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Research on Jacking Construction Process of Steel Truss Bridge Across Highway

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Abstract

In order to study the jacking construction process of steel truss bridge across the existing expressway, this paper takes a simply supported steel truss railway bridge as the research background, and uses the finite element software to simulate the jacking construction process. By analyzing the mechanical performance, deformation and anti overturning stability of the steel truss bridge during launching, the safety and stability of the temporary support and its foundation are analyzed. The results show that the stress values of steel truss and steel guide beam are within the limits under each pushing condition; The deformation of each position of the guide beam and the safety and stability of the temporary support foundation meet the requirements of the construction. It provides reference for similar projects.

Keywords

Push Analysis; Steel Truss; Support Foundation; Force Analysis.

1. Introduction

In recent years, with the continuous development of China's high-speed railway, a large number of bridge projects across the existing lines have emerged. In order to reduce the impact of bridge construction on the existing lines [1,2], and shorten the length of bridge landing connection, the simply supported steel truss bridge with push construction method has been widely used. At present, in the existing research, the analysis of steel truss bridge incremental launching construction process focuses on the research of construction technology [3,4,5], while there is little research on the incremental launching force process and the safety and stability analysis of temporary support foundation [6,7,8].

In order to ensure the structural stress safety of steel truss bridge in the process of launching construction, this paper takes a simple supported steel truss bridge as an example, uses the finite element software for numerical simulation, analyzes the mechanical performance, deformation, anti overturning stability and other aspects of the steel truss bridge during the launching period, and analyzes the safety and stability of the temporary support and its foundation, so as to ensure the normal work of each structure during the launching period.

2. Project overview

2.1 Bridge type and span layout

The beam is a double line 42m single node parallel chord triangle truss beam, with a calculation span of 42m (i.e. the center distance of support), a total length of 43.4mm, a length of 10.5m, a truss height of 11m, and a center distance of 6.6m between two main trusses. The main truss chords and end diagonal members are welded box sections. Other diagonal members (except end diagonal members) of the main truss adopt welded "I" section. Considering the convenient installation of the diagonal

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member inserted into the gusset plate of the main truss and the effective friction generated by the high-strength bolts, there is a 2mm gap between the outer side of the diagonal member and the inner side of the gusset plate. Both the bridge door and the transverse connection adopt the plate structure, which is composed of the bridge door (transverse connection) components overlapped and welded under the upper horizontal connection I-type transverse brace. At the same time, a certain amount of shrinkage should be reserved in advance for the fillet weld between the upper horizontal brace and the bridge door (transverse) to ensure the accuracy.

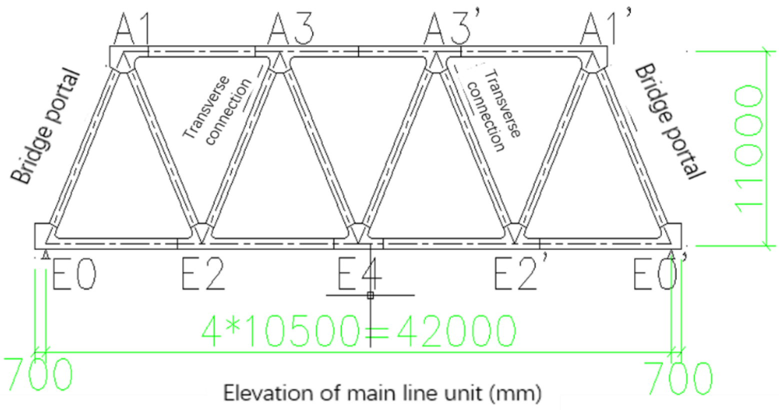

Figure 1. Elevation of steel truss beam

2.2 Support layout and type

According to the structural form and sliding requirements of the steel beam, the working platform of this bridge mainly adopts multiple lattice columns to form an integral sliding jig frame, and the specification of a single sliding bracket is 10600mm × 6600 mm, the column is mainly composed of φ four hundred and twenty-six × 10mm steel pipe is connected by channel steel to form three-dimensional steel buttress, and double 4-joint h440 is adopted at the top transverse direction of bridge × three hundred × eleven × The main forms of 18 steel beam are shown in the figure below.

