Structural Analysis of Zhihe Prestressed Concrete Aqueduct

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Abstract. With the help of software ANSYS, a finite element analysis model was established for the three-directional prestressed concrete aqueduct in South-to-North Water Transfer Project. The effect of the prestress value of steel tendon on the stress of aqueduct body was studied, and the stress states of aqueduct during construction and operation period were obtained. Results shows that the aqueduct structure is safe during operation period, however, the development of local crack must be restricted.

Introduction

When we talk about the prestressed concrete aqueduct, we know the value of prestress will have an important impact on the stress and deformation of aqueduct [1], and the form of the steel channel, stretching sequence or the friction between channel and steel all have effect on the value of prestress [2]. So, the value of prestress determines the carrying capacity of the aqueduct. In this article we take a large prestressed three-span rectangle aqueduct in Middle Route of South-to-North Water Transfer Project as research object, study the pretressed steel and aqueduct, get results about numerical simulation analysis, which can provide a reference for the design and construction of aqueduct in the future.

General Situation of the Engineering

The Zhihe aqueduct is located in Lincheng County in Hebei Province, which is constitute by four parts: import and export of transition Section, import and export inspection gate section, import and export segments and the aqueduct itself. The full length of the aqueduct is 270 m, divided into 9 spans, freely supported structure. The total width of the aqueduct is 25.5 m, adoption C50 concrete.

The support structure adopt the gravity pier broaden the base which is produced by reinforced concrete structure. Design depth of water within the aqueduct is 5.8m; increasing water depth is 5.98 m; longitudinal slope of aqueduct is 1/4100. The section size is 7.0m × 6.7m, side wall has 0.6m thickness ; the sidewalk panels which located at the top of the aqueduct has 2.7m width; the middle wall has thickness 0.7m, the middle walk panels which located at the top of the aqueduct has 3.0m width. The concrete of trolley adopt C30, and the pouring belt provided at each end of the cross-channel aqueduct, has 0.575m width.

The strands in vertical and horizontal directions of the aqueduct are of 1860MPa level, $E_s = 1.95\times10^5$ MPa, the longitudinal strand in bottom adopts ten bunches of strands $4\phi^s$ 15.2. The transverse beam under aqueduct has four bunches of strands $7\phi^s$ 15.2 in the upper part, and two bunches of strands $7\phi^s$ 15.2 in the lower part.

Two portrait beamed in the middle of aqueduct has one bunches of strand $12\phi^s$ 15.2, two portrait beamed side of aqueduct has one bunch of strand $7\phi^s$ 15.2. Vertical wall using one bunch of strand $12\phi^s$ 15.2 curved layout, the sidewalk plate on the aqueduct use three bunches of strand $7\phi^s$ 15.2. The prestressed steel in vertical wall adopts ϕ^{ps} 32mm rebar PSB930.

Computation Model

Model Parameters

The property of materials are shown in Table 1.

Tab. 1 the Strength Index of the Concrete and Steel

material	f_{ptk} / MPa	f_y / MPa	f_{cuk} / MPa	f_c / MPa	E / GPa
C50 concrete	2.64	1.89	32.4	23.1	34.5
ϕ^{ps} 32 rebar	1080	930	1080	930	200
ϕ^{s} 15.2 strand	1860	1265	——	——	195

Finite Element Model

The finite element software ANSYS is used to establish the computational model. The three-dimensional hexahedral solid element SOLID45 is used to simulate the aqueduct body, and the element LINK8 is adopted to simulate the prestressed strand and prestressed steel. In order to prevent concrete occurring stress concentration at anchor area, the shell element SHELL63 is used to simulate the anchor plate. The finite element model is shown in Figure 1.

Simulation of Prestressed Strand Stretching

The independent model coupling method is used in modeling. First, we establish the solid element and shell element, then establish the link element and couple them together [3, 4]. Model element SHELL63 used in this paper is shown in Figure 2.

