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Construction simulation of middle column of prefabricated box girder bridge in prefabrication stage

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Abstract: Through the finite element software abaqus, the finite element model of prefabricated segmental box girder with one joint and three spans(42m+66m+ 42m)in the section from the airport expressway to XinZheng is established. It is demonstrated that the stress of the box girder and the stress between joints are in the safe range during the symmetrical splicing construction of middle piers. By changing the value of the pre-stress, the influence of pre-stress on the mechanical performance of the box girder in the construction stage is discussed. As a result, during the construction process, the roof pre-stress has a bigger impact on the construction stage than the web pre-stress, and it is proposed that the loss of pre-stress should be reduced during the construction stage.

1. Introduction

With the continuous in-depth research on pre-stress and the continuous maturity of prefabricated assembly technology, prefabricated segmental bridges have been developed. The construction technology divides the main girder into sections, and prefabricates and maintains the main girder in the factory according to the long-line method or the short-line method. After the beam section reaches a certain strength, it is transported to the construction site, and the beam section is spliced together by a bridge erecting machine. It has the advantages of fast construction speed, small construction space, and less impact on traffic. The upper and lower structures of the bridge were constructed at the same time. At present, it has been widely recognized in the bridge construction of various countries in the world [1,2].

However, with the continuous application of precast segment splicing construction method, a lot of safety accidents occurred in the process of segment assembly due to the large loss of pre-stress. Such as cracks at the joints and concrete cracks at the joints, falling off of segments, excessive vertical displacement of beams during construction, etc., which cause serious economic losses to people.

In 2000, angel C. Aparicio and others carried out tests on beams constructed by integral pouring methods and segmental assembling methods, compared and analyzed the ultimate bearing capacity

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and joint shear performance of structures under bending and bending shear conditions, as well as the influence of external cable length on the ultimate bearing capacity of structures^[3]; Liu Zhao, a Chinese scholar, analyzed the overall mechanical performance of the segmental assembled box girder in the construction stage and operation stage through the full-scale model test of the box girder of the Fourth Nanjing Yangtze River Bridge in 2011. The mechanical properties of the segmental assembled bridge can meet the specification^[4]; Wang Yi used ansys software to simulate the cantilever construction process of a bridge, and pointed out that the stress condition of each segment of the bridge in the construction stage was good, and the concrete would not crack, so it was in a safe range^[5]; At the same time, Xiao Junyao analyzed the mechanical properties of a segmental prefabricated girder bridge, and pointed out that the elastic range in the construction stage, and the shear key can be ignored in the overall analysis process of the bridge^[6].

Based on previous research results, this paper simulates the construction of the symmetrical splicing of the piers in the segment beams. Aiming at some safety accidents caused by the excessive loss of pre-stress, it explores the influence of the pre-stress on the mechanical performance of the segment bridge box girder during the construction process.

2. Engineering background

This paper selected a three-span (42m+66m+42m) for construction analysis. The main line viaduct is mainly erected by prefabricated cantilever components of segmented beams. Each part of the beam is connected with pre-stressing and splicing adhesives. The length of the standard beam section is 2.9m or 2.4m, the width is 16.5m and 10m, and the maximum weight is about 88t.

2.1 Stress analysis of construction process

According to the deflection deformation principle of structural mechanics and the elastic calculation theory of pre-stressed concrete beams, the bridge deflection in the construction stage of the precast segmented box girder splice bridge consists of two parts, one is the deflection produced by the beam itself. ; The other is the deflection caused by the pre-stress^[7].

The deflection of the bridge under gravity and the load adopts structural mechanics method: $\Delta = \sum \int \frac{\bar{M}_K M_P}{EI} \, ds$

 \overline{M}_{K} is the virtual unifying force in the virtual state Bending moment at $\overline{P}_{K}=1$, M_{P} is the bending moment produced by the actual load.

Under the action of pre-stress, the arch value of pre-stressed concrete beam can be calculated by structural mechanics according to the given construction stiffness: $\delta_{pe} = \int_0^l \frac{M_{pe} \ \bar{M}_x}{\alpha B_s} dx$

Mpe is the bending moment value caused by effective pre-stress at any section x, Mx is the bending moment at any section x when the unit force is applied at the end of section 11; Bs is the construction of elastic stiffness, α is the reduction coefficient of elastic stiffness, taking 0.9.

The calculation results are as follows Figure 1.

