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ORIGINAL ARTICLE

APPLICATION AND ANALYSIS OF FULL FRAMING CALCULATION METHOD

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ABSTRACT

Full span support method is an indispensable construction method in bridge construction. Support collapse accidents occur frequently, and checking the support before construction is an important step to ensure safety. According to the newly issued Technical code for safety of cup lock steel tubular scaffolding in construction JGJ 166-2016 and Technical Specifications for Construction On Cast-in-situ Railway Concrete Girder by Falsework TB10110-2011 introduced a method of checking the components of full framing, and the system is demonstrated in the form of engineering examples to provide reference for similar engineering construction in the future. At present, the checking method has been successfully applied to the construction of most bridges in Xi'an metro line five, and the practice shows that the checking method is correct.

***Keywords*：** *Full framing; Cast-in-place continuous box girder; Checking method; Urban rail*

1 INTRODUCTION

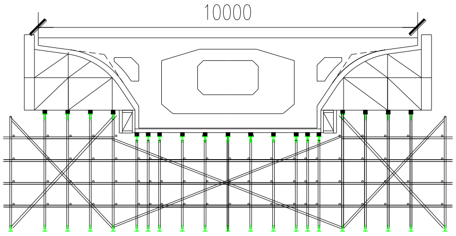
In recent years, with the large number of urban population and the substantial increase of China's economy, urban rail transportation is booming, urban rail construction will generally be accompanied by the construction of bridges. The new city track are tight deadlines, full support cast-in-place method is an important method of bridge construction, it has the characteristics of short construction period, convenient erection, easy to control, easy to remove, so the application in city rail bridges, railway bridges and other widely in bridge engineering.

In the construction of railway and highway bridge, for the construction of the bridge height lower adopts full scaffold construction, The rods of the brackets bear all kinds of construction loads from the upper part, which is an important bearing part and construction work platform for the construction of cast-in-place concrete structures. The calculation error will lead to the carrying capacity of the support structure, further lead to quality problems of construction safety accidents and engineering. Therefore,it is necessary to carry out integrity checking analysis for the full support system in actual construction. There are also in recent years occurred in the scaffold collapse, the author combined with the new "construction sized tubular steel scaffolding safety technical specifications" JGJ166-2016, the concrete application of calculation method is introduced in full support of cast-in-place box beam in city rail.

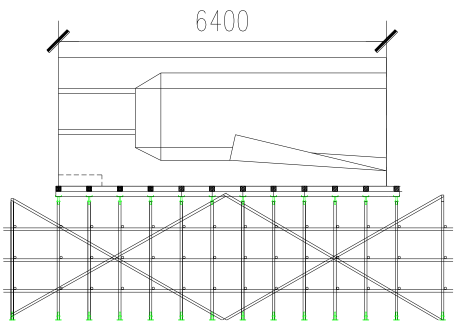
2. PROJECT OVERVIEW

The upper structure of Xi'an metro line five bridge is a continuous beam (45+75+75+45) m, the beam section is single box single room, The height of each section is equal, The longitudinal section is divided into 9 pairs of beams, The length is 6 3 m and 3 4 m respectively. The side span length is 6.4 m, The closing section is 2 m, Liang Dingkuan is 10 m, Liang Dikuan is 4.7 m, the cross section beam height is 4.5 m, the cross section beam height is 2.5 m, the beam height is changed by 1.8 times parabola, the roof thickness is 0.3 m, the thickness of the web is from 0.45 m to 0.7 m, and the floor thickness changes from 0.3 m to 0.5 m.

In the process of construction, Side span support uses steel tube scaffold, Continuous girder steel pipe supports are set with an average height of 3m, The scaffold structure is 0.6m, The step distance is arranged in three direction, The transverse step distance of the main bearing position of the web is set to 0.3m, so as to ensure the stability of the vertical pole. After the erection of the longitudinal, transverse and vertical main bars, the oblique strengthening bar is installed. The upper backwater placed 0.1m * 0.1m longitudinal timbers in scaffold erection is completed, and then put the 0.1m* 0.1m transverse timbers in the longitudinal timbers, finally placed in the horizontal timbers on the bottom formwork.The scope of the web and the chamber: template with 1.5cm thick bamboo plywood, bamboo plywood is arranged at the bottom of 10cm * 10cm square small transverse arris, vertical spacing of 30cm; 10*10 longitudinal timbers daleng arranged under transverse small ribs, lateral spacing of Web 30cm, lateral spacing box 60cm; vertical distance between transverse webs under 30cm. The chamber range 60cm, longitudinal spacing 60cm. Full framing of cast-in-place concrete section is shown in figure 1.



