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Proceedings of the International Conference on Computing in Civil and Building Engineering
W Tizani (Editor)

Finite element simulation of the composite continuous box-girder bridge with corrugated steel webs by CBCW

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Abstract

The prestressed concrete (PC) box-girder bridge with corrugated steel webs is a major improvement on the traditional one. In the past two decades, there has been an increasing interest in this kind of structure in bridge engineering. In this paper, the parameterized modeling module CBCW (Composite Bridge with Corrugated Webs), which has been developed based on commercial software - ANSYS by its APDL and UIDL languages, is presented. Despite the complexity of prestressed concrete box-girder bridges with corrugated steel comparing to the conventional PC bridges, CBCW makes it easy and convenient for bridge designers to perform 3-D finite element analysis. The module has been applied in the simulation of the Juancheng Yellow River Highway Bridge of China, which is currently the longest composite bridge with corrugated steel webs worldwide. The interface and menu functions of the module were introduced at first. Then the application of the module was discussed in detail. The comparison between the FEA and measurement results is made, which yields a satisfactory accuracy. It turns out that it is feasible for bridge engineer to carry out FE analysis of this kind structure by CBCW.

Keywords: composite bridge, corrugated steel webs, finite element analyses

1 Introduction

The prestressed concrete box-girder bridge with corrugated steel webs is a major improvement on traditional one. In 1986, the first prestressed concrete box-girder bridge with corrugated steel webs - Cognac Bridge was built by CB Company in France. Nowadays, they are flourishingly under construction all over the world. It has been adopted not only in simple supported bridges, continuous bridges and continuous frame bridges, but also in extradosed cable-stayed bridges as well as cable-stayed bridges (HONG-WEI REN et al., 2008).

In this paper, simulation of the Juancheng Yellow River Highway Bridge is presented. It is a composite continuous box-girder bridge with corrugated steel webs with a main span of 120 meters and span arrangement of 70m+11×120m+70m. The configuration of the corrugated steel web and the cross-section of box-girder are shown in Figure 1.

The structural behaviour of this kind of structures cannot be calculated exactly by the conventional beam element analyses method because of the shear deformation of corrugated steel webs. Since the shear deformation of this kind of structure has a great influence on the vertical displacement, it cannot be ignored in the structural deformation calculation (HONG-JIANG LI et al., 2002; JIAN-YONG SONG et al., 2002; QI-YUAN ZHOU and XUAN-NENG GAO, 2006). This is why results generated by the common plane beams system software can not make a good agreement with the measured ones.

Though the general 3-D FE software can be adopted to model the corrugated steel webs structure, but it is always time-consuming and inconvenient. Therefore, it is necessary to develop a customized FE module to simulate this kind of composite bridges.

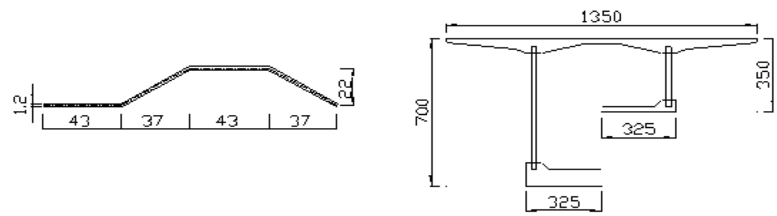

Figure 1, Configuration of the corrugated steel web and cross-section of box-girder.

2 Description of the module of CBCW

The parameterized modelling module CBCW (Composite Bridge with Corrugated Webs) was developed based on commercial general software - ANSYS by its APDL and UIDL languages (JIAN-YONG SONG et al., 2006). It consists of three parts including the pre-processor, solution and postprocessor modules. Based on the parameters inputted through dialog box interface, the model of composite bridges with corrugated webs can be established automatically.

2.1 The preprocessor module

The interface of the whole pre-processor module consists of four parts including element type, real constants, material properties, as well as modelling and meshing as shown in Figure 2.

