



Research on Dynamic Characteristics of Double-Layer Continuous Plate-Truss Composite Bridge with Three Main Trusses

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Abstract

Aiming at the dynamic characteristics of the plate-truss composite bridge, the effects of the thickness of the deck, the stiffness of the main truss chord, the overall stiffness of the main truss, the stiffness of the longitudinal beam, the stiffness of the transverse beam, and the stiffness of the parallel connection on the lateral stiffness of the structure were studied by the finite element method. The results show that increasing the thickness of the bridge deck is conducive to improving the overall stiffness of the structure, enhancing the overall stiffness of the main truss is conducive to improving the torsional stiffness of the structure, and enhancing the stiffness of the longitudinal beam is conducive to improving the vertical stiffness of the structure.

Keywords: Plate-truss composite bridge; Combined beam; Dynamic characteristics; Bridge deck; Stiffness

Introduction

The dynamic characteristics of bridge structures are important parameters in dynamic performance analysis, including structural natural vibration frequency, mode shape etc., which reflect the stiffness index of bridges [1-5]. The dynamic characteristics of bridge structures depend on the composition system, stiffness, mass distribution and support boundary conditions of the structure. It is of great significance for the correct seismic design, vehicle vibration analysis, wind stability analysis and maintenance of bridge structures. The three main truss double-layer continuous plate truss composite bridge has a novel structure, which is composed of three main trusses. Because of the new bridge type, there are few domestic research results on this type of bridge, so it

is very important to study the performance. In this paper, a three-main truss double-layer continuous slab truss composite bridge is used as a project, and the dynamic characteristics of this type of bridge type are studied by combining the characteristics of the beam [6-9], which is the basis for the future structural seismic design and anti-corrosion characteristics of this type of bridge type, and for wind stability analysis and other dynamic analysis provide an important reference.

Project Example

Dongguan Dongjiang Bridge is a three main truss rigid suspension stiffened continuous steel truss girder bridge with concrete deck. The main truss section of the bridge is 16m long, the

upper and lower truss heights are 10m, and the internode length is 8m. The bridge deck is composed of longitudinal, transverse beams and concrete slabs. The concrete slabs are combined with the longitudinal and transverse beams.

Finite element model is shown as Figure 1. Due to the wide bridge deck, the influence of the bridge deck system on the structural stiffness is considered in the dynamic analysis process,

and the flexural stiffness and torsional stiffness of elements such as chords, inclined webs, and vertical bars are calculated according to the actual section, and the longitudinal beams and transverse beams are calculated according to the actual section. The combined beam element is formed with the bridge deck, and the section characteristics of the combined beam adopt the equivalent section stiffness model, and the boundary conditions are consistent with those of the continuous beam.

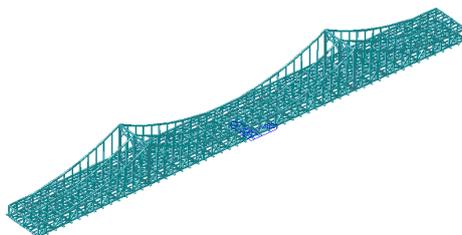


Figure 1: Finite element model.

Analysis of Dynamic Characteristics

The dynamic calculation method in this paper adopts the subspace iteration technique, which adopts the generalized Jacobi iterative algorithm, and adopts the complete stiffness matrix and mass matrix, which has high solution accuracy and is suitable for the modal analysis of large-scale structures. According to the principle of finite element method, the solution of the three-dimensional free vibration equation of the structure can be expressed as (1)-(7)

$$[K]\{x\} - \omega^2 [M]\{x\} = 0 \quad (1)$$

$$\omega^2 = \frac{\{x\}^T [K] \{x\}}{\{x\}^T [M] \{x\}} \quad (2)$$

$$\{x\} = [X]\{A\} \quad (3)$$

$$\omega^2 = \frac{\{A\}^T [X]^T [K] [X] \{A\}}{\{A\}^T [M]^T [K] [X] \{A\}} \quad (4)$$

$$[K]^* = [X]^T [K] [X] \quad [M]^* = [X]^T [M] [X] \quad (5)$$

$$\omega^2 = \frac{\{A\}^T [K]^* \{A\}}{\{A\}^T [M]^* \{A\}} \quad (6)$$

$$[K]^* \{A\} = \omega [M]^* \{A\} \quad (7)$$

Repeat the calculation according to the above calculation process until sufficient accuracy is achieved, and then the ideal frequency and mode shape can be obtained. Where: [X] is the initial mode shape; {A} is the undetermined column vector; [M], [K] are the overall mass matrix and overall stiffness matrix of the structure, respectively.