(a) cross section



(b) Elevation map

Fig.1 full framing layout

3. CALCULATION RANGE OF BEAM BADY AND SELECTION OF LOAD PARAMETERS

The box girder is divided into three parts from the transverse section, including the flange part, the web part and the web part. Because of the pouring of concrete, load distribution of beam bottom from the upper part of the bracket is not uniform, the maximum thickness of the web plate also means that the maximum load and the minimum flange thickness means the minimum load, between the web and flange load in the middle, but support is located in the middle part of the density of the layout is the same, so most of the load is calculated without considering the calculation of flange part. In order to simplify the calculation and analysis, it is assumed that the concrete is an ideal fluid material [1], and there is no shear stress between the particles. According to this assumption, the calculation range of section is checked according to the calculation range shown in figure 2.

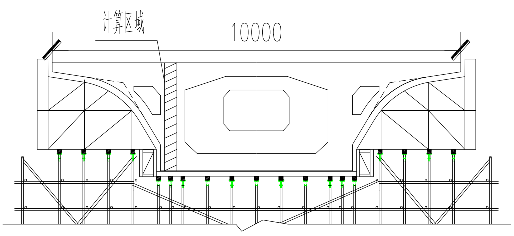


Fig. 2 Schematic diagram of calculation area

According to the standard **[2]**, the following loads should be taken into account in the design of the formwork and bracket, and load combinations shall be carried out by table 1. 1. new pouring beam gravity on the bracket; 2. support structure (including protection facilities and additional components) weight; 3. construction workers, materials and construction equipment load; 4. Load generated by vibrating concrete; 5.Impact load of concrete pouring; 6. the pressure of the new pouring concrete on the side of the formwork; 7. wind load; 8. water flow load; 9. impact loading of ships and drifts; 10. other loads, such as snow load, winter construction, thermal insulation facilities load etc..

Table 1 load combinations for design and calculation of formwork and support

Template structure name	Load combination	
	Strength	Rigidity
Bottom plate, longitudinal beam and	1.2（1+2）+1.4（3+4+5+10）	1+2+10

support structure under formwork

4. CHECKING CALCULATION OF FULL SUPPORT STRUCTURE

The main objects of the full frame calculation include: 1.5cm thick bamboo plywood strength and stiffness; 10cm * 10cm transverse bending strength and stiffness; 10cm * 10cm longitudinal bending strength and stiffness; bracket strength and stability checking; foundation bearing capacity checking. In limited space, only the scope checking of the web is described systematically.

4.1 Checking calculation of Web scope bracket

The web within the template with 1.5cm thick bamboo plywood, bamboo plywood is arranged at the bottom of 10cmX10cm horizontal square small arris, vertical spacing of 25cm; 10*10 longitudinal timbers daleng transverse small ribs, lateral spacing of Web 30cm; vertical rod lateral spacing of Web 60cm, the longitudinal distance of 60cm.

4.1.1 Checking calculation of bamboo plywood bottom formwork

Because the bamboo lower fulcrum is regularly arranged transverse timbers, so the bottom die force and deflection calculation, according to the load line of 3 span continuous beams, inside coefficient as shown in figure 3.

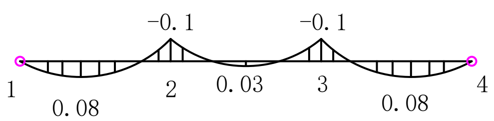


Fig.3 Interior coefficient of 3 span continuous beam under uniformly distributed load

The moment of inertia of the bottom template is:

$$I = \frac{bh^3}{12} = \frac{100 \times 1.5^3}{12} = 28.125cm^4$$

The resistance moment of the bottom template is:

$$W = \frac{bh^2}{6} = \frac{100 \times 1.5^2}{6} = 37.5cm^3$$

The upper load value of bamboo plywood is

1) Self weight of bamboo plywood: $q_1=h_0\gamma_s b_0$=0.015*9 * 1=0.135 kN/m

q_1——Line load generated by self weight of unit meter bamboo plywood;

h_0——Thickness of bamboo plywood,m;

