Thin-Walled Structures 131 (2018) 619–630

Contents lists available at ScienceDirect

Thin-Walled Structures

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

Full length article

Impact of wind loads on the resistance capacity of the transmission tower subjected to ground surface deformations

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ARTICLE INFO

Keywords:
Power transmission tower
Scaled tower model
Wind load
Ground movements
Axial stress

ABSTRACT

In this paper, two 1:2 scaled substructure models for a typical 110 kV transmission tower were designed and fabricated. The scaled tower substructure models were tested subjected to the stretching movements of horizontal ground surface under different wind load conditions. The wind speeds were assumed to be 15 m/s and 30 m/s, respectively in this study. The deformations of the tested tower models and the stresses and strains within the different members of the tower were fully measured. A large amount of the comprehensive test data was generated. Also a FE model using ANSYS was developed and validated by the test data. The research indicated that wind load has a significant unfavourable influence on the resistance of the transmission tower subjected to the ground surface deformation. Also the research showed that it is possible to use the FE model for the analysis and design of power transmission towers under ground surface movements.

1. Introduction

In recent years, with the increasing demands on electric power supply, it is very important to enhance the safety of power transmission line. Hence, considerable efforts have been made by different researchers to investigate the behaviour of power transmission towers under different loading and environmental conditions [1–6]. In some countries, such as China, many power transmission towers have to pass across coal mining areas. Therefore, the failure of the transmission towers are often happened due to the ground surface cracking, subsidence, non-uniform settlement, etc [7–10].

Another natural hazard to cause the failure of transmission tower is the strong wind load acting on the tower, resulted from tropical cyclones and tornados [11–13]. Hence, for the safety design of transmission towers in geological disaster areas, it is important to understand the behaviour of the transmission tower subjected to the combined effects of wind load and ground surface deformations.

Xie et al. [13] carried out an experimental study on a scaled tower model for a typical 500 kV transmission tower under strong wind load. The test investigated the failure mechanism of the transmission tower under combined static load and equivalent wind load. Momomura et al. [14] and Okamura et al. [15] investigated the dynamic characteristics of the transmission towers in mountainous areas. Yasui et al. [16] analysed the wind induced dynamic characteristics of the transmission towers with various bracing systems. A 1:2 scaled tower model was designed and tested by Moon et al. [12] to assess the failure mode of the transmission towers under wind load. Mara et al. [17,18] studied the effect of wind direction on the response and resistance capacity of a transmission tower, and evaluated the tower capacity by considering the uncertainty in material properties and geometric variables. These researches have well revealed the failure mechanisms of the transmission towers under wind loads.

In recent years, a number of researches have been done to assess the safety of the transmission lines in mining areas. The Island Creek Coal Company in Virginia enabled coal mining under high-voltage transmission towers through the controlling of the subsiding and deformation of ground surface by grouting [19]. Bruhn et al. [20] studied the response of the transmission towers subjected to ground deformations. White [21] reported an investigation of the effect of mining on transmission towers. Based on FE analysis for a typical transmission tower, Yuan et al. [22,23] studied the structural behaviour of the transmission towers subjected to ground movements. They conducted an experimental test on a scaled tower model based on a typical 500 kV self-supporting transmission tower. Shu et al. [24] studied numerically the

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https://doi.org/10.1016/j.tws.2018.07.020
Received 5 May 2016; Received in revised form 23 January 2018; Accepted 12 July 2018
0263-8231/

failure modes of the transmission towers in mining areas to obtain the limit state displacement of the supports under the ground surface deformations. Li et al. [25] investigated the effect of coupled interaction between vertical load and the ground surface deformation.

As mentioned above, according to the authors' knowledge, there were no experimental studies which have been conducted to study the structural behaviour of the transmission tower under combined wind load and ground deformation. Hence, the main objectives of this research are:

- Develop a FE model using ANSYS for modelling a typical prototype of 110 kV power transmission tower under combined wind loads and horizontal ground surface motion. Based on the FE analyses, two 1:2 scaled sub-structure tower model are designed and fabricated.
- Conduct the two tests on the 1:2 scaled sub-structure tower model with isolated tower leg's foundations to investigate the behaviour of the 110 kV power transmission tower under both the wind loads and horizontal ground surface motions. In this research the wind speeds acting on the towers were assumed to be 15 m/s and 30 m/s. The tests generate a series of valuable data on the failure modes of the transmission tower; stress and strain states within the structural members of the tower and the relationship between the tower's deformations and support's movements.
- Validate the developed FE model, using the test data, for modelling 110 kV power transmission tower with isolated tower leg's foundations under both wind loads and horizontal ground surface movements.

