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FRICTION TEST AND PARAMETER ANALYSIS OF PRESTRESSED CONCRETE CONTINUOUS BEAM BRIDGE

Qingxin Yu[1,2], Quansheng Sun[1] and Junyun Liu[1]

1. Northeast Forestry University, Department of Civil Engineering, Hexing road, Harbin, PR China; hrbsqs@126.com, w15776632879@163.com

2. Lianyungang Economic and Technological Development Zone Government Investment Engineering Service Center, Huaguoshan Avenue, Lianyungang, PR China; 2581814259@qq.com.

ABSTRACT

The prestressed ducts of prestressed concrete continuous girder bridges are usually three-dimensionally distributed and long in length. The control of prestress loss during construction is very important. In order to ensure the effect of prestress tensioning, the test and analysis of friction parameters of prestressed ducts are particularly important. Based on the tension process of a prestressed concrete continuous beam bridge, the initial tension stress, loading time and channel friction parameters of the prestressed concrete continuous beam bridge are tested by field tests. Combined with the measured friction parameters, the finite element software Midas / Civil is used to analyse the influence of friction parameters on the mechanical properties of prestressed concrete continuous beam bridge. The results show that when the prestressed steel with bending angle not more than 40° and length not more than 70 m is stretched, the initial tension stress is suggested to be set as 20 % of the tension control force and the loading time is 5 min. The measured tunnel friction parameters are larger than the standard value, and the tension control force should be adjusted during the formal tension construction ; The deflection of the key section of the main beam increases with the increase of the friction parameters, and the roof stress decreases with the increase of the friction parameters. The change of channel deviation coefficient has a greater impact on the deflection and roof stress than the change of friction coefficient.

KEYWORDS

Continuous beam bridge, Initial tensile stress, Loading time, Friction parameters, Deflection, Stress

INTRODUCTION

Prestressed concrete continuous beam bridge has been widely used due to its unique advantages, and has become the preferred bridge type for large-span bridges. With the continuous increase of the span of prestressed concrete continuous beam bridge, the length of the required prestressed reinforcement increases, but there are also some diseases caused by excessive prestress loss, such as mid-span deflection and box girder cracking [1]. According to the current design specification for highway bridges in China, among the six factors of prestress loss in prestressed concrete bridges, the friction loss of prestressed ducts accounts for a relatively large proportion compared with the prestress loss caused by other factors, especially for long prestressed beams with large bending angles. [2]. The method of calculating prestress loss by pre-tensioning method has been proved to be feasible by a large number of tests. However, there are many factors affecting prestress loss in post-tensioning method. There are still some deviations between theoretical and experimental results of calculating prestress loss by post-tensioning method in Chinese code. Due to the complex stress condition of long prestressed reinforcement in concrete structure, it may also be affected by construction technology, prestressed material performance, environmental factors and other factors, and the prestress loss will be greater than that of ordinary prestressed reinforcement. [3-4]. Therefore, it is very necessary to study the friction loss test of the relative long prestressed reinforcement, so as to ensure that the prestress in the bridge structure meets the design requirements and prevent the safety problems of the bridge structure caused by the lack of effective prestress in the bridge structure.

Many scholars have carried out relevant research on the loss of prestress of bridge, Zhang Kaiyin et al [5] have carried out relevant experimental research on the friction loss of bending channel. It is concluded that with the increase of tension control force and bending angle, the friction loss of bending channel will also increase rapidly. LvPan [6] conducted sensitivity analysis on the main factors affecting the prestress loss through the finite element software Midas / Civil, and obtained the main sensitive factors affecting the prestress loss of bridges. Zhang Jingwei et al [7] pointed out that the friction loss of bending prestressed steel is greater than that of linear steel through the test of prestressed friction loss of high-speed railway long-span continuous beam bridge. With the increase of steel length, the friction loss value also increases, and the friction loss cannot be ignored. Zhang Qi et al[8] through the friction test of a three-span continuous box girder bridge as the research background, it is concluded that the pipeline friction loss accounts for a large proportion of prestress loss. In the process of tension, the prestress loss can be reduced by symmetrical synchronous tension at both ends, super tension and lubricant coating on prestressed reinforcement. Robitaille et al. [9] deduced the theoretical calculation formula for the prestress loss of the curved pipeline during the prestress tension process, and pointed out that when the bending angle of the prestressed steel bar exceeds 2.5°, the prestress loss in the prestressed structure will exceed 5%. Zollman et al. [10] studied the prestress loss of prestressed steel bars at the bending, and obtained the relationship between the bending angle and the prestress loss. Sapountzakis et al. [11-14] deduced and predicted the loss calculation formula of prestressed steel bar bending starting point and bending point in prestressed concrete bridge structure. However, there are relatively few systematic experimental studies on long-span continuous girder bridge length prestressing beams. This paper takes the tension process of a prestressed concrete continuous girder bridge as the research background, and tests the initial tension stress, load holding time and friction parameters through field tests, which provides a reference for the design and construction of similar bridges, and combines the measured values of friction parameters. , using finite element software to analyse the influence of friction parameters on the mechanical properties of prestressed concrete continuous girder bridges.