γ_s——Weight value of bamboo plywood;

b_0——Calculate the width, this value is 1 meters per unit meter, that is, m;

2）Self weight of newly poured concrete: $q_2=h_1\gamma_{rc}b_0$=2.5*26 * 1=65 kN/m

q_2——Line load generated by dead weight of reinforced concrete per meter;

h_1——Calculation thickness of box girder,m;

γ_{rc}——Weight value of reinforced concrete（kN/m3);

According to the standard , the value is 26;

3) Construction personnel, materials and construction machinery load: When the template is calculated according to standard, The uniformly distributed load p_0 takes 2.5 kN/m2, In addition, the concentrated load f=2.5kN is used for checking computations, So the line load per unit meter q3=p_0*b_0=2.5*1=2.5kN/m，f=2.5kN (Checking load)

4) Load generated by vibrating concrete: According to the standard horizontal formwork, the vibrating load p1 is 2.0 kN/m2 So the line load per unit meter is q_4= p_1 *b0=2.0 *1=2.0kN/m.

5) Impact load of concrete pouring: According to the standard , the value of load p2 is 2.0 kN/m2,q5= p2 * b0=2.0 *1=2.0kN/m;

（1）strength calculation

Load combination Ⅰ: q=1.2*(q1+ q2) +1.4*(q3+ q4+ q5)= 87.262kN/m，The construction load shall be considered in accordance with the uniform load：Under the uniformly distributed load, the equal span continuous beam (internal force coefficient as shown in Figure 3) the maximum negative moment of the secondary pivot is the maximum,It's numerical value is:

M=0.1*ql2=0.1*87.262*0.252=0.545kN·m

Load combination Ⅱ: q=1.2*(q1+ q2) +1.4*(q4+ q5)= 83.762 kN/m，p=2.5kN。Checking load p=2.5kN

M=0.1*ql2+0.15*pl=0.1*83.762*0.22+0.15*2.5*0.2=0.410kN·m

From the above calculation can be seen M_{max}=0. 545kN·m

$$\sigma_{max} = \frac{M_{max}}{W} = \frac{0.545 \times 1000}{37.5}$$
$$= 14.5Mpa < [\sigma] = 37Mpa$$

（2）igidity calculation

Load combination: q=q_1+ q_2=65.14 kN/m

$$\omega = 0.677\frac{ql^4}{100EI}$$
$$= 0.677\frac{65.14 \times 25^4}{100 \times 10584 \times 28.125}$$
$$= 0.579mm < [\omega] = \frac{l}{400} = 0.625mm$$

4.1.2 Horizontal timber checking

Corner with 10 * 10cm square, longitudinal spacing is 0.25m, which takes the 0.25m wide weight, arranged under 10 * 10cm longitudinal arris, web 30cm spacing span is 30cm.

The wood transverse section moments:

$$I = \frac{bh^3}{12} = \frac{10 \times 10^3}{12} = 833.3cm^4$$

The transverse bending moment for timber:

$$W = \frac{bh^2}{6} = \frac{10 \times 10^2}{6} = 166.7cm^3$$

Load is above the horizontal timbers:

1）Weight of formwork and square block:

$q_1=h_0b_0\gamma_s+h_1b_1\gamma_{s1}=0.015*0.25*9+0.1*0.1*7=0.104kN/m$

h_1——Square section thickness

b_1——Square section width

γ_{s1}——The calculation value of wood density

2）Self weight of newly poured concrete:

$q_2= h_1\gamma_{rc}b_0=2.5*26*0.25=16.25kN/m$

3）The construction load: according to standard calculation of beam load at 1.5 kN/m^2, the construction load transverse timbers assumed by $q_3= p*b=1.5*0.25=0.375$ kN/m, in which b represents the square bearing load span.

4）Vibrating load: According to the standard vibrating load p_1 take 2.0 kN/m^2t.