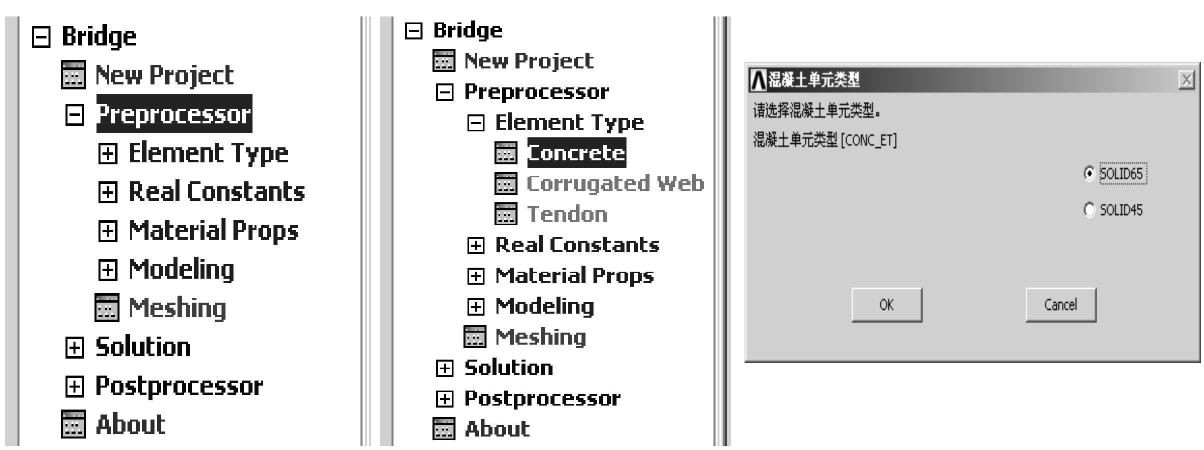

Figure 2, Preprocessor module.

In the pre-processor module, two types of concrete element including SOLID45 and SOLID65, which are common element types, are available for users, and the SHELL63 or SHELL181 element can be also chosen to model corrugated steel webs. In addition, LINK8 and LINK10 elements can be used to simulate the prestress tendon. The menu of "Real Constants" allows users to define the concrete top and button flange of box girder, corrugated steel webs and prestressing tendons conveniently through the corresponding commands as shown in Figure 2. Additionally, the material properties of concrete, corrugated steel webs and tendon can be inputted through the corresponding dialog box as shown in Figure 3.

The main menu for modelling is also demonstrated in Figure 3. After the structural parameters are inputted individually according to the corresponding menu, the finite element model will be established automatically and the mesh will be generated through clicking the menu of meshing.

In addition, advanced users can also take advantage of parameter files to decrease the workload, which avoids the tedious work of parameter input through dialog box interface. After loading parameters into the module, the parameters in the dialog box interface are assigned to corresponding value automatically, and then users can check relevant data by themselves.

2.2 The solution module

Twelve dialog boxes are listed in the solution module, see Figure 4. Combining the characteristics of Chinese Specifications for bridge, distribution modes of calculation load regulated in the Chinese bridge specifications are all added into the module, which is convenient for bridge designers to use.

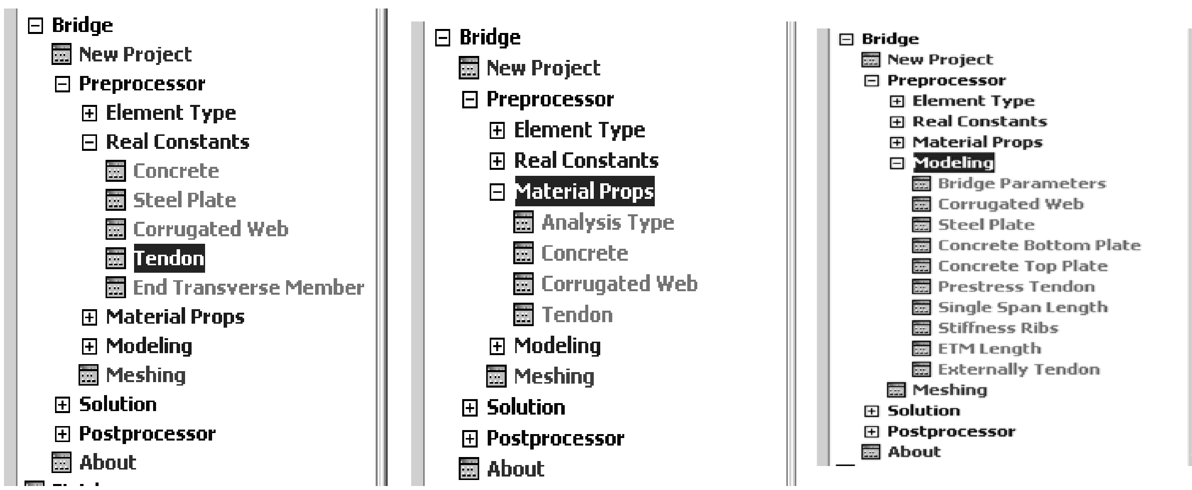

Figure 3, Preprocessor module.