BACKGROUND

The new prestressed concrete continuous girder bridge studied in this paper is located in Hainan Province, China, with a total length of about 201.2 m. The upper structure of the bridge is 35m+40m+45m+40m+35m=195m, and the cast-in-place continuous box girder of Class A prestressed concrete is used. The bridge pier adopts the vase-type bridge pier to connect the pile foundation, the bridge abutment adopts the rib-type bridge abutment to connect the platform pile foundation, and the bridge pile foundation adopts the friction pile foundation. The cast-in-place continuous box girder adopts C50 concrete with an elastic modulus of 3.45×104MPa. The prestressed material is a low-relaxation high-strength steel strand with a tensile strength standard value of 1860 Mpa, a nominal diameter of d=15.2mm, an elastic modulus of Ep=1.95×105 Mpa, and a relaxation coefficient of 0.3. The prestressed pipe is formed by plastic bellows. The elevation layout, cross-section and prestressed steel bundle layout of the bridge are shown in Figures 1-3.

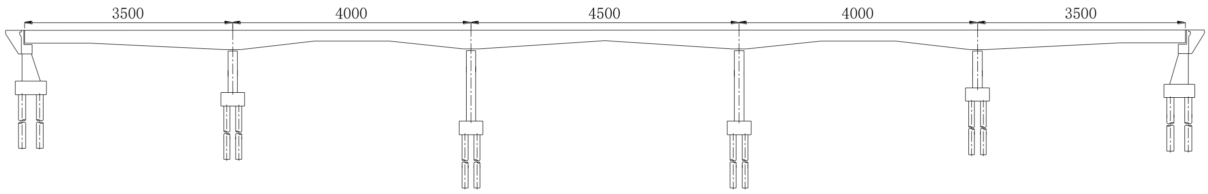

Fig.1 - Bridge Elevation Layout (Unit: cm)

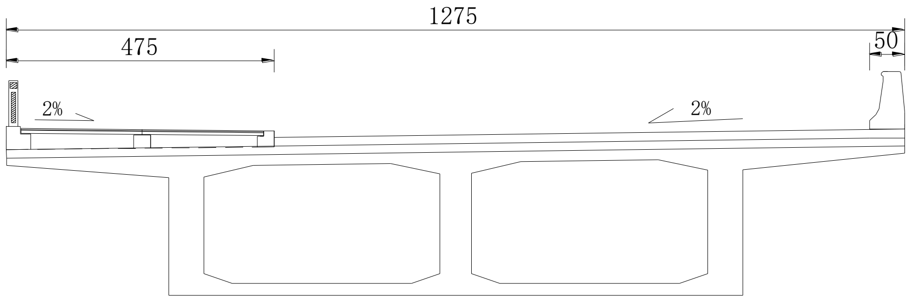

Fig.2 - Bridge cross section (Unit: cm)

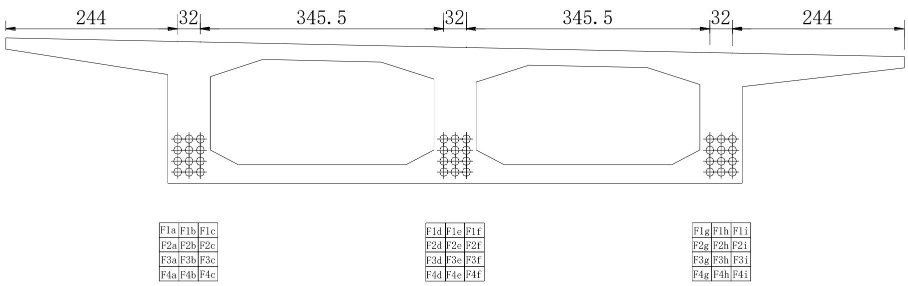

Fig.3 - Layout drawing of prestressed steel beams (Unit: cm)

Tab. 1 - Parameters of prestressed test bundles F1b, F3e, F4h in the first pouring section

Position of steel beam	Steel beam number	Length of steel beam /m	Channel bend angle /°	Specification
Side web	F1b	69.54	39.9°	9Φs15.2
Middle plate	F3e	69.07	33.4°	12Φs15.2
Side web	F4h	69.24	37.9°	12Φs15.2

TECHNICAL ROUTE

In this paper, according to the actual situation of the site, the prestressed test beam is selected for field test, and then the finite element software is used to establish the finite element model of the real bridge and the sensitivity analysis of the friction parameters of the prestressed pipeline is carried out in combination with the field test data. The influence of the value of the friction parameters of the prestressed pipeline on the mechanical properties of the bridge is studied and analyzed, so as to provide some reference for the construction and design.

