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Design Analysis of Variable-Height Simply Supported Steel Truss Bridge

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Abstract: This article analyzes the design of a variable-height simply supported steel truss bridge based on an actual project. It includes its basic situation, introduction to variable-height simply supported steel truss bridges, key design points of such bridges, and finite element analysis of the design effect. The analysis shows that for such bridges, reasonable main structure design and node design are the keys to determining the overall design idea, and through the reasonable application of the finite element analysis method, the design effect can be scientifically determined, providing a reference for the subsequent structural design of such projects.

Keywords: Bridge; Variable height; Simply supported beam; Steel truss; Finite element analysis

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1. Introduction

In modern bridge construction engineering, steel truss bridges have a smaller structural height, strong spanning ability, and greater structural rigidity, making them more suitable for bridge construction with larger spanning distances and stricter height requirements. In the practical application of such structures, reasonable structural design is crucial [1]. Based on this, designers need to combine various practical situations to reasonably determine their design ideas and implement design optimization through finite element analysis, so as to meet their actual design, construction, and application requirements.

2. Project overview

This study focuses on the reconstruction design project of a river-crossing bridge. The main span of the bridge in this project crosses the Beijing-Hangzhou Grand Canal, and the overall plan is a prestressed concrete continuous steel structure of single-box double-room type, with a specification of 508650 m. The current canal roadway in the area belongs to Grade IV, the planning grade is Grade III, and the planned navigation clearance is 80 × 7 m.

Because the current bridge cannot meet the actual navigation needs of the roadway, and the quality of the existing bridge structure is seriously insufficient, the engineering unit has decided to demolish and rebuild it. The rebuilt main bridge structure is a through-type variable-height simply supported steel truss with a span of 120 m. The main truss of the bridge is a triangular variable-height truss with 10 panels and a total length of 120 m. The height ranges from 9 to 15.915 m. The center-to-center distance between the two main trusses on the main bridge is 18.3 m, the ratio of width to span is 1:6.47, and the bridge deck width is 17.0 m. This article mainly analyzes its structural design based on the project overview.

3. Introduction to variable-height simply supported steel truss bridges

3.1. Basic information

Variable-height simply supported steel truss bridges are a common structure in modern bridge engineering. They have diverse truss forms, variable height designs, and rich rod section shapes. The main force in practical applications is axial force, which can adapt to different loads and has a large mid-span bending moment. Such bridge structures are suitable for modern small and medium-span bridges, urban roads and highways, and scenes with limited construction terrain and space [3].

3.2. Application advantages

Currently, the main advantages of variable-height simply supported steel truss bridges are manifested in the following aspects: Firstly, the structure has a large bending moment and shearing force, strong adaptability to load changes, and can effectively prevent deformation problems. Furthermore, the structure has a lightweight, low infrastructure cost, and the structural size can be reasonably adjusted according to the actual internal force distribution, achieving reasonable savings in materials and costs during construction [2]. Additionally, the structure height can be adjusted according to the actual terrain, and it has a good landscape effect, with strong overall environmental adaptability. Lastly, the structure is in a prefabricated and assembled form, and the components are relatively simple, making construction and operation, and maintenance more convenient.

4. Key design points for variable-height simply supported truss bridge structures

4.1. Main structure design

Based on the actual site conditions and practical application requirements of the bridge structure for this project, the designers have determined the following structural design scheme:

The upper and lower chord sections of the main bridge are designed as box shapes. The former has an inter-node length ranging from 11.84–12.17 m, a top plate, and web thickness between 28–32 mm, an internal width of 800 mm, and a height of 860 mm. The latter has an inter-node length of 11.84 m, an internal width of 800 mm, a height ranging from 1140–1466 mm (forming a cross slope on the bridge deck due to the height difference), and a top plate and web thickness between 20–24 mm.

