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Static behavior of a new type of cable-arch bridge

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ABSTRACT

Cable-arch bridge is a new type of hybrid bridge, and its development has great engineering significance. To understand the mechanical characteristics of cable-arch bridge, in the present work, a model cable-arch bridge was constructed, and its static behavior was investigated using the finite element method and experimental test. The analytical and experimental results were compared, and qualitatively good agreement has been exhibited. By considering the geometrical and/or material nonlinearity of the cable-arch bridge, the linear and nonlinear stability was studied further analytically. The results show that the cables and wind bracing have a significant influence on the mechanical behavior of the cable-arch bridge. Compared with arch bridges, the cable-arch bridge has a larger ultimate bearing capacity, a better in-plane and out-of-plane stability, and a superior capacity to resist various live loads. Such a cable-arch bridge should have a bright future in the development of long-span bridges.

1. Introduction

In the past two decades, benefiting from a strong growth in economy, construction of long-span bridges has been very active in the world. In turn, the continuous development of bridges plays an increasingly important role in promoting economic and social development.

As one of the most popular bridge types, arch bridge has been widely used and updated since ancient times due to its aesthetic pleasure and economic feasibility [1,2]. For instance, Zhao-Zhou Bridge located in China has outlived about 1400 years of the elements, earthquakes and floods [3]. The main issue with the development of arch bridge is its limitation in the length of arch span. This is because the rise-span ratio will become smaller and smaller and arch may become unstable under loads with the increasing of arch span. In fact, the longest span of arch bridge is only 552 m, which is the Chaotianmen Bridge located in China [6], compared with suspension bridge with a span of 1991 m (Akashi Kaikyo Bridge in Japan) [4] and cable-stayed bridge with a span of 1088 m (Sutong Bridge in China) [5]. To overcome the issue, much work has been carried out to develop hybrid bridges in the past. Melan and Steinman [7] ever proposed an arch suspension bridge and studied its mechanical behavior. Subsequently, several other hybrid bridges were developed [8–10]. These bridges are similar to cable-stayed arch bridge in structure. The only difference is that the stay cables in these bridges are anchored on the deck rather than the arch. These new hybrid bridges exhibit better mechanical behaviors than the traditional arch bridges. In 2007, a real cable-stayed arch bridge, the Liancheng Bridge, was opened in China [11]. The cable-arch bridge is a hybrid structure that combines the flexibility of cable and rigidity of arch. It can overcome the problem of large deformation in cable-stayed bridge and suspension bridge with large span. When the span of arch is increased, the height of arch would also be increased. Therefore, the stability of arch is a problem. In order to overcome the issue, the lower ends of the inclined cables are anchored on the arch rib and the upper ends on the pylon in the bridge. For long span bridges, compared with arch bridge, the economic advantage of cable-stayed arch bridge is competitive, since the cost of foundation for cable-stayed arch bridge could be reduced because the foundation with less horizontal thrust compared with that of arch bridge can be weakened. Additionally, the cost of arch rib also could be reduced because stiffness of arch could be weakened, which is due to the cables that can share the load added on deck.

Understanding the static and dynamical behavior of bridges is very important for bridge development. In the past, many studies have been conducted for this purpose with arch bridge [12], cable-stayed bridge [13] and suspension bridge [14]. However, there exist few literatures that are focused on cable-arch structure [15]. The general mechanical performance of cable-arch bridge has been paid limited attention, although understanding such performance is of significance for further development and application of this type of bridge.

In the present work, a model cable-arch bridge was constructed, and its static behavior was investigated experimentally and numerically. This paper is organized as follows. In Section 2, a model

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cable-arch bridge is introduced. In Section 3, experimental conditions are discussed. In Section 4, a finite element model is established based on the design drawings. In Section 5, the deflection and stress of some key points on the model bridge under dead and live loads are examined analytically and experimentally, and the stability of the model bridge is analyzed. In Section 6, the conclusion of the present study is lastly given.

2. A model cable-arch bridge

To study the static behavior of cable-arch bridges, a model bridge was designed. Fig. 1 shows the layout of the bridge structure, main cross sections and measured points. The main structure and dimensions of the model bridge are as follows.

The structure is a combination of arch bridge and two-pylon cable stayed bridge. The deck below the main arch is supported by arch hangers and the rest of the main span by stay cables, while the deck of the two side spans is supported by stay cables and side arches. All the members are made of Q345 steel. The main span is 16 m and two side spans are 4.8 m each. The vase shaped pylons are 3.458 m high and 2.74 m tall above the deck.

The model cable-arch bridge is also a half-through arch bridge, and the double-rib higher parabolic hingeless arches are adopted. The two parallel main arch ribs are stabilized by eleven bracings, including two K-shaped bracings and two connecting beams below the deck, and six K-bracings and one Ж-shaped bracing above. The connecting beams are composed of rectangle steel girders and other bracings are made of steel pipes. The vault of the main arch is 2.988 m high totally, with a height of 2.15 m above the deck. From the foot to the vault, the depth of the main arch varies from 0.2 to 0.36 m, and the distance between the center lines of the two parallel arches is 1.36 m. Each main arch rib is a space truss and the cross section consists of six steel tubes (Fig. 2) with the dimensions of Φ34×2.5 (2, 1) mm and connecting steel pipes.

The main arch floor system is composed of deck, I-shaped cross girder and longitudinal stringer. The rest consists of two longitudinal box girders. There are two expansion joints on the bridge deck between the main and side spans.