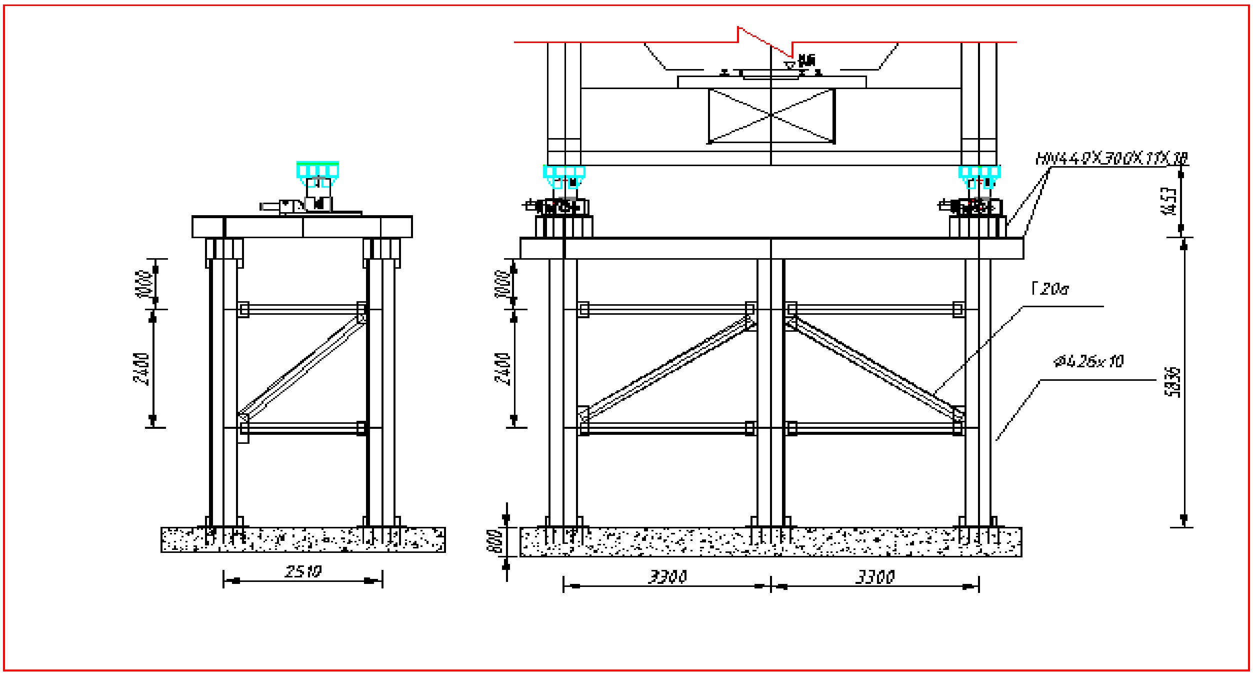

Figure 2. Layout of temporary support

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3. Establishment of finite element model

3.1 Model introduction

According to the geometric characteristics and boundary conditions of the structural calculation model must be consistent with the actual structure, and the structural calculation model must be able to reflect the characteristics of the structure formed in stages. According to the design material parameters, the finite element software is used to simulate the pushing process. The overall simulation model is shown in Figure 3. In the overall simulation model, the self weight of the structure is calculated according to the basic code for design of railway bridges and culverts, and the auxiliary facilities load is added to the main beam through the beam unit load. Among them, q345qe is used for main girder and Q235 is used for guide girder of simply supported steel truss bridge. The main mechanical properties are shown in Table 1.