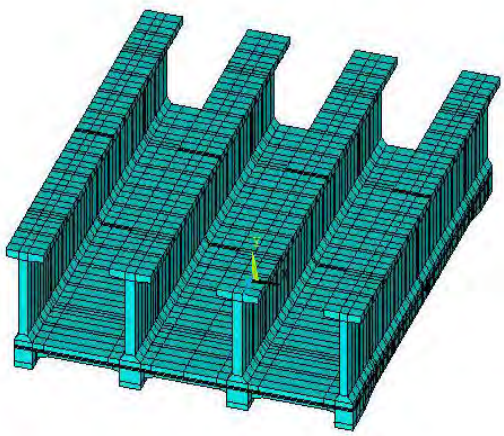

Fig. 1 The Finite Element Model

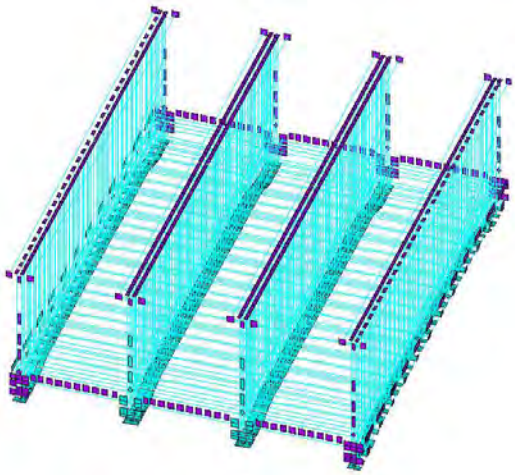

Fig. 2 Model Element SHELL63

Cooling method is used to implement prestressing[5]. The steel and concrete are defined as two different elements, with the nodes coupled to each other. Setting the anisotropic temperature gage factor to steel, we can bring the different prestressing by setting different temperature, i.e. different temperatures bring different strain. This method is consistent with the mechanical characteristics of the actual structure, which can simulate the prestressing loss in the structure.

Calculated Load Case

In the calculations of finite element simulation, prestressing loss is calculated according to standard values for prestressed concrete linear channel, but for curved channels, we need Consider the value of prestress loss caused by friction coefficient μ and yaw factor κ[6, 7], the friction loss parameters take according to design specifications: μ=0.15, κ=0.0015. Calculation parameters in the model are drawn as straight steel calculation parameters in Table 2, the curve steel are drawn in Table 3. Three kinds of different load cases are taken into account.

Load Case 1: Tension Stress level is 50%

Load Case 2: Tension Stress level is 100%
Load Case 3: According to standard simulated operators of aqueduct stress

Tab. 2 Parameters of Linear Reinforcement Calculation

Type of strand	Density /kg/m^3	μ	E /GPa	Area /mm^2	Tension level	Control stress /MPa	Final stress /MPa	strain
ϕ^s 15.2	7900	0.3	195	20	50%	697.5	718.4	3.70E-03
					100%	1395	1437	7.40E-03
PSB930	7900	0.3	200	804.2	100%	756	779	3.90E-03

Tab. 3 Parameters of Curve Reinforcement Calculation

Type of strand	Tension level	Actual stress / MPa	strain
ϕ^s 15.2	50%	472	2.42e-3
	100%	944	4.84e-3

The Analysis of Calculation Results

The stress nephogram of aqueduct under Load case 1 is shown in Figure 3. The maximum tensile stress occurs at the bottom of the stringer span region, with stress ranges from 0.14 to 1.17 MPa; the maximum compressive stress occurs at aqueduct across the upper portion of the flange, with range of -1.92 to -0.89MPa. Lateral stress manifested that aqueduct bottom effect by longitudinal compressive stress, stress ranges from -1.24 to -0.15MPa. The junction between the wall and the floor has a small tensile stress, about 0.95MPa. The maximum stress on the inside of the vertical supports of sidewall is obvious, stress ranges from -7.5 to -5.46MPa.