From the comparison of the results in Table 1, the vertical frequency is consistent with the measured results. The first-order cross bend frequency is 13% smaller than the measured value, the first-order twist frequency is 13% smaller than the measured value. From the comparison of the results, the vertical stiffness of the structure is weak, and the torsional stiffness of the structure is large. The comparison of modal parameters such as vibration frequency and mode shape show that the physical parameters such as torsion resistance, vertical bending stiffness and symmetry of Dongjiang Bridge are in good condition.

Table 1: Comparison of modal results.

Model	Order	Measured ①	Finite Element②	②/①	Mode Shape Description
Vertical	1	0.78	0.78	100%	Vertical symmetry, in-plane vibration
Bend					
Cross	1	1.07	0.93	87%	Lateral symmetry, out-of-plane vibration
Bend					
Twist	1	1.37	1.19	87%	Bending-coupling, out-of-plane vibration

Unit: Hz

Influence of Parameters on Natural Vibration Characteristics

The dynamic characteristics of this type of bridge are studied by changing the component parameters of the plate-truss composite

structure. The research parameters are respectively the thickness of the bridge deck, the stiffness of the main truss chord, the overall stiffness of the main truss, the stiffness of the longitudinal beam, the stiffness of the transverse beam, and the stiffness of the parallel connection.

Variation in deck thickness

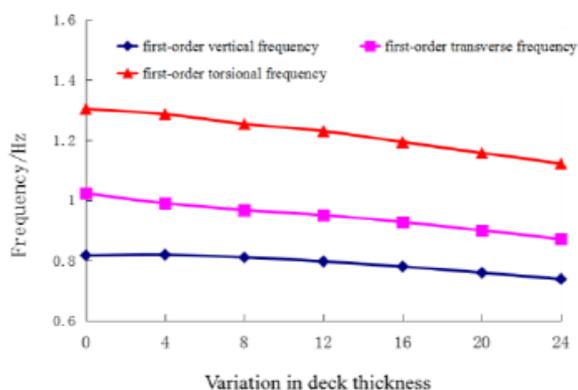


Figure 2: First-order frequency results of slab thickness diversification.

The stiffness of the bridge deck is one of the important parameters affecting the dynamic characteristics of the plate-truss composite structure. The natural frequency of the bending vibration, the natural frequency of the first-order transverse bending vibration, and the natural frequency of the first-order bending-torsional vibration are shown in Figure 2. The natural frequency of the first-order vertical bending vibration, the first-order transverse bending vibration The natural frequency and the natural frequency change curve of the first-order bending-torsional vibration basically satisfy the linear decreasing relationship.

Variation of main chord stiffness

When the stiffness of the three main truss chords changes according to the multiples of 1, 5, 10, 15, 20, and 25, the curve is shown in Figure 3. The natural frequency of the first-order

vertical bending vibration, the natural frequency of the first-order transverse bending vibration, and the natural frequency of the first-order torsional vibration are basically satisfying a linear relationship.

It can be found from Figure 3 that when the main truss chord increases according to the multiple shown in the figure, the natural vibration frequency corresponding to the first-order vertical bending vibration and the first-order transverse bending vibration increases relatively gently when the stiffness of the main truss chord increases from 1 to 25 times. The change has little effect on the lateral stiffness and vertical stiffness of the overall structure. Increasing the stiffness of the main truss chord will increase the torsional stiffness of the overall structure, but the effect is not obvious.

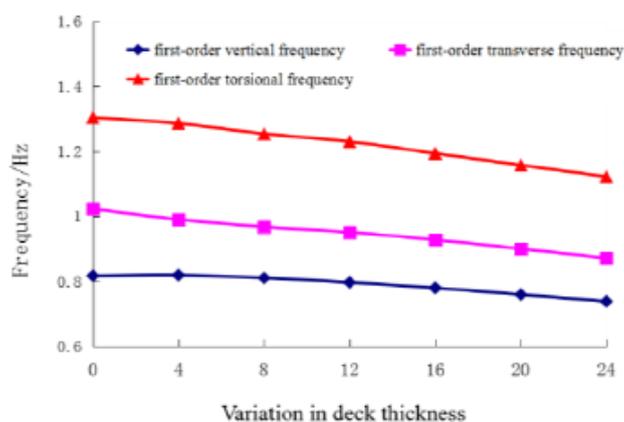


Figure 3: First-order frequency results of main truss chord stiffness diversification.

