Thin-Walled Structures 127 (2018) 51–61

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Full length article

Study on ultimate bearing capacity of main member in transmission tubular tower leg

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ARTICLE INFO

Keywords:
Transmission tubular tower
Secondary stress
Static test
Slenderness ratio ; Ultimate bearing capacity of main member

ABSTRACT

Transmission tubular towers are widely used as voltage increasing. One assumption usually made in transmission-tower analysis is that the joints are pinned. However, due to the fabrication difficulties, this assumption is rarely realized. Thus in practice, the tower members may produce secondary stresses not included in the analysis. Space tower leg structure model test and multi-scale FEM calculation were performed to investigate the magnitude of the secondary stresses and the effect on the ultimate bearing capacity of the main member in the tower leg according to the Chinese Standard Code of Practice. The result indicates that the secondary stresses of the main member in the tower leg could be up to 58% of the axial stress significant enough to cause failure of the main member even under normal working-load conditions. Meanwhile, it has been conclusively shown that the influence of the secondary stresses less than 30% of axial stress of main members is negligible, and the failure mode of the main member for the structure design is the plastic zone near the tower foot extends beyond the specifications' limit.

1. Introduction

Transmission towers play a key role in electric transmission grids as conductor support structures. Classical lattice towers are self-supported and usually constructed of angle section L-shape members which conveniently connected with bolted joints. Heretofore, many researches have been conducted on the angle towers : Roy et al. [1] studied the impact of the second order effect on the internal force and the secondary stress of members. Knight and Santhakumar [2] made a quarter-foot angle tower leg structure and carried out the static loading test on it. Prasad Rao et al. [3] studied the defected mode of angle tower. Jiang et al. [4] analyzed accurate modeling of joint effects in angle tower. McClure et al. [5] derived a two-node angle beam element and applied it to the analysis of the tower. Xie and Sun [6,7] explored the damage mechanism of the angle steel tower under wind load and snow load, and raised design suggestions. Nevertheless, as the power industry moving toward the use of high-voltage transmission lines to meet the demand for greater transmission capacity , taller and slender transmission towers are subjected to heavier loads and undergone larger displacements, thus, steel pipes are more inclined to be chosen as main members of transmission towers due to the good cross-section characteristics.

The tower structures are usually modeled as three-dimensional trusses in the analysis and design practice. However, towers are rarely fabricated in this way. When the joint is not a pin joint, there will arise secondary stresses in the members. Due to excellent plastic expansion ability of steel structure material, the cross section could withstand certain size secondary stresses. Bresle [8] indicated secondary stresses less than 20% of the axial stress could be neglected, consistent with the provision in Chinese standard code [9]. But Moris [10] reported that the secondary stresses of the component could be much greater than 20% according to the analysis of the space triangle truss caused damage to the joints of the members. The failure spot of transmission towers often concentrates in the leg of the towers according to full-scale tests (Fig. 1). Consequently, study on ultimate bearing capacity of main member in tubular tower is of great significance and urgency.

Space tower leg structure model was fabricated in accordance with the prototype transmission tubular tower, and static loading test was performed. In the test, secondary stresses of main members in tubular tower leg carrying the maximum load were investigated. Another objective of the test was to deals with the design ultimate bearing capacity and failure mode of the main member in tubular tower leg.

2. Test program

500/220 kV multi-high-voltage transmission tower with 84.8 m height, as shown in Fig. 2, was chosen for the test. This kind of latticed tower structures are commonly employed in Chinese urban transmission grids.

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https://doi.org/10.1016/j.tws.2018.01.025
Received 10 July 2017; Received in revised form 11 January 2018; Accepted 18 January 2018

Nomenclature

f_y	Yield strength	N	Axial force of the main member
E	Young's modulus	A	Area of the main member
σ_s	Secondary stress	M	Moment of the main member
σ_{max}	Maximum stress of section	W	Module of the bending section
σ_{axial}	Axial stress	f	Design strength
α	Secondary stress ratio	γ_R	Resistance partial coefficient
		α_{su}	Ultimate secondary stress ratio of the tower foot
		λ	Slenderness ratio

2.1. Test specimens

Space tower leg structure model was shown as Figs. 3 and 4. Cross sections of main member, diagonal member were Φ114 × 4 mm, Φ76 × 4 mm, respectively, and angle section of redundant members was L50 × 4 mm. The angle between main member and diagonal member was 20° and the slenderness ratio of main member was 36.