Table 1. Mechanical Properties of main materials

Material type	Elastic modulus (MPa)	Coefficient of linear expansion	Poisson's ratio	Bulk density(kN/m^3)
Q345qE Steel	2.06×10^5	1.2×10^{-5}	0.3	76
Q235 Steel	2.06×10^5	1.2×10^{-5}	0.3	76

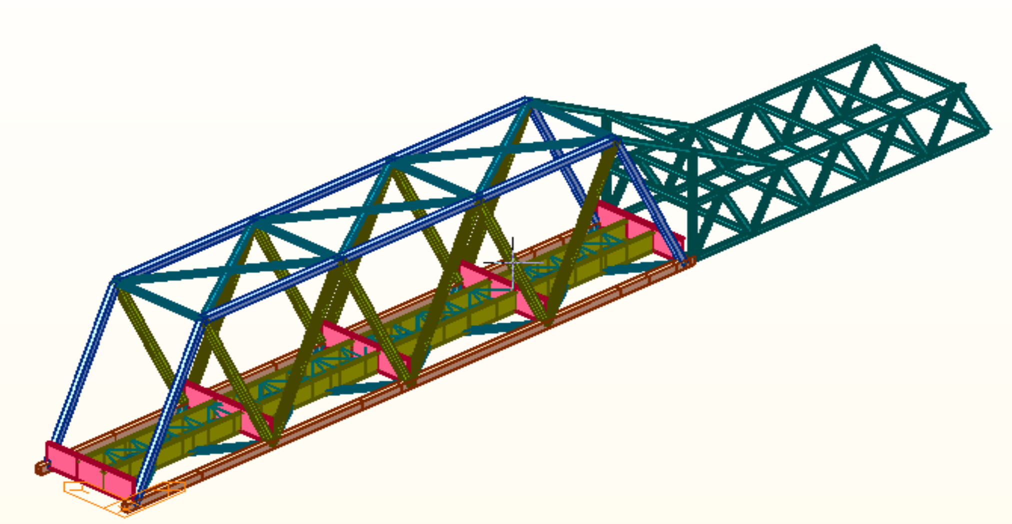

Figure 3. Finite element model diagram

3.2 Calculation condition

According to the jacking construction process of the bridge, the whole bridge is divided into five calculation conditions. The specific division of working conditions is shown in Table 2.

4. Analysis of launching process of steel truss

4.1 Analysis of jacking force of main girder of steel truss

During the launching of steel truss, the stress state of main girder changes with the change of boundary conditions. According to the force characteristics of the main girder structure during the pushing process, the stress of each member of the steel truss and the deformation of the main girder are analyzed.

4.1.1 Stress analysis of main girder of steel truss

According to the analysis of the finite element model, it is concluded that the maximum stress occurs in condition 3 (reaching D1) in the launching construction stage, as shown in Figure 4.8. The maximum bending stress of the steel truss in each construction stage is given in Table 3. From the

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figure, it can be seen that the maximum bending stress of the steel truss in the construction stage is 209mpa. According to the basic allowable stress in table 3.2.1 of code for design of steel structure of railway bridge, the allowable value of q345qe bending stress is 210mpa, so the tensile and compressive stress of steel truss in construction stage is less than the allowable value given in the code, which meets the requirements of the code.

