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RESEARCH STATUS AND THE PROSPECT OF CABLE-STAYED SYSTEM REINFORCEMENT OF CONTINUOUS & RIGID BOX-GIRDER BRIDGES

This scholarly article elucidates the prevalent pathological manifestations and underlying causes within the prestressed concrete continuous system bridges. It delves into the methodology of employing the low tower cable-stayed system to reinforce continuous system bridges. The low tower cable-stayed system reinforcement technique effectively mitigates beam deflection, augments the bridge's load-bearing capacity, and bolsters its structural integrity, thereby introducing an innovative paradigm for bridge reinforcement. Finally, the strengthening technology of the cable-stayed system of the low tower is prospected.

Keywords: prestressed concrete continuous system bridge; bridge disease; cable-stayed reinforcement; low tower cable-stayed system reinforcement; research status and outlook.

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СОСТОЯНИЕ И ПЕРСПЕКТИВЫ ИССЛЕДОВАНИЯ АРМИРОВАНИЯ ВАНТОВОЙ СИСТЕМЫ НЕРАЗРЕЗНОГО И ЖЕСТКОГО КОРОБЧАТО-БАЛОЧНОГО МОСТА

В статье рассматриваются распространенные патологические проявления и причины, лежащие на основе предварительно напряженного бетонного моста с непрерывной системой перекрытия, а также рассматривается методология использования вантовой системы с низкой башней для армирования моста с непрерывной системой перекрытия. Технология армирования вантовой системой с низкой башни эффективно уменьшает прогиб балки, увеличивает несущую способность моста и укрепляет его структурную целостность, тем самым внедряя инновационную парадигму армирования моста. Рассматривается также технология укрепления вантовой системы низкой башни.

Ключевые слова: предварительно напряженный железобетонный мост непрерывной системы перекрытия; заболевание моста; армирование вантовой системы; вантовая система с низкой башней; состояние и перспективы исследования.

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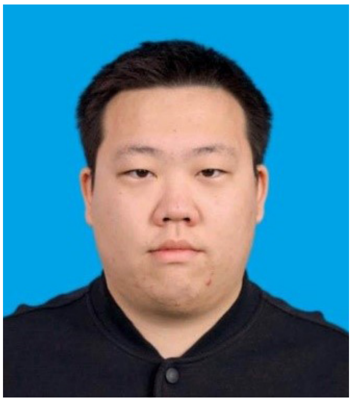

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Introduction

A continuous system girder bridge is a commonly used structural system in constructing large-span bridges. In the 1970s, the success of prestressing technology significantly improved and strengthened the concrete structure. With the perfection of the prestressed concrete process, German engineers took the lead in using hanging baskets cantilevered pouring concrete to build continuous girder bridges, which set the foundation for the bracketless construction method. Its wide adoption makes the construction of continuous concrete girder bridges, and the span of the bridges has been dramatically developed. China's prestressed concrete continuous girder bridge was built in the 70s for the first time in the city bridge project decades. The development is extremely rapid, and China has mastered various advanced construction methods [1; 2].

As the service life of bridges extends, the occurrence of bridge pathologies and the methodologies for addressing these conditions have emerged as significant topics of concern within the professional community. Scholars at home and abroad studying bridge disease and reinforcement methods have carried out much research. In recent years, diagonal cable system reinforcement technology, especially low tower diagonal cable system reinforcement, has become a relatively new and effective method. The author summarizes the research results obtained by scholars in recent years for this method and finally looks forward to the development and improvement of this method.

1. Overview of Pathology Research on Continuous System Bridges

Reinforced concrete or prestressed concrete materials to build various types of bridges account for the vast majority of bridges in service in China; due to various reasons, after many years of use, more or less have some disease, especially in recent years, many areas of increased traffic flow and the increase in the number of heavy vehicles, bridges have more disease, Some of the bridges have already had to be reinforced.

