Mechanism Analysis of Small Box Girder Diseases and Summary of Reinforcement Treatment Strategies

Kuan Li¹, Yuanxun Zheng¹* and Chengyong Liu²

¹School of Water Conservancy science and engineering, Zhengzhou University, Zhengzhou, Henan 450001
²Zhengzhou Branch Company of Henan Expressway Development Corporation LTD

*Corresponding author e-mail: yxzheng@zzu.edu.cn

Abstract. With the vigorous development of bridge construction in China, the structure of bridges is also more abundant. Among them, the prefabricated small box girder has been widely used in engineering fields at home and abroad due to its large section torsional strength, bending strength, and low cost and fast construction speed. However, due to poor design and improper construction in the early stage, coupled with the vehicle over-aging and inadequate material maintenance, the prefabricated small box girder bridges have different degrees of disease, how to study the disease generation mechanism and take targeted reinforcement. The treatment strategy is related to the safety of transportation in China. In this paper, the statistical analysis of the disease of small box girder in active service is carried out, and the mechanism of various diseases is analyzed and summarized. On this basis, the common methods of reinforcement and treatment of small box girder in China are comprehensively analyzed. The research results of this paper have important reference value for mastering the causes of the disease of small box girder in China's expressway and the corresponding reinforcement strategy.

Keywords: Small Box Girder, Crack, Disease Mechanism, Reinforcement Strategy, Review

Introduction

In China, in 1978, Xi'an Highway Research Institute took the lead in researching and developing the post-tensioned prestressed concrete small box girder bridge and built the first concrete small box girder bridge in China [1]. In 1979, a 20-meter simple-supported post-tensioned concrete small box girder bridge in Zhangye area of Gansu Province was tested. It was decided to use carbon steel wire as prestressed material, and the construction technology of post-tensioning of simply supported beam was determined. In the next two years, the successful construction of the Donghe Bridge in Hanyin County of Shaanxi Province and the Qianyou River Bridge in Lianshui County proved the maturity of the construction process of the post-tensioning of simply supported concrete small box girder bridges. Subsequently, the design units of China Communications First Hospital, Tianjin Municipal Government, Anhui Highway Design Institute and Gansu Highway Design Institute used a large number of small box girder structures in the design of high-grade highway bridges, and achieved good results in engineering practice [2-3].

In foreign countries, the research and application of small box girder started relatively early, and the technology is relatively mature. In Japan, the first box-shaped beam is similar to the domestic large hollow slab, and the span length is limited to 21.9m. The Japanese Ministry of Construction and the Japan Standards Association have standardized regulations for their design [4], and their graded span increases by 1 m. The rear frame beam is generally winged and spans 20 to 40 m. The standardization of the post-tensioned precast box...
girder is mainly used for thin bridges with medium spans, and their height can be reduced by 20%-30% compared with T-beams. Mainly through the use of 59Mpa or higher strength concrete, each beam uses more prestressed steel, and reduce the beam spacing to achieve. Japan’s design concept is that the horizontal post-tensioned cast-in-situ concrete beam can make the whole system stronger and the load distribution between the beams more effective. The small box girder of the United States adopts a form similar to the domestic large hollow slab, adopts a flat box girder system, and uses a special mortar to form a small shear bond. Precast beam bridges are often made of various off-site concrete beams, such as prefabricated concrete beams connected by welded steel plates and K-shaped steel tie rods. The US construction process is conducive to reducing on-site operations [5], facilitating the reconstruction and expansion of the bridge superstructure, but also taking into account the corrosion problems at the joints of these fabricated bridge members and their impact on the service life of the deck.

