The Scheme Research on Aqueduct with Three -way Prestressed Steel Strand Tension in South-to-North Water Diversion Project

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Abstract—**The large aqueduct has the characteristics of large streamflow, heavy load and complicated structure and so on. Different from the high dams, most of the aqueducts are constructed with the thin-walled concrete structures. When analyzing the structure of the aqueduct, people often only consider that after the completion of the overall project, whether the aqueduct meets the design requirements or not, ignoring the large thin-wall aqueduct deformation and stress distribution under different working conditions during the construction period, and other construction technical issues that may emerge. It is not so clear whether the prestressed tension load classification and tensioning sequence changes may significantly affect the aqueduct structure system. Therefore, further study is needed. Under the premise of ensuring the safety of the aqueduct structure and the convenient construction, this paper puts forward a feasible plan of three hierarchical tensioning of prestressed steel strand and the suitable release time of the aqueduct body weight, providing the theoretical and technical support for the similar large three-way prestressed aqueduct and hydraulic structure construction.**

Keywords: aqueduct; prestressed steel strand; tension by stages; thin-walled concrete structure; construction

I. INTRODUCTION

Located in Shenxing town, Mancheng county, Baoding city, Hebei province, the Caohe aqueduct , which is about 30 km away from Baoding and 9 km northwest of Mancheng county, is a larger span cross structures on the mid- route of South - to - North Water Transfer Project. The Caohe aqueduct consists of import period, trough body(Including the landing rectangle slot, 20 meters across three slots for more than a league of side wall section and more than a league of 30 meters across three slot side wall sections and the import and export connections) and export period[1-3]. The building in this project is level I. The primary building is level I building, the intensity of resisting an earthquake is 6 on the Richter scale.

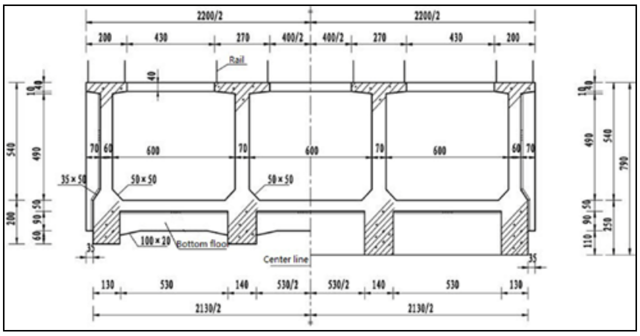

Fig. 1 The Caohe aqueduct`s cross-sectional dimensions

Trough body using three-way prestressed structure, prestressed steel strand in main trough body using both straight and curved shape, the diameter of the prestress wire is 15.2 mm [4]. Prestressed reinforcement arrangement is as follows:

(1) Longitudinal prestressed steel strand

To each side beam configuration layout total 9 hole, 83 Φ j15.2 steel strands, 33 is curve, and another 50 is straight line, adopt tensioning on both ends. Hole prestressed tendon respectively: A1 type channel for 8 Φ j15.2 x5, B1 type channel for 11 Φ j15.2 x3 and G1 type channel for 10 Φ j15.2 x 1.18 hole on both sides of the side beam, beam of 166 strands.

To each longitudinal beam, each longitudinal beam configuration with 13 channel, 128 Φ j15.2 steel strands, including 44 is curve, another 84 is straight line, adopt tensioning on both ends. Channel of prestressing tendon is

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respectively: C1 hole is 10 Φ j15.2 x5, D1 type channel for 9 Φ j15.2 x 2, E channel for 11 Φ j15.2 x 4, type H1 channel for 8 Φ j15.2 x 2.Two floor, decorate a 24 hole, configuration 96 beam Φ j15.2 steel strand, each groove 32 beam, channel prestressed tendon is: 4 Φ j15.2 x 24.