Overall stiffness of main truss

When the overall stiffness of the three main trusses changes respectively according to the multiples of 1, 5, 10, 15, 20, and 25, the natural frequencies of the first-order vertical bending vibration, first-order transverse bending vibration, and first-order torsional vibration corresponding to the structure. The change curves are shown in Figure 4. The natural frequency change curves of the first-order vertical bending vibration, the first-order transverse bending

vibration, and the first-order torsional vibration basically satisfy a linear increasing relationship.

It can be found from Figure 4 that when the main truss increases according to the multiple shown in the figure, the natural frequency curve corresponding to the first-order vertical bending vibration and the first-order transverse bending vibration increases relatively gently, and the slope of the natural frequency curve corresponding to the first-order torsional vibration is relatively large.

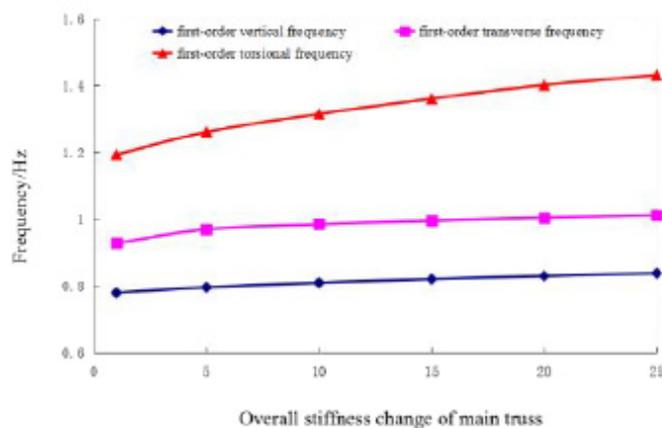


Figure 4: First-order frequency results of main truss stiffness diversification.

Variation in Stringer stiffness

When the stiffness of the longitudinal beam changes according to the multiples of 1, 5, 10, 15, 20, and 25, the corresponding first-order vertical bending vibration, first-order transverse bending vibration, and first-order torsional vibration of the structure correspond to the natural vibration frequency curve as shown in the figure. As shown in Figure 5, the natural frequency change curves of the first-order vertical bending vibration, the first-order transverse bending vibration, and the first-order torsional vibration basically satisfy a linear increasing relationship.

It can be found from Figure 5 that when the longitudinal beam

increases according to the magnification shown in the figure, the natural vibration frequency corresponding to the first-order transverse bending and the first-order torsion of the structure increases relatively gently, and the natural vibration frequency corresponding to the first-order vertical bending vibration increases relatively large. The stiffness change of the longitudinal beam has a relatively obvious influence on the vertical stiffness of the structure, but the influence on the transverse bending stiffness and torsional stiffness of the structure is relatively small. Adjusting the stiffness of the longitudinal beam can improve the vertical stiffness of the structure.

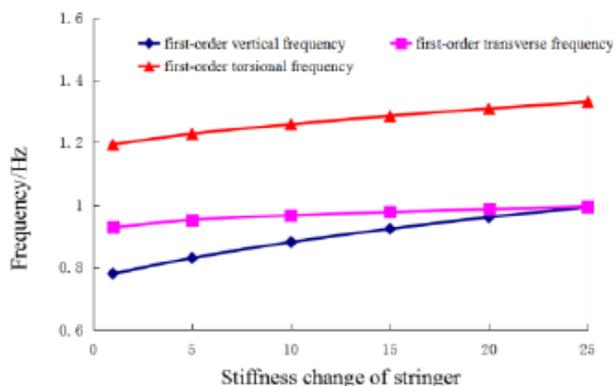


Figure 5: First-order frequency results of Longitudinal stiffness diversification.

