Research and Application of Cross Spatial Grid Method in Combined Box Girder Bridge with Corrugated Steel Webs

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Abstract—In order to further study the application of corrugated steel web composite box girder bridge in practical engineering, this paper selects a corrugated steel web box girder bridge with transverse diaphragms as the theoretical model, and uses the cross space grid method to simulate the model. Beam188 is the element type selected for this ANSYS modeling. The longitudinal element of the web is equivalent to a flat plate according to the plate and shell theory. The shape of the vertical element remains unchanged. Under the condition of its own weight, the natural frequency and deflection of the model are compared. The research results show that when the web is divided into whole and separated, the errors of the first-order natural frequencies of the two spatial mesh models and the solid finite element model are both within 10%, and the accuracy of the overall division is higher.

1. INTRODUCTION

The corrugated steel web PC composite box girder bridge is a new type of steel-concrete composite bridge structure proposed and constructed by French engineers in the 1980s. It consists of a concrete top and bottom plate, corrugated steel webs, transverse beams, and internal precast composed of stress beams and external prestressed beams, the corrugated steel webs are used in composite box girder bridges with corrugated steel webs due to their light weight, high buckling strength and orthotropic properties.

For the analysis of the box girder structure, the traditional methods generally adopt three methods: three-dimensional rod system modeling, grid-girder modeling or three-dimensional solid modeling to simulate the structural characteristics of the box girder. However, the disadvantages of the traditional three methods of modeling are obvious: the three-dimensional modelling of the beam system cannot reflect the spatial force effect of the box girder structure; the beam grid method modeling adopts the principle of equivalence, except that the cross-section spatial effect cannot be reflected, the shear stress distribution of the structure cannot be analyzed. Although solid modeling avoids the problems of the first two methods, it has some of the most obvious shortcomings: the modeling is complex, the number of units is huge, and the calculation time is long. It cannot be directly applied to the overall design of the project. Compared with these three methods, the cross space grid method can not only take into account the space effect of the box girder structure, but also avoid the problems of complex solid modeling and large calculations. The most important thing is the cross space grid. The lattice model is a mechanical characteristic modeling, which can directly obtain the internal force of the structure instead of the stress, which is of great value for practical engineering applications, so the advantages of this...
method are obvious. Previously, most scholars used the spatial grid method to build box girder bridges. The theoretical model selected was generally a box girder bridge with a corrugated steel web of about 20-30m, and there were no diaphragms at the ends and the middle of the span. There are certain discrepancies in the engineering structure. Therefore, this article is to explore the application of the cross space grid method in corrugated steel web box girder bridges with transverse diaphragms.

2. CROSS SPACE GRID METHOD

2.1. Method introduction

The spatial grid model discretizes the box girder into multiple plate elements, and each plate element is discretized into a crossed orthogonal beam grid. The rigidity of the crossed longitudinal and horizontal beams is equivalent to the rigidity of the plate element. In this way, the box girder consists of multiple The "grid" expression of the equivalent plate element. Figure 1 is a schematic diagram of a grid model of a single-box single-chamber box girder.

Before modeling, it is necessary to divide the top plate, bottom plate and web into smaller rectangular plates(hereinafter referred to as plate elements, as shown in Figure 2), and determine the cross space grid according to the force of the rectangular plates. The section characteristics of the beam element. Figure 2 shows two common division methods of the cross space grid method. The left side of the symmetry axis is the cross space grid division method of web separation; the right side of the symmetry axis is the cross space grid division method of the web as a whole.

![Figure 1 Schematic diagram of spatial grid model](image1)

![Figure 2 Sections of the spatial mesh model](image2)

2.2. Sectional properties calculation

In the spatial grid model obtained after being discretized according to Figure 3, there are three main sections: the overall section of the web, the section of the web, and the section of the vertical and horizontal top and bottom plates, as shown in Figure 4. The calculation of these cross-sections and characteristics is consistent with the calculation of traditional element cross-section characteristics, which are calculated from the actual cross-sectional size after discrete.

![Figure 3 Common cross-sections of spatial grid models](image3)
Taking a rectangular section as an example, the calculation formula for its section characteristics is as follows:

Axial area:

\[ A_x = bh \]  

(1)

Shear area:

\[ A_y = A_z = bh \]  

(2)

Bending moment of inertia:

\[ I_z = \frac{bh^3}{12}; \quad I_y = \frac{bh^3}{12} \]  

(3)

Torsional moment of inertia:

\[ I_T = \frac{4I_zI_y}{\beta(I_z + I_y)}; \quad \beta = 1.3 \sim 1.6 \]  

(4)

2.3. Sectional characteristics of corrugated steel web

Since the corrugated structure of the corrugated steel web has the characteristics of structural anisotropy (as shown in Figure 5), its longitudinal (X-axis direction) and vertical (Y-axis direction) stiffness are very different. The mainstream solution at home and abroad is to equate the original corrugated steel web into a flat plate of equal height based on the principle of equivalence. The conclusions of the built model need to be investigated, and the data is not very convincing. The method adopted in this paper is to equate the corrugated steel web longitudinally to a flat steel plate, while maintaining the original section form vertically.

