

Design and analysis of Wanbian Bridge in Fuzhou, China

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ABSTRACT: The Wanbian Bridge, crossing over the Wulong River in Fuzhou, carries 3 lanes in each direction with a total width of 34m. The main bridge has five spans with a total length of 376m and the span arrangement is 45m+90m+106m+90m+45m. Each direction of the bridge is a rigid-frame and continuous PC box girder with V-shape pier and the two box girders are combined together by cross beams and strengthened by a concrete filled steel tubular arch in the central. The structural design is introduced at first. A 3-D FEM in MIDAS is established to analyze the global structure. For the main joint, photo-elastic experiments with a scale of 1: 80 were carried out and a 3-D FEM-mode with solid elements in ANSYS are used to perform the stress analysis.

1 INTRODUCTION

Fuzhou city is the capital of Fujian province, China, in the west of the Taiwan Strait. It is 12 thousand square kilometers in area. The population is 5.5 million. Fuzhou is a famous ancient city in Chinese history. The city is old more than 2200 years. The Min River runs through the city, which is the largest river in Fujian Province with an annual runoff volume of 63 billion cubic meters. It divides into two branches when it enters into the city and combines to one again when run out the city and enters into the sea. The north branch is still called as Min River and the south one is called Wulong River. Among the two rivers, there is the Jinshan New Area of Fuzhou, which is the center district of implementing the "Policy of shifting its center to its south end and extending to its east end" in Fuzhou, about 8.8 kilometers from the urban area. The Wanbian Bridge is located in the south entrance road of this new district and is one of the important projects in this developing plan. The bridge is also a part of the city round expressway, and will play an important role in the city road network.

The Fujian Provincial Communications Planning, Survey and Design Institute wined the open design competition. The main bridge in the selected scheme is an arch-frame composition bridge with five spans. The north approach bridge has 2 spans of 40m continuous box girders and the south approach bridge has 35 spans of 40m continuous box girders. The deck with a width of 34m carries six highways and two side walkways. The total length of the bridge is 1856m. Fig.1 is the image view of the Wanbian Bridge.

2 STRUCTURAL DESIGN

As shown in Fig. 2, the total length of the main bridge is 376m with a span arrangement of 45m+90m+106m+90m+45m. In the central three spans, the two separated prestressed concrete continuous rigid-frames are combined in transverse direction by cross beams which is hangered

to arch ribs fixed at the V-shape pier (Fig. 3). The section of the arch rib is made of concrete filled steel tubes (CFST).

Prestressed continuous box girders for the approach bridges and prestressed concrete continuous rigid-frame with V-shape pier for the main structure for the main bridge were selected based on the economic reason. For the three arches in the main bridge, it is not so much for strengthening for the continuous rigid frames as esthetic advantages.



Figure 1: Image view of Wanbian Bridge

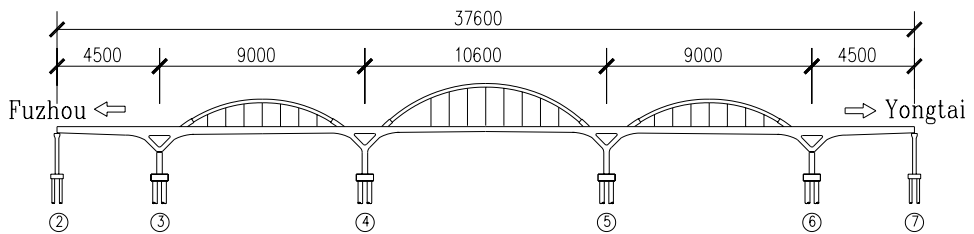


Figure 2: Longitudinal layout of Wanbian Bridge

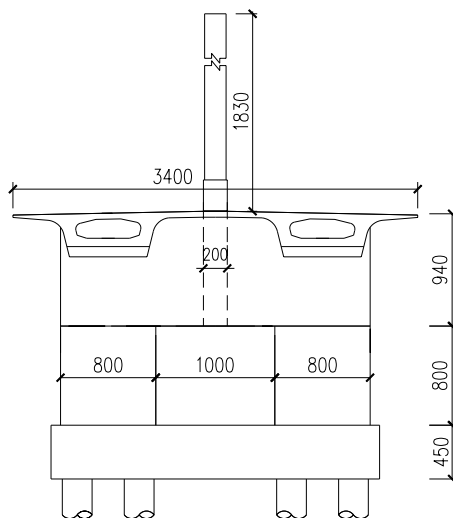


Figure 3: Cross-section of Wanbian Bridge

The girder has a trapezoid box section, in which the top flange is 16.0m width. The box soffit varies in a parabolic profile of 1.6 exponents from 4.0m (at bearing) to 2.4m (at midspan) in the central span and from 3.6m to 2.4m in the other four side spans.