5）Impact loading: Load values according to the standard p_2 take 2.0 kN/m^2,$q_5= p_2 * b=2.0*0.25=0.5kN/m$;

（1）strength calculation

It can be obtained from the upper load combination

$q=1.2*(q_1+ q_2) +1.4*(q_3+ q_4+ q_5)= 21.550$ kN/m

The maximum bending moment under the action of load is

$$M_{max}=0.1*ql^2=0.1*21.550*0.3^2=0.194kN\cdot m$$

$$\sigma_{max} = \frac{M_{max}}{W} = \frac{0.194 \times 1000}{166.7}$$
$$= 1.164Mpa < [\sigma] = 13Mpa$$

（2）Rigidity calculation

It can be obtained from the upper load combination $q=q_1+ q_2=16.354$ kN/m

$$\omega = 0.677\frac{ql^4}{100EI}$$
$$= 0.677\frac{16.354 \times 30^4}{100 \times 10000 \times 833.3}$$
$$= 0.011mm < [\omega] = \frac{l}{400} = 0.75mm$$

4.1.3 Vertical timber checking

10X10cm square block is used for main beam, The transverse spacing is calculated according to 30cm, and the main beam bears its 30cm wide weight,The column support is taken into account according to the longitudinal spacing 60cm of the middle section, and the span of the main beam is 60cm. According to the calculation of 3 span continuous beam (inner coefficient is shown in Figure 3)

The moment of inertia of longitudinal square block is:

$$\mathrm{I} = \frac{bh^3}{12} = \frac{10 \times 10^3}{12} = 833.3cm^4$$

The longitudinal square section resistance moment is:

$$\mathrm{W} = \frac{bh^2}{6} = \frac{10 \times 10^2}{12} = 166.7cm^3$$

The load value above the longitudinal square block is:

1）$q_1= h_0b_0\gamma_s+h_1b_1\gamma_{s1}= 0.015* 0.3*9+0.1*0.1*7=0.048$kN/m

Weight of formwork and square wood block

2）Self weight of new concrete: $q_2= h_1b_0\gamma_{rc}=2.5*0.3*26=19.5$kN/m

3）Construction load: Uniformly distributed load is 1.5 kN/m^2 q_3= p*b=1.5*0.3=0.45 kN/m

4）Vibrating load: q_4= p_1 * b=2.0 * 0.3=0.6kN/m

5）Impact loading: Load is 2.0 kN/m^2 ， q_5= p_2* b=2.0 * 0.3=0.6kN/m，

（1）strength calculation

The combination of loads can be obtained ：q=1.2*(q_1+ q_2) +1.4*(q_3+ q_4+ q_5)=25.768 kN/m

The maximum bending moment under the action of load is

$$M=0.1*q_l^2=0.1*25.768*0.6^2=0.928kN\cdot m$$

$$\sigma_{max}=\frac{M_{max}}{W}=\frac{0.928\times 1000}{166.7}$$
$$=5.567pa<[\sigma]=13Mpa$$

（2）Rigidity calculation

It can be obtained from the upper load combination：q=1.2*(q_1+ q_2)=23.458 kN/m

$$\omega=0.677\frac{ql^4}{100EI}$$
$$=0.677\frac{23.458\times 60^4}{100\times 10000\times 833.3}$$
$$=0.025mm<[\omega]=\frac{l}{400}=1.5mm$$

4.1.4 Column checking calculation

According to the latest specification [3] in 3.3.1, the steel pipe with nominal diameter of φ48.3X3.5mm shall be adopted. The transverse distance should be 30cm, the longitudinal spacing is 60cm, and the step distance should be 0.6m.According to the specification [4] in 5.1.10, the section characteristics of steel tube are as follows: sectional area A=4.93cm^2; section inertia moment I =12.43cm^4; section modulus W=5.15 cm^3; section modulus i=1.59cm.

The load value above the column is as follows

1）Weight of formwork and support：1) according to the specification [5], this item is determined according to the design scheme of the formwork and the bracket structure, according to the height of the project, the value is $q_1=2kN/m^2$

2）Self weight of new concrete： $q_2=h_1\gamma_{rc}=2.5*26=65kN/m^2$

3）Construction load: according to the standard [6] in 4.3.9 calculation of support column and other structures, the uniformly distributed load is $q_3=1\ kN/m^2$

4）Vibrating load： $q_4= p_1= 2kN/m^2$

5）Impact loading： $q_5= p_2 =2.0\ kN/m^2$

（1） strength calculation

Load combination： $q=1.2*(q_1+ q_2) +1.4*(q_3+ q_4+ q_5)=87.4\ kN/m^2$，

Axial force of each vertical pole N=87.4*0.3*0.6=15.732kN

According to the calculation of axial compression bar, according to standard [7] 4.4.4 $L_0=B+2a=1.2+2*0.65=2.5m$； L_0 is the vertical rod length is B; pole top horizontal bar to the top of the backwater distance is 650mm; so the slenderness ratio is

