Finite Element Simulation of Cast-In-Place Box Girder Combined Support for Side Span of Zishui Bridge

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Abstract

Combined bracket for cast-in-place girder using the most, the most common, higher safety factor construction method. This paper takes Yichang high-speed Zishui Bridge side span cast-in-place box girder combination bracket as an example, due to the influence of site constraints, the conventional bracket can not meet the requirements of the bridge construction, so it adopts the steel pipe column plus beribboned beam combination structural design. Midas Civil is used to calculate the stresses of the beams and components, so as to provide calculation methods and optimization ideas for similar projects.

Keywords

Cast-In-Place Box Girder; Combined Brace; Finite Element; Force Condition.

1. Introduction

Cast-in-place box girders are widely used because of their structural stability and wide applicability, and the use of bracing is a common construction method for cast-in-place girder bridges[1] . Bracket construction is a key part of cast-in-place girder construction, so it is necessary to calculate and analyze the mechanical characteristics of cast-in-place girder bracket before construction to ensure construction safety and improve the quality of the project[2] .

Common stenting methods include full-tower stenting and steel pipe beret combination stenting. Under special terrain conditions, the use of steel pipe beret beams as stent load-bearing can make up for the disadvantages of full-tower stenting, and the reasonable and comprehensive use of steel pipe beret beams stenting and full-tower stenting can break through the limitations of their respective use and achieve good construction results[3] . When using finite element method to analyze the overall structural safety of the bracket, the first step is to establish a calculation model that is consistent with the actual project, and the correct and reasonable calculation model is the key work of the bracket design and analysis[4].In this paper, based on the Yichang Expressway Zishui Bridge side-span cast-in-place box girder combination bracket, numerical simulation method is adopted to establish the finite element model of the bracket, and the strength, stiffness, and stability of some important rods are calculated, so as to provide research references for solving this kind of engineering problems.

2. Project Overview and Finite Element Modeling

2.1 Overview of the Project

Zishui Bridge is located in the second contract section of Yiyang-Changde Expressway Expansion Project. The main bridge adopts (64+102+196+102+64)m prestressed rigid-continuous combined structure girder bridge, the side center-span ratio is 0.52, the side span is set to be 64m across the east bank flood control embankment, the upper main girder adopts the prestressed rigid-continuous box girder structure, the transversal adopts the split design, the width of the single bridge is 16.75m, the lower main pier adopts the double-limbed thin-walled pier, and the sub-main pier and the crossing pier adopts the pillar pier, the foundation adopts the bearing platform to receive the pile foundation, the box girder adopts the bowl-button type support cast-in-place construction. The foundation adopts bearing platform and pile foundation, and the side span box girder adopts bowl buckle type support cast-in-place construction. The main bridge superstructure adopts prestressed concrete variable cross-section box girder, and the single main girder section is single box chamber with straight web box section. The girder height is 13m at the root of the box girder, 4.4m at the center of the span and the cast-in-place section of the side span, and the bottom of the girder varies according to 1.8 parabolic changes; the width of the top plate of the box girder is 16.75m, and the width of the bottom plate is 8.75m, and the length of the cantilever is 4m; the thickness of the top plate is 0.32m, and the thickness of the bottom plate is thickened from the center of the span of 0.35m according to 1.8 times the parabolic thickening to 1.5m at the root, and the thickness of the end of the cantilever is 0.2m; and the thickness of the bottom plate is thickened to 0.4m, and then the thickness is thickened to the cantilever. Thickened to 0.85m at the root; web thickness from the middle of the span or side span cast-in section to the root of the box girder using 0.6m, 0.7m, 0.9m three sizes, due to the planning of lanes, $4^{\#}$~$5^{\#}$ pier using steel pipe columns and berries beam structure for construction, the steel columns using Φ630 mm × 10 mm steel pipe. In this paper, only $4^{\#}$ ~$5^{\#}$ pier combined bracket components for strength, stiffness and stability calculation, and the steel pipe pile bearing capacity calculation.