The two separated box girders are connected together in every 8m by a cross beam. There are 9 and 7 cross beam made of PC box girder in the central span and two side spans, respectively. The cross beams are hanged to the arch rib by hanger of 7 steel strands of 55 ϕ 15.24 with strength of 1860MPa and protected by double PE layer coats.

The arch rib has a parabola axis. It has a span of 88m and a height of 17.5m, giving a ratio of rise-to-span of 0.2 in the central span; and a span of 72m, height of 12m, giving a ratio of rise-to-span of 0.17 in the two side span. A rib with a width of 1.8m and height of 1.6m consists of four CFST chords, each chord is composed of a Q345c steel tube, which diameter is 550mm and the wall thick is 12mm; and the tube is filled by C50 concrete. The cross section of arch rib is shown in Fig. 4.

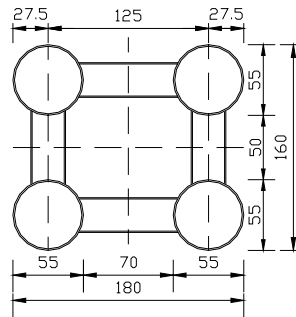


Figure 4: Cross section of arch rib

The main girders are locked to the V-shape pier to form a frame structure. The rigid arm in the V-shape pier has a thickness of 2.5m and it is wide of 26.0m. In construction, the V-shape piers are divided into two in transvers (each has a width of 12m) and constructed dependently with the continuous girder by cantilever method. After they are completed, the 2.0m width joint strips between the two rigid arms in transverse direction are casted with concrete to form a global structure. Then the cross beams in the two separated girders are connected together too. At the same time, the arch ribs and the hangers are erected to form the designed structure. The pier foundations are made of the drill and cast in-situ piles.

3 GLOBAL STRUCTURAL ANALYSES

A 3-D FEM structural model was built for structural analyses. All the main elements of the structure including arch ribs, box girders, cross beams, V-shape piers as well as their foundations were treated as spatial beam elements, except hangers were treated as cable elements. All data implemented to the FEM model were collected on the basis of the workshop drawings. This model made in MIDAS Civil 6.7.0 environment has 1420 nodes and 1548 elements of 26 kinds, as shown in Fig. 5.

Presented FEM model was used to calculate internal forces and deflection of the bridge under its state of construction and service, the analysis was based on Chinese codes, including the Criteria of the General Code for Design of Highway Bridges and Culverts (JTG D60-2004) and Code for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts (JTG D62—2004).

From the analysis results, the maximum displacements of the mid-section in the main span was only 7.5cm, much less than the allowable value $L/800=13.25$ cm. The maximum tensile strain of the box girder was only 0.97MPa, which is smaller than the designed tensile strength 1.89MPa. The displacements and stress of the arch rib are satisfied the design requirement.

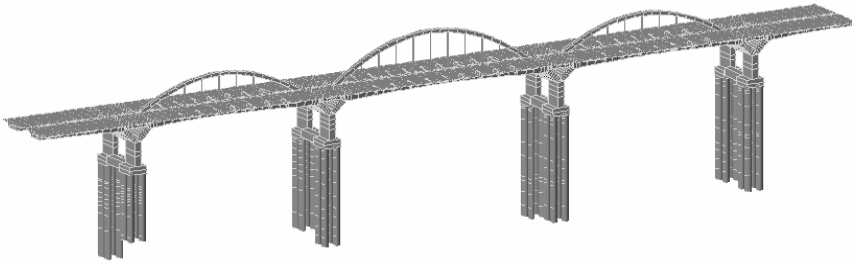


Figure 5: Spatial FEM model of Wanbian Bridge

The first buckling mode from the Eigenvalue buckling analysis is out-of-plan in symmetric shape (Fig. 6) with a critical load 8.84 times of the design one. It shows that the arch has small stiffness in out-of-plane than that in-plane.