Table 2. Description of pushing conditions

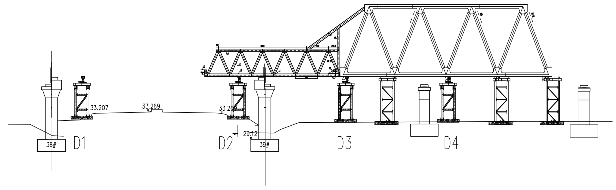
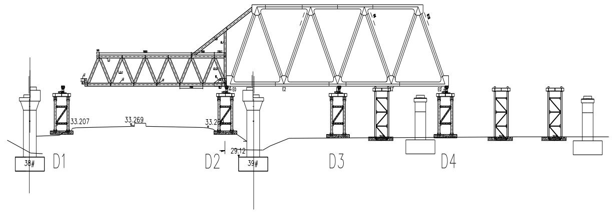
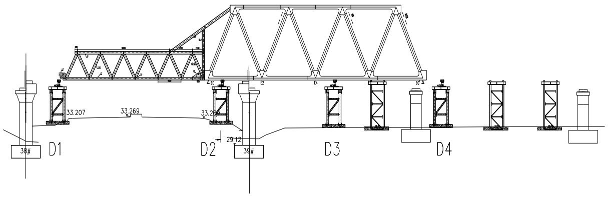
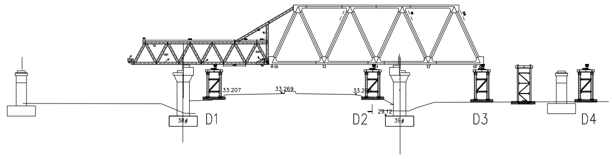
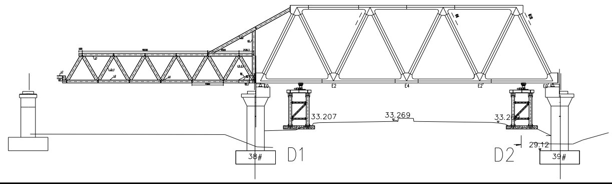
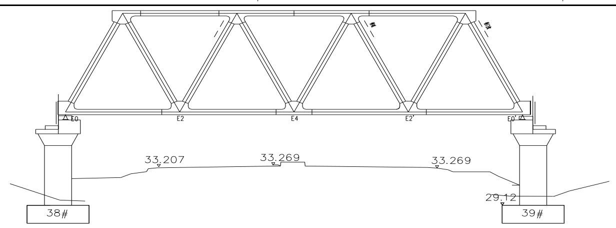
Condition number	Working condition name	Working condition diagram
CS1	Construction phase 1	
CS2	Construction phase 2	
CS3	Construction phase 3	
CS4	Construction phase 4	
CS5	Construction phase 5	
CS6	Construction phase 6	

Table 3. Summary of maximum tensile stress and maximum compressive stress under various construction conditions

Construction conditions	Maximum bending stress(MPa)
Mode 1	67.1
Mode 2	39.2
Mode 3	209.4
Mode 4	94.9
Mode 5	39.2
Mode 6	38.1

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4.1.2 Displacement analysis of steel truss girder

During the launching construction, the maximum upward deflection of the steel truss occurs in condition 2 (leaving D4), which is 1.8mm; The maximum downward deflection occurs in condition 3 (reaching D1), which is 35.8mm; The maximum deflection value of each construction stage is shown in Table 4.

Table 4. Summary of maximum deflection values during launching

	Maximum upward deflection(mm)	Downward maximum deflection(mm)
Mode 1	1.7	11.9
Mode 2	1.8	6.3
Mode 3	0.35	35.8
Mode 4	1.5	7.4
Mode 5	1.5	8.4
Mode 6	1.3	9.1

4.2 Deformation analysis of guide beam

In order to ensure that the steel guide beam can be put on the pier smoothly during the pushing process, it is necessary to analyze and calculate the deformation of the guide beam during the pushing process, so as to determine the maximum deformation during the pushing process and ensure the normal operation of the construction. It can be seen from the table that the maximum downward deflection of the front end of the guide beam is 10.167mm during the launching construction stage, which occurs in condition 2 (leaving the launching support D4). The maximum deflection value of the front end of the guide beam in the process of pushing is summarized in the following table 5.

Table 5. Summary of maximum deflection of guide beam

construction stage	Deflection value(mm)
CS1(Jacking girder)	-0.619
CS2(leave D4)	-10.167
CS3(arriveD1)	-7.228
CS4(leaveD3)	-4.018
CS5(Reach the bridge)	-8.840

4.3 Anti overturning analysis of launching

In order to avoid the structure overturning during the launching construction and ensure the safety of driving under the bridge, the anti overturning stability of the whole structure is analyzed. According to the specific construction situation, the guide beam is in the maximum cantilever state when it is pushed 32m and is about to go up to pier D1. The overturning coefficient is analyzed at this time.