2.2 Finite Element Modeling

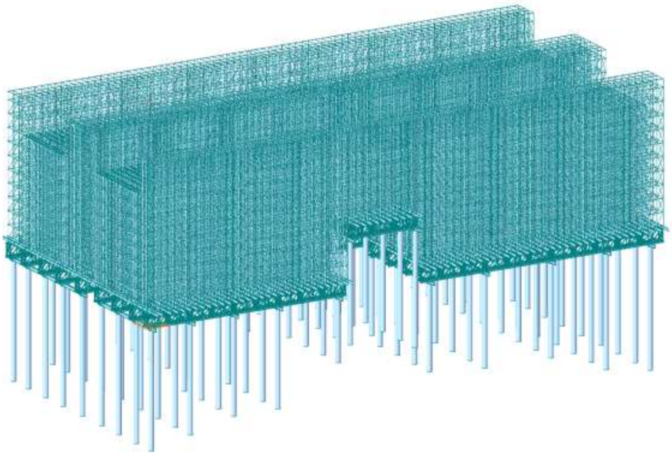

Fig. 1 Overall view of the bracket

(1) Coordinate system: longitudinal bridge direction is the X axis of the overall coordinate system, transverse bridge direction is the Y axis, and vertical direction is the Z axis.

(2) Section characteristics: Φ60.3 mm×3.2 mm steel pipe, Φ630 mm×10 mm steel pipe column, I32b double-spliced load-bearing beam, I25b distributing beam, and 321 bailey beam.

(3) Boundary conditions: The riser, load bearing beams, berth beams and distribution beams are connected in a simply supported manner, and the bottom of the steel pipe piles are cemented to the ground.

(4) Load: The self-weight of the upper structure of the stent, such as box girder, bottom mold, square wood, channel steel, etc., are all converted into homogeneous load by reference to the specification, which acts on the top plate unit of the finite element model of the bowl buckled stent to simulate that the top support of the stent is subjected to the upper load in the actual construction.

The integral model of the combined support is used for strength and stiffness checking of distributor beams, load bearing beams and berth beams, and stability checking of steel pipe piles.

3. Calculation Parameters

3.1 Load Values

According to the specification JGJ/T231-2021 building construction socket type coil buckled steel pipe scaffolding safety technical standards to take the value:

Permanent loads:

①Self-weight of the frame, G_1 , 1.8kN/m^2

② template weight G_2 take 0.5kN / m ² (template including bamboo glue board and square wood)

③ Reinforced concrete deadweight load: 25.5kN/m² for reinforced concrete deadweight G_3

Top plate, bottom plate: P=25.5×(0.32+0.35)=17.085kPa

Web: P=25.5×1.763=44.268kPa

Flange plate: P=25.5×0.46=11.73kPa

Variable loads:

④Construction load Q_1 take 3kN/m^2

⑤ Additional horizontal load Q_2 from pumping concrete, dumping concrete, etc. take 2kN/m^2

⑥Wind load Q_3 Standard value:

There is a code to get the calculation formula as:

$$w_k = \mu_z \mu_s \omega_0 \tag{1}$$

Calculated:

$$w_k = 1.30\times 1.1\times 0.35 = 0.50\text{kN/m}^2$$

3.2 Load Combinations

When wind load is not combined:

1.3(①+②+③)+1.5(④+⑤)

When combined wind load:

1.3(①+②+③)+0.9×1.5(④+⑤+⑥)

4. Bracket Calculation

4.1 Distribution Beam Checking

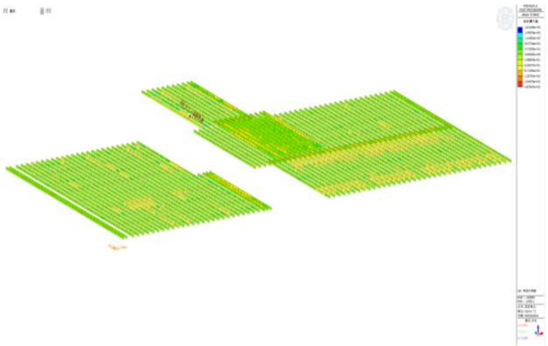

Fig. 2 Schematic representation of the maximum value of stress in the distributing beam