2.3 The postprocessor module

Users have three choices in results postprocessing menus including read results, plot results and list results. These three menus allow users to obtain the results of stress distribution and structural deformation with the selected way as shown in Figure 5. Users can define the combination coefficient of various load cases in the menu of "Read Results", while three options are ready for user to select the manner of displaying results nephogram. In addition, the menu of list results allows users to output or save the results with different file formats.

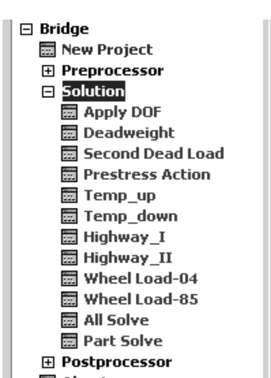

Figure 4, The solution module.

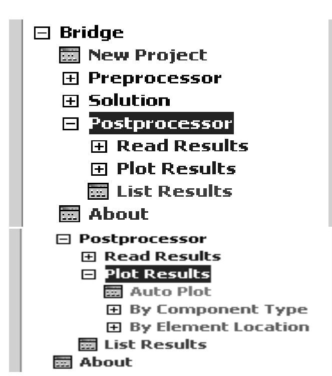

Figure 5, The postprocessor module.

3 Application in the Juancheng Yellow River Highway Bridge

The part of FE model of Juancheng Yellow River Highway Bridge created by CBCW is shown in Figure 6. In the 3-D FE model, the SOLID45 element is employed to model the top and bottom concrete plate, SHELL43 element model the corrugated steel webs, while LINK8 element model both the internal and external prestressing tendons. The construction process of concrete pouring and closure is simulated through the birth and death of elements. In addition, the prestress is applied by cooling method.

Cantilever casting construction method is adopted in the Juancheng Yellow River Highway Bridge construction, and the main beam is composed of twelve standard segments. Construction simulation of the Juancheng Yellow River Highway Bridge is performed with the module CBCW, and the comparison between FEA and measured results is reported and discussed in the following sections.

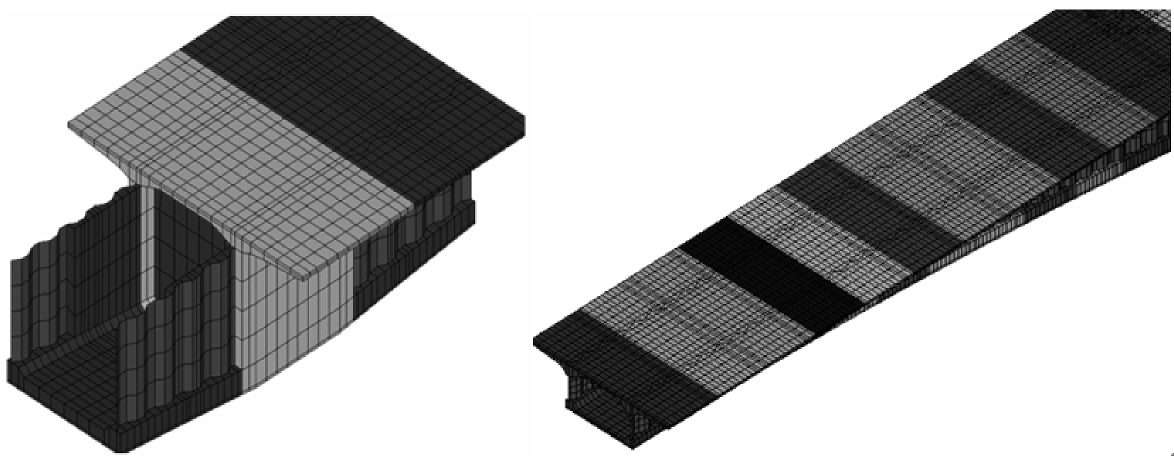

Figure 6, FE model of Juancheng Yellow River Highway Bridge.