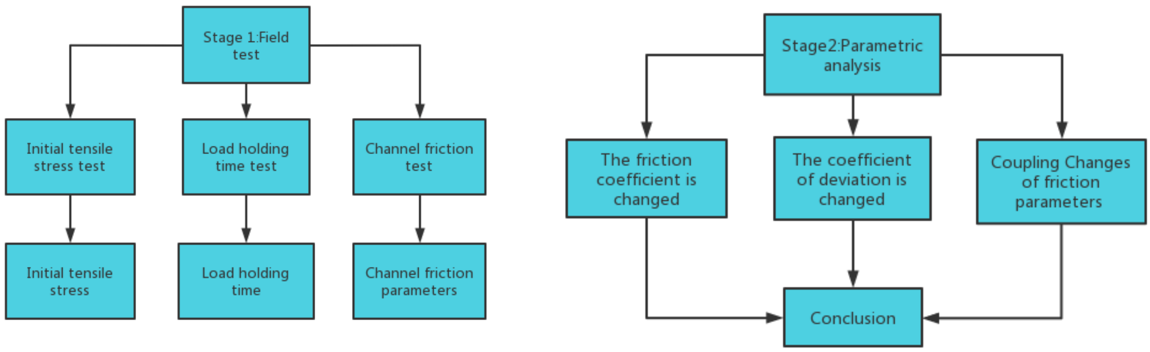

Fig.4 - Technology roadmap

FIELD TEST

In order to successfully complete the friction test, the initial tensile stress test and the load holding time test are usually carried out first. The initial tensile stress test can determine the initial tensile control stress, so as to offset the nonlinear influencing factors of the prestressed steel bundle in the tensioning process and reduce the prestress loss in the tensioning stage. The load holding time can be accurately determined by the load holding time test, and the stress loss can be reduced by controlling the load holding time during the prestressed tension construction process [15].

The field test instruments mainly include: pressure sensor, comprehensive tester, prestressed intelligent tensioning equipment, etc.

Fig. 5 - Field diagram of the pressure sensor

Fig. 6 - Field test diagram of comprehensive tester

Fig. 7 - Field Diagram of Intelligent Tensioning Equipment

Fig. 8 - Field test diagram

Initial tensile stress test

The initial tension is the first tension process in the tension stage of prestressed concrete bridges. The main purpose of the initial tension stage is to eliminate the inelastic deformation of prestressed reinforcement, which can also be understood as the process of gradual straightening of prestressed reinforcement. China ' s Technical Specification for Construction of Highway Bridges and Culverts ' (JTG / T3650-2020) points out that the tension control stress should be adjusted to the initial tension stress in the construction of prestressed bridges. The technical specification for construction of highway bridges and culverts requires that the initial tension stress should be 10 % ~ 25 % of the tension control stress. [16]. However, for the prestressed steel bars with long length or large bending angle, the prestressed transmission speed applied at the tensile end is slow and the prestress loss is large. It is necessary to measure the initial tensile stress through the field initial tensile stress test [17].

In order to determine the initial tensile stress of the bridge, this test selects the first pouring section of longitudinal web prestressed steel beam F1b, F3e to test the initial tensile stress. The test method is to apply prestress load to the tensile end from 0, and load according to 5 %, 10 %, 15 %, 20 %, 25 %, 30 %, 40 % load. For each stage of load after loading, test reading records tension and elongation data; when the elongation of the prestressed steel beam at the tensile end tends to be stable under various loads and the tension ratio between the tensile end and the fixed end tends to be constant, the load grade can be defined as the initial tensile stress. The test results are shown in Tables 2, 3 and Figures 9, 10.