As early as the early 1980s, the Ministry of Communications organized and implemented the "Research on the reinforcement of technical measures for the carrying capacity of old bridges". "Research on the treatment of displacement of arches in double-curved arch bridges". "The causes of road water damage and prevention measures" Research on the maintenance and reinforcement technology of a large number of old bridges has formed a more mature theoretical method and technical measures for the repair and reinforcement of old bridges [6-9]. At the same time, with the improvement of the international bridge reinforcement technology level, domestic scholars have followed the world's advanced steps and carried out special research on the modification of structural systems, the application of steel plates and carbon fiber (FRC), and the use of high-performance carbon fiber concrete (HPFRC) reinforcement methods. These special studies lay the foundation for the engineering application of these new materials and new technologies. After entering the 21st century, the Ministry of Communications vigorously promoted the engineering application of the complete set of road reinforcement technology, and systematically summarized and improved more than 20 kinds of bridge reinforcement methods commonly used at home and abroad. In addition, the basic principles of the old bridge reinforcement, the characteristics of the reinforcement method, the applicable conditions, the material requirements, the quality control of the construction process, the quality inspection and assessment of the reinforcement engineering, and the post-reinforcement evaluation have been innovated, and a complete system of bridge reinforcement technology results has been formed. The application guide for the complete set of highway old bridge reinforcement has laid a solid foundation for the scientific standardization of bridge repair and reinforcement [10-13].

This paper mainly analyzes the types of diseases of existing small box girder, analyzes the causes of different diseases, and summarizes the advantages and disadvantages of different reinforcement measures.

1 Analysis of disease types and causes of small box girder

Concrete small box girder is widely used due to its excellent cross-section characteristics. However, due to poor design considerations, improper construction, insufficient aging and inadequate maintenance, material properties will gradually deteriorate, performance will decline, various diseases will occur, and reliability will be seriously reduced.

1.1 Crack

1.1.1 Cracks in the web of the box girder

(1) Crack morphology

Such cracks generally occur at the end of the beam to a quarter of the span, and cracks in the box girder with severe disease extend to the entire web section. The cracks are mostly at an angle of about 45° to the beam plate, or extend obliquely to the bottom plate, and develop longitudinally at the joint of the bottom of the web and the bottom plate. Or extending up to the top plate, the longitudinal crack between the web and the top plate is connected, and the crack width is generally above 0.2 mm. The width of the web oblique crack of individual bridges even exceeds 2 mm, and the crack depth generally runs through the entire web section.

(2) The main causes of cracks

① Design is not well thought out

In the last century, due to the limitations of the conditions at the time, the design of small box girder was often unilaterally pursued for economic benefits and was over-optimized resulting in a lower safety factor. In particular, the webs of some small box girder are too weak, the web stirrups are designed as single limbs, and are sparse, which is difficult to meet the shear requirements and the web cracks occur when the beam body does
not reach the design load.

2. Construction reasons

For example, when the support is hollowed out, the box beam is subjected to force distortion, or the template positioning is inaccurate, which causes the thickness of the web to be further weakened, etc., which may cause cracks in the web.

1.1.2 Longitudinal crack of the roof

(1) Crack morphology

Such cracks generally occur at the location where the web meets the top plate, or where the beam is wet. Intermittent or uninterrupted longitudinal distribution, local concrete fragmentation phenomenon, resulting in damage to the bridge deck waterproof layer, beam joint leakage is serious, lateral connection failure, single beam stress phenomenon is more obvious.

(2) The main causes of cracks

The generation of such cracks is mainly caused by the local load of the wheel load on the roof of the box girder. The common lateral arrangement of small box girder is shown in Fig.1. In many cases, the distance of L2 in Fig.1 tends to be longer than the distance of L1, such that the bending moment at the wet seam tends to be large. In addition, the construction quality of the site is often relatively poor, and the phenomenon of domestic car overload is more common. A variety of factors are combined to make the longitudinal joint cracks appear in the wet joint location of the small box girder.

