Design and Research of Externally Prestressed Box Girder with Corrugated Steel Web based on Finite Element Method

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Abstract: Corrugated steel web composite box girder is widely used in bridge engineering because it can fundamentally solve the problem of cracking of box girder web. However, due to the complexity of corrugated steel web composite box girder structure, it is inconvenient for finite element modeling. How to refine the modeling and ensure the speed and efficiency of modeling has become a difficult problem in the process of modeling. In this paper, on the basis of summarizing various modeling methods, the idea of docking MIDAS FEA and MIDAS Civil software was put forward, and the method of finite element refinement model of corrugated steel web box Girder Bridge was discussed. Firstly, the model of concrete and internal prestressing tendons of composite box girder was established by MIDAS FEA software. After imprinting, the model was connected with MIDAS Civil, and the corrugated steel webs and external prestressing tendons were established in MIDAS Civil. Finally, the operation calculation was carried out.

1. Introduction

Prestressed composite box girder with corrugated steel webs is a composite structure composed of concrete top and bottom slabs, external prestressing tendons and corrugated steel webs. Compared with the traditional concrete web box girder, the corrugated steel web prestressing composite box girder can reduce the dead weight, improve the efficiency of prestressing and reduce the amount of prestressing steel. Corrugated steel webs have no restraint on creep and dry shrinkage deformation of concrete at upper and lower edges. External prestressing tendons can be replaced, which is conducive to maintenance and reinforcement, and the overall aesthetic feeling of the bridge. Since France built the Cognac Bridge, the first corrugated steel web continuous Girder Bridge in the world in 1986, this structural form has been more and more widely used, especially in Japan and France. At present, more than 40 bridges of this type have been built in the world. In China, this type of bridge was first seen in 2005 in Sandao River Middle Bridge in Qinghai Province, Changzheng Bridge in Jiangsu Province (footbridge) and Pohe River Bridge in Henan Province. Thus, corrugated steel web bridges are developing rapidly in China, from simply supported girder bridges and continuous girder bridges to rigid frame bridges and cable-stayed bridges. However, as a new type of structure, the research on corrugated steel web prestressing composite box girder started late in our country. At present, there are only a few engineering examples in our country and the design theory is not perfect. In this paper, on the basis of summarizing various modeling methods, a simple and effective modeling method using MIDAS FEA and MIDAS Civil is found, which can provide reference for similar engineering calculation, and can also be extended to the local calculation and analysis of various complex structures.

2. Finite element modeling and analysis

2.1 Key and difficulty of finite element modeling

The key problems of modeling are: Composite box girder with corrugated steel webs is relatively complex. Because of the folding effect of corrugated steel webs, the size of plate elements used to simulate steel webs is very small, which makes the number of calculation model elements very large, and the modeling of folded corrugated plates is complicated [1]. The torsional stiffness of corrugated steel web composite box girder is smaller than that of traditional concrete box girder, and a certain number of diaphragms are needed [2]. The local structures of diaphragms and external bundle steering blocks are complex, and the effect of local stress concentration is significant, so subdivision units are needed to improve the accuracy [3]. How to deal with the shear connectors between steel webs and concrete [4]. If these connectors are not properly handled, it is easy to distort the calculation results of finite element model. External prestressing tendons are inconsistent with cross-section deformation. How to simulate the stress of external prestressing tendons becomes a difficult problem in calculation [5]. On the basis of summarizing the existing research, it is considered that the key problems to be solved by finite element modeling are as follows: (1) How to reasonably establish solid elements with different thickness according to the structural characteristics to make effective transition between them and improve the accuracy and speed of calculation; (2) Reasonable simulation of internal and external prestressing tendons; (3) Treatment of connection between corrugated steel webs and concrete [6].

2.2 Technology roadmap

In view of the above characteristics of modeling, in this paper, MIDAS FEA and MIDAS Civil software were used to dock, making full use of MIDAS FEA's three-dimensional geometric modeling function and mesh generation function, and utilizing MIDAS Civil's unit expansion function, analysis and calculation function and post-processing function [7]. The following methods are proposed: (1) MIDAS FEA software is used to establish the overall geometric model including concrete roof and floor, diaphragm and external bundle steering device. According to the specific structure, the solid elements with different thickness are divided [8]. The mesh generation is automatically completed by software, and the transition between the coarse and fine elements can be realized, which effectively improves the calculation accuracy and speed [9]. (2) As the interior line of the space entity, the internal prestressing tendons are divided into truss elements when meshing, and the external tendons are considered in MIDAS Civil. (3) Corrugated steel plate and concrete roof and floor are connected by common joints. The shear nails connected by corrugated steel plate and diaphragms are simulated by truss element, and the joint of shear nail truss element and steel web element is rigidly joined to simulate welding. Using the "imprinting" function of MIDASFEA, the corrugated shape is printed at the intersection of corrugated steel plate and concrete top and bottom plates to ensure the accuracy of common joints.