Tab. 2 - F1b Initial tensile stress test data table

Steel beam number	Load level	Driving end /kN	Passive end /kN	Passive end than active end /%
F1b	5%	84.9	15.3	18.2
	10%	169.9	76.5	45.3
	15%	254.8	153.4	60.2
	20%	339.7	234.4	69.4
	25%	424.7	293.0	69.3
	30%	509.6	351.6	69.3
	35%	593.3	411.8	69.4
	40%	679.4	468.8	69.5

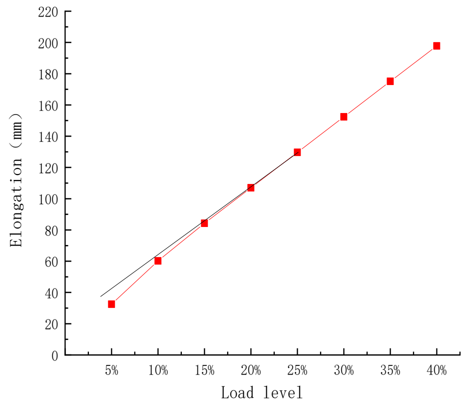

Fig. 9 - F1b Tension and elongation relationship curve

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Tab. 3 - F3e initial tensile stress test data table

Steel beam number	Load level	Driving end /kN	Passive end /kN	Passive end than active end/%
F3e	5%	108.6	24.9	23.2
	10%	217.2	110.8	51.3
	15%	325.7	211.7	65.4
	20%	434.3	309.4	71.2
	25%	542.9	385.5	71.4
	30%	651.5	464.5	71.3
	35%	758.1	541.3	71.4
	40%	868.6	619.2	71.3

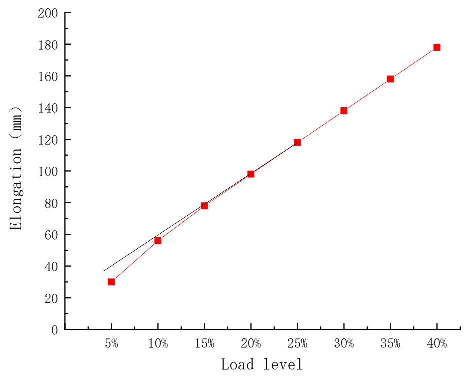

Fig. 10 - F3e tension and elongation relationship curve

From Table 2, 3 and Figures 9, 10, it can be seen that due to the large internal bending angle of prestressed pipe of prestressed concrete continuous beam bridge and the long steel, the stress is uneven, and the elongation of prestressed steel shows an irregular growth trend when the loading grade is small.

When the loading level gradually increases, the prestressed reinforcement eliminates the deformation caused by nonlinear factors; when the loading level is 20 % of the design load, the tensile ratio of the fixed end to the tension end tends to be stable, and the elongation of the prestressed reinforcement and the tensile force are linearly distributed. Therefore, in the tension process of this bridge, the initial stress is 20 % of the tension control stress.

Load holding time test

Because the prestressed reinforcement of the bridge is long and the bending channel is relatively complex, it takes a long time to pass the prestressed load on the tensile end to the fixed end. If the size of the load holding time can be accurately grasped in the prestressed tension construction process, the prestress loss of the reinforcement can be reduced. In this experiment, the loading time of longitudinal web prestressed reinforcement F1b and F3e in the first pouring section was tested. The test method is to apply pre-stress load on the tension end. When the load is up to 40 %, the load is stopped, and the corresponding load is kept unchanged for 10 min. The pressure sensors at the tension end and the fixed end are recorded with time [18]. In order to facilitate the analysis, the test data of load holding time are plotted in this paper for analysis as shown in Figures 10 and 11.