Variation in beam stiffness

When the beam stiffness changes according to the multiples of 1, 5, 10, 15, 20, and 25, respectively, the natural frequency change curves of the first-order vertical bending vibration, the first-order transverse bending vibration, and the first-order torsional vibration of the structure are shown in Figure 6. It is shown that the natural frequency change curves of the first-order vertical bending vibration, the first-order transverse bending vibration and the

first-order torsional vibration basically satisfy the linear increasing relationship. It can be found from Figure 6 that when the beam stiffness increases by the multiple shown in the figure, the natural vibration frequencies corresponding to the first-order vertical bending vibration, the first-order transverse bending vibration, and the first-order torsional vibration increase relatively gently, and the beam stiffness increases while the vertical stiffness, lateral stiffness and torsional stiffness of the structure have little effect.

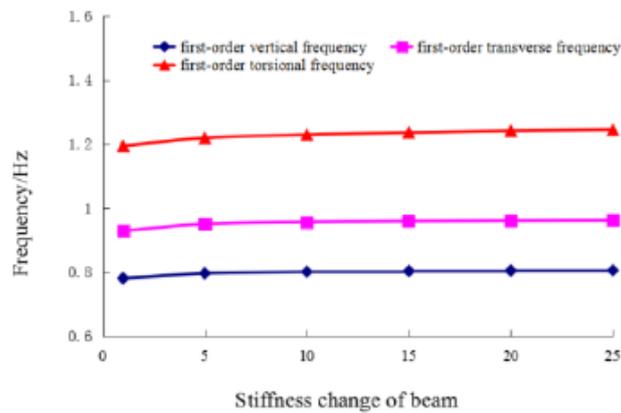


Figure 6: First-order frequency results of crossbeam stiffness diversification.

Variation in parallel stiffness

When the stiffness of the parallel connection changes according to the multiples of 1, 5, 10, 15, 20, and 25, the corresponding first-order vertical bending vibration, first-order transverse bending vibration, and first-order torsional vibration of the structure correspond to the natural vibration frequency curve as shown in the figure. As shown in Figure 7, the natural frequency change curves of the first-order vertical bending vibration, the first-order transverse

bending vibration, and the first-order torsional vibration basically satisfy a linear relationship. It can be found from Figure 7 that when the stiffness of the parallel coupling increases according to the magnification shown in the figure, the corresponding frequency increases of the first-order vertical bending vibration, transverse bending vibration and torsional vibration are quite small. It shows that the influence of the stiffness change of the parallel coupling on the vertical stiffness and torsional stiffness of the structure can be ignored.

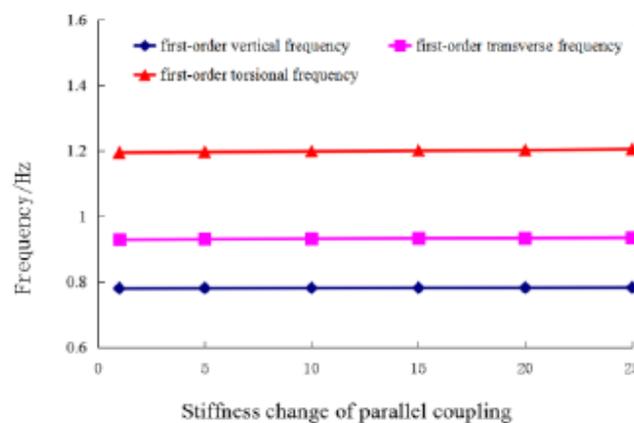


Figure 7: First-order frequency results of cross joint stiffness diversification.

Conclusion

From the above analysis, the following conclusions can be drawn:

- The change of the bridge deck thickness has a relatively large influence on the natural vibration frequency of the composite structure and has a relatively obvious influence on the changes of the vertical stiffness, lateral stiffness and torsional stiffness of the overall structure.
- The change of the stiffness of the main truss chord has relatively little effect on the first-order vertical bending and transverse bending frequencies but has a relatively large effect on the first-order torsional frequency. Increasing the stiffness of the main truss chord will increase the torsional stiffness of the structure.
- The change of the overall stiffness of the main truss has a relatively large influence on the first-order torsional frequency and has an effect on the vertical bending stiffness and transverse bending stiffness of the structure. The noise is not obvious, but the impact on the torsional stiffness of the structure is relatively large.
- The change of longitudinal beam stiffness has a relatively large influence on the vertical frequency of the structure, and the vertical bending stiffness of the composite structure is relatively large, but for the lateral stiffness, the torsional stiffness is relatively weak.

Acknowledgement

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Conflict of Interest

No conflict of interest.

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