The end diagonal web member has a box-shaped section, with an inter-node length of 10.77 m, an internal width of 800 mm, a height of 800 mm, and a top plate and web thickness of 36 mm. Other diagonal web members have I-shaped sections, with inter-node lengths ranging from 10.77–16.98 m, a width of 800 mm, heights between 600–800 mm, and flange plate and web thicknesses between 20–32 mm.

The bridge deck system consists of closely spaced crossbeams, and the bridge deck plate is made of orthotropic steel with a top plate thickness of 16 mm. The crossbeams are spaced at 2.96 m intervals, stiffened with U-shaped ribs that are 8 mm thick and spaced 600 mm apart. The longitudinal beams have heights ranging from 1140–1466 mm, a web thickness of 16 mm, a bottom plate thickness of 24 mm, and a width of 600 mm.

The horizontal members of the bridge portal frame and cross members have box-shaped sections, with an internal width of 370 mm, a height of 440 mm, and a top plate and web thickness of 12 mm. The diagonal members have I-shaped sections, with a width of 260 mm, a height of 346 mm, a flange plate thickness of 12 mm, and a web thickness of 10 mm.

4.2. Structural node design

For the variable-height simply supported steel truss structure of this bridge project, the designers have determined the following node design scheme:

Two main trusses are used in the cross-section, with end web members positioned outside the bridge portal frame. Cross members are provided at all other upper chord node locations, and the slopes of the centerlines of the portal frames and cross members align with the web slopes.

The main truss has a one-way transverse slope, and the upper and lower chord nodes are designed as integral units. High-strength bolts are used to connect the members and nodes, as well as to join the web plates, top plates, and bottom plates of adjacent chord members. The end web diagonal members are assembled from four pieces, while other diagonal members are inserted into place [4].

The top plate of the lower chord is welded to the steel bridge deck plate. The main truss web plates are bolted to the crossbeam web plates, and the main truss members are welded to the bottom plate.

A truss-type bridge portal frame, with a height of 3.0 m, is installed at the main truss support location. Truss-type cross members, with a height of 4.5 m, are positioned at other support locations.

5. Finite element analysis of design effects for variable-height simply supported steel truss bridges

5.1. Establishment and settings of the finite element analysis model

To analyze the overall design effects of this variable-height simply supported steel truss bridge, designers utilized MIDAS Civil finite element analysis software. Modeling was completed using beam and plate elements, neglecting participating structural forces, and calculations were performed by applying self-weight loads. According to design standards, all steel plates are bridge-specific Q345QD high-strength low-alloy steel plates, with a tensile and compressive strength of 200MPa and a shear strength of 120MPa. Dead loads include the weight of the truss, pavement, and guardrails; live loads consider the one-way 4-lane highway class I vehicle load with patch load effects, and the impact coefficient is set according to the “General Specifications for Design of Highway Bridges and Culverts” JTG D60-2015 (hereinafter referred to as “Specification 2015”). Temperature loads are taken as the maximum (25°C) and minimum (-38°C) values according to the “Highway Specifications”, and the local temperature gradient for the deck is set at ± 10°C. Wind loads are based on the annual average wind speed (25m/s) at the project site for operational values, while also considering the local 100-year wind load value of 28.6m/s, both in the transverse direction of the bridge. Three load combinations are set according to the “Specifications for Design of Steel Structures of Railway Bridges” TB 10091-2017 (hereinafter referred to as “Railway Specifications”): the first is a combination of dead and live loads, the second is a combination of dead, live, temperature, and operational wind loads, and the third is a combination of dead loads, temperature, and 100-

year wind loads [5].

5.2. Finite element analysis of member design effects

For the strength of the main truss upper and lower chords, web members, cross members, and bridge portal frames in this bridge structural design scheme, designers imported various design and load parameters into the finite element analysis model for verification. Through calculation, it was found that the maximum compressive stress in the standard combination mode is -167MPa for the upper chord, -168MPa for the web members, and -100MPa for the cross members and bridge portal frames. The maximum tensile stress is 152MPa for the lower chord, 134MPa for the web members, and 58MPa for the cross members and bridge portal frames. The maximum compressive and tensile stresses in all locations do not exceed the 200MPa specified in the "Railway Specifications", indicating that the member strength design is qualified [6].