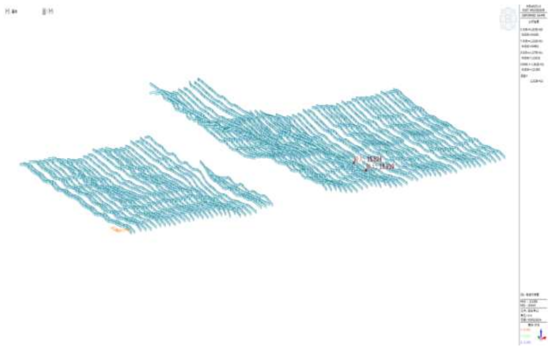

Fig. 3 Schematic representation of the maximum value of displacement in the distributing beam

The distribution beam is located below the socketed bowl-button type bracket, the material is Q355, and the cross-section form is I25b I-beam, according to the specification, the strength and stiffness of the distribution beam is checked.

Extracting the calculation results, the maximum stress of the distribution beam is 187.80MPa <300MPa, and the maximum deformation is 15.6mm <l/400=33500/400=83.75mm, which meets the specification requirements for strength and stiffness.

4.2 Load-bearing Beam Calculations

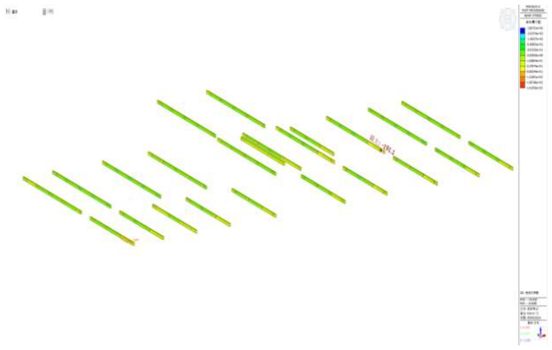

Fig. 4 Schematic diagram of maximum stress in load bearing beam

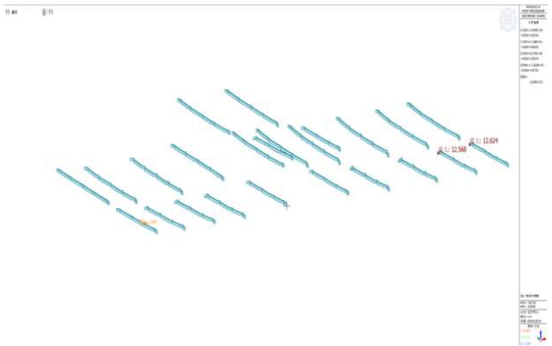

Fig. 5 Schematic diagram of maximum displacement in load bearing beam

The load-bearing beam is located between the steel pipe pile and the beribboned beam, and the three are connected by simple support, the material is Q355, and the cross-section form is double-spliced I32b I-beam, and the strength and stiffness of the load-bearing beam girder is checked according to the specification.

Extracting the calculation results to get the maximum stress of the distribution beam is 190.70Mpa<300MPa, the maximum deformation is 12.6mm<l/400=45mm, the strength and stiffness meet the specification requirements.

4.3 Bayley Beam Checking

The support is made of 9 groups of 23 pieces of 321-type berets, which are arranged in double rows and single layers with a maximum span of 6 m. Due to the design needs, some of the support points of steel pipe piles are misaligned with the nodes of the berets. Although the berries are high-strength truss structures, when the nodes and support points are misaligned and the load value of the beam is large, excessive stresses will occur locally in the lower chord of the berries, leading to structural damage.