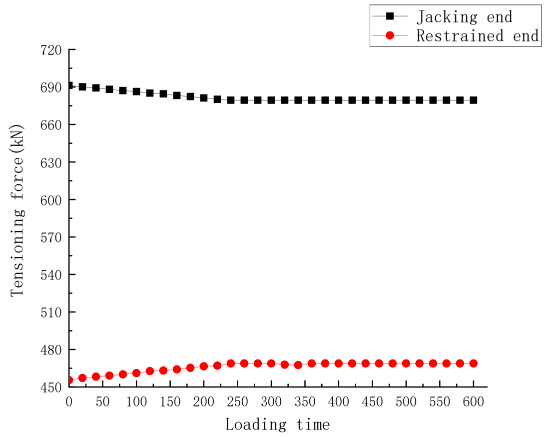

Fig.11 - Relationship curve between load holding time and tension of F1b steel

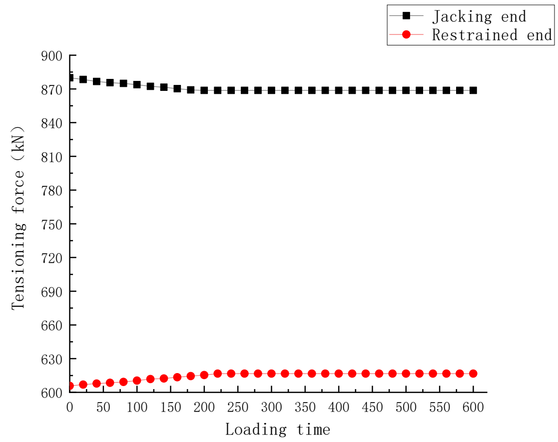

Fig.12 - Relationship curve between load holding time and tension of F3e steel

It can be seen from Figures 11 and 12 that with the increase of loading time, the tensile force of the tension end of the prestressed test steel wires gradually decreases, and the tensile force of the fixed end gradually increases, and the load of the tension end gradually transfers to the fixed end. When the prestressed load is applied at the tension end, the tension speed from the tension end to the fixed end is faster, and the tension of the fixed end increases rapidly. With the increase of loading time, the transfer rate of prestress gradually slows down and finally tends to be stable. It can be seen from the curve diagram of the relationship between the load holding time and the tensile force that the change of the

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slope of the image can represent the change of the tensile force at both ends. At the beginning, the slope of the curve is larger and the tensile force at both ends is also larger. Then the slope of the curve gradually decreases and finally tends to zero, and the change speed of tension at both ends also gradually decreases and finally remains unchanged. When the load grade of F1b steel wires is 40 %, the tensile force at both ends reaches a stable time of 240 s. When the load grade of F3e steel wires is 40 %, the tensile force at both ends reaches a stable time of 220 s. Considering the actual construction situation, the loading time is finally set to 5 min.

Channel friction test

Calculation Theory of Duct Friction Loss

According to China's Code for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts' (JTG3362 – 2018), among the several factors that cause the prestress loss of bridge structure, the channel friction loss has a great influence on the prestress loss of prestressed concrete continuous beam bridge. The formula of channel friction loss of prestressed concrete continuous beam bridge under post-tensioning tension can be calculated according to the following equation [2]:

It is assumed that the reading of the tension end penetrating pressure sensor is , the reading of the fixed-end pressure sensor is N_2,the calculated length of the prestressed channel is x , the bending angle of the channel is θ :

Formula for calculating friction loss $\sigma_{s1} = \sigma_k[1 - e^{-(\mu\theta + kx)}]$, The following formula can be obtained:

$$N_2 = N_1[e^{-(\mu\theta + kx)}] \tag{1}$$

Taking logarithm of equation (1), the following formula can be obtained:

$$\ln(N_1 / N_2) = \mu\theta + kx \tag{2}$$

make $C = \ln(N_1 / N_2)$, then equation (2) is:

$$C = \mu\theta + kx \tag{3}$$

Due to the influence of construction factors, there are errors in the test, Let the test error be ΔF_i then there are:

$$\mu\theta_i + kx_i - C_i = \Delta F_i \tag{4}$$

Using the least squares method, the sum of squares of all prestressed steel bar test errors is:

$$\sum(\Delta F)^2 = \sum(\mu\theta_i + kx_i - C_i)^2 \tag{5}$$

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To minimize the test error, so

$$\frac{\partial \sum (\Delta F)^2}{\partial \mu} = 0 \tag{6}$$

$$\frac{\partial \sum (\Delta F)^2}{\partial k} = 0 \tag{7}$$

From equations (5), (6) and (7), the following equations can be obtained:

$$\mu \sum \theta_i^2 + k \sum x_i \theta_i - \sum C_i \theta_i = 0 \tag{8}$$

$$\mu \sum x_i \theta_i + k \sum x_i^2 - \sum C_i x_i = 0 \tag{9}$$

The measured values of friction parameters can be obtained by solving the simultaneous equations (8) and (9) of test data.

Duct friction loss test scheme

In this tunnel friction test, combined with the actual construction situation on site, the longitudinal web prestressed steel bundles F3e and F4h of the first pouring section were selected for tunnel friction test. The detailed parameters of the test bundles are shown in Table 1. In the prestressed tunnel friction test, the through-centre pressure sensor should be installed at both ends of the test bundle, and then the tensioned end and the fixed end should be defined respectively to apply prestressing load to the tensioned end [19].

The results of friction loss test of pore channels

According to the test, the tensile force and elongation of the prestressed test beam F3e and F4h at the tensile end and fixed end of the prestressed steel beam under various loads are measured. The test results are shown in Table 4.