According to Timoshenko's plate and shell theory, the longitudinal stiffness of the wave version is:

\[ D_x = \frac{l}{s} \frac{Eh^3}{12(1-v^2)} \]  

(5)

Among them: \( l \) is the horizontal length of the half wave, \( s \) is the arc length of the half wave, \( v \) is the Poisson's ratio, and \( h \) is the plate thickness.

Let the longitudinal equivalent width of the corrugated steel web be a flat plate of \( t \), which is equivalent according to the material force mechanics formula:

\[ D_x = \frac{Et^3}{12(1-v^2)} \Rightarrow t = \frac{1}{s} \sqrt[3]{\frac{l}{h}} \]  

(6)
3. Engineering Example

3.1. Geometry parameters

In this section, a 20m-long end and a simple-supported box girder bridge with corrugated steel webs containing transverse diaphragms in the span are selected as the theoretical model. A simply supported composite beam bridge with corrugated steel webs, the top and bottom plates of the box girder and the diaphragm are made of C50 concrete (the modulus of elasticity is 3.45×10^4 MPa, the weight is 26 kN/m^3, and the Poisson's ratio is 1/6), and the webs are made of KL400 steel plate (the modulus of elasticity is 2.0×10^5 MPa, the weight is 78.5 kN/m^3, and the Poisson's ratio is 0.3). The dimensions of each part of the box girder are shown in the figure, and the thickness of the steel web is 1 cm.

3.2. Model building

1) Entity model establishment instructions

The solid model is modeled using finite element software ANSYS. SOLID65 elements are used for the top and bottom plates and transverse partitions, and SHELL63 elements are used for the web. Ignore the relative slip between the top, bottom, and web. For the convenience of modeling, the height of the corrugated steel web is taken as 1.6 m, and it is completely inserted into the concrete top and bottom plate to restrain the rotational freedom of the shell element node.

2) Modeling instructions for spatial grid model

Because the cross-space grid model needs to be divided into modules before modeling the cross-space grid model, the form and size of the box girder section in this paper are shown in Figure 9. The top and bottom plates are divided separately, and the webs and diaphragms are divided in two ways. For division, one is separate division (shown on the left of the dashed line), and the other is vertical overall division (shown on the right of the dashed line). The grid spacing in the longitudinal direction is 0.2 m. The spatial mesh model in this article is still modeled by ANSYS software, and the element type is selected as Beam188.

3.3. Calculation results

This article compares the first three-order natural frequencies and vibration shapes and the maximum deflection of the mid-span section between the solid model and the spatial mesh model (the overall web division and separation division) under the condition of its own weight.
The natural frequency represents the inherent properties of the structure itself, and its value has nothing to do with the initial conditions and the magnitude of the external force. The natural frequency is related to its own mass and its distribution (stiffness), boundary support conditions and the form of vibration (called "mode shape"). Low-order frequencies generally reflect the overall stiffness of the structure, and high-order natural frequencies reflect the local stiffness of the structure. Therefore, the evaluation criteria of modeling can generally be compared by the natural frequency. If the natural frequency is close, it means that the overall stiffness is similar and the model establishment is more accurate.

4. CONCLUSION

The following conclusions can be drawn from the data in Table 1:

| Spatial grid model  | Natural frequency (Hz) | First order | Second order | Third order | Maximum mid-span deflection (m) |
|---------------------|------------------------|-------------|--------------|-------------|---------------------------------|
| Entity model        | 8.2316                 | 16.185      | 16.573       | 0.004565    |
| Separate division   | 7.4872                 | 13.842      | 17.502       | 0.00566     |
| Difference rate      | 9.04%                  | 14.48%      | -5.61%       | -23.99%     |
| Overall division     | 8.3597                 | 14.639      | 17.029       | 0.00458     |
| Difference rate      | -1.56%                 | 9.55%       | -2.75%       | -0.33%      |

1) The error between the first-order (frequency overall stiffness) of the two spatial grid models and the solid model is within 10%, so the modeling method in this article can be more accurately applied to corrugated steel web boxes with diaphragms. Establishment of the spatial grid model of the beam bridge;

2) The error of the overall division model is smaller than the error of the separation division, and the accuracy is higher. The later space grid model can give priority to the overall division modeling;

3) Although the error of the maximum deflection in the middle span is too large, the deflection may have a large deviation due to the constraint difference between the support and the web end, which is also needed to be studied later.

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