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Short Communication

The nonconventional thin-walled arch rib design and its numerical verification of a long span steel arch bridge

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ABSTRACT

Arch bridges have been widely constructed in China owing to their versatile structural configurations and competitive costs. The concept of using high performance prestressed steel wires to withstand the huge horizontal thrust at arch ends has greatly encouraged the engineering practices of large span arch type bridges constructed on soft soil foundations where normally arch structure is an inappropriate selection. However, many technical challenges including the design details, structural behavior and construction method still need to be carefully investigated to ensure the bridge′s safety. As a new practice of such tied arch bridge with nonconventional thin-walled steel box rib and the longest span of this type in the world, this paper presents the innovative design concept and the corresponding studies in regard to its structural behavior compared with conventional single arch design, the shear lag effect of the thin-walled arch rib and its stress distribution via numerical analysis of different finite element models are also investigated. The results show that the current design can reach a very good structural behavior under design load cases, and moreover, provides another very useful engineering practice for long span arch bridge constructed on soft soil foundations.

1. Introduction

Over the past few decades, many major bridges have been built in China [1], among which arch bridges played a very important role in highway transportation system with their great variety of structural layouts [2]. Meanwhile, owing to the successful application of high performance prestressed steel wires, the traditional requirement of solid foundation that can provide large horizontal resistance for most arch type bridges is no longer a hamper, as a result, self-balanced tied arch bridge theoretically and practically can be built on soft soil foundations [3]. In design practices, one of the main challenges for these bridges is to reduce the dead load induced thrust transmitted to their foundations, prestressed cables are therefore installed at the two ends of longitudinal girder and expected to minimize this force as possible as they can. Encouraged by the successful design and construction of Lupu bridge [4], several large span steel arch bridges have been constructed nationwide in China thereafter and these engineering practices have shown that given the appropriate structural design, steel arch bridge can still be a competitive alternation spanning over 500 m or less.

However, despite these successful applications, for each specific bridge, there still could be some difficulties related to the design and construction. Among which, one of the most important problem is the structural behavior of thin walled steel box rib in regard to the ultimate bearing capacity [5], global or local buckling [6–9] and shear lag effect [10–14]. Luo and Li [10] proposed a simple and efficient method for analysis of thin-walled curved box girder bridges considering the shear lag, bending and torsion. Lertsima et al. [11] investigated the shear lag induced stress concentration in a flange of a simply supported box girder by using shell elements. Sa-nguanmanasak et al. [12] studied the shear lag effect in a continuous box girder by modeling the whole girder with shell elements, and proposed empirical formulas to compute stress concentration factors including the shear lag effect. Zhang et al. [13] conducted experimental and numerical studies for a new type of streamlined girder bridge with a thin-walled steel box girder to investigate the effect of shear lag in thin-walled box girder bridges with large width to-span ratios. Lertsima et al. [14] also investigated the effect of shear lag on the deflection at the mid-span for various box girders.

Though the effect of shear lag has been studied by many researchers, most of the previous studies focused on steel box girder bridges, few concentrated on the thin-walled steel arch rib. Therefore, as a new practice of such tied arch bridge with nonconventional thin-walled arch ribs, in addition to the innovative design concept and the corresponding studies in regard to its

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structural behavior compared with conventional single arch design, this paper also presents the shear lag study of the thin-walled arch rib and its stress distribution through numerical analysis of different finite element models.

2. Design concept and features of the bridge

2.1. Brief discription of the bridge

Located on the coast of East Sea, Ningbo (Yong, for short) is the transportation junction for coast areas of Zhejiang province, and the second largest harbor of China as well. According to its urban general planning, high-tech zone and urban rehabilitation zone will be constructed in the near future along the Yong River banks. Mingzhou Bridge is just designed as the connection of these two zones aiming to improve the surrounding investments and promote the development of the city. With a clearly navigation requirement for two way 1000 t seagoing vessels and a river bed width of about 420 m, although the fact of typical soft soil foundation is going to be faced, being encouraged by the recent engineering practices, arch type has become the prior consideration for the design of this bridge. However, for each large span bridge, its structure is unique and location dependent, many technical challenges, such as design details, structural behavior and construction method still need to be carefully investigated to ensure the safety of the bridge.