Tab. 4 - Test data of prestressed beam friction test

Steel beam number	Load level	Tensile force of tension end /kN	Fixed end tension/kN	Measured elongation /cm	C_i	
F3e	20%	434.4	309.4	8.5	0.3391	0.3391
	40%	868.7	619.2	16.9	0.3385	
	60%	1303.1	928.2	26.1	0.3393	
	80%	1737.4	1237.0	33.9	0.3397	
	100%	2166.1	1543.6	42.8	0.3388	
F4h	20%	452.9	316.4	8.3	0.3588	0.3591
	40%	905.9	632.7	17.1	0.3589	
	60%	1358.9	948.7	25.9	0.3593	
	80%	1811.8	1264.7	34.1	0.3595	
	100%	2266.2	1582.7	42.7	0.3590	

Substitute the measured data of the prestressed steel bundle friction test into the calculation formulas (8) and (9) to calculate the measured values of the prestressed tunnel friction parameters and are shown in Table 5.

Tab. 5 - Pairs of prestressed drag parameters

Item	Coefficient of friction μ	Deviation factor k
Theoretical design value	0.18	0.0015
Measured value	0.25	0.0028

The friction coefficient of the channel measured by the on-site friction test is 0.25, which is greater than the theoretical design value of 0.18, and the channel deviation coefficient of 0.0028 is also greater than the theoretical design value of 0.0015. There is a certain deviation between the measured value and the theoretical design value. The measured friction parameters can play a guiding role in the design and construction of the bridge type. The tension control force should be adjusted during the formal tension construction. For prestressed tunnels with large bending angles, the friction parameters should be determined through field tests.

ANALYSIS OF CHANNEL FRICTION PARAMETERS

The channel friction parameter has a great influence on the prestress loss of the prestressed concrete continuous girder bridge. In the bridge design, the value of the friction parameter should be comprehensively considered in combination with the actual situation. If the value is too large, the bridge prestress loss estimation is too large, the actual stress applied to the beam is too large, and the bridge structure is too safe, which will damage the prestressed structure or construction material; If the value is too small, the estimated value of the prestress loss of the bridge is too small. The prestress applied to the beam is too small, and the prestress cannot play its performance. During the operation of the bridge, the mid-span deflection and box girder cracking will occur [20].

The finite element simulation model of the whole bridge is established by MIDAS / Civil. The factors such as dead load, prestress tension, sectional construction, temperature effect and construction load are considered in the calculation. The finite element model adopts beam element. According to the control points of bridge construction section and key section, the whole bridge section is divided into 301 nodes and 300 elements. The finite element model of the whole bridge is shown in Figure 13.

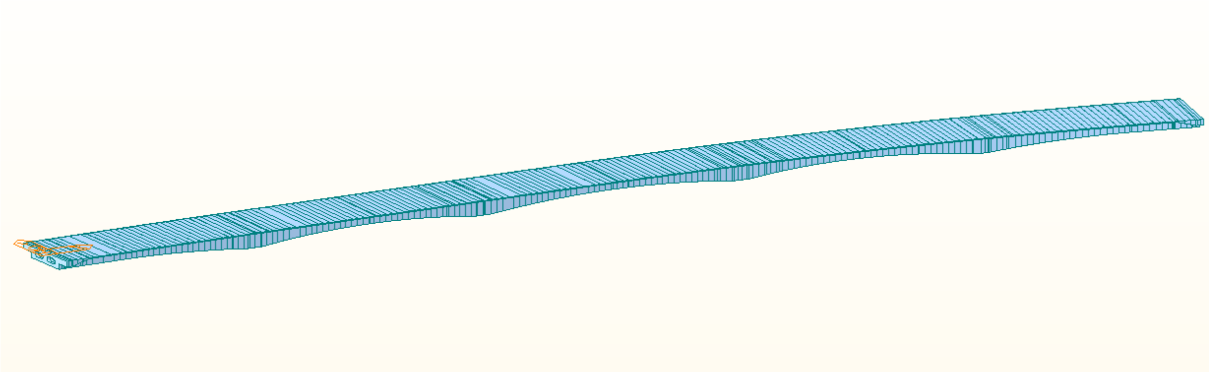

Fig. 13 - Finite element model diagram of the whole bridge

The bridge adopts the molding method of plastic bellows. China's "Code for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts" (JTG3362-2018) stipulates that the value of friction coefficient is in the range of 0.15 to 0.20, and the value of deviation coefficient is 0.0015. In this paper, 0.18 is taken, and 0.0015 is taken as the normative design value. The finite element software is used to simulate the influence of different friction coefficients and deviation coefficients on the deflection and stress of the bridge. According to the calculation results, the value of friction parameter has the greatest influence on the deflection and roof stress of the section at L / 2 of the middle span of the bridge. In this paper, the section at L / 2 of the middle span is selected for research and analysis.