Regarding the overall stability of the main truss upper and lower chords and web members in this bridge structural design scheme, designers considered reduction factors and imported various design and load parameters into the finite element analysis model to verify their combined stresses and judge their stability. **Table 1** presents the finite element analysis verification results for the combined stresses of the main truss upper and lower chords and web members in this variable-height simply supported steel truss bridge design scheme.

Table 1. Finite element analysis verification results for combined stresses of main truss upper and lower chords and web members in the variable-height simply supported steel truss bridge design scheme

Serial Number	Member	Section number	Combined stress limit	Check Value	Qualification
1	Top chord	3#	200MPa	-181MPa	Qualified
2		4#	200MPa	-181MPa	Qualified
3	Bottom chord	--	200MPa	Tension bar	Qualified
4	Web member	5#	200MPa	-107MPa	Qualified
5		6#	200MPa	-124MPa	Qualified
6		7#	200MPa	-154MPa	Qualified
7		8#	200MPa	Tension bar	Qualified
8		9#	200MPa	-141MPa	Qualified

Among them, the tension bar adopts a movable structure, and its state is not affected by combined stress. Through calculation, it can be seen that the combined stress of each member does not exceed the limit, and the overall structure can remain stable, indicating that the overall structural stability of the members is qualified.

Based on this comprehensive judgment, the design effect of the members in the variable-height simply supported steel truss structure of the bridge project is qualified.

5.3. Finite element analysis of bridge deck system design effects

For the deck system of the variable-height simply supported steel truss structure in this bridge project, designers first verified the tensile and compressive stresses by importing the design parameters and load parameters of the crossbeam into the finite element analysis model. The maximum tensile stress calculated was 104MPa, and the maximum compressive stress was -158MPa, both within the prescribed limit of 200MPa. This demonstrates that the design of the crossbeam is satisfactory.

Next, designers imported the design parameters and load parameters of the bridge deck panel into the finite element analysis model, using element modeling to verify the tensile and compressive stress values of the transverse and longitudinal bridges [7]. The maximum transverse tensile stress was found to be 27MPa, with a maximum compressive stress of -79MPa. For the longitudinal direction, the maximum tensile stress was 93MPa, and the maximum compressive stress was -8MPa. All these values are within the specified limit of 200MPa, indicating that the design of the bridge deck panel is satisfactory.

Based on this comprehensive evaluation, it can be concluded that the design effects of the deck system in the variable-height simply supported steel truss structure of this bridge project are qualified.

5.4. Finite element analysis of steel truss design effect

Regarding the design effect of the steel truss in the variable-height simply supported steel truss structure of this bridge project, designers first imported the steel truss design parameters and load parameters into a finite element analysis model to check its deflection. According to the relevant regulations in the "Highway Specifications", without considering impact stress, when the lane vehicle load is at the frequent value, the deflection of the steel truss of the bridge structure should be L/500 (L represents the total length of the steel truss bridge) or less, which is considered qualified. After this calculation, it is concluded that under the above conditions, the maximum deflection of the steel truss is 30 mm, which is less than L/500 (240 mm), indicating that the design effect of the steel truss deflection is qualified.

On this basis, the designer used the first-order elastic buckling calculation method in the finite element analysis software to perform a first-order buckling calculation on the steel truss. The calculation shows that the critical value of its buckling coefficient is 7.4. Further finite element analysis reveals that the buckling coefficient of the steel truss will only reach the critical value in the case of web member instability. However, according to the above finite element analysis and calculation results, there is no risk of instability in the structural web members, so there will be no instability issues in the steel truss, indicating that the design effect of the first-order buckling of the steel truss is qualified.

Therefore, it can be comprehensively judged that the design effect of the steel truss in the variable-height simply supported steel truss structure of this bridge project is qualified.