(2)Transverse prestressed steel strand

Transverse prestressed reinforcement is configured by the unit of cross rib, cross section in each unit layout 3 channel, for 14 Φ j15.2 x 1 (L1), 5 Φ j15.2 x 2 (K1).The 10 hole layout for curve, both ends tension;20 channel for linear layout, single tension. Bearing cross section per unit 3 channel, 17 Φ j15.2 x 1 (J1), 3 Φ j15.2 x 2 (I1).J1 type channel for curve layout, both ends of the tension;I1 channel is linear layout, unidirectional tension

(3) Vertical prestressed steel strand

Vertical prestressed reinforcement is linear arrangement, still configured by the unit of cross rib and symmetrical configuration, a total of 36 hole, 252 Φ j15.2 steel strands ,each unit have 3 channel configurations, the inside bore 2 (M1), lateral 1 (N), is 7 Φ j15.2 x 3, top tensioned.

II. Introduction to the Three-way Prestressed Classification Tensioning Calculation Model

Due to the Caohe's characteristics of large streamflow, large span and large cross section, etc and the first phase of the south-to-north water transfer project, and the overall space structure of aqueduct, which needs an overall analysis, the paper adopts the ANSYS software to simulate calculation.

A. Coordinate direction rules

(1) The X direction: the aqueduct transverse direction, to the right for positive

(2) The Y direction: the aqueduct vertical, to the upward for positive

(3) The Z direction: the aqueduct at the direction of flow, Z direction Cross out for positive

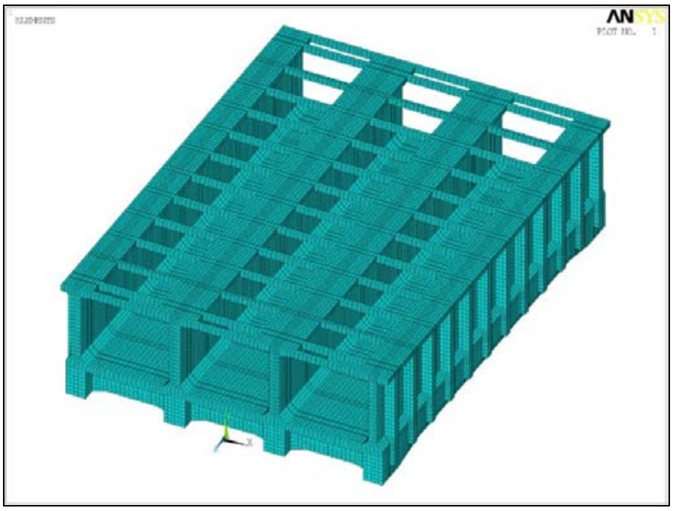

Fig. 2 Finite element analysis model of aqueduct

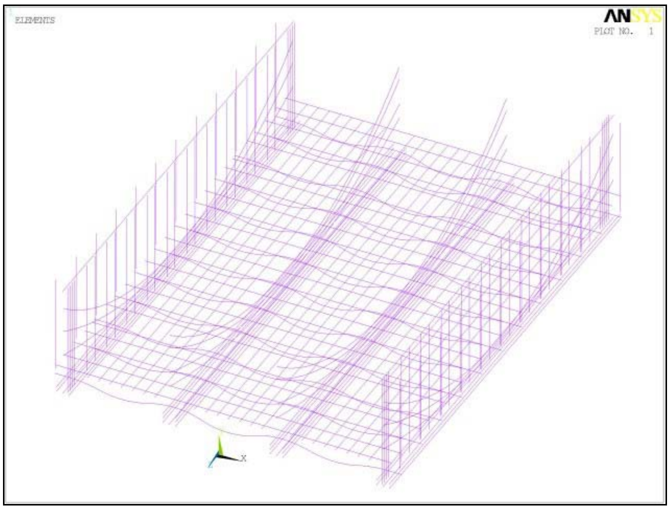

Fig.3 Model for calculating the aqueduct three-way prestressed steel strand

B. Calculated parameters

(1) Concrete. Strength grade C50, according to the hydraulic concrete structure design code (DL/T5057-1996) [5-6], structural calculation design parameters: elastic modulus EC = 3.45 x 104 N/mm; Poisson's ratio= 0.167; Density ρ= 2515 kg/m3.