To suspend the main arch floor system, there are 39 steel wire rope hangers with the dimension of Φ7 at each main arch rib. There are in total 28×4=112 stay cables with the dimension of Φ6.2. Some stay cables are anchored on deck with a 400 mm interval and others on the arch rib with a 320 mm horizontal interval. It is worth noting that there are two parallel cables anchored on the same cross-section of a main arch rib as shown in Fig. 2.

The pylons are vertical in the longitudinal direction and vase-shape in the lateral direction. The tower legs simply supporting the deck are hollow rectangle steel box and connected by three hollow steel box struts, two above the deck and one below. The 56 cables are anchored on the upper segments of each pylon with an interval of 80 mm.

The main arch foot, pylon socket and side arch foot are on the same abutment which is supported by the piled foundation with 24 bore Φ80×5 piles as shown in Fig. 1. The abutment is made of concrete C50. The side arch rib is lower parabolic hingeless arch with the hollow rectangle steel box cross section. The main arch rib and side arch are fixed at the abutment to balance the horizontal forces. As tie bars, four pre-stressed cables are used to connect the upper ends of the two side arches. Each cable is pre-stressed by 14.8 kN force and composed of 7 strands with a diameter of Φ5.

Based on the design above, a model bridge was constructed, and shown in Fig. 3(a). The construction procedure of this bridge is a combination of erection procedure of arch bridge and cable-stayed bridge. It includes several steps: (1) foundation and piers construction; (2) side arches erection by scaffolding construction; (3) towers and side beams construction; (4) tension of tie bars between two side arches; (5) symmetric lifting of arch segments, installation of stay cables and tension of tie bars; (6) installation of floor system of main

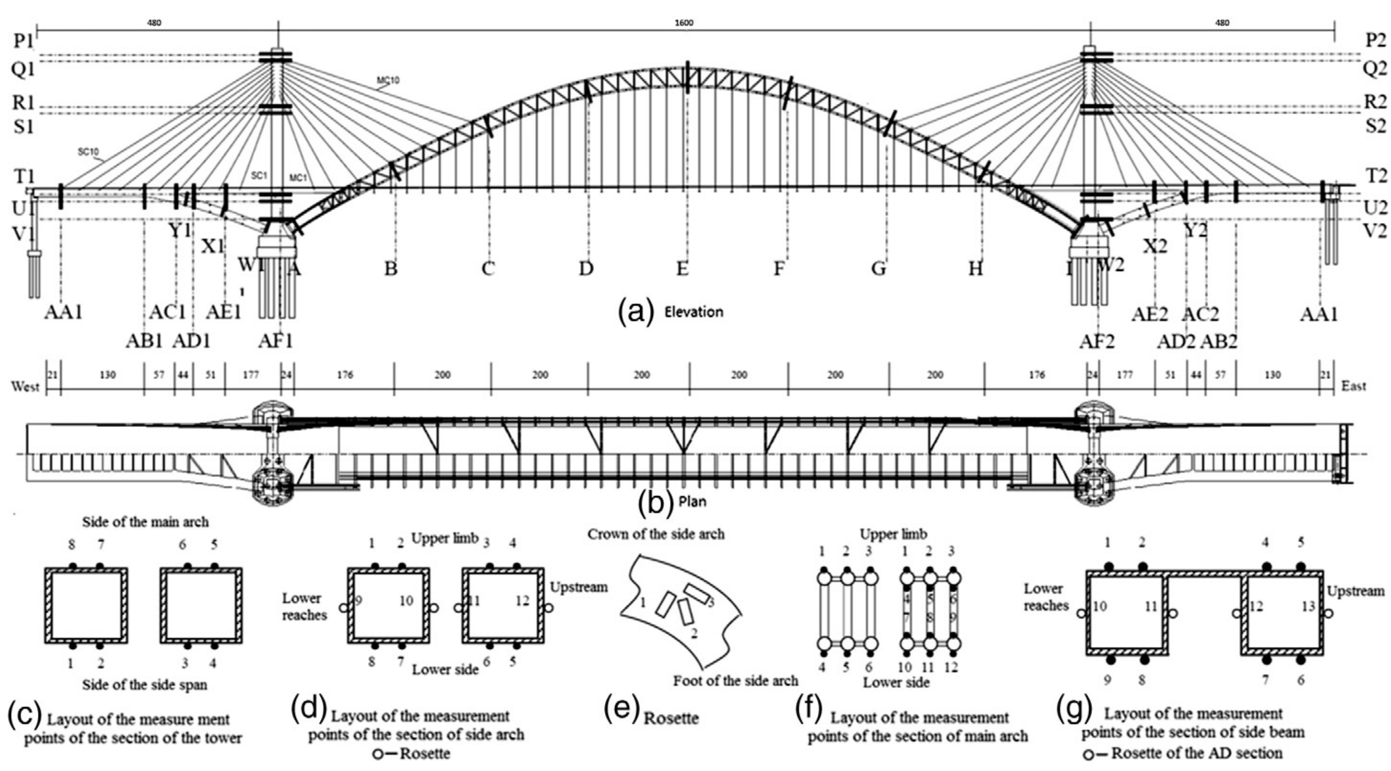

Fig. 1. Layout of the model cable-arch bridge, cross sections and measured points. The upper and lower parts in (b) show the vertical projections of the half bridge from top view (top to bottom) and from bottom view (bottom to top), respectively.