$\lambda=l_0/i=250/1.59=157$,$\varphi=0.312$

$$\sigma=\frac{N}{\varphi A}=\frac{15.732}{0.312\times 0.493}=102.278<f=205$$

4.2 Bearing capacity and anti overturning checking computations

（1） Bearing capacity calculation

From the above calculation results, the maximum axial force of single column is the column under the web, and the maximum axial force is N=15.732kN.The axial force is taken as the most unfavorable axial force to calculate the bearing capacity of the foundation.The bearing capacity value of the foundation under the support is not less than 100kPa, and the surface is treated with

20cm thick C20 concrete for surface hardening.The column base is made of 15cm *15 cm steel plate.

$$\sigma_d = \frac{N}{A} = \frac{15.732}{0.2025} = 78.769 < f_g = 100$$

N——Design value of axial force of vertical pole to the top of foundation

f_g——Characteristic value of subgrade bearing capacity

A——Bottom area of vertical pole foundation

A=B*D，B=b+2h*tanα，D= d+2h*tanα

h——Thickness of foundation cushion

b、d——Length and width of vertical pedestal

α——°The stress diffusion angle should be determined according to the relevant provisions of the different cushion materials, and the value of the project is 45°

B、D——The calculation value should not be greater than the distance between adjacent vertical poles, otherwise the distance between adjacent vertical poles should be taken

（2）Checking calculation of overturning resistance

The height of the bracket is set according to the highest 5m, the step distance is 1.2m, and the lateral support extends 1m on both sides of the beam body, The total width is 11.5m, and 21 rows of steel tubes are arranged transversely. According to the design of the bracket, the maximum longitudinal spacing is 60cm，Under the action of wind load, the overall stability coefficient of overturning resistance is the least, and a spacing section is taken to calculate the overall overturning resistance.

According to the specification in 4.4.7

$$K = \frac{M_k}{M_q}$$

K——Stability against overturning of structure, K is not less than 1.5

M_k——The overturning moment of the structure is determined by the moment of the gravity load of the formwork system and the support structure

Mq——The overturning moment of the structure is determined by the wind load acting on the support structure and the formwork system

Because the standard [8] does not make a specific formula for the calculation of Mk and Mq, the calculation method of overturning moment and overturning moment of structure is adopted in the standard.Length of steel tube with a spacing bracket L=5*21+11.5*6+0.6*21*6=249.6m

Only consider the weight of the support steel pipe, ignore the connectors, templates and other weight,The overturning moment is

M_k=96.596*11.5/2=555.427kN·m

According to the specification [9] $\omega_k=\mu_z\mu_{stw}\omega_0$

The coefficient of variation of wind pressure heightμ_z is adopted in accordance with appendix B of the code,The roughness of ground surface is 1.09 according to class A, and the basic wind pressure ω_0 is 0.25kN/m2; According to the standard, the calculation formula of 8.3.3 in the standard should be adopted in the standard STW[10]. According to the engineering situation, the partial safety value is 0.2.

$$\mu_{stw} = \varphi\mu_s\frac{1-\eta^n}{1-\eta}=1.467$$

According to the specification in μ_s is 1.3 ,η is 0.97, n is 21, the surface roughness in accordance with a consideration, μz=1.09, according to the "basic wind load standard" in Appendix E.5 of Xi'an city value of ω_0=0.25kN/m^2

ω_k=0.7*1.25*1.467*0.35=0.493kN/m^2

Overturning moment Mq =H^2 *q_{wk}/2=H^2 *l_a *ω_k/2

=5*5 * 0.6*0.493/2=14.8kN·m

Meet the requirements of standard anti overturning checking.

5 Conclusion

The above full support checking method has been successfully applied to the construction of most overhead bridges in Xi'an metro line five, and the calculation results are relatively safe and economic.Practice results show that the method is reasonable and effective. Since the method is based on the classical mechanics theory and assumes that concrete is an ideal fluid material, there is no shear stress between the particles, so the calculation results must be in a certain deviation from the actual results. According to the engineering practice experience, a safety factor should be taken into account in the design and calculation of the support. The design and checking work of the support is of great importance to the quality, safety and cost of the project, so it should be paid more attention to in the practical work.

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