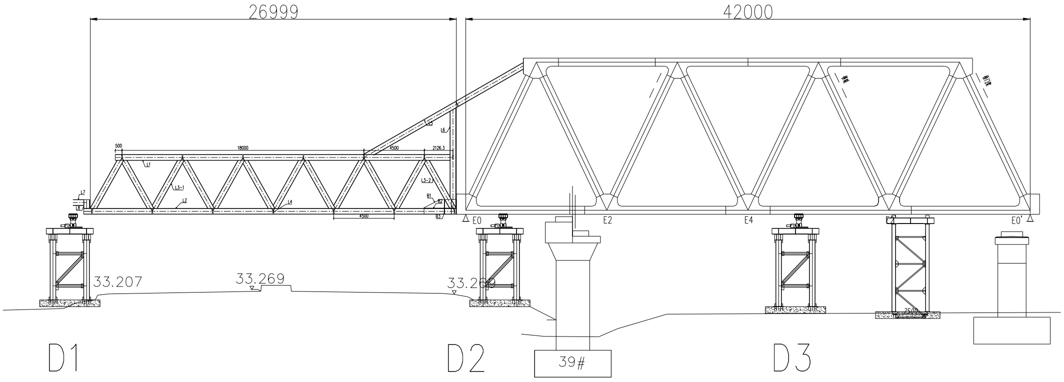

Figure 4. Schematic diagram of maximum cantilever state of guide beam

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According to 4.1.8 of code for design of highway reinforced concrete and prestressed concrete bridges and culverts, the calculation of anti overturning stability coefficient during launching construction should meet the following requirements:

$$\frac{\sum S_{\mathrm{bk,i}}}{\sum S_{\mathrm{sk,i}}} \geq k_{\mathrm{qf}}$$

Where: k_{qf} is the anti overturning stability factor, k_{qf}=2.5; $\sum S_{\mathrm{bk,i}}$ is the effective design value to stabilize the superstructure; $\sum S_{\mathrm{sk,i}}$ is the design value of the instability effect of the superstructure.

The stress diagram is as follows: the steel truss weighs 39.1kn per linear meter; The length of the guide beam is 27m, the weight of the guide beam is 383.55kn, and the center of gravity is half.

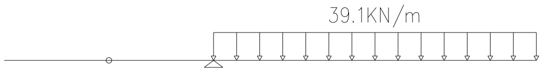

Figure 5. Stress diagram of maximum cantilever state

Overturning moment M=383.55 × 13.5=5177.9kN·m

Anti overturning moment M=39.1 × 42 × $\frac{42}{2}$=34486.2kN·m

safety factor k=34486.2/5177.9=6.66>2.5, Therefore, it meets the requirements.

5. Force analysis of temporary support

5.1 Load case

In the process of steel truss pushing construction, because the pushing equipment is placed on the temporary support, the force of Jack acting on the main beam also acts on the temporary support, so it is necessary to consider the safety of the temporary support during the pushing process, so the pushing temporary support is analyzed according to two working conditions.

Working condition 1: the force acting on the temporary support is the largest, and the jack is used to push the construction. The load combination is: support reaction F2 + Jack jacking force t + support roof friction F2 + structure weight.

Working condition 2: the force acting on the temporary support is the least, and the jack is used to push the construction. The load combination is: support reaction F1 + Jack jacking force t + support top friction F1 + structure weight.

In this paper, the total weight of steel truss and guide beam is 206.6t. According to the construction scheme, the horizontal force of pushing is 5% of the total weight, then the required horizontal force t is 103.3kn; If the friction coefficient is 0.1, the friction F1 is 3.68kn and F2 is 76.46kn;

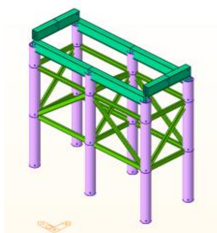

Figure 6. Overall model of push support

Midas software is used to model the support separately, and the two working conditions are substituted into the model for calculation, in which the safety factor is 1.2. The stress and stability of the support under the most unfavorable working conditions are checked. The model is shown in Figure 6.

