Research on construction cracks of wide box girder

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Abstract: Based on the numerical simulation and field test, combined with the engineering case, this paper studies the causes of construction cracks in wide box girder, and proposes for the first time that the three-dimensional prestressed tendons tension sequence is an important cause of construction cracks in wide box girder. The research results show that: the hydration heat of concrete and the tension sequence of three-dimensional prestressed tendons are the two main reasons for the construction cracks of wide box girder. The lag tension construction technology of transverse and vertical prestressed tendons makes the tensile stress of bottom plate increase rapidly in the early stage of construction, and makes the tensile stress of web plate increase in the construction process, which leads to cracks pouring in the early stage of box girder, but the tension of prestressed tendon has little effect on the final state stress of box girder. The research results of this paper can be used for reference for the construction crack control of prestressed concrete box girder.

1. Introduction

Prestressed concrete box girder is widely used in modern bridges because of its outstanding advantages: good integrity, large torsional stiffness, and being able to withstand positive and negative bending moments\cite{1-3}. Prestressed concrete box girder has a wide application space from simple simply supported girder bridge to complex long-span cable-stayed bridge and suspension bridge.

Prestressed concrete box girder is widely used in modern cable-stayed bridges, especially in single cable plane cable-stayed bridges. The larger torsional stiffness is conducive to bearing deflection load, and the box girder is also conducive to the connection of stay cables and main girder\cite{4-5}. Many prestressed box girder cable-stayed bridges in use in China have achieved good operation results, such as Tongling Yangtze River Bridge, Wuhan Yangtze River Second Bridge, Ehuang Yangtze River Bridge, Qianjiang River Second Bridge.

In practical engineering, various kinds of cracks often appear in the construction and operation of prestressed concrete box girder, and the crack problem has become a major problem in the engineering field\cite{6-8}. CCCC highway planning and Design Institute has carried out investigation and Analysis on partially prestressed concrete box girder bridges in use in China, which shows that concrete cracking is the most important influence on the structural stress and normal use of concrete box girder bridges\cite{9}. There are many reasons for cracks. Concrete hydration heat is often considered to be the main reason for prestressed box girder construction cracks. Many scholars have done a lot of research on concrete hydration heat\cite{10-12}. The research shows that hydration heat is indeed an important reason for concrete box girder construction cracks. In this paper, the hydration heat of Jialingjiang bridge is analyzed by simulating the field measured temperature field.

Prestressed concrete box girder is generally arranged with prestressed reinforcement in the longitudinal, transverse and vertical directions. In practical engineering, in order to speed up the construction
progress, the transverse and vertical prestressed reinforcement is often tensioned 1-2 segments behind the longitudinal. Different construction techniques will cause structural stress changes. In view of the construction cracks of Jialingjiang bridge, this paper analyzes the influence of three-dimensional prestressed reinforcement tensioning sequence on the structural mechanical characteristics.

2. Engineering background
The main bridge of Jialing River Bridge adopts the cable-stayed structure with single cable plane and low pylon, and the pier tower beam consolidation system. The span of the bridge is (122+220+122)m. The main bridge is a prestressed concrete low tower cable-stayed bridge with double towers and single cable plane. The total length of the main bridge is 464m. The main girder adopts single box three chamber cantilever variable cross-section prestressed concrete continuous box girder, the height of fulcrum beam is 8.0m, the height of mid span beam is 3.8m, and the beam height within 106.5m from the mid fulcrum beam changes according to the quadratic parabola. The width of the top plate of the box girder is 31.5m, the length of the cantilever plate is 4.75m, the width of the bottom plate of the box girder is 16.602-19.828m, and the angle between the inclined web of the side chamber and the vertical plane is 21°.

There are different degrees of cracks in the construction of the main girder of Jialing River Bridge, as shown in Fig. 1. Cracks at the root of the 0# block are distributed outside the side web. The starting point is the connection between the pier body and 0# block. There are 4 cracks on the left and right sides, which are distributed in an oblique direction. Inclined and horizontal cracks appear in the web of each section. The cracks in the bottom plate are longitudinal cracks, which are mainly distributed in the middle of the bottom of the bottom plate and the outside of the middle web plate.