Aiming at the various diseases of continuous system bridges, domestic scholars have carried out much research; Sun Xiaohuan et al. [3] found that the concrete girder bridges have diseases, analyzed and summarized the typical locations of the diseases, and put forward the treatment methods of joint diseases; Zhang Xinghai et al. [4] summarised the application of extracorporeal prestressing reinforcement technology with engineering examples; Xu Gangnian et al. [5] combined with the situation of the Huanghe River Highway Bridge in Dongming, summed up the low tower cable-stayed system reinforcement method.

2. Continuous system bridge diseases analysis

2.1. Summary of Pathologies in Continuous System Bridges

The common diseases of continuous concrete girder bridges are as follows: defects and diseases of the upper structure include cracking, breakage, and bearing capacity reduction of the main girder tensile parts; cracks, subsidence, and cracking of the bridge deck pavement; jumping of the bridgehead; imperfect waterproofing layer drainage function; water seepage disease caused by corrosion of reinforcing steel and concrete stripping; incorrect or damaged bearing position causing tilting, misalignment and displacement, etc. The number of vertical bending cracks at the bottom of the girder near the span increases with the span diameter. Vertical bending cracks near the bottom of the beam from the bottom up near the middle of the span, the number increases with the increase in span diameter, and constant load crack width may exceed the specification limit value, especially with excessive deflection in the middle of the span; the principal tensile stress causes diagonal cracks on the web near the end of the two supports is too significant or insufficient shear web shear, etc. Shear damage, lower piers, and foundations of foundation of defects and diseases are mainly manifested as follows: insufficient load-bearing capacity to make the foundation unevenly Uniform subsidence; the foundation of the slip and tilt, as well as the base of the local washout; foundation structure of the abnormal stress and cracking. Defects and diseases of bridge piers and abutments are mainly manifested as horizontal, vertical, and network cracks; concrete peeling, hollowing, material aging; damage caused by external impact; steel leakage and corrosion; structural deformation, displacement, etc., of which the deflection in the middle of the span is too significant for the bridge of the continuous system is the most critical problem.

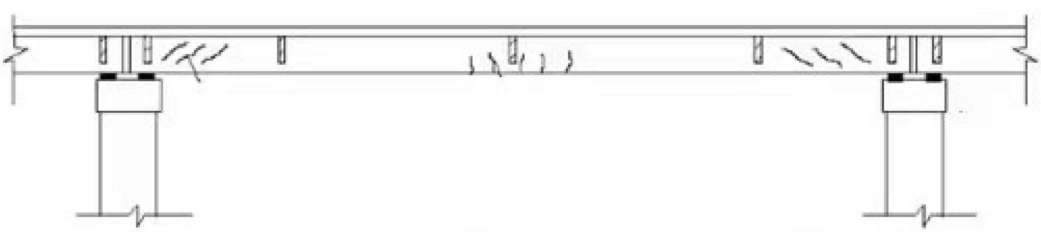

Fig. 1. Vertical cracks at the bottom of the beam and diagonal cracks in the web near the bearing end.

2.2. Continuous system bridge disease causes

Disease causes are as follows: low design load standard, insufficient bearing capacity, insufficient capacity, artificial and natural factors causing structural damage, natural aging, overdue service, overloaded use, inherent deficiencies in design and construction, and improper maintenance and reinforcement measures.

Vertical cracks on the beam web, primarily located in the middle of the thin web, broad in the middle and thin at both ends, not extended upward and downward, primarily due to poor maintenance of concrete, temperature, or too few horizontal tendons on the web due to shrinkage cracks, mainly affecting the durability of the structure.

Longitudinal cracks under the anchor of the tensioning anchorage, the length of which is generally not more than the beam height, are mainly caused by the splitting tension produced by the local stress concentration under the anchor; longitudinal cracks along the prestressing steel bundle are mainly caused by the thin protective layer of the prestressing steel bundle, the splitting produced by the local stress at the steel bundle, or the rusting of prestressing tendons after the carbonization of the protective layer of the concrete.

Loss of prestress in the longitudinal steel bundles and concrete shrinkage creep effect are the main factors contributing to the mid-span downward deflection of the main girder after the continuous system bridge [6].