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5.2 Strength checking calculation

According to table 6 of the model calculation results, the stress value of each component of the temporary support under load case 1 is the largest, and the maximum bending stress of the temporary support is 132.1mpa, which appears at the distribution beam; The maximum shear stress of the temporary support is 39.3mpa, which also appears at the distribution beam. According to table 4.4.1 of steel structure design standard, the allowable bending stress of Q235 is 205mpa, and the allowable shear stress is 120MPa. Therefore, the bending stress and shear stress of the support are less than those given in the specification, meeting the requirements of the specification.

Table 6. Stress value of pushing support under two working conditions

	Bending stress(MPa)	Shear stress(MPa)
Load case 1	132.1	39.3
Load case 2	70.5	8.4

5.3 Checking calculation of overall stability

According to the steel pipe section characteristics of the temporary support, combined with the maximum axial force results of the temporary support calculated by the model, the overall stability of the temporary support is checked. The section characteristics of support steel pipe are as follows:

Table 7. Section characteristics of support steel pipe

external diameter F(mm)	wall thickness t(mm)	Sectional area A(cm^2)	Section moment of inertia I(cm^4)	Radius of gyration i(cm)
426	10	194.8	93615	21.923

The maximum member spacing of the support is 3.3m, When L_0=330cm, Then the slenderness ratio of the member is

$$\lambda_1 = \frac{L_0}{i_1} = \frac{330}{21.932} = 15$$

According to the slenderness ratio, the stability coefficient can be obtained $\phi_1 = 0.932$;

According to the calculation results of the model, the maximum axial force of the support is $N_1 = 1371\text{kN}$, Considering the comprehensive influence coefficient of 1.8 for the maximum axial force, the maximum axial force is:

$$\sigma_1 = 1371 \times 1.8 = 2467.8\text{MPa};$$

According to the stability calculation formula of axial compression members in code for design of steel structures (GB 50017-2017), there are: $N/\phi Af = 0.632 \leq 1.0$; Therefore, the overall stability of the temporary support meets the requirements.

6. Stress analysis of temporary support foundation

6.1 Force analysis

The expanded foundation is adopted for the temporary support foundation, which mainly bears the force transmitted by the superstructure and heavy support. The top surface of the foundation is flat and the size is 8m × 4.5m × The buried depth of reinforced concrete foundation of temporary pier is 0.8m. During the actual jacking construction, the support foundation mainly bears the support reaction generated by the superstructure, the dead weight of the temporary support and support foundation, and the reaction transmitted by the jack jacking force. By calculating and combining all the loads, it is concluded that the vertical load borne by a single foundation is 1303.8kn, and the bending moment borne by a single foundation is 871.56kn M.

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6.2 Checking calculation of foundation bearing capacity

6.2.1 Strength analysis of bearing stratum:

The formula of base stress under eccentric load is

$$P_{k\,max} = \frac{F_k + G_k}{A} + \frac{M_k}{W}$$
$$P_{k\,min} = \frac{F_k + G_k}{A} - \frac{M_k}{W}$$

The allowable stress of foundation shall be calculated according to the following formula:

Where MK is the moment value (KN · m) acting on the bottom of foundation when corresponding to the standard combination of action; W is the resistance moment of foundation bottom (M^3); P_K is the pressure value (kPa) at the bottom edge of the foundation corresponding to the action standard combination.

