

Numerical analysis of the behavior of Yingbin Bridge

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ABSTRACT: Yingbin Bridge located in Jiangshan City, Zhejiang Province, China is designed as a landmark centrepiece of the city. It is an open spandrel deck tied concrete arch bridge. It is composed of three spans, the central span of arch and two side spans of half-arches. A spandrel arch without spandrel column or wall crosses the main pier. After a introduction of the aesthetic and structural characteristics of such arch bridge, the design of Yingbin Bridge is described and the main calculation results from 2-D and 3-D finite element models are given out in this paper.

1 INTRODUCTION

In deck arch bridge, the space between the deck and the arch may be filled with earth retained by side walls. This structure is called a filled spandrel arch and is used widely in short span bridge, especially stone arch bridge, from ancient to nowadays. In order to cut down the dead load and save material, an open spandrel arch was proposed for long span bridge, in which spandrel columns or walls are adopted to transmit loads from deck to the arch. The existing earliest one is the Chaw-Zhou Bridge in China, which was completed in A.D. 606 with a span of 37.4m.

Sometimes, spandrel arches without spandrel column or wall are utilized in an open spandrel arch bridges to achieve a special aesthetic effect, such as the Jiang-kou Bridge in Putian, Fujian Province of China, as shown in Fig. 1. It is a multi concrete arch bridges with double-curved sections and has a span of about 10m.



Figure 1: Jiang-kou Bridge in Putian, Fujian Province.

Deck arch bridge generally is a true arch bridge, the thrust forces of the arch are supported by abutments or piers and their foundations. If the horizontal reactions to the arch rib are supplied

by a tie at deck level, the bridge generally is composed of three spans and the ties are anchored at the ends of the two side half-arches. The Yuxizhou Ming River Bridge located in Fuzhou of China, shown in Fig. 2 is such a bridge. The bridge has a main span of 120m, completed in 2004. It is also called a prestressed concrete rigid-frame arch bridge without spandrel columns.



Figure 2: Yuxizhou Ming River Bridge in Fuzhou.

Adding spandrel arch in the tied deck arch bridge can short the deck span over the pier and save prestress bars in the deck structure. It is considered to have a more good looking appearance and can make the bridge more attractive. The Jiefang Bridge located in famous scenery city—Guilin of China, is a five span tied deck arch bridge with spandrel arch with a main span of 72m, see Fig. 3.



Figure 3: Jiefang Bridge in Guilin.

The analyzed Yingbin Bridge in this paper is a bridge with a similar structure to Jiefang Bridge. Yingbin Bridge is located in Jangshan City, which is in the southwest Zhejiang Province of China. The bridge located in the entrance road, crossing over Xiujiang, is wished to be a landmark centrepiece of the city and required different appearance from the two bridges in its upper and down stream, one is a half-through CFST arch bridge and the other is a self-anchored suspension bridge. The most important of the design concept is that the bridge should harmony between the engineering project and the natural environment. Through an open design competition, the three-span deck tied arch bridge with spandrel arch (Fig. 4) proposed by Hangzhou City Construction Design and Research Institute was selected from ten schemes (Wu et al.2006). The profile of the bridge looks fluent and elegant, without pylons or other structures above deck can give a better view for the passengers to enjoy a picturesque background, i.e., the Jianglang Mountain, one of the “National Key Scenic Area”.

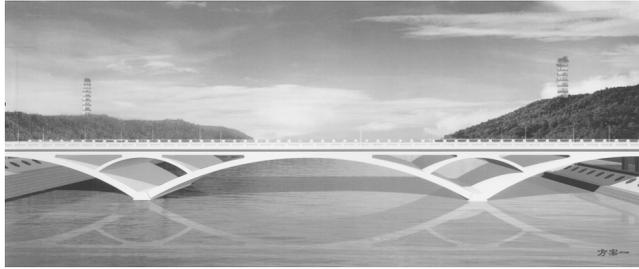


Figure 4: Image View of Yingbin Bridge in Jiangshan.

2 THE BRIDGE DESIGN

The project has total length of 305.5m, in which the main three-span bridge has a span arrangement of 55 + 90 + 55m and the two side approach bridges are continue prestressed concrete bridges, each has two spans with a span of 25m (Fig. 5).