2.3. Shortcomings of general reinforcement methods

Since the most significant problem with large-span prestressed box girders is girder deflection at mid-span, this problem dramatically affects structural safety and durability. If this problem occurs in such bridges in essential locations and is not reinforced in time, it will significantly affect traffic safety and cause substantial economic losses. The reinforcement measures for mid-span deflection and girder cracking mainly include increasing extracorporeal prestressing, affixing steel plates, carbon fibers, thickening webs, and rigid frames [7] . These methods have been researched and then applied to many engineering examples. However, the existing method of applying extracorporeal prestressing cable is more evident for improving bridge cracks. However, it is difficult to improve the problem of girder deflection. After years of reinforcement treatment, the bridge will also have new cracks, deflections, and even excessive internal force, resulting in girder damage and other unfavorable situations.

3. Reinforcement technology of diagonal cable system

3.1. Introduction to the technology

The problem of girder deflection can be solved entirely by the relatively new diagonal cable system reinforcement method. This method belongs to changing the structural system reinforcement method, the original continuous girder bridge or continuous rigid structure bridge, into the cable-stayed bridge reinforcement, a kind of passive-to-active reinforcement method [6]. The cable-stayed system reinforcement has the following advantages:

1) Enhancement of the load-bearing capacity and stability of the structure.
2) Reduced traffic impacts.
3) The methodology is relatively new.
4) Multiple design parameters and flexible design methods.

Compared with the ordinary cable system reinforcement method, the low tower cable system reinforcement has more outstanding advantages. Firstly, the structural height is lower, and the low tower cable-stayed system reinforcement technology adopts a shorter main tower structure; compared with the ordinary cable-stayed system, the overall height is lower. This means it is easier to implement and adapt in the city's limited height sites. Secondly, the wind resistance of the low tower is better. Due to the lower overall height of the low tower cable-stayed system, the wind resistance of the structure is relatively better, and the lower main tower height reduces the impact of wind loads, thus improving the stability and safety of the structure. So, the low tower cable-stayed system reinforcement method is the direction of more current scholars' research.

3.2. Principles of reinforcement

Adopt low tower cable-stayed bridge reinforcement, form a single tower double cable-stayed low tower cable-stayed bridge with hanging beams of the new structural system. Structure upstream and downstream sides of the bearing platform, combined with thin-walled piers to expand the cross-section method of reinforcement, the use of the original bridge pile foundation enough surplus bearing capacity in the original bridge bearing platform piers on both sides of the new steel box low tower, with the steel box beam connection; box beam cantilever end to the cantilever span in the region of the new cable-stayed cable-stayed, the low tower cable-stayed towers anchorage area to set up a cable saddle [8]. The reinforcement pattern is shown below.

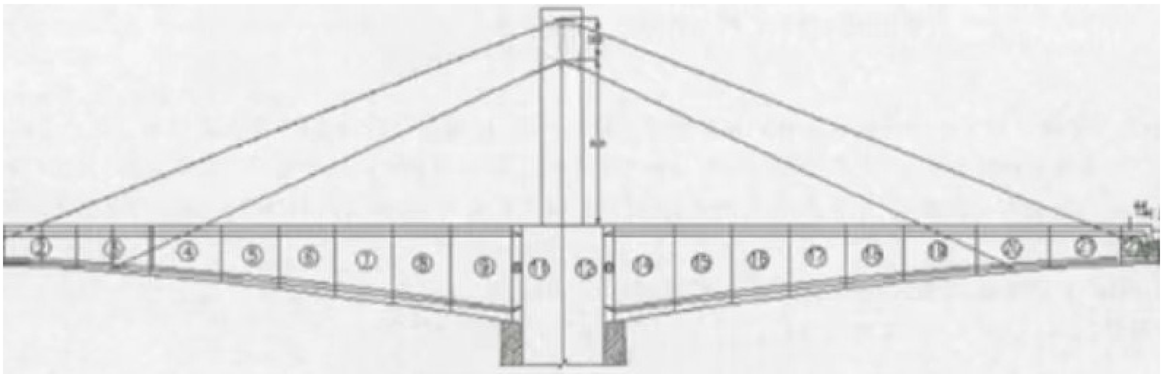

Fig. 2. Sample of single tower reinforcement.