2.2. Design concept

According to the owner's requirement, Mingzhou Bridge has eight lanes in two way traffic and a deck width of 45.8 m, the layout of bridge deck is shown in Fig. 1. In addition, under the basic design requirements [15], Mingzhou Bridge is designed with 650 m long in total, consisting of 3 spans arranged as 100 m +450 m+100 m in a curvature with a vertical radius R of 4500 m. The main span is designed as a half through tied arch bridge with nonconventional arch ribs and steel box girder, as shown in Fig. 2.

Two groups of horizontal cables, each consisting of 8 bonds of 367Φ7 parallel steel wires are placed between two end cross-beams of the main span to balance the huge horizontal thrusts induced by main arches, and thus to avoid excessive strengthening of the soft soil foundation at the bridge site. Four of which are placed inside the box girder and the other 4 outside as shown in Fig. 1 by black dots at the two edges of the box section.

Actually, during the construction stage, cables are progressively tensioned to a target value in order to keep the arch end thrust as minimum as expected, as can be seen from Table 1, on completion of the whole bridge, the prestressed force is 75,000 kN in total at each arch end, the existing unbalanced thrust is only 338 kN, which means almost majority part of the dead load induced horizontal force is balanced by the prestressed cables.

As can be seen in Table 1, the horizontal force of arch end that induced by dead load can be balanced by progressively pretension the tied cables, but not the thrust that caused by live load such as vehicle and temperature variation, which can only be borne by the pier and its foundation. As a result, the horizontal

Table 1
Cable forces at construction stages (unit: kN).

Construction stage	1st Prestress tie cable to	After installation of the stiffening girder	2nd Prestress tie cable to	After the additional dead load	3rd Prestress tie cable to
Pretention of cables	52,000	52,000	69,625	69,625	75,000
Horizontal thrust at arch end	2407	−257	7019	417	338

Note: (1) the pretention of cables herein is for one group consisting of 8 bonds, and (2) the thrust is for one single arch end at the main span and positive value indicates the thrust towards the main span, the negative side span.

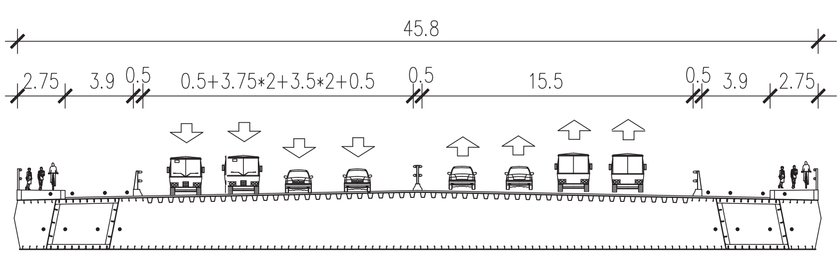

Fig. 1. Layout of bridge deck (unit:m).

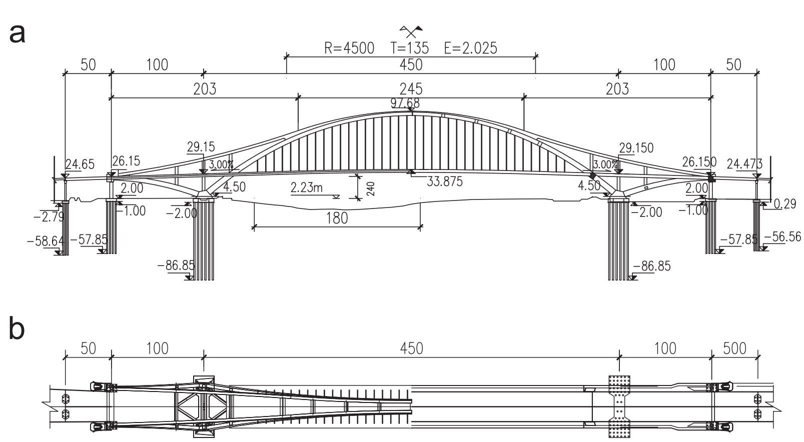

Fig. 2. Bridge elevation and plane (unit:m). (a) Elevation and (b) Plane.