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Experiment and design investigation of a multi-planar joint in a transmission tower

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ABSTRACT

This paper focuses on a multi-planar steel tubular joint, which is in the slope change position of a new transmission tower. This slope change joint (SCJ) had six branch tubes and five chords in total, which led to complex interaction in the joint behaviour. To achieve experimental loading, a three-dimensional setup was designed for this joint. Detailed information of this SCJ and the test equipment were introduced. Then numerical model was established and validated by test results. Stress conditions of primary members, failure modes, influencing factors of the ultimate load as well as load transmission path were investigated by taking advantage of numerical analysis. Furthermore, a criterion for joint capacity was established referring to steel structure standards in different countries. Based on the established criterion, critical members were revealed and strengthened. In the end, procedures to optimize critical members and recommendations for joint design were proposed. Results proved that this SCJ can well meet the strength requirements after optimization.

1. Introduction

Focus in this paper is a complex multi-planar joint, which is in a new transmission tower with built-up columns, shown in Fig. 1. This tower was a 1000 kV ultra-high-voltage alternating current transmission tower that was designed to be constructed in China. There were two notable features in this new tower: Firstly, its height reached to 455 m, higher than any other towers of its kind in the world [1,2]. Secondly, it was a new structural form. From 361 m to the top of the tower, it was tower head, in which each leg was single steel tube. From 286 m to 361 m, it was a built-up column that was composed of four steel tubes. This column was named as quartet-steel-tube-column (abbreviated as QSTC). From the tower foot to 286 m, each leg was QSTC that was filling with reinforced-concrete. More detailed information about this tower was introduced in paper [3].

At present, the most popular structural forms applied in the electric transmission grids are angle steel lattice towers [4,5], steel tube towers [6,7] and steel tube towers with concrete filled [2,8]. The latter two kinds of towers are preferred [9] in large-span transmission towers. However, with the development and increasing special needs in electric transmission grids, some distinctive structural forms or member shapes are proposed. The quartet-steel-tube-column transmission tower introduced in this paper is a new type of tower which has never been applied in practice [3]. For such a high transmission tower, if single column leg was adopted, high diameter-to-thickness ratio (about 75) cannot meet the design standards [10,11]. QSTC could effectively control the diameter-to-thickness ratio to a reasonable value.

In this tower, one of the difficulties was designing a joint to connect the upper single tube with the QSTC. At the same time, this joint can realize the transition from single branch to double branches. The joint's position is depicted in Fig. 1(a)—it is at the slope change position of the tower leg. Deng [3] proposed a new joint to solve this problem and research results proved that the new joint can well meet the requirements. In this paper, another new type of joint is proposed.

Massive experimental and numerical researches on multi-planar steel tubular joints have been undertaken. To name a few, multi-planarity tubular KK-joints [12], TT-joints [13], KT-joints [14,15], and DKT-joints [16] are common in onshore and offshore structures and there are a large number of researches about them. Lie [17] proposed new equations to determine the reduction factor of cracked multi-planar SHS TT-, YT- and KT-joints. Chiew [18] conducted a full-scale test about a multi-planar tubular DKYY-joint with eight branch tubes. Ji [19] studied a welded hollow spherical joint connecting two cables and twelve bars. Due to the complexity of these joints mentioned above, there are no mature design methods or design codes for such connections. However, due to the requirements of some special projects, experimental and numerical studies are indispensable. More importantly, they have great values for future reference. The SCJ in this paper is much more complicated, which has to deal with the transition of one single chord to four chords. Meanwhile, it has to connect six branch tubes—two diagonal tubes and four horizontal tubes.

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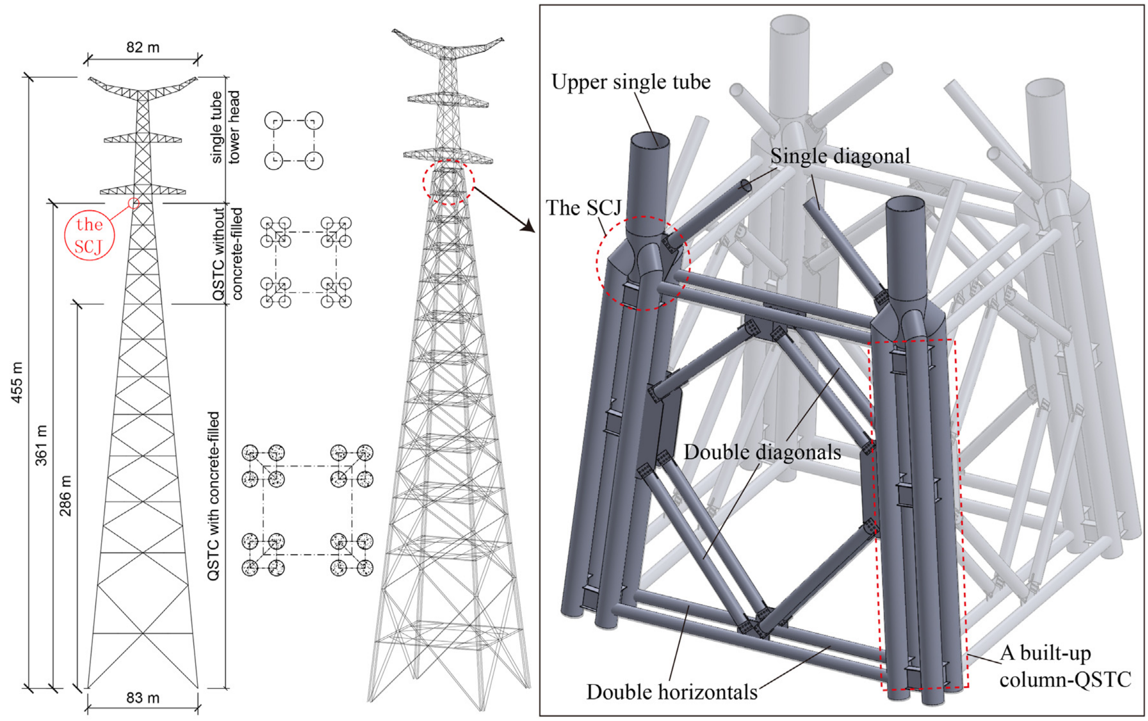