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The graph multiplication method is used to calculate the vertical displacement of the 11-segment end caused by gravity and construction load, $\Delta \approx -0.075$ m, and the vertical displacement of the 11-segment end caused by the pre-stressed steel, $\delta_{pe} \approx 0.0352$ m.

In the process of bridge construction, the overall deformation is very small, and it is approximately considered that the spliced bridge segments are in the elastic range, and then each section of the bridge conforms to the linear superposition principle, that means, the total deformation of the bridge is equal to the total deformation of each component^[8]. $y = \Delta + \delta_{pe} \approx -0.04$ m.

3. Finite element calculation model

3.1 Simplification of finite element model

The section box girder involved in this article has a large span, and the spatial connection method and beam element method used in traditional bridge structures can no longer meet the requirements of bridge finite element analysis. Combining the spatial solid element can obtain the stress of each part of the segmented box girder, and can simulate the advantages of concrete cracking. Therefore, the physical elements of space are used for finite element simulation^[9, 10].

3.2 Material parameters

According to structural design instructions, the segment beams are made of C60 concrete, the steel bars are HRB400 ordinary steel bars, and the pre-stressed steel bars are $1 \times 7 \ 0^{j}15.2$ high-strength, low-relaxation steel strands $f_{pk} = 1860$ MPa, tensile stress $\sigma_{con} = 1395$ MPa The mechanical parameters of materials are shown inTable 1

Table 1 Material mechanical parameters					
Name	Material	Elastic Modulus /Pa	Poisson's ratio	Bulk density /kg	
Segment beam	C60	3.6E10	0.2	2600	
Wet joint concrete	C50	3.45E10	0.2	2600	
Pre-stressed steel	Stranded wire	1.95E11	0.3	7850	
Steel bar	HRB400	2.0E11	0.3	7850	

3.3 Pre-stressing

The pre-stress loading is applied by the cooling method. Since the cooling method in the abaqus cannot simulate the pre-stress loss of the pre-stressed steel bars, the pre-stressed steel bars are segmented three parts in Figure 2 and given different temperatures to simulate the pre-stress loss.

Transverse pre-stressed steel

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three strands according to the length of the section: 2.4m section contains three

strands, and 2.9m section contains four strands. The pre-stress cooling value is

Before applying the pre-stressed load to the pre-stressed steel bar, according to the specification, combined with the characteristics of small shrinkage and creep of the precast segment box girder, the only pre-stress loss considered in the construction stage is the superposition of anchor deformation, friction loss and pre-stressed steel relaxation^[11]. The size of the pre-stress is shown in Table 2.



Figure 2 The part of pre-stressed steel

Pre-stress position	Numbering	Part 1 cooling (°C)	Part 2 cooling (°C)	Part3 cooling (°C)
Web pre-stressed steel	F-7	680	645	614
	: F-0	: 592	: 565	: 543
Roof pre-stressed steel	T-0	587	585	585
	: T-10	: 681	: 663	: 643

Table 2 Pre-stress value

3.4 Finite element model constraints and load arrangement

H-x

650°C

According to the construction process and the distribution of load constraints, the loads and constraints involved in the model are symmetrically arranged. The whole model is created according to the 1/4 structure of the middle pier splicing box girder, and symmetrical constraints are set at the longitudinal and transverse end faces of the box girder, as shown in

Table 3.The steel plate is set at the support to establish the constraint with the bottom of the beam and restrict the vertical displacement. Ordinary reinforcement and pre-stressed reinforcement are embedded in concrete with embedded constraints. The joint was simplified^[12, 13], and the type of constraint between segments was tie. Solid element (C3D8R) is adopted for concrete element; Ordinary reinforcement is modeled by reinforcement layer method (SFM3D); The pre-stressed reinforcement adopts truss element (T3D2). The overall finite element model is shown in Figure 3.

Table 3 Loads	s and	constraints
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Construction stage	Release part	Load	Pre-stress	Constraint
JOB-1	0#、0#' Wet joint 1#、1'# T0、F0	G+F	T0、F0	The bottom end is fixed, the beam end is symmetrically constrained (Y direction), Beam side symmetric restraint (X direction) Simply supported at the bottom, symmetrical restraint at the side of the beam (X direction)
JOB-2 : JOB-11	2#、2'# T1、F1 : 11#、11'# T10	G+F : G+F	T1、F1 : T10	Beam side symmetric restraint (X direction)

When the Nth section is constructed, the Nth and the (N-1)th sections are applied with machinery (epoxy glue mixer and temporary pre-stressed tensioning machine) load 5KN/m².