5.5. Finite element analysis of pre-camber design effect

According to the relevant regulations in the "Highway Specifications", for steel bridge structures in bridge engineering, pre-camber settings should be properly made during design. Under normal circumstances, the pre-camber should be taken according to the deflection formed under the condition of dead load plus 1/2 of the frequent live load value, and the frequent value coefficient is taken as 1. For the variable-height simply supported steel truss structure of this bridge project, based on its basic design conditions and the actual situation of the construction site, the designer set the camber method as not changing the length of the lower chord and web members, but only by lengthening or shortening the length of the upper chord, so that the steel beam structure is cambered upwards, and its camber value is close to the theoretical pre-camber [8]. To verify the design effect of its pre-camber, the designer imported the overall bridge structure design parameters and corresponding loads into the finite element analysis model to analyze the design effect of its pre-camber.

Table 2 shows the finite element analysis and calculation results of the pre-camber of the entire bridge structure in the design scheme of the variable-height simply supported steel truss bridge.

Table 2. Finite element analysis and calculation results of the pre-camber of the entire bridge structure in the design scheme

Serial number	Member number	Node number	Extension of top chord	Theoretical pre-camber	Actual pre-camber	Pre-camber deviation
1	A1A2	1#	8 mm	85 mm	84 mm	-1 mm
2	A2A3	2#	8 mm	186 mm	185 mm	-1 mm
3	A3A4	3#	13 mm	235 mm	238 mm	3 mm
4	A4A5	4#	13 mm	286 mm	283 mm	-3 mm
5	A5A6	5#	18 mm	290 mm	292 mm	2 mm
6	A6A7	6#	14 mm	274 mm	275 mm	1 mm
7	A7A8	7#	14 mm	221 mm	221 mm	0 mm
8	A8A9	8#	9 mm	163 mm	160 mm	-3 mm
9	A9A10	9#	8 mm	49 mm	51 mm	2 mm

After calculation, the maximum difference between the actual pre-camber and the theoretical pre-camber of the bridge is 3 mm, which does not exceed the standard deviation limit of 5 mm. This indicates that the design value of the upper chord extension is completely reasonable, and the design effect of the pre-camber of the overall bridge structure is qualified.

6. Conclusion

In summary, for the variable-height simply supported steel truss structure in bridge engineering, during specific design, designers should first complete various structural parameter designs based on actual conditions and needs, and then verify the design effect through finite element analysis. After the finite element calculation of the bridge design scheme in this project, the designer confirms that the design effect is completely qualified and can be put into practical application.

Disclosure statement

The author declares no conflict of interest.

References

[1] Wu S, Li Y, Liu J, et al., 2024, Key Construction Technology of Steel Truss at Super High-Rise Transfer Floor. Steel Construction (Chinese and English), 2024(9): 52–59.

[2] Zhao K, Hu Y, Zhang T, 2023, Experimental Study on Fire Resistance of One-Way Simply Supported Steel Bar Truss Concrete Composite Slab. Building Structure, 2023(19): 13–18.

[3] Zhao K, Wei X, Ren X, 2023, Experimental Study on Fire Resistance of Four-Side Simply Supported Steel Bar Truss Concrete Composite Slab. Engineering Mechanics, 2023(6): 122–130.

[4] Su Z, 2022, Study on the Overall Stability of Simply Supported Spatial Truss with Trapezoidal Cross-Section, thesis, Shandong Jianzhu University.

[5] Ren J, 2024, Setting of Pre-Camber for Through-Type Simply Supported Steel Truss Bridges. Engineering and Technological Research, 9(10): 200–202.

[6] Wang J, 2023, Design Analysis of Simply Supported Steel Truss Bridges for City Viaducts. Engineering and Construction, 37(4): 1174–1177.

[7] Mu B, 2024, Design and Analysis of Long-Span Steel Truss Bridges. Urban Roads, Bridges, and Flood Control, 2024(10): 99–102.

[8] Meng L, Liang M, Xie X, et al., 2023, Design and Experimental Study on the Combined Reinforcement of Hollow Slab Bridges with Trusses. World Bridges, 51(4): 114–121.