3. Hydration heat

3.1. 0# block of box girder
The cantilever construction method is used on the Jialing River Bridge. The 0# block is first poured. It has these characteristics: high strength, large volume, large cross-section size. In this case, The 0# block has severe hydration heat reaction, which causes larger temperature inside it. The larger temperature difference between the inside and outside of the 0# block may cause the generation of temperature cracks. In order to analyze the effect of hydration heat on the 0# block, a spatial finite element solid model of 0# block is established based on Midas FEA. And ten calculation points are chose to analyze the mechanical characteristics of the 0# block, as shown in Fig. 2.
Fig. 2 Hydration heat solid model of segment No.0

Fig. 3 are the temperature diagram and the first principal stress diagram respectively of 0# block at 720h under hydration heat. Here we only analyze the tensile stress, which contributes to the generation of construction cracks. So we just show the results of the first principal stress. At 720h, the temperature of all parts of the 0# block has been cooled to 14°C (the ambient temperature). Meanwhile, the hydration heat of concrete causes three secondary stress zones in the 0# block. Two of them are larger, located at two corners of the junction of 0# block and pier body (one on the left and one on the right), and the other secondary stress zone is relatively small, located in the middle of the two large secondary stress zones (the junction of 0# block and pier). The 0# block is poured on the pier body that has been completed. Its stress and deformation are caused during hydration heat, but the pier body restricts its deformation at the junction. As a result, greater secondary stress is generated at the junction. So the junction between the part under construction and parts that have completed is particularly noteworthy, at which greater secondary stress would be generated. The main reason for the web cracks at the junction of the old and new girders of Jialing River Bridge is the secondary stress caused by hydration heat.

Fig. 4 First principal stress diagram of 0# block

From Fig. 4, we can see that the first principal stress of the 0# block increases gradually in the early stage of hydration heat. The two fastest growing points (1, 2 nodes) appear at two corners of the junction of 0# block and pier body. As the hydration heat of concrete develops, the concrete gradually
cools, and the tensile stresses of the 0# block gradually decrease mostly. The maximum tensile stress of them is 1.8MPa. On the contrary, the tensile stresses at two points (1 and 2 nodes) is still increasing and maintain a higher growth rate. If the concrete does not crack, the tensile stress of the two points can reach 20MPa. Therefore, construction cracks will appear at two corners of the junction of 0# block and pier body under the action of hydration heat, which is completely consistent with the actual cracks in the construction of Jialing River Bridge. From Fig. 3, we know that the segment No.0 has a another secondary stress zone under the action of hydration heat, at which there are not cracks in Jialing River Bridge. This is because that the concrete cracks first appeared at the 1, 2 nodes due to the fastest growth rate of tensile stresses, and the secondary stress is released. Besides, The release of secondary stress further increases the growth of cracks at the two corners. Therefore, the 0# block of Jialing River Bridge appears larger cracks at the two corners.

3.2 General beam section

Various cracks have appeared on the base and web plates of the box girder of Jialing River Bridge during its construction. In order to knowledge the variation of concrete temperature during hydration heat reaction of the box girder, four strain gauges are placed on the same section of 8# segment, as shown in Fig. 5.

The simulated temperature fields of the finite element model are compared to the actual measured temperature fields of the box girder. Fig. 6 and Fig. 7 are the contrast diagram, from which we can see that the finite element model has better simulation results.

Based on ten calculation points shown in Fig. 8 of the base and web plates respectively, begin analyzing the influence of hydration heat reaction on the tensile stress of them.
From Fig. 9, we can see that the base plate of box girder gets the maximum tensile stress under the hydration heat reaction at 6:00 nearly, and the maximum tensile stress is 2.3MPa. The trend of the change of its tensile stress is basically the same as that of temperature field. So the hydration heat reaction is one of the main causes of cracks in the base plate of box girder of Jialing River Bridge.

![Stress diagram of hydration heat of base plate](image1)

![Stress diagram of hydration heat of web](image2)

From Figure 10, we can see that the web plate of box girder gets the maximum tensile stress under the hydration heat reaction at 6:00 nearly, and the maximum tensile stress is 1.1MPa. The trend of the change of its tensile stress is basically the same as that of temperature field. The tensile stress of node basically maintains at 1MPa during the later stage of the hydration heat reaction. Because it is located at the junction of the web and the base plates, which is the secondary stress zone. Therefore, single hydration heat reaction can not cause cracks in the web plate.

4. Tension sequence of prestressed tendons

Prestressed tendons are instilled to the box girder of prestressed concrete cable-stayed bridges in three directions: longitudinal, vertical and transverse. But the tension sequence of them is not clear in many bridge construction, which may be one of causes of construction cracks of prestressed concrete box girder bridges.

In actual construction, the transverse and vertical prestressed tendons are tensioned later than longitudinal prestressed tendons for 1-2 segments usually. In this paper, three different tension sequences are selected to analyze the influence of the hysteresis of vertical and transverse prestressed tendons on the mechanical characteristics of box girder. The three processes are vertical and transverse prestressed tendons tensioned at the current stage, vertical and transverse prestressed tendons tensioned fall behind one stage, vertical and transverse prestressed tendons tensioned fall behind two stage.

