Crack Control Technology of SPMT Transportation Structure of Long-span and Special-shaped Concrete Box Girder

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Abstract: By analyzing the engineering characteristics of SPMT transportation of long-span and special-shaped box girder, this paper took asynchronous displacement as the master control parameter of large concrete box girder transportation and stress as the auxiliary control parameter, and put forward the crack control method of spatial four-pivots driven concrete box girder transportation structure. Through numerical simulation, this paper set up the control values of girder posture and stress in box girder transportation, constructed the information monitoring system of girder posture and stress to realize remote real-time monitoring and real-time display, and shaped the stress and posture control technology of SPMT transportation structure for long-span special-shaped box girder, which helped the box girder of Cross Bay Link, Tseung Kwan O project to be successfully barged. The research results of this paper can be used for reference for similar projects in the future.

1. Introduction

From a global perspective, large-scale sea-crossing transportation infrastructure projects are developing in the direction of being “large-scale, standardized, industrialized and assembled”, that is, large prefabricated components are adopted, standardized and industrialized production is realized, and then large mechanical equipment, large floating cranes and offshore working platforms are adopted to install components, so as to minimize offshore operations, speed up project progress and reduce construction risks\cite{1}.

Concrete box girder has a fragile structure, requires large storage space, and has poor overall tensile and torsional resistances. During the transportation of concrete box girder, the concrete structure is at risk of being damaged by tensile crack\cite{2-3}. In the construction process, cracks of concrete box girder must be well controlled to ensure the smooth transportation of concrete box girder. At present, the transportation control of concrete structures is generally based on simple stress and deformation index control. Although stress and strain can reflect the force and deformation of key sections of box girders, they cannot directly instruct how to make adjustment after early warnings, and cannot define the main reasons for the deformation condition of the structure in time. However, the transfer and barge process of long-span concrete box girder is continuous, and especially the floating barge is often uninterrupted,
so that in-time adjustment needs to be made if there are early warnings, and the traditional monitoring method can no longer meet the demands of construction control of complex engineering.

In order to support the girder crack control and on-site rapid process adjustment during box girder transfer and barge of Cross Bay Link, Tseung Kwan O project, this paper proposed to take the girder posture as the master control parameter of SPMT transfer and barge of long-span box girder, and the girder stress as the auxiliary control parameter to form the girder stress and posture control technology of SPMT transportation of long-span special-shaped concrete box girder, which finally helps the box girder of Cross Bay Link, Tseung Kwan O project to be barged smoothly.

2. Project Background
Cross Bay Link, Tseung Kwan O project and its related projects builds another large-scale sea-crossing landmark bridge in Hong Kong after Tsing Ma Bridge and Stonecutters Bridge. The project involves the prefabrication of 18 large-span prestressed curved special-shaped box girders, and the transfer and rolling to barge of SPMT transportation. Barges are transported to the site of Cross Bay Link, Tseung Kwan O for installation. The maximum length of a single box girder is 75m and the maximum weight is 3344t. It is the first time in China that SPMT sets are used for transferring and barging of large-tonnage and long-span prestressed concrete box girders, and there is little experience to learn from.

![Swiping to barge diagram of SPMT for long-span box girder](image1)

In this paper, the box girder NE4-5 is taken as an example. The box girder NE4-5 weighs 2452 t, and is 74.4 m long, 15.2 m wide and 3.857 m high. Its layout of SPMT sets are shown in Figure 2.

![Layout of Box Girder NE4-5 SPMT Vehicle](image2)

3. SPMT Transportation Control Parameters for Long-span Special-shaped Box Girder
According to the occurrence probability of each working condition and its influence on the structure upon occurrence, the transportation control parameters of long-span box girder can be divided into master control parameters and auxiliary control parameters. The master control parameters are subdivided into single parameter control and multiple parameter control. The auxiliary control parameters are the collection of other remaining control parameters.