Fig.1 Horizontal layout of small box girder

1.1.3 Longitudinal crack along the bellows

(1) Crack morphology

Such cracks are mainly distributed in the position of the small box girder web about 20 cm near the bottom plate, mostly in the range of 1/4 to 3/4 of the beam length, along the corresponding surface of the prestressed steel bundle. The crack width is basically between 0.1 and 0.2 mm, and the crack depth is generally between 1 and 2 cm. It is generally in the protective layer range, and some cracks penetrate the protective layer.

(2) The main causes of cracks

① The construction space is too small and the effect of concrete performance

Taking a typical 25m small box girder design as an example, the web thickness is designed to be 16cm, the bellows diameter is 8.7cm, the corrugated pipe is 3.65cm away from the template on both sides, and there is a layer of structural reinforcement less than 10mm in the middle. In fact, the clear distance for concrete to pass on each side of the bellows is 2.65 cm. Such a small distance has high requirements on the working condition and working performance of the concrete, especially the maximum particle size restriction on the coarse aggregate. However, in the actual construction, the quality of the coarse aggregate is not necessarily well controlled, and the aggregate is too thick, which may cause localized segregation of the concrete at the position of the bellows, which leads to the occurrence of cracks.

② Prestressed tunnel grouting is not timely

The small concrete beam corrugated pipe has a small concrete bearing surface corresponding to the web part, such as the center of the bellows, and the bellows width accounts for 54% of the total width of the web. Such a small pressure bearing area requires that the grouting must be carried out in time, the sooner the better, as far as possible to provide an effective bond between the prestressed tendons and the structural concrete. However, in fact, due to construction organization and other reasons, some of the small box girder has not been grouted within a few days after stretching, resulting in a large pressure on the concrete around the corrugated pipe for a long time, plus the protective layer is thinner and appears smooth. Longitudinal cracks in the direction of the prestressed pipe are inevitable.

③ Construction joint impact
Some small box girders are placed in the joint of the web and the bottom plate in the pouring, and the straight line section is basically at the position of the bellows, so that the bellows position forms a weak band of concrete, which is also a cause of the longitudinal crack.

1.1.4 Circumferential crack in the beam body

(1) Crack morphology

Taking a highway as an example, two small box girders are poured into the concrete, and the formwork is removed and placed on the pedestal. Without prestressing, the web, the top plate and the bottom plate of the middle cross section are interpenetrated.

(2) The main causes of cracks

(①) Sunshine temperature difference, rain and other reasons lead to sudden cooling, night temperature drop, etc.

If the concrete of the small box girder is completed, unexpected events such as rain will occur before the concrete strength has formed. As a result of a sudden drop in temperature, the tensile stress generated by the small box girder concrete under the foundation constraint may exceed the tensile strength of the material, eventually leading to the occurrence of circumferential cracks. By the same token, if a small box girder is poured at the highest temperature during the day, the temperature of the night will also cause the small box girder to crack.

(②) Basic constraint

When the small box girder pedestal foundation is cast on a hard bedrock or a pedestal using a concrete surface, there is no measure of loosening the restraint layer such as a smooth steel plate. Under the action of atmospheric temperature and its hydration heat temperature, the internal temperature rises. When the shrinkage deformation of concrete due to cooling is restrained by the pedestal, a large tensile stress will appear inside the concrete to produce a constrained crack. Such cracks often occur when concrete is cast and demolded, and the cracks are deep and sometimes penetrating.

1.1.5 Longitudinal crack of box girder

If the longitudinal crack of the box girder floor is simply present, the cause of such cracks may exclude design factors, and the longitudinal cracks should be caused by construction factors. According to the calculation and analysis of Zhang Yong et al., when the prestressed tendons of the box girder floor are not laid out according to the specifications, the prestressed pipe may deviate from the original design position when pouring the floor concrete. For this reason, the deviation of the bellows will cause the prestress to generate radial force on the local beam section of the box girder, and the radial force will have a greater impact on the mechanical performance of the box girder floor. According to the "Technical Specifications for Highway Bridges and Culverts", the prestressed radial force and the applied load are used to make the transverse tensile stress of the box girder floor 2.35 MPa (normal bearing condition), less than the tensile strength design of C50 concrete. The value is 2.45 MPa and there is no longitudinal crack in the bottom plate. However, if the deviation of the bellows exceeds the allowable value of the specification, there is a high possibility that the bottom plate is cracked.