![Stress calculation points of top, bottom and web plates](image3)

Based on ten calculation points shown in Fig. 11 of the base, web and top plates respectively, begin analyzing the influence of different tension sequences of three-dimensional prestressed tendons on the tensile stress of them.
4.1. Tensile stress of the base plate
Here we only analyze the tensile stress, which contributes to the generation of construction cracks of the box girder. The tensile stress of the base plate mainly occurs at the bottom surface during the whole construction process. So we just show the results of the first principal stress of the bottom surface of the base plate, as shown in Fig. 12.

From Fig. 12, we can see that the tensile area of the bottom of the floor can be regarded as three parts: the main tensile area (nodes 4, 5, 8), the secondary tensile area (nodes 1, 2, 3, 6, 9) and the transition area (node 7). When the transverse and vertical prestressing tendons lag behind, the stress characteristics of the main tensile zone are as follows: the tensile stress increases rapidly, and reaches a larger tensile stress quickly in the next stage of construction, and improves the final tensile stress of the main tensile zone; the stress characteristics of the secondary tensile zone are as follows: the tensile stress is smaller than that of process one, the farther away the node from the main tensile zone is, the more obvious the final tensile stress is. The tensile stress of transition zone is between them. In practical engineering, if the transverse and vertical prestressing tendons lag behind, we must pay attention to the main tensile area of the bottom plate, especially to ensure that the concrete has enough strength in the next section of construction. This is one of the reasons for the construction cracks in the floor of Jialing River Bridge.

Fig. 12 Stress diagram of the base plate

4.2. Tensile stress of the web plate
Begin analyzing the first principal stress of the web plate, and Fig. 13 is the tensile stress diagram of the web plate under three different processes.
From Fig. 13, we can see that the hysteresis of vertical and transverse prestressed tendons greatly increases the tensile stress of the web plate during the construction process. And the change of process three is more starkly than process two. That is, the more the quantity of lag segment when the transverse and vertical tendons are tensioned, the greater the tensile stress of the web plate. But the hysteresis shows little contribution to the ultimate tensile stress. So, it is considered that the hysteresis of vertical and transverse prestressed tendons will not affect the ultimate tensile stress of the web plate. It is important to pay more attention to mechanical characteristics of the web plate in practical engineering, when the vertical and transverse prestressed tendons are tensioned fall behind 1-2 segments. In this case, the hysteresis becomes one of the reasons for the construction cracks on the web plate of the box girder of Jialing River Bridge.

### 4.3. Tensile stress of the top plate

Begin analyzing the first principal stress of the top plate, and Fig. 14 is the tensile stress diagram of the top plate under three different processes.

From Fig. 14, we can see that the tension zone of the bottom surface, similar to the base plate, can be divided into three parts: the main tension zone (nodes 3, 4, 5, 7), the secondary tension zone (nodes 1, 2, 6) and the angular zone (nodes 8, 9). The hysteresis of vertical and transverse prestressed tendons greatly increases the tensile stress of the top plate at the main tension zone and the secondary tension zone during the construction process. And the change of process three is more starkly than process two. The hysteresis also makes a contribution to get greater ultimate tensile stress. Conversely, the tensile stress at the angular zone (the junction of the top and web plates) shows the opposite character. For the main tension zone, the hysteresis not only greatly increases the tensile stress in the construction process, but also increases the ultimate tensile stress. Compared to the main tension zone, the secondary tension zone exhibits the same characteristics. However, the maximum tensile stress occurs in the construction of 6th segment, and the subsequent tension of prestressed tendons does not increase the tensile stress of the top plate.
5. Conclusion

The tension sequence of three-dimensional prestressed reinforcement is one of the key reasons for the construction cracks in the bottom slab and web of Jialingjiang bridge

1. The main cause of cracks in the web of the new and old beams of Jialingjiang bridge is the temperature secondary stress caused by hydration heat.

2. The lag tension of transverse and vertical prestressing tendons makes the box girder bottom plate reach large tensile stress quickly in the next stage of construction, which is one of the important reasons for the cracks in the bottom plate of Jialingjiang bridge.

3. The single hydration heat can not make the box girder web crack. The lag tension of transverse and vertical prestressed tendons is the main reason for different degrees of cracks in box girder webs.

4. The lag tension of transverse and vertical prestressing tendons increases the ultimate tensile stress of box girder, but the increment is very small. Therefore, it can be considered that the lag tension of transverse and vertical prestressed tendons will not affect the final structural stress state of the box girder.

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