(a) Single diagram of the tower

(b) Diagram of tower segment

Fig. 1. Diagram of the tower.

In this paper, both experimental and numerical researches were conducted to analyse this new SCJ. Stress conditions of primary members in this joint were studied. Load transmission path was also analysed. Furthermore, failure modes were discussed and factors that influenced the ultimate load were investigated. In the end, some joint design suggestions were proposed.

2. Experimental design program

2.1. Connections in the experiment

Static tests were conducted on three testing specimens, denoted as "SCJ-2-1", "SCJ-2-2" and "SCJ-2-3". They were 1:3.6 scale of the prototype and were all the same in dimensions. Detailed dimensions are listed in Table 1. Detailed configuration of the scaled SCJ is illustrated in Fig. 2. Some distinguished features of the joint are listed as follows.

(1) This SCJ is a three-dimensional joint (Fig. 2(a)–(c)). The core area of the SCJ was a tapered tube, which was connected with the upper single tube through a flange. Transitional tubes were adopted in order to connect the QSTC to the tapered tube. Dimensions of the tapered tube were as follows: height (580 mm), thickness (12 mm), top tube diameter (480 mm), bottom tube diameter (380 mm). Two diagonals were linked to the tapered tube with diagonal tube plate. Four horizontals were connected to the QSTC with horizontal tube plate.

(2) Five I beams were adopted to connect the four tubes in the QSTC together (Fig. 2(a)–(d)). Their layout is shown in Fig. 2(d). These five I beams were marked with G1–G5 and had same cross-section dimensions. The top surface of I beams was 50 mm below the bottom of the tapered tube (Fig. 2(e) (h)).

(3) For the sake of clarity, some dimensions are illustrated in axis diagram (Fig. 2(e)–(g)). The intersection point (Point A in Fig. 2(e)) of the diagonal tube axis and the upper single tube axis was 50 mm below the bottom surface of the tapered tube. The intersection point (Point B in Fig. 2(e)) of four transitional tubes' axes was 30 mm above the top surface of the tapered tube. Point C (Fig. 2(g)) was the intersection point of the transitional tube axis and the tube axis in the QSTC. Plane T (Fig. 2(g)) which Point C was in was 180 mm above Point A. Axis Q was the axis that was parallel to tube axis in the QSTC and at the same time was through Point A. The upper single tube axis had a spatial angle of $\theta_1 = 175^\circ$ with Axis Q, $\theta_2 = 88^\circ$ with the horizontal tube axis, $\theta_3 = 42^\circ$ with the diagonal tube axis.

(4) Distance between tubes in the built-up column was 550 mm (Fig. 2(e)). C-C cross section in Fig. 2(b) was the plane of symmetry. In order to strengthen the tapered tube, two rib plates were arranged inside it. They were oriented in the direction that there were transitional tubes (Fig. 2(b), (c)). For the convenience of analysis below, four tubes in the built-up column and four transitional tubes were marked with I–IV (Fig. 2(d)). Member 9J was QSTC in the joint zone, while member 9 was QSTC below the SCJ. In the tower installation, they were connected together with a flange (member 10 in Fig. 2(h)).

Design concept of this SCJ is illustrated in Fig. 2(h), (i). The aim of this SCJ is to make loads transmit vertically in the joint zone. That is

Table 1
Member dimensions in the test.

No.[a]	Size/mm	No.[a]	Size/mm
1[b]/1 J	Φ480 × 10	7	Φ140 × 4
3	Φ194 × 5	8	Thickness 12
4	Thickness 16	9[b]/9J	Φ273 × 10
5	Thickness 12	13	Thickness 12
6	Φ273 × 10	11	Flange 92 × 7 Web 216 × 5

[a] Shown in Fig. 2.
[b] Members not in the joint.