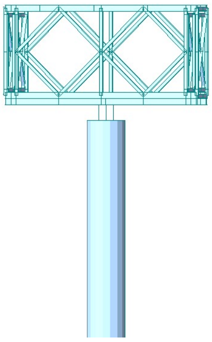

Fig. 6 Schematic diagram of the misalignment of the beribboned nodes

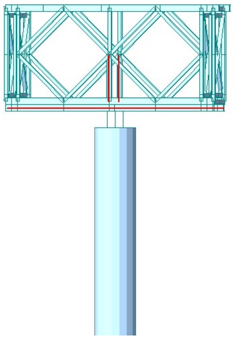

Fig. 7 Schematic diagram of the misaligned local reinforcement

Beam node dislocation is more common in the construction site, in order not to affect the structural performance of the beribboned piece, in the dislocation of the part of the structure of the reinforcement, reinforcement measures: in the top range of I-beam beribboned piece of the upper and lower chord bars and vertical bars using C20 channel steel reinforcement. As shown in Figure 7 (strengthening position marked in red).

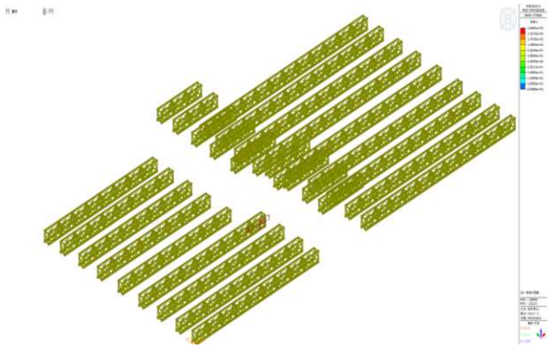

Fig. 8 Schematic diagram of the maximum value of stress in the berley beam

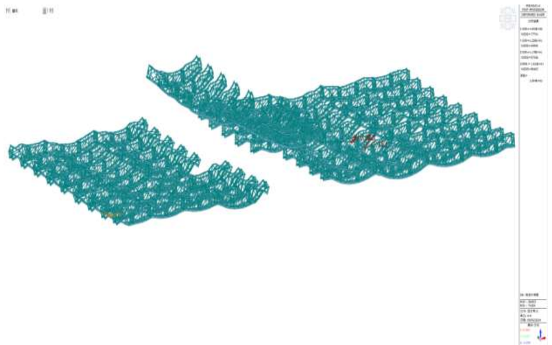

Fig. 9 Schematic diagram of the maximum value of displacement in the berley beam

Extracting the calculation results to get the maximum stress of the distribution beam is 260.7Mpa<300MPa, the maximum deformation is 9.07 mm<l/400=18.75mm, and the strength and stiffness meet the specification requirements.

4.4 Calculation of Uprights

4.4.1 Calculation of Axial Force Values for Uprights

According to the specification "JGJ/T231-2021" the design value of axial force of vertical rod should be calculated according to the following formula:

Without combining wind loads:

$$N = \gamma_G \sum N_{Gk} + \gamma_Q \sum N_{Qk} \tag{2}$$

For combined wind load:

$$N = \gamma_G \sum N_{Gk} + 0.9\gamma_Q \sum N_{Qk} \tag{3}$$

Load combination value: take the maximum unfavorable load web section area single limb vertical rod axis force:

(1)Wind load combinations are not considered

$$N=[1.3\times(1.8+0.5+44.268)+1.5\times(3+2)]=68.03\text{kN}$$

(2) Consideration of wind load combinations

$$N=[1.3\times(1.8+0.5+44.268)+0.9\times1.5\times(3+2+0.5)]=68.0\text{kN}$$

4.4.2 Calculation of Stability of Uprights

The socket type coil buckled steel pipe scaffold structure is essentially a kind of semi-rigid space frame steel structure, the connection between the horizontal rod and the vertical rod is a kind of connection form between "articulation" and "rigid connection". The use of socketed buckled steel pipe scaffolding as a supporting frame generally ensures that the scaffold's uprights are axial compression rods[5].