The stress of aqueduct under Load case 2 is shown in Figure 4. Aqueduct longitudinal stress showed the characteristic of the working-beam under gravity effect, the upper is pressure across the region and the lower is the tension across the region. The local maximum tensile stress occurs in the vertical prestressing tendons at the anchor plate, stress ranges from 0.11 to 0.74MPa. Transverse stress on the bottom plate is obvious. Transverse stress on the bottom surface has little change in overall, stress range from -2.62 to -0.91MPa. Vertical stress occurs at the vertical wall. The stress in two vertical wall is almost equal, has less compressive stress; the inside of the side wall has the performance for compression state, in the span range side wall pressure stress range from -6.47 to -3.40MPa. But pressure stress at the end of span increases, range from -7.50 to -6.47MPa.

The stress in aqueduct under Load case 3 can be seen in Figure 5. The stress distribution of the aqueduct of longitudinal compression is similar to a simply supported beam under uniform load. The maximum longitudinal tensile stress appears in the bottom beam, range from 0.73 to 2.02MPa, the maximum horizontal tensile stress appears at the junction between the bottom of the vertical wall edge of the beam and floor, about 2.20 MPa. Therefore, these two regions are more prone to crack. The distribution of vertical stress is uniform, no stress concentration phenomenon, but at the junction of beams in the support and the bottom plate compressive stress is larger, especially when cross-section of beam changes, it will produce a small range of compressive stress, range from -7.18 to -4.63MPa.

Conclusion

By means of ANSYS, a large prestressed three-span rectangle aqueduct in Middle Route of South-to-North Water Transfer Project was analyzed, and the stress states of aqueduct during construction and operation period were studied. Useful numerical simulation results were obtained, which can provide a

reference for the design and construction of aqueduct in the future. Through analysis, the following conclusions can be drawn:

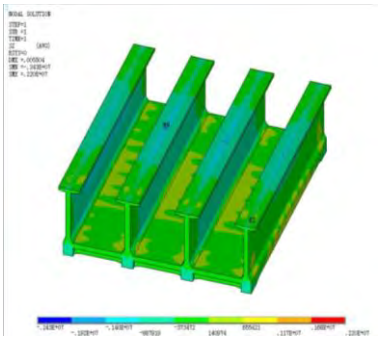

Fig. 3 The Stress in Load Case 1

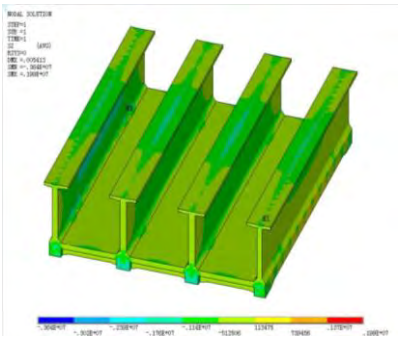

Fig. 4 The Stress in Load Case 2

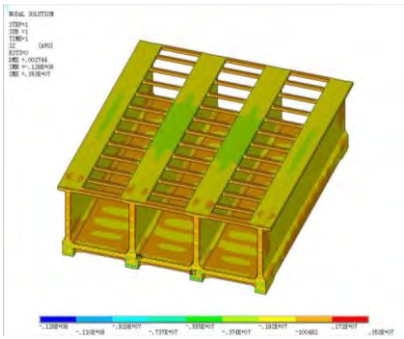

Fig. 5 The Stress in Load Case 3

(1) The stress distribution of aqueduct is symmetrical about cross section, in each case the law of stress distribution are consistent with simply supported beam. The lower part of the structure is in tension and the upper structure in compression. Specifically, the maximum tensile stress occurs at the longitudinal and transverse beam at mid span section and the upper span and inside support of the aqueduct have obvious compression stress.

(2) As the load level gradually increased, the aqueduct stress field changes. For the performance of the aqueduct, the bottom stress by early less tensile stress state gradually changing to compressive stress state the late. When the prestressing is completed, the press is about -0.91MPa at the bottom of the aqueduct under its self-weight. In the condition of normal water level during the period of operation, the maximum tensile stress at the bottom of aqueduct is about 2.20MPa.

(3) The result of the final stress shows that, when we get parameters μ, κ according to the design document, the aqueduct structure is safe in the normal operation period. But more attentions should be paid and control more measures should be taken in order to restrict the development of the local cracks.

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