The SPMT sets adopt 4-pivots synchronous jack-up, which is converted into 3-pivots support during transportation\textsuperscript{[4-6]}. The asynchronous SPMT jack-up, asynchronization caused by uneven ground
during transportation, the hull deformation and posture change during the floating barge of the box girder, and the height difference between the hull and the wharf will all cause the change of the box girder postures, causing the box girder to twist, thus adversely affecting the stress of the box girder structure. On the contrary, the posture of box girder can also reflect the postures of SPMT sets and ships to a certain extent, so controlling the posture of box girder to avoid torsion can not only control the stress on girder, but also provide decision support for the posture adjustment of SPMT sets and ships.

This paper proposes to take the girder posture as the master control parameter of SPMT transfer and barge of long-span box girders, and the girder stress as the auxiliary control parameter. The force bearing form of long-span box girder SPMT transportation is simplified as a four-pivots support system, and the girder posture is controlled by controlling the four-pivots asynchronous displacement. The calculation formula of asynchronous displacement is: \( \Delta = (\Delta_1 - \Delta_3) - (\Delta_2 - \Delta_4) \), and 1, 2, 3, 4 are the four corners circling around the girder. The elevation variation is respectively \( \Delta_1, \Delta_2, \Delta_3, \Delta_4 \).

4. Structure Stress and Posture Control Value for Long-span Special-shaped Box Girder

The finite element calculation model of box girder NE4-5 is constructed, as shown in Figure 3. The elastic modulus and bulk density of C60 concrete in the model are \( 3.65 \times 10^7 \text{ kN/m}^2 \) and \( 25 \text{ kN/m}^3 \) respectively. The prestressed 19\( \Phi \)15.7 steel strand is used for the prestressed steel base plate, 27\( \Phi \)15.7 prestressed steel strand is used for the web plate, 19\( \Phi \)15.7 prestressed steel strand is used for the top plate, and 1*7 steel strand is used. The nominal area of the section is 150 mm2, the stress of tension control is 1395 MPa, and the SPMT jack-up force is applied to the supporting beam in the form of uniformly distributed load, as shown in Figure 3.

![Figure 3 NE4-5 Simulation Model](image)

| Table 1 Early warning value of asynchronous displacement of box girder NE4-5 (mm) |
|---------------------------------|----------------|
| Warning level                  | Warning value |
| First level warning            | 50            |
| Second level warning           | 80            |
| Third level warning            | 100           |

This paper carries out simulation analysis of the whole process of jack-up, transfer and barge of box girder NE4-5, and the sensitivity analysis of asynchronous displacement of the girder. Based on the crack control requirements of box girder, the girder posture and stress control values are put forward. The standard value of C60 concrete tensile strength is 2.85MPa and the standard value of compressive strength is 38.5 MPa. As the transportation of long-span box girder is a temporary working condition during construction, 70% of the standard value is taken as the stress control value, which means the tensile and compressive stresses are controlled within 2MPa and 27MPa respectively. After calculation and analysis, the asynchronous displacement and strain control values of box girder NE4-5 are shown in Table 1 and Table 2 respectively. The asynchronous displacement of the box girder is the main control parameter and three-level early warnings are set here. When the monitored data is close to the value of first-level early warning, a warning is given without having to make adjustment. When the monitored data is close to the value of second-level early warning, the box girder should be slowed down and the box girder moves while making adjustment. When the monitored data is close to the value of third-level early warning, the box girder stops running and cannot continue until the posture is adjusted. 1#, 2#, 3# and 4# in Table 2 are support beam numbers.
### Table 2 Strain warning value of box girder NE4-5 (με)

|                | Theoretical value | Warning value |
|----------------|-------------------|---------------|
|                | The first jacking |               |
| process        | process           |               |
| 1#             | 9 (0.32)          | 153 (5.51)    |
| 2#             | 22 (0.79)         | 170 (6.12)    |
| 3#             | 31 (1.12)         | 193 (6.95)    |
| 4#             | 38 (1.37)         | 219 (7.88)    |
| Middle span    | -76 (-2.74)       | -341 (-12.28) |
| 1/4 span       | -71 (-2.56)       | -252 (-9.07)  |

#### 5. Information Monitoring of Structure Stress and Posture

During transportation, the box girder is in a multi-support structural state, with the maximum positive bending moment in the midspan and the negative bending moment at the support beam. Therefore, a test section is selected at the support beam to control the tensile stress of the box girder’s top plate and a test section is selected in the midspan to control the compressive stress of the base plate, as shown in Figure 4.