The allowable stress of foundation shall be calculated according to the following formula:

$$f_a = f_{ak} + \eta_b \gamma (b-3) + \eta_d \gamma_m (d-0.5)$$

Where: f_a is the modified characteristic value of foundation bearing capacity (kPa); f_{ak} is the characteristic value of foundation bearing capacity (kPa), which is determined according to the principle of article 5.2.3 of this code; η_b, η_d is the correction coefficient of foundation bearing capacity of foundation width and buried depth. According to the category of soil under the foundation, refer to table 5.2.4; γ is the weight of the soil below the bottom of the foundation(kN/m^3); b is the base width (m); γ_m is the weighted average weight of the soil above the foundation bottom (kN/m^3); d is the buried depth of foundation (m);

The maximum and minimum base stress calculated by the above formula are 68.50kpa and 3.93kpa respectively; The allowable bearing capacity of the foundation is 218.82kpa.

According to Article 4.2.2 of code for design of foundation of highway bridges and culverts, when the base is eccentrically compressed and subjected to the combined action of vertical force N and bending moment M, the following conditions shall be met:

$$p_{max} = \frac{N}{A} + \frac{M}{W} = 68.50 \le \gamma_R [f_a] = 1.25 \times f_a$$

Therefore, the bearing capacity of the support foundation meets the requirements.

6.2.2 Checking calculation of base resultant force eccentricity

According to the formula listed in 5.2.5 of "code for design of subgrade and foundation of highway bridge and culvert", it is required to e_0 <[e_0]

$$e_0 = \frac{M}{N} = \frac{871.56}{1303.8} = 0.67$$

$$\rho = \frac{e_0}{1 - \frac{P_{min} A}{N}} = \frac{0.67}{1 - \frac{3.93 \times 4.5 \times 8}{1303.8}} = 0.75$$

As the foundation is non rock foundation, it can be seen from table 5.2.5 of code for design of highway bridge and culvert foundation that [E0] is 0.75, so E0 is less than [E0], and the eccentricity of base resultant force meets the requirements.

6.3 Checking calculation of foundation stability

6.3.1 Checking calculation of anti overturning stability

The anti overturning stability of bridge piers and abutments shall be calculated by the following formula

$$k_0 = \frac{S}{e_0} = \frac{4.5 \div 2}{0.67} = 3.36$$

Where k_0 is the anti overturning stability coefficient of abutment foundation; s Is the distance (m) from the gravity center of the section to the overturning axis of the check calculation on the extension

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line from the gravity center of the section to the action point of the resultant force; e_0 is the eccentricity of the base bottom resultant force.

According to table 5.4.3 of code for design of subgrade and foundation of highway bridges and culverts, the limit value of anti overturning safety stability coefficient in construction stage is 1.2, so the calculated value k_0 is greater than 1.2, which meets the anti overturning stability requirements.

6.3.2 Checking calculation of anti sliding stability

Sliding stability coefficient of foundation $K_c = \frac{fN}{T} = \frac{0.25\times 1303.8}{107.6} = 3.03$

According to table 5.4.3 of code for design of subgrade and foundation of highway bridges and culverts, it can be known that the anti sliding safety and stability coefficient $3.03 \geq 1.2$ in the construction stage meets the requirements of the specification.

7. Conclusion

In this paper, combined with the launching construction process of simply supported steel truss bridge, the stress and deformation of the superstructure under key working conditions are analyzed by using the simulation software to verify the mechanical performance of the temporary support and support foundation

(1) During the launching period of the steel truss bridge, the stress and deformation of each member of the main beam are within the limits required by the code, which ensures the safety and stability of the structure in construction.

(2) In the process of pushing, the safety factor of anti overturning calculation under the maximum cantilever state is 6.66, which is greater than 2.5 given in the code, so the anti overturning performance of the guide beam meets the requirements.

(3) In the process of pushing, the overall stability coefficient of the pushing support is 0.632 < 1, so the stability of the support meets the requirements. However, it is suggested that the pushing support plus horizontal cross bracing and other auxiliary components can better ensure the safety in the construction process.

(4) The foundation bearing capacity, base resultant force eccentricity and stability checking calculation of the support foundation all meet the requirements of the specification.

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