirements, and under this background, the advantages of the reinforcement technology can be brought into play.

2) Arch leg reinforcement. In the range of the arch crown and arch foot 3 m, carry out the arch foot reinforcement work, adopt the rectangular rib method to achieve the connection of the arch foot. To ensure the close connection between the new and old concrete, methods such as roughening, steel bar implantation, and cement slurry spraying can be used. To control the influence of the shrinkage and creep of the newly poured concrete within the minimum range, micro-expansion concrete is used for arch foot reinforcement, starting from the two side arch legs and adopting the symmetrical pouring method [10]. If the surface position is not suitable for scaffolding, the arch legs can be used as supports for formwork erection. During the concrete formwork pouring, the wooden structure method can be used, mainly to reduce the load of the concrete structure.

4.2 Strengthen the Arch Crown by Bonding Steel Plates

When strengthening the arch crown by bonding steel plates, the following work should be done: Pay attention to crack repair. Before pasting the steel plates, use epoxy resin to repair the cracks on the concrete surface; Concrete surface treatment. Carry out lofting work in combination with the design drawings. Except for the area where the steel plates are to be pasted, chisel off the mortar surface layer in other areas, which can play a good role in promoting the effective bonding between the bonding steel glue and the concrete surface; Embedded anchor bolts. Before starting drilling, the staff should clarify the position of the main arch rib bars to prevent damage to the main bars during the drilling process; Steel plate assembly. The staff should fix the flat steel bars on the anchor bolts according to the design position, pad each anchor bolt point well to ensure the designed bonding thickness; Glue injection. After the glue injection work is completed, the glue should cure on its own. Generally speaking, the final strength can be basically achieved in 7 days. Within 24 h after injection, the curing strength can reach 80% of the design strength.

4.3 Improve the Professional Qualities of the Staff

The staff should master more different strengthening techniques and methods to ensure the smooth progress of the strengthening work of the steel arch bridge and achieve good strengthening effects.

Therefore, before participating in the reinforcement and repair work, the staff should learn professional knowledge and organize them to participate in different training activities. Through education and training, the responsibility, safety and quality awareness of the staff should be continuously strengthened. Before the start of the reinforcement work, the construction personnel should do a good job in investigation in advance to understand the bearing capacity, deflection and stiffness of the bridge project [11]. For the implementation of the reinforcement work, supervisors should be arranged to conduct full - range supervision. Once it is found that the staff operate improperly, the supervisors should stop them immediately and deal with the staff, continuously strengthening the responsibility awareness of the staff, which can also play a good warning role for other staff, ensuring that the staff can correct their work attitudes during the reinforcement process and strictly reinforce according to the specific situation and process, so as to achieve a good reinforcement effect. In addition, the staff should have an accurate grasp of the non - destructive testing technology for steel - framed arch bridges. In the bridge detection, the staff should give full play to the advantages of the non - destructive testing technology to accurately judge the bridge disease problems and the degree of the diseases, so as to give targeted adjustment measures, effectively handle the bridge problems and improve the structural stability and safety of the bridge.

5. Conclusion

In the process of detecting and evaluating steel - framed arch bridges, the staff themselves should have strong professional qualities and comprehensive abilities, and strictly implement the detection and evaluation work according to the process and regulations. During the detection and evaluation of steel - framed arch bridges, the staff should have a correct understanding of different non - destructive testing technologies such as acoustic wave detection technology and magnetic detection technology. According to the specific situation of the bridge, different types of non - destructive testing technologies should be applied to the detection of bridge disease problems and the determination of disease locations. On the basis of having a correct understanding of various bridge problems, reasonable control measures should be taken. By bonding steel to reinforce the arch top and reasonably using reinforcement technologies, the bridge can be reinforced to ensure that the deflection, strength, stiffness, etc. of the bridge after reinforcement can meet the specified standards, meet the needs of people for highway bridges, and create a safer and more stable traffic environment.

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