3.3. Status of research

Ma Jianzhong [9] et al. proposed this method in the research and design of the reinforcement of the Fenglingdu Huanghe River Bridge but failed to realize the reinforcement of the bridge with this method due to technical reasons.

Wu Zhaoxia [10] et al. conducted a comparative study of tensioning schemes for low tower inclined strengthening methods and concluded that the deflection change of the main girder under the sequence of tensioning from short to long cables is more gentle and the stress change in the cross-section is more uniform.

The use of finite element modeling can effectively help to analyze the structural internal force, the establishment of an analytical model to understand the state of the constant load internal force of the old bridge before strengthening, and the results of this calculation as the basis for the calculation and analysis of the reinforcement construction process. Gao Qing [11] used finite element modeling and analysis to study this reinforcement method. Firstly, the bridge model was established and used for operation, and then the low tower cable-stayed system reinforcement was carried out to analyze the bridge stress condition. After the reinforcement with the low tower cable-stayed system, it can be known from his modeling analysis that the stress reserve of the box girder of the T-frame main bridge is increased after the reinforcement with the change of the structural stressing system.

The primary reinforcement method used is joist brackets to provide support. Diagonal cables provide vertical support to the main girder through the joists and brackets. The cables are directly anchored to the end of the joists, which are transferred to the main girder box girder through the steel joists. Chunming Zhang [12] showed that the strength of joist brackets meets the use requirements of load rating by checking the joist bracket software and load test. Wang Shimin [13] et al. conducted example analysis and limited element model analysis and concluded that: the theoretical values of stresses at the measured points of joists and brackets match well with the measured values; the theoretical values of maximum principal tensile stresses at the measured points of the web plate of the concrete box girder are generally higher than the measured values, but they do not exceed the standard value of tensile strength of the concrete; the measured values of the deflection of joists match basically with the theoretically calculated values.

3.4. Engineering examples

3.4.1. Project Example 1 – Putzander Bridge

The Putersand Bridge, located in Putersand, Norway, about 100 km south of the capital city of Oslo, is a single-cell box girder bridge constructed of prestressed concrete using the cantilever construction method, with a main span of 138 m. A diagonal tension system strengthened the bridge after analyzing the time-varying cantilever over flexure and the lack of shear capacity in some parts of the bridge [14].

The bridge was designed with inverted Y-shaped steel towers at the original pivot points of the main spans of the original structure and two pairs of cable-stayed cables on each part of the cantilever. The "main span" and "back span" cables were tensioned at the outer edges of the superstructure box girder base plate and the rock-filled anchorage section (abutment), respectively. All fixed-end anchors of the cable-stayed cables are located on the upper part of the bridge tower, which is 33,5 m high above the highway surface. This reinforcement method significantly solved the shear and deflection problems of the bridge.

3.4.2. Project Example 2 – Dongming Huanghe River Highway Bridge

Dongming Huanghe River Highway Bridge is located northwest of Heze City, Shandong Province. State Road 106 across the Hunaghe River is the longest highway bridge in Shandong Province, known as the "Qilu first bridge".

Bridge length 4142,14m, width 18.5 m, two-way four lanes. In October 1991, the bridge's construction began, and in August 1993, it was opened to traffic. After ten years of reinforcement and operation by external beams, new stress cracks, and deflections appeared on some spans. In 2014, the bridge was proposed to be strengthened for the second time using the diagonal tension system.

A diagonal tension system, i.e., strengthen the main girder of Dongming Huanghe River Highway Bridge, the bridge tower is added on both sides of the original pile foundation, joists are added transversely at the lower part of the main girder, the joists are connected to the main girder through the brackets at the bottom of the box girder, and the diagonal cable is anchored in the direction of the tower to the joists. The diagonal cable is transferred to the main girder through the coordination of the joists and the brackets. The cable-stayed system mainly consists of new pile foundations, bridge towers, joists, brackets, steel supports in the box, and cable-stayed cables [5].