Static water levels are arranged at the four corners of the box girder, as shown in Figure 5 (both sides are arranged in the same way). One of the measuring points is taken as the base point to test the elevation difference of the other three measuring points relative to the base point. An automatic monitoring system is adopted to realize real-time monitoring of the uneven displacement of the four corners of the girder during the transfer and barge of the box girder.

This paper proposes for the first time to use static water level to test the posture of box girder. The static water level applies the principle of communicating vessels to keep the liquid surfaces of multiple liquid reserve tanks connected by communicating vessels always at the same level. The real-time test of the elevation difference of static water levels can be realized by using information monitoring system, as shown in Figure 6.
With the help of information technology, an information monitoring system for structural stress and posture of long-span box girder SPMT is constructed. The system consisting of a perception layer, a transmission layer and an application layer, realizes real-time remote collection, transmission and display of monitoring data.

6. Results of Structure Stress and Posture Control
The posture monitoring results of box girder NE4-5 are shown in Figure 7.

As can be seen from Figure 7, the torsion of the girder is basically controlled within 10 mm, which does not reach the early warning value, during the process of box girder barging and transferring.

While ensuring that the girder posture meets the control requirements, the girder stress is monitored in real time. The stress monitoring results of the box girder NE4-5 are shown in Figure 8.
Figure 8 Strain change diagram of measuring points of box girder (με)

Table 3 Maximum strain of measuring points of box girder NE4-5 (με)

| Test section | Measured value | Warning value | Results                      |
|--------------|----------------|---------------|------------------------------|
| Section 1    | Node 1: 44     | /             | 153 Not reaching the warning value |
|              | Node 2: 41     | /             |                              |
| Section 2    | Node 1: 136    | /             | 193 Not reaching the warning value |
|              | Node 2: 132    | /             |                              |
| Section 3    | Node 1: -255   | /             | -341 Not reaching the warning value |
|              | Node 2: -255   | /             |                              |
|              | Node 3: -259   | /             |                              |
| Section 4    | Node 1: 157    | /             | 219 Not reaching the warning value |
|              | Node 2: 155    | /             |                              |
| Section 5    | Node 1: 113    | /             | 170 Not reaching the warning value |
|              | Node 2: 111    | /             |                              |

The maximum strain monitoring results of measuring points during the barging process of box girder are shown in Table 3. As can be seen from Table 3, the strain of each measuring point has not reached the early warning value. The maximum tensile stress of the box girder is -0.05 MPa (indicating that no tensile stress occurs), which is less than the control value of 2 MPa, and the maximum compressive stress is 17.0 MPa, which is less than the control value of 27 MPa. The stress of the box girder is in a safe range.

7. Conclusions

1) For the first time, the girder posture was taken as the master control parameter of SPMT transfer and barge of the long-span box girder and girder stress as an auxiliary control parameter. The girder posture control can not only control the structure cracks in the transfer and barge of long-span box girder, but also provide decision support for the posture adjustment of SPMT and ships, supporting the rapid process adjustment on site.

2) In this paper, the asynchronous displacement was proposed as the control index of box girder transportation posture for the first time, and the calculation formula of asynchronous displacement is proposed. For the first time, the static water level was used to realize the real-time posture monitoring during the transportation of box girder.
3) The torsion of the box girder NE4-5 was basically controlled within 10 mm during the barge process. The maximum compressive stress of the box girder was 17.0 MPa, and there was no tensile stress. Both the stress and torsion of the box girder did not reach the early warning value, and the stress of the box girder was in a safe range.

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