2. Experiment's design and implementation

2.1. Design of the scaled tower substructure models

The prototype of full tower selected here is a typical 110 kV single-circuit tower. As shown in Fig. 1, the total height of the tower is 26.7 m. The support spacing is 4.035 m in the direction normal to the power line, and 3.125 m along the power line. According to the references [22–24], it is reasonable to select the lower part of the tower (within the rectangular dash line, as shown in Fig. 1) as the prototype of the 1:2 scaled tower substructure model (called scaled tower model in the rest of this paper). As shown in Fig. 2, the height of the scaled tower model is 4 m, the dimensions of the top and bottom of the scaled tower model are 1530 × 1200 mm and 2018 × 1563 mm, respectively.

The scaled tower models were fabricated in the State Grid Jiangsu Huadian Steel Tower Manufacturing Co., Ltd. The tower's legs were made of hot-rolled angle steel, and the bracings, diaphragms and subsidiary members were made of cold worked angle steel. The sectional details of the structural members of the prototype tower substructure and scaled tower model are given in Table 1. The tested yield strengths of the steel angles are listed in Table 2. The bolts used in the prototype whole tower were the Grade 4.8 galvanized M16 bolts. According to the scale of 1:2, the bolts used for the scaled tower model should be not less than Grade 4.8 M8 bolts. In order to avoid the premature failure of the joints caused by the bolts' stress concentration, in this study the Grade 8.8 galvanized M8 bolts were used. To keep the bolt pre-tightening force as constant, the tightening torque was controlled in accordance with the standards of magnitude 4.8 M8 bolts. The yield torque of the Grade 8.8 galvanized M8 bolts was calculated based on the Chinese National Standard (GB/T 16823.2–1997), which was 18.1 N·m. Hence, in this research, the tightening torque of the bolts for the scaled tower model was set to be 18 N·m.

2.2. Load and support's displacement

Research conducted by Manis and Bloodworth [26] indicated that for the case of UK transmission towers it is the 45 degree wind

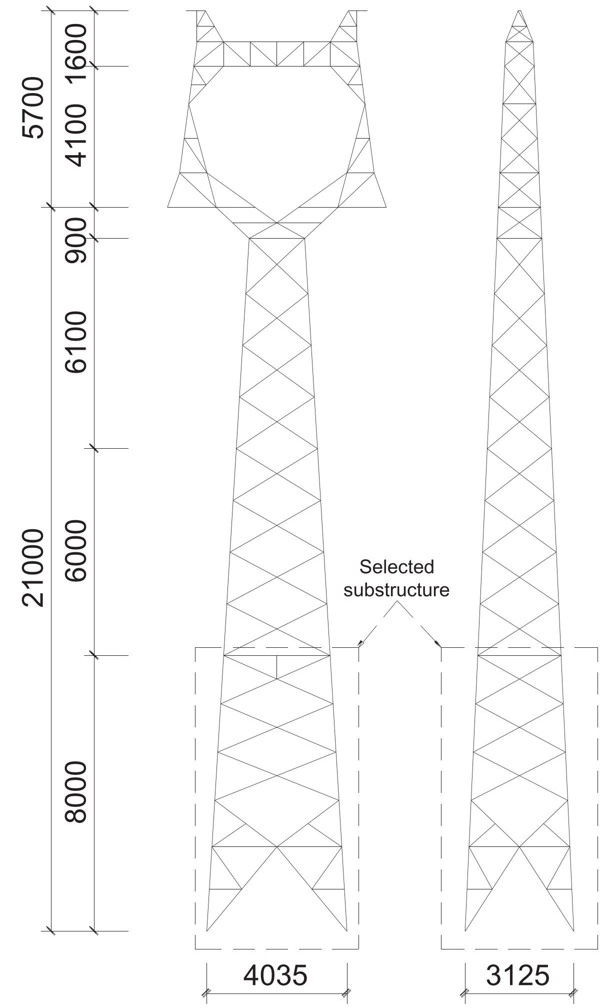

Fig. 1. A prototype of 110 kV single circuit transmission tower (all dimensions in mm).

orientation that gives lower load capacity of the tower due to one leg becomes more heavily loaded in compression rather than two. Previous design experience indicated that, for those towers without influence by mining subsidence, the 45 degree wind orientation normally gives failure of tower's leg while the 90 degree wind orientation gives failure of X-cross bracing members. The background of this research is to consider the behaviour of the transmission towers located in the subsidence areas caused by coal mining. Previous research [27] pointed out that one of the main failure modes of the transmission towers subjected to horizontal ground movement is the failure of X-cross bracing members. Therefore, in this research, only the ground deformation and wind load along the direction perpendicular to the wire is considered. The test results will be used to validate finite element model. The validated FE model can be used to investigate in more details for the influences of different ground deformation and wind load directions on the behaviours of the towers.

In this research, the combined wind load, normal vertical load due to self-weight of the tower and power line and support's movement resulted from the ground movement were considered. The wind speed considered in this test was based on the current design recommendation specified in Chinese code for the prototype transmission tower. The maximum wind speed of the tower in the design is 30 m/s. In order to take into account the influence of different wind speeds, a wind speed of 15 m/s was also used for comparison. The comparison can clearly reveal the influence of wind load on the tower's ability to resist ground surface deformation caused by mining. Hence, for the wind load, two