Analysis of the effect on the bridge when the friction coefficient is changed alone

The contribution of the value of the prestressed tunnel friction coefficient to the tunnel friction loss cannot be underestimated, and it has a great influence on the overall alignment and stress changes of the bridge structure. Therefore, it is of great significance for the study of prestressed concrete continuous girder bridges to explore the influence of the prestressed tunnel friction coefficient on the deflection and stress of the key sections of the bridge [21]. According to the tunnel friction test results, it can be known that the maximum measured value of the friction coefficient is 0.25, and the tunnel friction coefficients are taken as 0.20, 0.23, 0.26, and 0.29 for this parameter sensitivity analysis. The comparison and analysis results of the influence of the value of the channel friction coefficient on the deflection of the critical section and the roof stress of the prestressed concrete continuous girder bridge and the value of the standard value are as follows:

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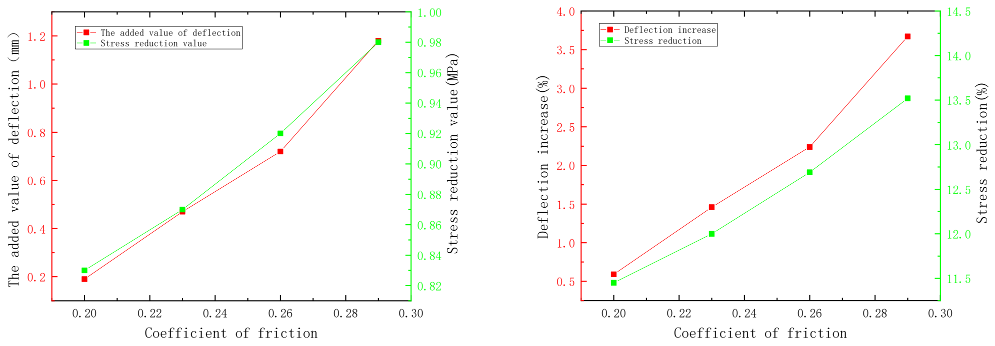

Fig. 14 - Influence of friction coefficient alone on deflection and stress of main beam

It can be seen from Figure 14 that when the friction coefficient of the tunnel is 0.29, the maximum deflection value is 1.18mm, an increase of 3.67% compared with the specification value; the maximum stress change value of the roof is 0.98MPa, a decrease of 13.52% compared with the specification value. When the friction coefficient value of the pipeline increases by 0.02, the deflection increases by 0.78%~1.43% compared with the specification value, and the roof stress value decreases by 0.55%~0.83% compared with the specification value. When the pipe friction coefficient changes alone, the influence on the roof stress of the key section of the prestressed concrete continuous beam bridge is greater than that on the deflection.

Coefficient of deviation Analysis of the effect of individual changes on bridges

The value of the pipe deviation coefficient also has a great influence on the prestress loss of the bridge structure, which in turn affects the deflection and stress of the prestressed concrete continuous girder bridge [22]. According to the results of the tunnel friction test, it can be seen that the maximum measured value of the deviation coefficient of the pipeline is 0.0029. In this parameter sensitivity analysis, the values of the deviation coefficient of the pipeline are 0.0020, 0.0025, 0.0030 and 0.0035 respectively. The influence of numerical variation of deviation coefficient on deflection and roof stress of key section of prestressed concrete continuous beam bridge is compared with the standard value. The results are as follows:

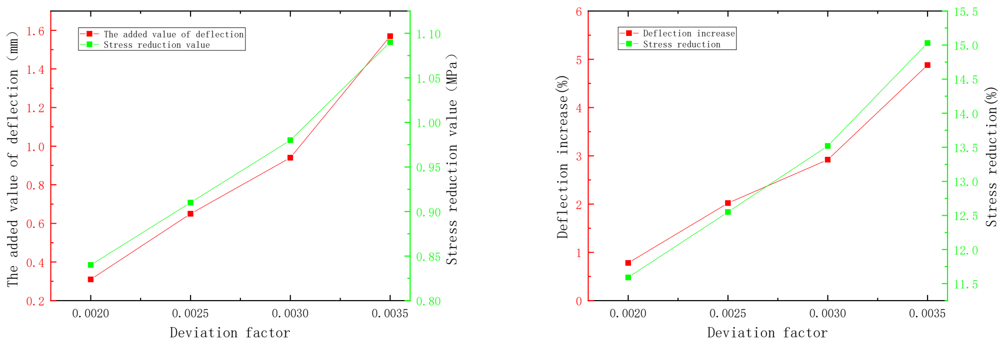

Fig. 15 - Influence diagram of deviation coefficient alone changes on deflection and stress of main beam