In order to verify the module CBCW, the comparison between the numerical and measured results is made. The comparison results of displacement increment of the twelve segments both at the maximum cantilever stage and at the stage of side span closure were listed in Table 1 and Table 2, respectively. The data (CBCW) is the numerical results calculated by CBCW.

Table 1. Displacement increment of each segment at the maximum cantilever stage.

Disp. / No.	U1(mm)		U2(mm)		U3(mm)	
	CBCW	MEASURED VALUE	CBCW	MEASURED VALUE	CBCW	MEASURED VALUE
1#	-0.2	0	0.1	0	0.1	0
2#	-0.7	-1	0.3	0	0.5	1
3#	-1.6	-2	0.6	0	1.1	2
4#	-3	-3	1	1	2.1	3
5#	-5	-6	1.7	2	3.5	5
6#	-7.6	-8	2.5	2	5.3	6
7#	-10.9	-10	3.5	2	7.5	8
8#	-14.9	-11	4.8	3	10.1	10
9#	-19.6	-15	6.3	5	13.2	15
10#	-24.7	-23	8	7	16.4	17
11#	-30.8	-28	10	8	20	20
12#	—	—	12	10	23.1	23

where

Disp. =Displacement increment
No. =Segment number
U1 =Displacement increment of each segment at maximum cantilever stage under the load case of concrete pouring of the twelfth segment
U2 =Displacement increment of each segment under the load case of prestress tensioning of the twelfth segment
U3 =Displacement increment of each segment under the load case of form traveller removal.

Table 2. Displacement increment of each segment at the stage of side span closure.

Disp. / No.	U1(mm)		U2(mm)		U3(mm)	
	CBCW	MEASURED VALUE	CBCW	MEASURED VALUE	CBCW	MEASURED VALUE
1#	-0.1	0	0.2	0	0	0
2#	-0.2	0	0.6	1	0	0
3#	-0.6	0	1.1	2	0	0
4#	-1.0	0	2.0	2	0	0
5#	-1.6	-1	3.1	3	0	0
6#	-2.4	-3	4.5	5	0	0
7#	-3.4	-4	6.4	7	0	0
8#	-4.5	-4	8.3	8	0	0
9#	-5.9	-6	10.0	11	0	1
10#	-7.4	-8	10.0	11	0	0
11#	-9.0	-10	9.2	10	0	-1
12#	-10.6	-12	7.5	9	0	0

where
Disp. =Displacement increment
No. =Segment number
U1 =Displacement increment of each segment at the stage of side span closure under the load case of concrete pouring of the closure segment
U2 =Displacement increment of each segment at the stage of side span closure under the load case of prestress tensioning of the closure segment
U3 =Displacement increment of each segment at the stage of side span closure under the load case of scaffolding removal.

It can be noted from above two tables that the predicted results agree well with the measured ones whether at the maximum double cantilever stage or at the stage of side span closure. Meanwhile, if plane member system software is adopted, the numerical results calculated by either Euler beam element or Timoshenko beam element would lead to a great error. Because the deflection calculated employing the Euler beam element cannot consider the effect of shear deformation, while the calculation results employing the Timoshenko beam element always magnify the shear deformation. So it is suggested that the deformation calculation and construction control of this kind bridge should be conducted with the 3-D finite element model. Now the side span has naturally closed and the cantilever construction is illustrated in Figure 7.

Figure7, Photos of cantilever construction.

4 Conclusion

The 3-D simulation module CBCW concerning the composite bridges with corrugated steel webs was proposed to deal with finite element analysis in the construction process. It is verified during the construction control of the Juancheng Yellow River Highway Bridge that:

1- There is no special simulation module for bridge structure in ANSYS software, while the module CBCW provides an easy and high-efficient tool for bridge engineers.
2- The solution and postprocessor modules of CBCW combine with the latest Highway Bridge design specifications of China, which brings convenience for bridge designers.
3- The numerical results match measured results excellently, which turns out that it is credible to simulate this kind of bridges with the module CBCW.

Acknowledgements

The research work is supported by the National Natural Science Foundation of China (No. 50908105). Special thanks are due to the workers in the project for their help in the height survey. The opinions, findings, and conclusions of the papers are the authors' and do not necessarily reflect the views of those acknowledged here.

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