(2) The steel strand: elastic modulus EC = 1.95 x 105 N/mm; Poisson's ratio u = 0.30; Linear expansion coefficient 2 E-005; Density ρ = 7850 kg/m3.

The selected material parameters are shown in Table 1.

TABLE 1 ATERIAL PARAMETERS

Parts	**material**	**density (Kg/m^3)**	**elastic modulus (GPa)**	**Poisson's ratio**	**CTE**
The entity part	C50 concrete	2500	34.5	0.167	—
Side walls and baseboard	Prestressed steel strand	7850	180	0.3	1.2×10^{-5}

C. Calculation unit and failure criterion

Use SOLID65 element to simulate the concrete unit, the unit is designed for concrete and rock compressive capacity greater than the tensile capacity of non-uniform material development unit. LINK8 element for prestressed steel strand, the unit of which is composed of 2 nodes, can simulate under axial force, not under bending moment, etc., and have plastic, creep, stress players, large strain and unit anyway, and other functions.

The constitutive relation of concrete material adopts the multiple linear and isotropic and strengthen model MISO, and use five parameters simulation William - Warner failure criteria are adopted to simulate failure criterion of concrete material.

TABLE 2 SINK BODY UNIT INFORMATION

Unit type	Unit number	Analog parts
SOLID65	174616	concrete
LINK8	11020	prestressed steel strand

D. Constraint conditions and prestressed load

30 meters span range can be seen as a simply supported beam aqueduct structure, namely one end is fixed hinge bearing, and the other end hinged support for activities, simulation of the load of the prestressed steel wire by the method of temperature drop. The original design of steel strand tension control stress of 1302 N/mm, the prestress loss value is calculated as 192.2 N/mm2, therefore, this paper takes effective prestress of 1110N/mm2. According to the stress and the corresponding temperature change formula $\Delta T=\sigma/E\alpha$[7], we can calculate the effective prestress value converted to the equivalent temperature.

III. THE SCHEME RESEARCH ON CAOHE AQUEDUCT WITH THREE-WAY PRESTRESSED STEEL STRAND TENSION

The Caohe Aqueduct has the characteristics of large streamflow, heavy load and complicated structure [8]. In the analysis of aqueduct structure design, after the completion of operation period, people often only consider under different working conditions, whether the whole aqueduct can meet the design requirements or not, ignoring how to safely and effectively carry out large thin-wall aqueduct as so much steel strand prestressing construction and the problems may encounter. People pay less attention to the problem that the tensile load classification and tensioning sequence changes may significantly affect the aqueduct structure system.

The purpose of this paper is to find a feasible plan for the optimization of the Three-way prestressed steel strand by the premise of ensuring the structure safety and the construction convenience, for the similar large three-way prestressed aqueduct and the structure of hydraulic construction to provide theoretical and technical support.

A. The basis and thinking of the tension of prestressed steel strand

There are more than 1000 prestressed steel strands in the aqueduct, and it's too multifarious for one-way prestressed optimized [9-10]. In order to simplify the process of the application of the prestress, the three-way prestressed steel strand should be divided into groups first. In the actual construction process of the aqueduct, it is impossible to satisfy one time stretch-draw according to the technical requirements, we need to grade tensioning, and in the process of tensioning to remove the scaffold in order to release self-respect. In this paper, the prestressed steel strand is divided into 10 stages and the release of the weight is gradually carried out, the minimum sink body maximum principal stress as the optimization goal, calculate and analyze the time to release the weight, and determined the three-way prestressed steel strand grading loading plan.