During this bridge's main girder reinforcement project, critical technologies such as additional pile foundation construction, installation of additional steel members, and tensioning control of diagonal cables were adopted. The bridge reinforcement started on December 8, 2014, and the construction was completed on December 8, 2016, which took two years. The bridge was load tested at the end of December 2016 after reinforcement and rehabilitation. The results of the load test show that the bridge force is improved, the height of the cross-section in the middle of the span is lifted, the structural self-resonance frequency is greatly improved, and the vertical displacement response of the structure is also significantly reduced. The reinforcement effect is evident [15].

Fig. 3. Strengthened Dongming Huanghe River Highway bridge.

4. Deficiencies and Prospects of the Reinforcement Technique of the Low Tower Tilting System

4.1. Inadequacy of reinforcement techniques

Overall, the author believes there are some problems with this reinforcement technology, the biggest of which is the need for more support from relevant literature. Compared with traditional bridge reinforcement methods, low tower cable-stayed system reinforcement is a relatively new technology that needs more relevant research literature. This means that limited information is available for reference at the theoretical and practical levels, and researchers and engineers need to explore and verify more details. There are also relatively few engineering examples of practical applications associated with the need for more literature support. More extensive practical experience is needed to validate the effectiveness and feasibility of the low tower inclined system reinforcement technique. Because the low tower inclined system reinforcement technique is relatively new, the collection and analysis of the long-term performance data still needs to be increased, which affects the evaluation of the long-term effectiveness and durability of the technique.

Other problems include the relative complexity of the construction technique, which requires changes to the original bridge's structural system, including adding additional elements such as diagonal cables and towers, which results in a more complex reinforcement process: more incredible construction difficulty and cost. The strengthening technique requires many complex construction processes, including pile construction, removal of the original components, fabrication, installation of components, drilling, and lifting. These processes require a high degree of construction precision and complex coordination, which increases the difficulty and risk of construction; the maintenance and care needs of the bridge may increase after strengthening. Additional components such as diagonal cables and towers need to be regularly inspected and maintained to ensure their performance and safety; the seismic performance of the low-tower diagonal strengthening technique under seismic loading needs to be further studied and improved. The stiffness and seismic performance of the diagonal cables and towers have an essential impact on the overall seismic capacity of the bridge.

4.2. Future prospects

First of all, strengthen the theoretical research on the reinforcement technology of the low tower cable-stayed system, and accumulate more engineering examples, so as to provide reference and reference for the subsequent design and construction; in terms of construction, for the complexity of the construction process and the cost of the problem, study the more efficient and economical construction technology, simplify the construction process, and reduce the difficulty and cost of the construction; explore the application of new materials, new techniques and new technologies in the reinforcement of low tower cable-stayed system, such as Using high-performance materials, intelligent monitoring and adaptive control technology to improve the performance and reliability of the reinforced bridge; focusing on environmental protection and resource conservation, exploring the concept of green construction and sustainable development in the reinforcement process to reduce the impact on the environment; introducing an intelligent monitoring system to realize real-time monitoring and management of the reinforced bridge to improve the bridge's safety and operational efficiency.

5. Conclusion

Through data collection and analysis, this paper summarizes the common disease characteristics and causes of prestressed concrete continuous system bridges. It discusses the method of strengthening continuous system bridges using the diagonal cable system reinforcement method, especially the low tower diagonal cable system reinforcement method. It was found that the low tower cable-stayed system reinforcement technology can effectively improve the beam deflection problem, enhance the load-carrying capacity and structural stability of the bridge, and have the advantage of less impact on traffic during construction. However, some shortcomings in the low tower cable-stayed system reinforcement technology need to be further studied. Given these problems, the author proposes future research and direction for improvement.

In summary, the low tower cable-stayed system reinforcement technology is a bridge reinforcement method with a wide range of application prospects, which can significantly improve the structural performance and service life of bridges and is of great significance for improving traffic safety and economic benefits. With the progress of science and technology and the accumulation of engineering practice, this technology is expected to be applied and developed in more bridge reinforcement projects.

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