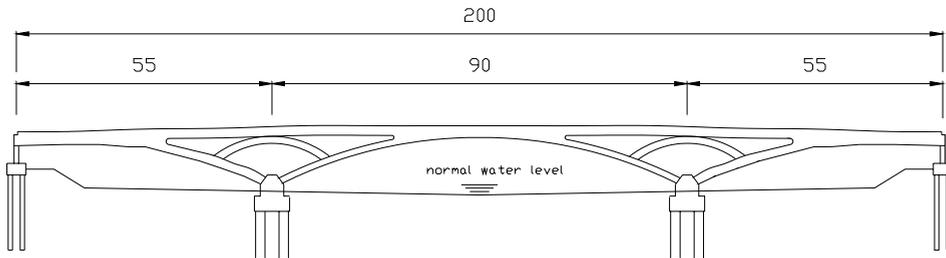


Figure 5: Layout of Yingbin Bridge (unit: m).

The design flood frequency is 1 per 100 years and acceleration peak value of earthquake is 0.05g which is equal to basic earthquake intensity. The design load was based on the Chinese Standard of Loadings for the Municipal Bridge Design (CJJ 77-98).

The bridge is very wide, so the structures is separated by a deformation joint of 1cm width into two units in road section, each has a width of 24.5 m, see Fig. 6. The arch rib in the central span has an eight-cell box section with parabolic axis, made of reinforced concrete, fixed at two springs. The calculated span is 86m and ratio of rise to span is 1:8.6. The side span is a curved beam with one end fixed at the central pier and the other one simply support at the side pier and its section is also an eight-cell box section. High strength wire strands are utilized as tied bars anchored at the ends of the two side spans to balance the thrust forces of the arches, therefore, the deck structure can be considered as a prestressed concrete girder with external post-tensioning.

The spandrel arch is circle and has a span of 25.2 m, rise of 4.65 m, giving a rise-to-span ratio of 1:5.42. The deck structure is continuous prestressed concrete girder with eight-cell box section. The piers are reinforced concrete structures. Piles with a diameter of 180cm and shallow foundation are adopted in the north and south central piers respectively. And other foundations are all made of piles with a diameter of 120cm.

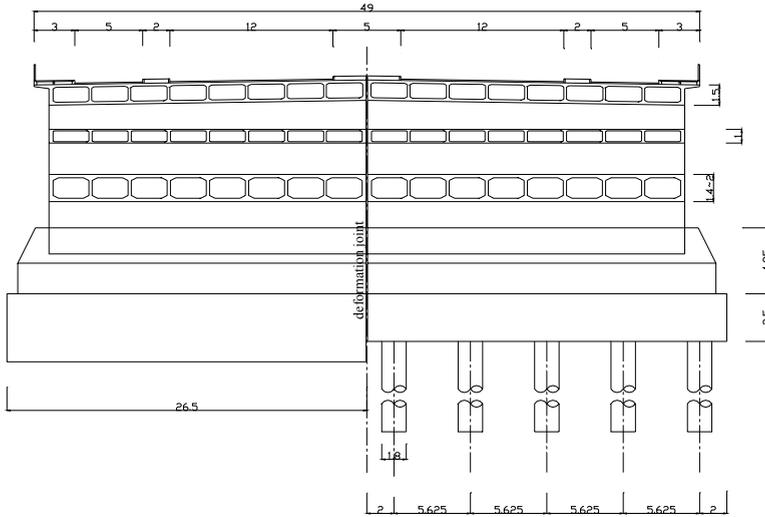


Figure 6: Cross-section of Yingbin Bridge (unit: m).

3 STRUCTURAL ANALYSES

At first a two dimensional finite element model (Fig. 7) is established to analysis basic mechanic behaviours of Yingbin Bridge, including the influence lines of forces in critical sections as well as prestress forces of the tie bars. The model includes three-span super-structure and the sub-structure as well as their foundation. All of the bridge structure members are simulated by beams except the tie bars by cable elements and the support by link element in ANSYS environment. Similar to other arch bridge with prestressed tie bars, the prestressed forces were calculated by the assumption that the compressive rigidity of the bar is infinite and its flexural rigidity is infinitesimal (Chen 2006).

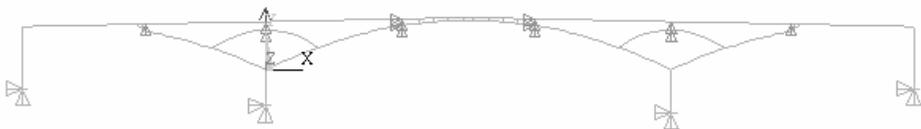


Figure 7: 2-D FEM of Yingbin Bridge (unit: m).