This paper adopts the form of single-pole stability check to check the overall stability of the supporting scaffold. According to the "safety technical specification for steel pipe scaffolding in building construction", the data are as follows:

Table 1. Φ630mm×10mm riser cross-section characteristics and related parameters

The stabilization factor φ	Design values for tensile, compressive and flexural strength f	Riser section modulus W	Riser cross sectional area A	Longitudinal distance between uprights l_a	Maximum step distance of horizontal bar h	Standard value of wind load w_k
0.68	300MPa	7784mm³	574mm²	0.9m	1.5m	0.50kN/m²

(1) Calculation of bearing capacity without combination of wind loads

Take the calculation results without combining the maximum value of wind load 68.03kN to check the bearing capacity of the vertical rod.

Calculation of axial bearing capacity of single-limb riser without combined wind load:

$$\frac{N}{\varphi A} \leq f \tag{4}$$

Calculated:

$$\frac{N}{\varphi A} = \frac{68.03\times1000}{0.68\times574} = 174.29\text{MPa} \leq f = 300\text{Mpa}$$

Meet the specification requirements.

(2) Calculation of wind load bearing capacity of vertical rod combination

Take the maximum value of combined wind load 68.0kN to calculate the bearing capacity of the vertical rod.

Calculation of axial bearing capacity of single limb riser for combined wind loads:

$$\frac{N}{\varphi A} + \frac{M_W}{W} \leq f \tag{5}$$

Where: MW is the bending moment generated by the wind load design value of the calculated riser section;

$$M_W = \frac{0.9\times1.4 w_k L_a \times h^2}{10} \tag{6}$$

Calculated:

$$M_W = \frac{0.9\times1.4\times0.5\times0.9\times1.5^2}{10} = 0.12\text{kN}\cdot\text{m}$$

$$\frac{N}{\varphi A} + \frac{M_W}{W} = \frac{68.0\times1000}{0.68\times574} + \frac{0.12\times10^6}{7784} = 189.63\text{MPa} < f = 300\text{Mpa}$$

Meet the specification requirements.

4.5 Steel Pipe Pile Calculations

The cross section of steel pipe pile is made of Φ630 mm×10 mm round steel pipe, and the material is Q355 steel. The bottom of the pile is embedded in the soil layer, which can be regarded as consolidation. Pile strength, stability and pile bearing capacity are checked according to the specification.

4.5.1 Strength and Stability Calculation of Steel Pipe Piles

Table 2. Φ630mm×10mm steel pipe column cross-section characteristics

Cross-sectional area of steel pipe *A*	Slewing radius *i*	Tube resistance moment *W*	Design value of compressive strength of steel *f*
19468mm²	219.6mm	36985mm³	300MPa

Take the pier height 8m, steel pipe outer diameter D = 630mm, wall thickness t = 10mm, check the "Steel Structure Design Manual" to get the length and slenderness ratio $\lambda = \frac{ul}{i} = \frac{2\times 800}{21.96} = 72.84 < [\lambda] = 150$, check the table to know the stability coefficient of axial compression member $\varphi = 0.694$, extract the data to get the maximum value of the vertical force of a single column: N = 1062kN.

According to the formula of stability calculation of compression bar, the stability calculation of steel tube column is carried out:

$$\frac{\gamma_0 N}{\varphi A} \leq f \tag{7}$$

Substituting all the data into the formula gives.

$$\frac{\gamma_0 N}{\varphi A} = \frac{1.1\times 1062\times 1000}{0.694\times 19468} = 86.46\text{MPa} < f = 300\text{MPa}$$

The strength and stability of the columns were calculated to meet the code requirements.

4.5.2 Calculation of Vertical Bearing Capacity of Pile Foundation

When the standard value of vertical ultimate bearing capacity of single pile of steel pipe pile is determined according to the empirical relationship between physical index of soil and bearing capacity parameters, it is calculated according to the following formula:

$$Q_{uk} = Q_{sk} + Q_{pk} = u\sum q\, l_{siki} + \lambda_p\, q_{pk}\, A_p \tag{8}$$

Where Q_{sk} is the standard value of total ultimate lateral resistance, Q_{pk} is the standard value of total ultimate end resistance, q_{sik} is the standard value of ultimate lateral resistance of the ith layer of soil around the pile, and q_{sk} is the standard value of static touch ratio penetration resistance near the pile end.