B. The prestressed steel strand influence on the stress of the sink body structure

(1)The calculation of sink body stress under only the effect of longitudinal prestressed reinforcement

Under the condition of empty slot, assuming that only longitudinal tensioning prestressed steel strand in the tank body, calculation and analysis the longitudinal prestressed steel strand influence on sink body structure, the influence of relevant results are shown in table 3.

TABLE 3 LONGITUDINAL PRESTRESS FOR THE IMPORTANT PARTS OF THE STRESS COMPONENT AND VERTICAL DISPLACEMENT RESULTS

mid-span	σ_x(MPa)	σ_y(MPa)	σ_z(MPa)	μ_y(mm)
Side wall top	0.007	-0.004	0.594	1.682
Edge bottom beam	-0.065	0.007	-3.909	1.645
Side wall and floor board	-0.341	-0.132	-2.687	1.707
Middle wall top	0.062	0.002	1.065	1.990
Middle bottom beam	-0.085	0.012	-4.284	1.954
middle wall and floor board	-0.014	-0.047	-2.711	2.009
Upper bottom plate	0.105	0.000	-2.514	2.052
Lower bottom plate;	-0.261	-0.002	-3.368	2.045
bottom floor	-0.059	-0.023	-0.010	2.025
Tie rod	0.404	0.000	0.000	1.943
Side rib	0.008	0.367	-0.014	1.684

(2)The calculation of sink body stress under the effect of transverse prestressing reinforcement

Under the condition of empty slot, assuming that only transverse tensioning prestressed steel strand in the tank body, calculate and analysis the horizontal prestressed steel strand influence on sink body structure, the results are shown in table 4.

(3)The calculation of sink body stress under the effect of vertical prestressed reinforcement

Under the condition of empty slot, assuming that only vertical tensioning prestressed steel strand in the tank body, calculate and analysis the vertical prestressed steel strand influence on sink body structure, the results are shown in table 5.

TABLE 4 TRANSVERSE PRESTRESS FOR THE IMPORTANT PARTS OF THE STRESS COMPONENT AND VERTICAL DISPLACEMENT RESULTS

mid-span	σ_x(MPa)	σ_y (MPa)	σ_z(MPa)	μ_y(mm)
Side wall top	0.020	0.002	-0.194	-0.158
Edge bottom beam	0.066	-0.001	0.118	-0.177
Side wall and floor board	-2.158	-0.424	-0.418	-0.071
Middle wall top	-0.005	-0.001	0.165	0.037
Middle bottom beam	0.081	-0.003	0.125	0.031
middle wall and floor board	-3.083	-0.625	-0.474	0.052
Upper bottom plate	-0.910	0.000	-0.048	0.273
Lower bottom plate;	-2.896	-0.002	-0.033	0.269
bottom floor	-4.794	-0.312	-0.084	0.277
Tie rod	0.146	0.000	0.000	0.138
Side rib	0.000	0.156	-0.001	-0.253

TABLE 5 VERTICAL PRESTRESS FOR THE IMPORTANT PARTS OF THE STRESS COMPONENT AND VERTICAL DISPLACEMENT RESULTS

mid-span	σ_x(MPa)	σ_y (MPa)	σ_z(MPa)	μ_y(mm)
Side wall top	0.673	-0.065	1.426	-0.253
Edge bottom beam	-0.078	0.004	0.673	-0.005
Side wall and floor board	-0.052	-0.152	-0.017	-0.025
Middle wall top	0.020	0.001	-0.008	-0.022
Middle bottom beam	-0.001	0.000	0.049	-0.022
middle wall and floor board	0.015	0.003	0.034	-0.022
Upper bottom plate	0.015	0.000	0.030	-0.023
Lower bottom plate;	0.021	0.000	0.041	-0.023
bottom floor	0.019	0.000	0.000	-0.022
Tie rod	0.056	0.000	0.000	-0.016
Side rib	0.001	-1.854	-0.002	-0.175