It can be seen from Figure 15 that when the deviation coefficient of the pipeline is 0.0035, the maximum deflection value is 1.57mm, which is an increase of 4.88% compared with the specification value; the maximum stress change value of the roof is 1.09MPa, which is 15.03% lower than the specification value. When the deviation coefficient value of the pipeline increases by 0.0005, the deflection increases by 0.9%~1.96% compared with the standard value, and the roof stress decreases by 0.96%~1.51% compared with the standard value. To sum up, it can be seen that the independent change of the pipe deviation coefficient has a greater influence on the deflection and stress of the prestressed concrete continuous girder bridge than the independent change of the pipe friction coefficient.

Analysis of the Influence of Coupling Changes of Friction Coefficient and Deviation Coefficient on Bridges

According to the friction test, the maximum value of the friction parameter is (0.25, 0.0028). In order to study the influence of the coupling change of the friction coefficient and the deviation coefficient on the deflection of the key section of the main beam and the stress of the roof, the friction parameters are respectively (0.20, 0.0020), (0.23, 0.0025), (0.26, 0.0030), (0.29, 0.0035) and the standard values for comparative analysis. The comparative analysis results of the influence of the coupling change of friction coefficient and deviation coefficient on the key section deflection and roof stress of prestressed concrete continuous beam bridge and the standard value are as follows:

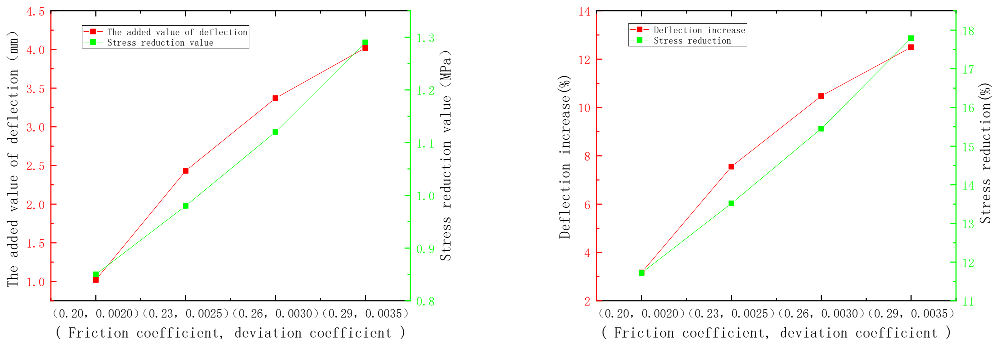

Fig. 16 - Coupling changes of friction coefficient and deviation coefficient on deflection and stress of main beam Influence diagram

It can be seen from Figure 16 that when the value of the channel friction parameter is (0.29, 0.0035), the maximum deflection value is 4.02mm, which is an increase of 12.49% compared with the specification value; 17.79% less than that. When the channel friction parameter increases by (0.03, 0.0005), the deflection increases by 2.02%~4.38% compared with the standard value, and the stress decreases by 1.8%~2.34% compared with the standard value. The influence of the channel friction parameter on the deflection and stress of the main beam when the coupling changes is greater than that when it changes alone.

CONCLUSION

(1) For prestressed steel bundles with a bending angle of not more than 40° and a length of not more than 70 meters, it is recommended that the initial tensile stress be set to 20% of the tension control force, and the load holding time is 5 minutes;

(2) The measured value of friction parameters is greater than the theoretical design value, and there is a certain deviation between the measured value and the theoretical design value. The measured friction parameters can play a guiding role in the design and construction process of this type of bridge. In the formal tension construction, the parameters such as tension control force and holding time should be adjusted.

(3) For the continuous beam bridge with large bending angle and long prestressed tendons, in order to reduce the prestress loss during the tensioning process, the initial tension stress, load holding time and channel friction parameter values should be tested before the formal tensioning construction of prestressed steel tendons.

(4) The value of channel friction parameter has great influence on the deflection and roof stress of the key section of prestressed concrete continuous beam bridge. The deflection of main girder increases with the increase of friction parameters, and the roof stress decreases with the increase of friction parameters. The influence of channel deviation coefficient on the deflection of main beam and roof stress is greater than that of friction coefficient. The influence of the coupling change of the channel friction parameters on the deflection and stress of the main beam is greater than that of the single change.

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