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Stability of a pretensioned latticed three-dimensional arch structure with cross cable-strut arrangement

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ABSTRACT

An innovative pretensioned latticed three-dimensional (3D) arch structure with cross cable-strut arrangement is proposed based on the concept of beam string structure with consideration of the indoor headroom. Three cable-strut arrangement schemes of the cable latticed 3D arch are analyzed and the in-plane stabilities of the arches with different cable-strut schemes are compared. Also, the influence of cable anchorage position on the in-plane stability of the pretensioned latticed 3D arch is investigated. The configuration and stability of the parallel cable-arch integral structure with the optimal cable-strut arrangement are studied. The effect of both the transverse diagonal cross bracings and the amount of the longitudinal latticed 3D beams on the buckling mode and stability capacity of the integral structure is studied. Additionally, the relationship between the structural stability capacity and the amount of parallel cable arches is discussed. Two simplified models for stability analysis of the integral structure are presented, and the corresponding calculation accuracies are also discussed. All this work will provide theoretical guidance to the actual engineering application of this structure.

1. Introduction

With the development of human society, people have put forward higher requirements for the span of spatial structure [1,2]. An arch receives the applied loads mainly in compression, so it is widely used in large-span structures to reduce the bending moments [3,4]. And with the ceaseless innovation of arch styles, larger and larger structural span can be realized. Theoretical studies and engineering practices indicate that the combination of modern prestressing technology with long-span spatial structures is an effective method for the construction of super-long-span structures [5–7].

Based on the excellent performances of steel arches, as well as the light weight and high tensile strength of cables, the pretensioned cable arch structure has been proposed and widely used in long or super long span buildings over the past decades [8–11]. According to the configuration of steel arch [12], the pretensioned cable arches can mainly be divided into two categories, i.e., the pretensioned cable solid-web arch and latticed one. In comparison with the former, the pretensioned cable latticed arch possesses the advantage of both arch and truss, which makes it more generally applicable. In recent years, a great deal of investigation on the form innovation and performances of pretensioned cable latticed arch has been carried out, and a lot of productions in theory and practical engineering application were obtained [10,11,13–15].

The beam string structure (BSS) [16–18] is a typical hybrid structure, which is composed of upper structural members, lower cables and struts. Through the subtle arrangement of struts among the upper structural members and cables, the BSS can be self-balanced to achieve the best utilization of all materials. Thus, it can be more economical and reasonable to span large space. However, with the increasing of structural span, the lengths of struts increase and the indoor headroom decreases correspondingly. To further improve the spanning capacity of the latticed 3D arch and avoid the decrease of the indoor headroom, an innovative cable arch system, cross cable latticed 3D arch structure, is proposed in this paper based on the concept of beam string structure.

For this innovative system, three different cable-strut arrangement schemes are analyzed and the optimal one is selected by comparison of the in-plane stability of single cable arch. The cable anchorage positions are optimized in terms of the in-plane stability of the cable latticed 3D arch, and the configuration as well as stability of the parallel cable-

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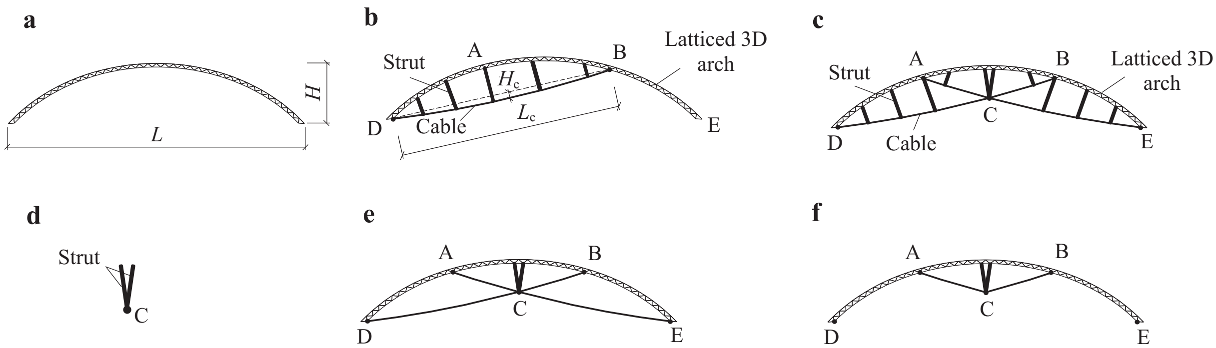

Fig. 1. The cable-strut arrangement schemes of the cable latticed 3D arch. (a) Pure arch without cable-strut system. (b) One side cable-strut system. (c) Scheme 1. (d) V-shaped strut. (e) Scheme 2. (f) Scheme 3.

arch integral structure with the optimal cable-strut arrangement is studied. Besides, two simplified models for stability analysis of the integral structure are discussed.