(4) Results analysis

By considering separately longitudinal prestressed steel strand, transverse prestressed steel strand and vertical prestressed steel strand on sink body structure deformation and stress distribution, a conclusion can be reached that the longitudinal prestressed steel strand give the bottom beam floor about -4.83MPa~-2.514MPa longitudinal compressive stress, as well as it produce about 0.118MPa~1.103MPa longitudinal tensile stress near to the top of the sidewall in across; the transverse prestressed steel strand give the bottom and bottom rib about -4.794MPa~-2.158MPa transverse compressive stress, as well as it produce about 0.594MPa~1.065MPa longitudinal tensile stress at the end of beam; the vertical prestressed steel strand mainly give the side ribs maximum vertical compressive stress is -1.854MPa ,and longitudinal tensile stress of 0.673MPa~1.426MPa in the top and bottom of the side wall.

It can be seen that the longitudinal prestressing strand is a large amount of longitudinal tensile stress produced by the gravity, and the transverse tensile stress caused by the gravity force, and the vertical prestressed strand is not obvious. Therefore, it should be the first one to pull the longitudinal prestressed steel strand, and then pull the transverse prestressed steel strand, to a certain extent, the release of self-weight, and the final tension of vertical prestressed steel.

C. Study on the classification of the three- way prestressed steel strand

From the above analysis, it can be known that the cross section of the side wall and the floor of the transfer, the middle wall and the bottom of the slab, and the role of the side ribs in the prestressing tendons, stress is not large, so it will not be considered in the following analysis.

(1)The study of the longitudinal prestressed steel strand tensioning grading

All longitudinal reinforcement are divided into 10 levels (according to the steel strand tension load / 10) and release the weight at the same time, it can be seen in fig. (4): the tensile stress in the side sill and sill transform into compressive stress in the process of 30% ~ 40%, and tensile stress on the floor and floor transform into compressive stress in the process of 10% ~ 20%.

(2)The study of the transverse prestressed steel strand tensioning grading

All transverse prestressing tendons are divided into 10 stages with the release of self-weight at the same time, it can be seen from fig. (5) that on the bottom plate and the bottom plate in the 20%~30% process, the tensile stress transform into compressive stress.

(3)The study of the vertical prestressed steel strand tensioning grading

All vertical prestressing tendons are divided into 10 stages with the release of self-weight at the same time, it can be seen in Fig. (6): the sink body structure of vertical prestressed caused by gravity stress has little effect, so it could be considered the last applied vertical prestressed reinforcement.

From the above calculation, a conclusion can be drawn that the longitudinal and transverse prestressing tendons play a major role in the release of self-weight, after the sink body concrete pouring is completed and maintenance to 75% of design strength of concrete, In case of no installation of the groove top rod, Three levels of 40%, 70%, 100%, the tensile steel strand, and after 40% of prestressed tendons are applied in demolition lower support scaffolding, to release of weight. The reinforcement tensioning sequence is that: first longitudinal, than transverse and vertical in the end. The placement or installation of the top rod of the groove is carried out after the prestressing force is applied.

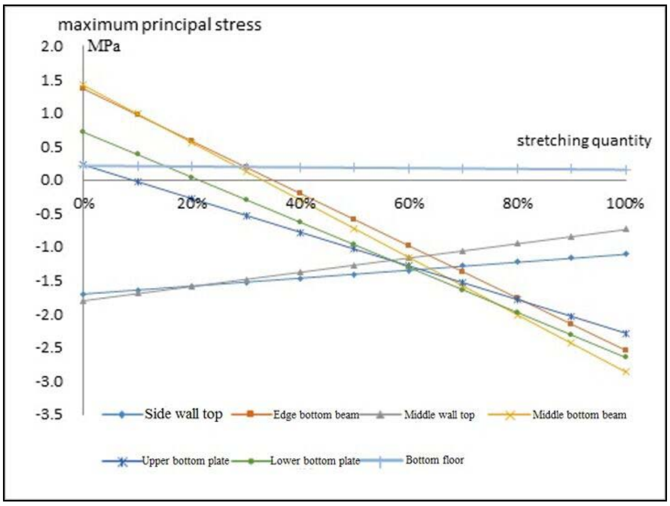

Fig.4 Relationship between the maximum principal stresses of the longitudinal pre stressed tendons and the release of the gravity of the load