1.2 Other forms of disease and its causes

(1) The design load standard is low and the bearing capacity does not meet the current traffic load requirements. Bridges designed and constructed according to different versions of technical standards promulgated before 1981 have low design load standards and narrow bridge deck widths. Although they have undergone a comprehensive technical transformation, they are mainly based on reinforcement and expansion. After years of heavy load accumulation, bridges are generally aging and have severe performance degradation.

(2) The erosion of bridge structures or components by the natural environment. The erosion of concrete by harmful substances in the natural environment causes physical and chemical reactions, damage to concrete and damage to the underlying foundation.

(3) Structural damage caused by overload. The bridge design standard is low, and the traffic load is continuously improved. The most serious is that there are a large number of large-tonnage overloaded vehicles passing through, resulting in the bridge structure being overloaded for a long time, causing serious fatigue damage. With the rapid development of the transportation industry, the grades of some road bridges have been unable to serve the existing traffic and accelerate the damage of the bridge.

(4) The design flaws and improper construction of the bridge. Some bridges are not very reasonable in design. The defects of the bridges in the early operation are not obvious, but after a certain period of operation, the
disease gradually emerges. Some bridges have certain technical defects due to the limitations and influences of the construction conditions at that time. With the increase of operation time, their diseases have gradually revealed and developed.

2 Summary of the treatment plan for small box girder reinforcement

(1) Increase the main beam section method
This method is a kind of traditional reinforcement method and a very effective reinforcement method. It can effectively improve the bending, compression, shear and tensile strength of the components, and can also be used to repair the concrete cross section that has been damaged and improve its durability. The advantage of this method is that the construction technology is relatively mature, the reliability is good, the resistance of the component and the rigidity of the component are relatively large, and the stability of the structure is also greatly improved. The disadvantage is that the construction period is long, the engineering quantity is large, the structural weight is increased, and the cross-sectional size of the reinforced member is increased, which makes the original use building space smaller. Typically, this method consists primarily of thickened decking and thickened main beam webs.

(2) Outsourcing steel reinforcement
For greatly improving the compression and bending resistance of the components, an outer steel reinforcement method can be used. Due to the use of steel materials, the construction period is relatively short, the occupied space is not large, and it is not allowed to increase the cross-sectional size, but it is widely used in the axial compression and small eccentric compression members which need to greatly increase the bearing capacity. The reinforcement of the bent members or the large eccentric compression members can also be reinforced with outer steel, but wet outer steel reinforcement is preferred.

(3) External paste reinforcement
The external adhesive reinforcement method is a reinforcement method in which a steel sheet or a fiber reinforced composite material or the like is adhered to a portion to be reinforced by a member to improve the bearing capacity and rigidity of the member. The sticking steel reinforcement method is a kind of reinforcement method for improving the bearing capacity of structural members. The surface of the components is made of special structural adhesive-bonded steel sheets. The fiber reinforced composite material is formed by placing high-performance fiber fabrics such as glass fibers, carbon fibers, and aramid fibers on a substrate such as an epoxy resin and solidifying by gluing.

(4) Auxiliary structure reinforcement
The auxiliary structure reinforcement method is an in vitro reinforcement method. It is a load that is directly applied to the reinforcing member by a profile steel, a steel frame or other prefabricated members (such as piles, etc.) disposed at the position of the member to be reinforced. The method is suitable for the serious damage of the original component, and requires reinforcement of the component to greatly improve the bearing capacity and rigidity, and can also be used for the reinforcement of the foundation.