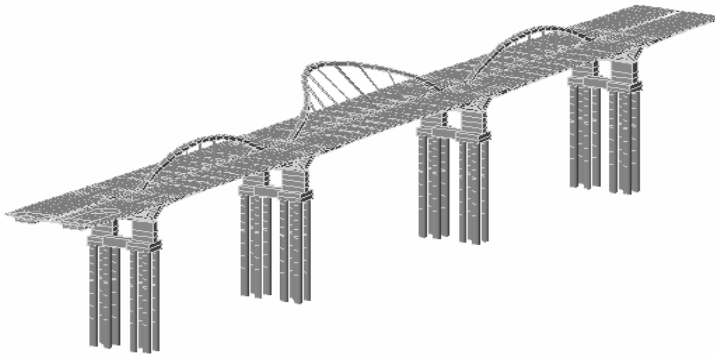


Figure 6: The first buckling mode of arch rib

The Wanbian Bridge is an indeterminate structure, creep and shrinkage of concrete will produce secondary forces in it. These secondary forces are less than 10 % of the first forces calculated by the FEM in software MIDAS. In the analyses, the creep and shrinkage strains were calculated by CEB-FIP and variation coefficients of 115, 210 and 215 were taken into account.

4 ANALYSES ON THE MAIN JOINTS

The main joint in this bridge is in the V-shape pier's top connected with arch rib springing and box girder is complex in geometrics, structure and mechanism behaviors.

A photo-elastic experiment of the joint model (Fig. 7) with a scale of 1: 80 was carried out. Meanwhile, the joint was discretized by solid element to a 3-D FEM-mode (Fig. 8) and a stress analysis of the joint was performed in ANSYS. The calculated deformation and stress components from the global FEM in MIDAS as mentioned in the Section 3 were applied as boundary conditions to the sections of the joint in both photo-elastic model experiment and the FEM analysis.

The test results and the FEM analysis results agree well each other. Fig. 9 and 10 show one case of the comparison. Analyses show that the general stresses inside the joint are small except some local stresses in the places where the rigidity changes abruptly, the anchorage devices and supports are acted. Therefore, the structure measurement and reinforcing were strengthened in the design.

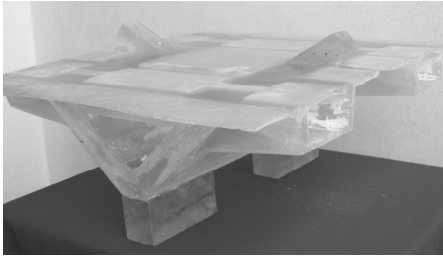


Figure 7: Model for photo - elastic experiment

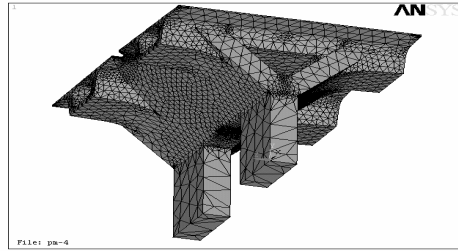


Figure 8: Finite element model

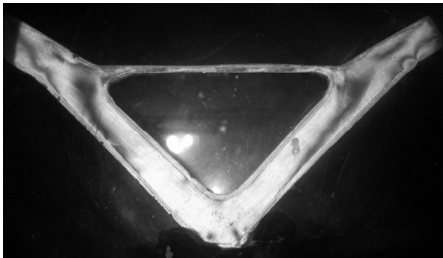


Figure 9: Isochromatic line of photo-elastic experiment

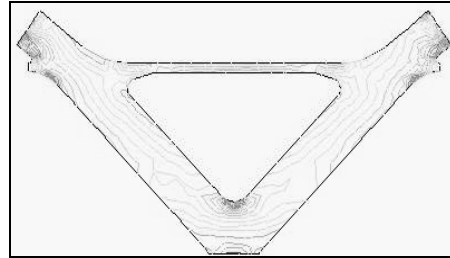


Figure 10: Isochromatic line of FEM

5 CONCLUSIONS

In Wanbian Bridge, a prestressed concrete continuous rigid frame with V-shape piers was designed as the main structure for economic reason and three CFST flexible arches stand in the central line to give a pleasing configuration for aesthetic reason.

In construction, the cantilever casting method is used for the continuous prestressed concrete box girders after the V-shape piers completed by scaffoldings. The steel tubular arch rib can be erected by mobile crane and supported by falseworks over the deck. Then concrete is filled into the tubular arch ribs to form CFST arch ribs. Therefore, it is not difficulty in building such a bridge as a real arch bridge. However, the cross beams add difficulty in building the two separated box girders by cantilever method. And the structure is complex in the arch springs. Structural analysis shows that the structure can meet the design requirement. The bridge is under construction now and will be completed at the Sept. 2008.