2.2. Material properties

The material properties of steel tubular members were obtained by conducting uniaxial tension tests on coupons cut from the members of the same batch as those used in specimen fabrication. For each type of the member, three coupons were machined and tested. Table 1 presented the measured material properties of main legs, diagonal bracings and diaphragms.

2.3. Strain gauges arrangement

The test was repeated three times to ensure the reliability of the test results. Every time , one of the four main members was taken turns loading to obtain detailed data. In the first and second time, the test specimen was guaranteed in the elastic range for investigating the secondary stresses of the main member. Third test loading until failure was used to observe the ultimate bearing capacity of the main member.

Members in transmission towers almost endured axial force, and stresses were distributed equally in theory. Nevertheless, due to the stiffness of joints, the stresses distribution at the end of the members were uneven influenced by the joint moment. The forces of the members were evaluated from strain gauge readings mounted on six cross sections distributed at the ends or in the middle of the main member, respectively (Fig. 5). Initial loading, 8 strain gauges were placed in each section, while in the second and third time, only the measured points with larger strain were observed.

The Gauges (Nos. 1.1, 1.4, 1.6, 1.7, 1.8) were scrutinized to capture maximum stresses on Section 1 (S1) near the foot of the tower. The sections S3 (gauges Nos. 3.4, 3.5, 3.8), and S4 (gauges Nos. 4.4, 4.5, 4.8) were used to observe maximum stresses in the position near the auxiliary material. Strain gauges at 2.4, 2.8 in S2, and 5.4, 5.8 in S5 were to monitor the axial stress of main member. Because of the load-end location of S6, stresses at points of 6.4, 6.5, and 6.8 were not taken as selective data points for analysis.

2.4. Test load

Prototype tower FEM was established with ANSYS (Manual 12.0) in consideration of geometric non-linear effect. Members in the whole tower were simulated with beam element BEAM188, an element based on Timoshenko beam theory and suitable for analyzing slender to moderately stubby/thick beam structures, shear deformation effects were included simultaneously. With invariant force distribution from the testing main member to its corresponding part in prototype tower, the test load of the space tower leg structure model was extracted. Detailed steps are shown as follows (Fig. 6):

(a) In the prototype tower FEM, measure the displacements (including both translational and angular displacements) of the upper end of the testing main member near the diaphragm.
(b) Built prototype leg structure FEM and apply displacement load got in step (a) with the model to extract the node counterforce of load point.

Fig. 1. Tower Collapsing During Full-Scale Test.

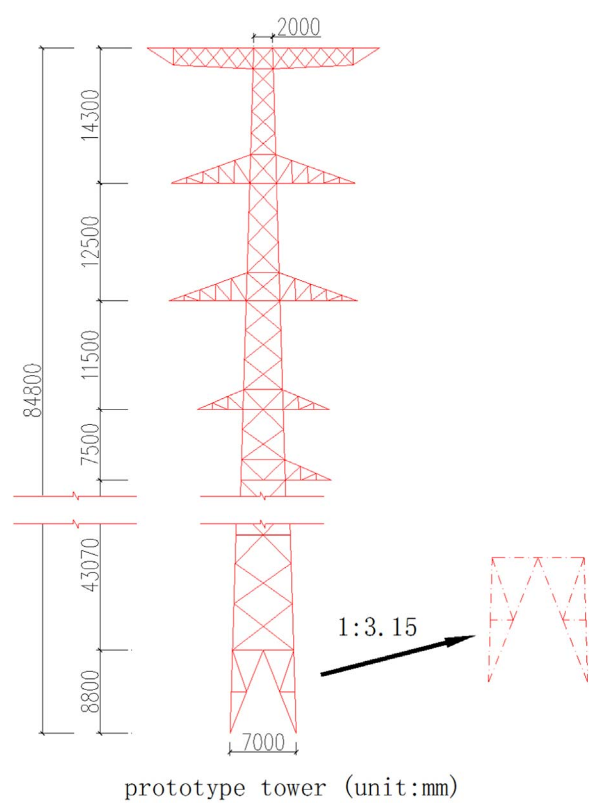

Fig. 2. Prototype Transmission Tower and Test specimen.