(5) Grouting reinforcement
The grouting reinforcement method uses pressure to inject a material having better bonding properties into the voids inside the reinforcing member, thereby improving the integrity and compactness of the strengthened member and improving the strength of the material. The method is widely used in the repair and reinforcement of internal defects such as cracks in concrete or masonry structures, and in foundation reinforcement.

(6) External prestressing reinforcement
The prestressed reinforcement method uses the tensile properties of the prestressed tendons to reinforce the structure. The method can be divided into two types, one is to install prestressing tendons in the outer beam of the original beam, and transmit the force through the anchoring end and the supporting point; the other is to first tension the prestressing tendons, and then pour the concrete through the new and old concrete. Bonding to transmit force. This method is convenient to construct and can improve the structural bearing capacity without increasing the beam height and the plate height.

3 Conclusion

(1) The structural advantages of concrete small box girder bridge are analyzed. The development history and application status of small box girder bridge are summarized. The research status of concrete small box girder bridge detection and reinforcement technology at home and abroad is summarized. The mechanism analysis of concrete small box girder Bridge is described.

(2) The common types of cracks in small box girder are summarized, and the causes of different cracks in
concrete box girder are analyzed. Based on the inductive analysis of the causes of concrete small box girder disease, it can be used as a countermeasure and reference for the treatment of concrete small box girder diseases.

(3) This paper introduces various reinforcement methods for concrete small box girder bridges at home and abroad and briefly compares its application scope and advantages and disadvantages. The construction points and key technologies of different reinforcement methods are proposed to ensure the effectiveness and safety of reinforcement.

Acknowledgements
This work was supported by National Natural Science Foundation of China (No. 51878623), Science and Technology Tackling Project of Henan Science and Technology Agency (No. 172102210500), Program for Young Backbone Teachers in Colleges and Universities in Henan(2018GGJS005), and foundation for postdoctoral students in Henan province (1901024).

References:
[1] Tongji University Bridge Department. Research report on small box girder bridge with large curvature[R](1997).
[2] Guo Shouqi: Characteristics and application status of small and medium-span winged small box girder [J]. Sichuan Architecture.27(4),122-127(2007).
[3] Yu Quan: Analysis and experimental study on the mechanical behavior of multi-box continuous small box girder bridge [D]. Hangzhou: Zhejiang University(2006).
[4] Wei Jianhui, Li Baogiang: Small box beam reinforcement [J]. highway.(8),290-292(2004).
[5] Podolny J W: The cause of cracking in post-tensioned concrete box girder and retrofit procedures[J]. PCI Journal.30(2),82-139(1985).
[6] Long Zhiqin: Experimental study on strength performance of carbon fiber reinforced reinforced concrete beams [J]. Journal of Chongqing Jiaotong University.4, 10-14(2005).
[7] J K M Ckenna, M A Erki: Strengthening of reinforced concrete flexural members using externally applied steel plated and fiber composites sheet a survey[J]. Canadian Journal of civil engineering.21,16-24(1994).
[8] G Giannopoulos, J Vantomme: Numerical analysis and experimental validation for static Loads of a composite bridge structure[J]. Composite Structures.62(2),235-243(2003).
[9] Amir M. Hamid Saadatmanesh: Predition of failure load of RC beams strengthened with FRP plate due to stress concentration at the plate end[J]. ACI Structural Journal. 3(4), 25-32(1998).
[10] Zong Zhou-hong, Wang T L, Huang D Z: State-of-the-art report of bridge health monitoring[J]. Journal of Fuzhou University (Natural Science).45(8),127-152(2002).
[11] Liu Muyu, Yuan Weiguo: Research status and development of bridge nondestructive testing technology [J]. Chinese and Foreign Highways. (6), 24-26 (2002).
[12] Huang Qiao: External prestressed reinforcement technology of highway reinforced concrete simply supported beam bridge[M]. Beijing: China Communications Press, 1998.
[13] Liu Zhigang: Research progress in the application of concrete bridge bonding reinforcement technology[J]. Highway (5): 23-25(2003).