3. Establishment of geometric model and mesh generation

The geometric models of roof, floor and diaphragm are established and meshed by utilizing the CAD-level three-dimensional geometric modeling function and advanced mesh generation functions such as automatic mesh generation and mapping mesh generation of MIDAS FEA.

3.1 Establishment of geometric models for roof, floor and diaphragm

According to the size of the structure, the geometric models of concrete top, bottom and diaphragm of box girder are established, as shown in Figure 1.

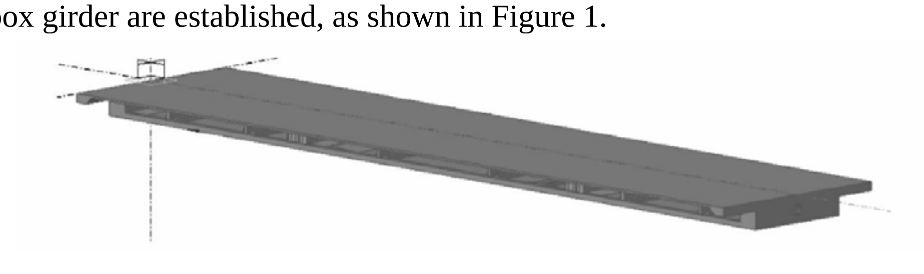

Fig.1 Geometric model of roof, floor and diaphragm

3.2 Incoming steel beam

The position curves of steel bundles and shear nails are drawn in CAD, and the DXF file is formed, which is imported into the established geometric model. As required, the imported strands can be produced into different "wire groups", which can facilitate the management and operation of the imported strands and shear nails, and improve the efficiency of modeling. At the same time, due to the coordinate system of CAD and MIDAS FEA, the imported "strand" should be rotated properly to the correct position. The model of imported steel bundle and shear nail is shown in Figure 2.

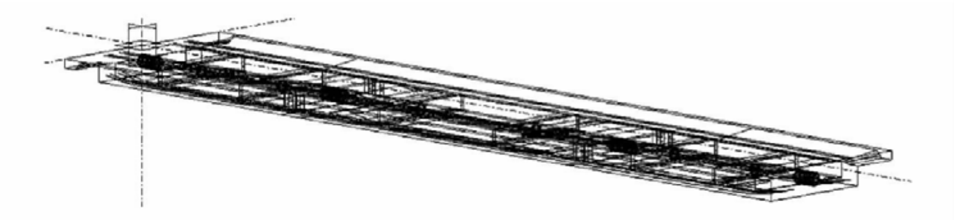

Fig. 2 Imported steel bundles and shear pins

3.3 Seal printing

"Printing" is to use projected curves and vertices to generate internal objects on the surface after projecting a curve or vertex onto a surface. And the joint of steel web plate element and concrete roof and floor entity element is realized by using the "imprint" function of MIDAS FEA.

3.4 Mesh generation

When meshing, the prestressing tendons and shear nails in concrete are taken as internal lines, and the internal lines are divided into truss elements. In order to accurately simulate the spatial shape of prestressing tendons and the interaction between prestressing tendons and concrete, the boundary lines of truss elements and solid elements are collinear, and the joint of truss elements and solid elements is shared. At this time, the characteristics of solid elements and truss elements are defined. When defining the characteristics, the characteristic values can be input at will. After importing the MIDAS Civil software, the characteristic values need to be revised. The meshed finite element model is shown in Figure 3.

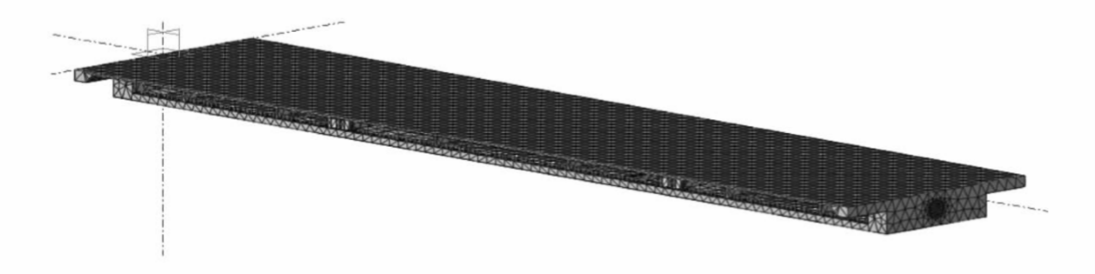

Fig.3 The meshed finite element model

3.5 Docking MIDAS FEA with MIDAS Civil Software

The generated grid model is exported to the MCT file format required by MIDAS Civil, and a file named 1.mct is set. Then, the MIDAS Civil software is run, the same unit system as MIDAS FEA is set up, and the 1.mct file that has been established is imported to realize the docking between MIDAS FEA and MIDAS Civil software.