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Figure 3 Segmental beam 1 / 4 finite element model

4. Analysis of calculation results

Figure 4 is a stress diagram of a cross-sectional beam. From the longitudinal stress diagram of the bridge, it can be seen that, except for the end stress of the No. 11 line segment, the stresses of the other line segments are all pressure, which will not cause the joint to crack or fall off. The stress of the segmented beam in the maximum main tension diagram of the bridge is very small, about 0.9MPa, so the concrete will not crack.

Figure 5 shows the longitudinal stress at the top and bottom of the segmented beam. The stress change trend is greater at the support and gradually decreases at the far end of the support. Sudden changes in longitudinal stress occurred in beams 0, wet joints and beam 1, which were caused by restraints and reduced concrete strength of the joints. In Figure 6, the final vertical displacement of the segmented beam is about 44mm, which is close to the 47mm of the top of the No. 11 segmented beam in actual construction and the 40mm vertical deflection calculated by the structural mechanics method.



(a)Longitudinal stress diagram of segment beam (b)Main tensile stress diagram of segment beam

Figure 4 Segmental beam stress diagram

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Figure 5 Segment beam longitudinal stress



Figure 6 Displacement of segment beam top

5. Influence of pre-stress value on bridge stress during construction

In the actual construction process of tensioning pre-stress, the corrugated pipes are not cleaned cleanly, the pipeline deviation or due to improper operation may cause the pre-stress loss to be far greater than the normal construction pre-stress loss, and the actual pre-stress of the pre-stressed reinforcement of the segment bridge is less than the design pre-stress. Explore the roof and web by reducing the pre-stressed steel bar stress on the top plate and the pre-stressed web on the web (condition 1), the stress of the pre-stressed steel bar only on the top plate (condition 2) and the stress of the pre-stressed steel bar and roof web on bridge stress and deflection during splicing.

Figure 7 shows the longitudinal stress at the top and bottom of the beam under different working conditions. When the pre-stress loss is too large, tensile stress may appear on the top of the beam, which may cause joints and concrete cracks. Moreover, in the cantilever construction state, the sensitivity of the longitudinal stress of the beam to the stress loss of the web pre-stressed steel is less than the sensitivity of the roof pre-stressed steel.

Figure 8 shows the vertical displacement of the segmented beam under different working conditions. It can be seen that as the pre-stress decreases, the vertical displacement of the segmented beam gradually increases, and the pre-stress decreases by 10% each time. The vertical displacement Δ_{T+F} increases by about 6mm. In the second working state, only the pre-stress loss and pre-stress of the top plate are reduced by 10%, and the vertical displacement Δ_T at the end of the sector beam is increased by about 5mm. In the third working state, only the web pre-stress loss and pre-stress were reduced by 10%, and the vertical displacement Δ_F at the end of the sector beam increased by about 1mm. This shows that in the cantilever construction state, the stress loss of the roof pre-stressed steel bar has a greater impact on the bridge route than the pre-stress loss of the bridge web. And the bridge construction section is in the elastic section.



Figure 7 Longitudinal stress on top under different working conditions

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Figure 8 Vertical displacement of beam top under different conditions

6. Conclusion

The simulation results of symmetrical assembling of the piers in the box girder bridge of pre-stressed concrete precast section are carried out by abaqus.

During the construction, the segment beam is in the elastic stage. The maximum main tensile stress of the top plate and web of box girder is less than that of concrete, and the box girder will not crack. The maximum deflection of box girder is 44mm, which is close to the actual construction of 47mm.

The restraint of pre-stressed steel beam plays an important role in the deformation of the beam section. During the construction stage, the sensitivity of beam deflection to the stress loss of web pre-stressed reinforcement under cantilever state is less than that of the top slab pre-stressed reinforcement, and the stress loss of the top slab pre-stressed reinforcement has more influence on the bridge alignment than that of the web pre-stressed reinforcement on the bridge alignment.

Too much pre-stress loss may cause the maximum main tensile stress of the section girder construction process to be close to the cracking stress. The epoxy resin adhesive tensile cracking may occur or even the whole segment beam will fall off. The maximum deflection of the box girder construction process will increase continuously, which will bring safety risks and other safety problems to the construction. The loss of pre-stress will also affect the normal use of the bridge. In the construction, it should be strictly controlled to reduce the loss of pre-stress.

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