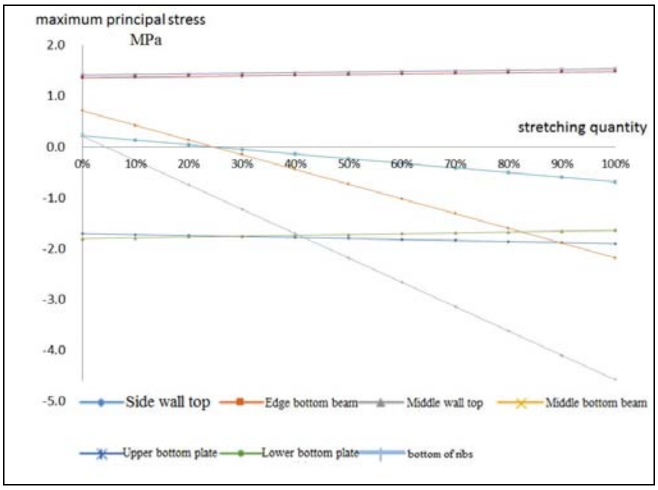

Fig.5 Relationship between the maximum principal stresses of the transverse pre stressed tendons and the release of the gravity of the load

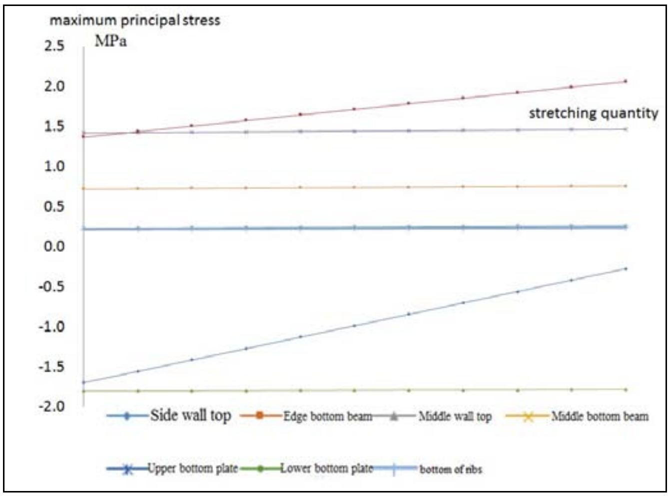

Fig.6 Relationship between the maximum principal stresses of the vertical pre stressed tendons and the release of the gravity of the load

IV. MAIN CONCLUSIONS

Taking the Caohe Aqueduct on the Beijing-Shijiazhuang section of route project as the research object, the author adopts three dimensional finite element analysis method to analyze the prestressed steel strand prestressed steel strand, horizontal, vertical prestressed steel strand on sink body structure deformation and stress distribution. The following conclusions can be got from the above analysis:

(1) The longitudinal prestressing strand is mainly shared by a large number of longitudinal tensile stresses produced by the gravity at the tank body structure. The transverse prestressing strand is shared by the transverse tension stress generated by the gravity at the bottom and the bottom ribs. There is no obvious effect of vertical prestressed steel strand on the stress relief of the groove body. Transverse prestressing stress steel strand is not significant in reducing the stress of the groove body than longitudinal prestressing strand.

(2) After the sink body concrete pouring is completed and maintenance to 75% of design strength of concrete, in case of no installation of the groove top rod, three levels of 40%, 70%, 100%, the tensile steel strand, and after 40% of prestressed tendons are applied in demolition lower support scaffolding, for the purpose to release weight.

(3) The three-way prestressed steel strand tensioning sequence is that: first longitudinal, than transverse and vertical for the final tensioning construction.

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