Table 3. Basic information on steel pipe piles

Outer diameter of steel pipe pile	Pile bottom section circumference u	Pile end soil plug effect coefficient λ_p	Wall thickness of steel pipe pile	Pile cross sectional area A_p	Pile bottom cross sectional area A_p
0.63m	1.98m	1m^2	0.01	19.5 x $10^{-3}$$m^2$	0.31m^2

Table 4. Standard values of vertical ultimate bearing capacity

Stratigraphic number	Soil layer name	Thickness l_i	Standard value of resistance on the extreme side q_{ik}	$u\Sigma q_{ik}$ $\times l_i$	λ_p q_{pk} A_p	Q_{uk}
④-1-3	silty clay	8.2m	95KPa	1542	318	1860
⑦-1-3	pebbles	11.0m	300KPa	8076	2170	10866
⑪-1-3	pebbles	5.8m	300KPa	11522	2790	14312
⑩-1-4	boulder	10.0m	180KPa	15086	2480	17566

From the values taken from Table 3 and Table 4: the maximum axial force of pile foundation: 57.3MPa×19.5×$10^{-3}$$m^2$ =1117.4kN, when the depth of steel pipe pile into the soil is 10m:

$Q_{uk}=Q_{sk}+Q_{pk}=u\sum q_{sik}l_i+\lambda_p q_{pk}A_p$ =4781.2kN>1128.8kN, which meets the requirements.

5. Conclusion

In this paper, with the background of cast-in-place box girder combination bracket, the steel pipe berth combination bracket model is established by Midas Civil, and the force, deformation and stability of the bracket during the cast-in-place construction of this box girder are analyzed, and the following results are obtained:

(1) The maximum stress of the distribution beam is 187.80MPa and the maximum vertical deformation is 15.60mm, the maximum stress of the load-bearing beam is 190.70MPa and the maximum vertical deformation is 12.6mm, and the maximum stress of the beret beam is 260.70MPa and the maximum vertical deformation is 9.07mm. the strength, stiffness, and stability satisfy the specification requirements.

(2) The maximum axial force of single-limb vertical rod without combined wind load is 68.03kN, and the maximum bearing capacity is 174.29MPa, the maximum axial force is 68.00kN, and the maximum bearing capacity is 189.63MPa when combined wind load is applied, and the ratio of length and slenderness of steel pipe pile is 72.84, and the maximum axial force of single vertical column is 1062kN, and the maximum bearing capacity is 78MPa. the strength, stiffness, and stability meet the requirements of the specification. Strength, stiffness and stability all meet the specification requirements.

(3) The strength and stiffness of the main stress components of the combined stent have reached the requirements of the load-bearing standards, and the stent structure is safe, but there is still room for optimization, and some of the rods can be replaced by Q235 steel, and the spacing between the steel pipe piles can be increased the number of steel pipe piles can be appropriately reduced.

The computational procedure and model construction of cast-in-place box girders described in this paper can provide a reference for finite element modeling as well as force testing of similar projects.

References

[1] Hongxing,Shao, Shuzhen,Li, Weiping,LI. Costing analysis of common cast-in-place bridge support schemes[J]. Highway,2014,59(08):221-223.

[2] Zhang W, Wang Y, Liu H, et al. Analysis of the dynamic characteristics of construction frame of thin-walled high pier cover beam crossing method [J]. Journal of Henan University of Science and Technology (Natural Science Edition), 2023, 44(3):61-69, 78, 8.

[3] Xiaoping,He. Application of steel pipe bailey girder combined full-tower coil buckling bracket method in cast-in-place continuous box girder[J]. Transportation Construction and Management,2024,(03):79-81.

[4] Weimin,Chen, Shi Jie, Yao Jun. Finite element analysis of cast-in-place box girder beret-fastener steel pipe combination brace [J]. Highway and Transportation Science and Technology (Applied Technology Edition), 2015(5):159-162.

[5] Safety Technical Standard for Socket-type Coil-buckled Steel Pipe Scaffolding for Building Construction (JGJ/T231-2021).