The deflection of the bridge under dead load is shown in Fig 8, in which the maximum deflection of main arch rib and deck is 1.82cm and 3.27cm, respectively; and the maximum one of side arch rib and deck is 1.75cm and 2.24cm. Sum of absolute value of positive and negative deflection of rib comes to 0.67cm under live loads. It is smaller than the allowable deflection ($L/800=11.25\text{cm}$).



Figure 8: Deflection of Yingbin Bridge subjected to dead load.

A 3-D FEM structural model was built for precise structural analyses. The model includes three-span super-structure and the sub-structure as well as their foundation. All of the bridge structure members are simulated by space beams except the tie bars by two-node cable elements. The model shown in Fig. 9 has a total of 1725 elements of 2 types and 1260 nodes.

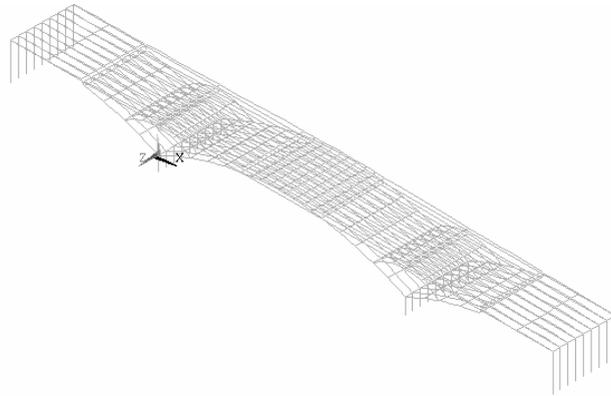


Figure 9: FE model of Yingbin Bridge.

Twenty-four tie bars are used to resist reacting horizontal force of the arch and each bar's tension comes to 4000kN, which bars are covered with epoxy and has a strength of $R_y^b=1670\text{MPa}$.

The first Eigenvalue buckling mode of the bridge subjected to dead load is in-plan (Fig. 10) with a critical load 34.872 times of the design one. The ratio of critical load to design one is 33.347 in the case the thrust force in the springs are maximum under live loads, in which the buckling mode is similar to Fig. 10.

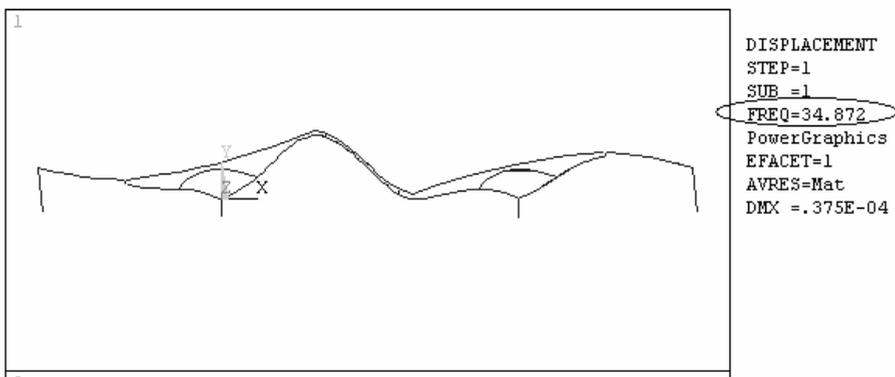


Figure 10: Buckling model of Yingbin Bridge subjected to dead load.

The first 5 mode shapes obtained from FEM analyses are all on the in-plan shapes, as shown in Fig. 11. It shows that this bridge has good stiffness in out-plane direction, the corresponding frequencies were 2.028, 2.916, 3.055, 3.202 and 3.72.

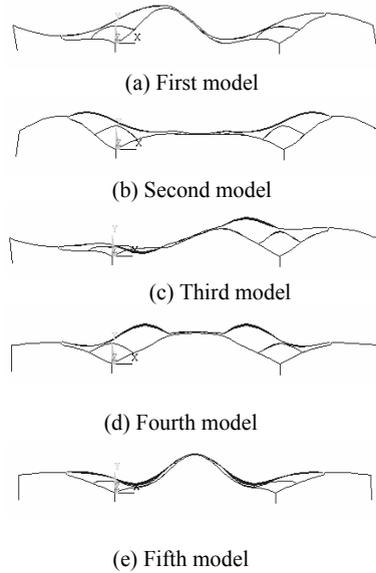


Figure 11: Vibration Mode shapes

4 FINAL REMARKS

The Yingbin Bridge was constructed on scaffoldings (Fig. 12). The construction started at the end of 2004 and will be completed in July 2007.



Figure 12: Construction Site

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