4. Establishment of computing model in MIDAS Civil software

4.1 Establishment of corrugated steel webs and external prestressing elements

In MIDAS FEA, the contact line between corrugated steel webs and concrete is printed. When meshing, the boundary line between corrugated steel webs and concrete roof and floor is automatically changed into the unit boundary line, and the corner of corrugated steel webs is automatically generated as the unit node. In Civil software, corrugated steel plate is simulated by thin plate element. First, the beam element is established along the "printed" broken line, and then the beam element is extended to plate element. The external beam is simulated by truss element.

4.2 Definition of material properties and boundary conditions

In MIDAS Civil software, the material and section characteristics need to be redefined. The corresponding dialog box is selected to define the material characteristics of concrete, prestressing steel bundle and steel web, and the section characteristics of prestressing steel bundle and the thickness characteristics of corrugated plate. The shear nail truss element is connected with the corrugated steel web element at the corresponding position by the rigid connection in the elastic connection, and the corresponding constraints are applied at the support. The final model is shown in Fig.4.

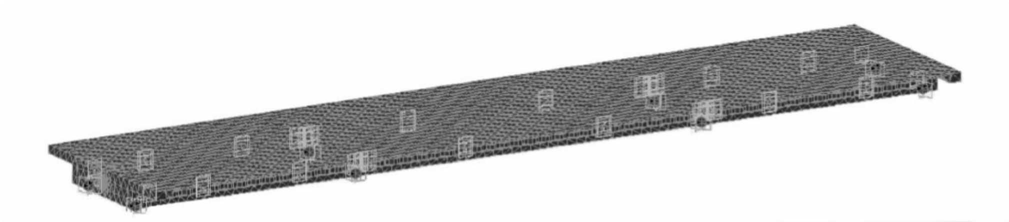

Fig.4 Finite element model

4.3 Analysis of Loading and Operation

Applying design loads: Before operation analysis, it is necessary to check the "degree of freedom of rotation of restrained truss/plane stress/solid element" in the "analysis" master control data.

4.4 Model validation

In order to verify the correctness of the finite element modeling method proposed in this paper, a middle bridge was selected as an experimental example. The bridge was a 3-span composite continuous box girder bridge with corrugated steel webs of (20+30+20) m, and the girder was 2.2 m high. There were 10 diaphragms along the longitudinal direction. The diaphragms of each span were 0.3m thick, the diaphragms of pier top were 2.0m thick and the diaphragms of bridge abutment end were 1.7m thick. The steel webs were made of Q345-C steel with a thickness of 12 mm, a length of 330 mm, a bending angle of 36.5 degrees and a wave height of 200 mm. In the experiment, 10 kN/m 2 uniform loads were applied to the middle span (working condition 1) and the whole bridge (working condition 2), respectively. The deflection values of the bottom of the beam at the side span L/2, middle span L/4 and middle span L/2 were calculated. The results were compared with the deflection of the bottom of the beam affected by the shear deformation of corrugated steel webs calculated by theory. The results are shown in Tab.1.

Tab.1 Deflection comparison of beam bottom

working condition	Section location	Finite element value	Theoretical value
1	the side span L/2	-0.85	-0.95
	the middle span L/4	3.98	3.87
	the middle span L/2	5.75	5.57
2	the side span L/2	1.39	1.25
	the middle span L/4	3.21	3.02
	the middle span L/2	4.83	4.67
Note: "-" means upper torsion			

It can be seen that the calculated value of the finite element model presented in this paper is basically in agreement with the theoretical value, which shows that the finite element modeling method proposed in this paper is reliable.

5. Conclusions

The modeling method proposed in this paper is that MIDAS FEA software and MIDAS Civil software are docked, and the advantages of the two software are well combined. It can accurately simulate corrugated steel web structure, and it can also be applied to the simulation of other composite structures and complex structures. In this paper, a 3-span continuous corrugated steel web composite box girder bridge is taken as an example for finite element analysis. The calculated value of the finite element method is basically consistent with the theoretical value, which shows that the proposed finite element modeling method is reliable. Although considerable achievements have been made in the research of external prestressing box girders with corrugated steel webs, there are still many problems that need to be further studied and discussed by engineers and researchers in our country. I hope this paper can provide some reference value and new ideas for this research.

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