2. The cable-strut arrangement schemes of the pretensioned latticed 3D arch and structural model

2.1. The cable-strut arrangement schemes of the pretensioned latticed 3D arch

It is well-known that, the latticed 3D arch as shown in Fig. 1(a) is sensitive to half-span loading and initial imperfection. To further improve the stiffness and bearing capacity of the latticed 3D arch, an innovative pretensioned cable latticed 3D arch is proposed based on the concept of BSS, and three cable-strut arrangement schemes can be considered as follows.

Scheme 1. Two cables are symmetrically arranged beneath the latticed 3D arch and intersect at point C. One end of a cable is anchored at the arch end E while the other end is anchored at a lower chord joint A. Symmetrically, another cable is anchored at another arch end D and the lower chord joint B. The position of anchorage joints A and B at the lower chord is flexible and can be adjusted to meet certain requirements in practice. The struts are evenly distributed among the arch and each cable. Consequently, two symmetrical cable-strut systems, one of which is depicted in Fig. 1(b), are achieved with a similar function to BSS. This scheme is finally obtained by the overlap of parts of the two cable-strut systems at the vault, as shown in Fig. 1(c). And the lower ends of two struts at the top of the arch both anchored at the point C, forming a V-shaped strut as illustrated in Fig. 1(d).

Scheme 2. On the basis of Scheme 1, the struts are all removed except the V-shaped one at point C as shown in Fig. 1(e).

Scheme 3. Based on Scheme 2, the cable segments between the intersection point C and the two ends of the arch are further eliminated. And only the cables between the two anchorage joints as well as the V-shaped strut at the top of the arch are retained, as displayed in Fig. 1(f).

Compared with the traditional BSS, the cable arch with one of the three cable-strut arrangements can effectively increase the structural indoor headroom. On the other hand, the structural stiffness and bearing capacity are expected to be significantly improved relative to the pure arch without the cable-strut system.

2.2. Configuration of the parallel cable-arch integral structure

Generally, the actual structure is a spatial integral structure composed of multiple parallel cable latticed 3D arches, longitudinal components, and the transverse bracings. In this paper, the parallel latticed 3D beams are taken as the longitudinal components and intersect perpendicularly with various parallel latticed 3D arches. Meanwhile, a row of diagonal cross bracings are set in the middle of the structure between two adjacent cable latticed 3D arches along the transverse direction to enhance the structural integrity, as shown in Fig. 2, in which, S_1 and L_1 denote the arc length of the arches between two adjacent longitudinal latticed 3D beams and the interval of two adjacent cable latticed 3D arches, respectively. The longitudinal latticed 3D beams can not only transfer loads, but also provide out-of-plane supports for various cable arches, and thus improve the out-of-plane stability of the cable arches. The triangular cross section of the latticed 3D arches and the longitudinal latticed 3D beams as shown in Fig. 3 is considered in this paper.

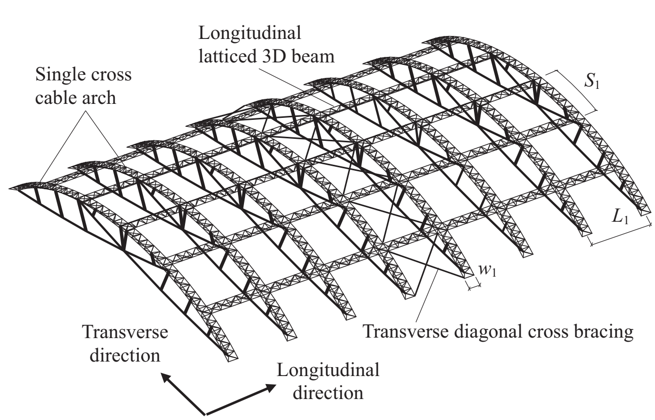

Fig. 2. Configuration of the parallel cable-arch integral structure.

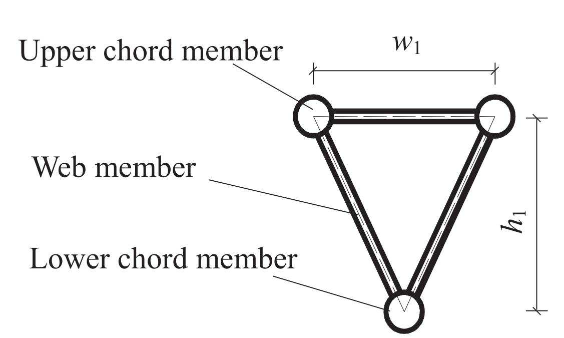

Fig. 3. Cross section of the latticed 3D arches and the longitudinal latticed 3D beams.