Engineering Structures 123 (2016) 166–180

Contents lists available at ScienceDirect

Engineering Structures

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

The behaviour of the power transmission tower subjected to horizontal support's movements

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ARTICLE INFO

Article history:
Received 21 September 2015
Revised 22 April 2016
Accepted 17 May 2016
Available online 11 June 2016

Keywords:
Power transmission tower
Horizontal support's movements
Scaled test tower model
FE analysis

ABSTRACT

In this paper, two half-scaled test tower models for a typical 110 kV single-circuit power transmission tower were designed and fabricated. The scaled test tower models were tested under the horizontal support's stretching (tensile) and compressive movements with the normal working loading conditions. The deformations of the tested tower models and stresses within the different bracing members were fully measured. A large amount of comprehensive test data was generated. Also a finite element (FE) model using the software ANSYS was developed and validated by the test data. The research indicated that the designed half-scaled test tower model can reasonably represent the behaviour of the whole transmission tower under the horizontal support's movements. The magnitude of the stresses was reduced from the bracing members at lower part to the bracing members at higher part of the tower. The effect of the ground surface deformations is more significant on the truss members closed to the supports. Hence, for the design of transmission tower against the horizontal support's movements, it is important to reduce the slenderness of those bracing members.

1. Introduction

With the increasing demands on electric power supply, more and more power circuits have been developed in the serious geological disaster areas, such as coal mining areas, massive backfilling areas, and frost heaving soil or in permafrost soil areas [1–3]. These geological disasters cause the horizontal stretching or compressive movements, overall sinking and uneven settlement and deformation in the ground surface, which may break the ground circuits, even leading to power failure, relocation of power transmission tower, or re-routing power circuits [1]. In certain countries or areas, excessive excavation of coal resources has caused serious geological disasters, threatening the safe running of power supply. This problem has been much concern in engineering sectors [2]. The Island Creek Coal Company [4] in Virginia, USA, developed a grouting method to control the ground surface settlement and deformation in excavated areas to enable the coal mining under the pylons. Bruhn et al. [5] studied the structural response of a steel-lattice transmission tower to mining related ground movements. Bruce [6] investigated the impacts of underground coal mining on the surface constructions, including the pylons. Yuan et al. [7,8] studied numerically the influences of the ground surface deformations on the internal forces within the structure members of transmission tower, and also assessed the safety of the tower due to the ground surface deformation. An experiment investigation was also conducted on a scaled tower model of a 500 kV power transmission tower subjected to the horizontal stretching followed by compressive deformation of the supports. Shu et al. [9] utilised FE method to analyse the failure modes of the transmission tower under various ground surface deformation conditions to obtain the displacement limits of the supports against various ground surface deformation conditions.

No doubt, full scale testing is very important on the determination of transmission tower type and their structural designs. At recent years, China Electric Power Research Institute conducted a full scale test on a 220 kV power transmission tower with heavy ice load [10]. Prasad Rao et al. [11] conducted the full scale tests and FE analyses on the five power transmission towers of 132 kV, 275 kV and 400 kV and compared the failure modes under various load combinations. The research indicated that the calculated load resistances of the tower structural members with different slenderness ratios by using ASCE code were greater than the test results. The load resistances of the cross bracing members calculated using BS specifications were less than but closer to the test data. However, the load resistances of the single bracing members calculated using BS code were still greater than the test results.

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http://dx.doi.org/10.1016/j.engstruct.2016.05.027

Due to the unfavourable action, single bracing should be avoided in practice. The research also demonstrated that nonlinear analysis was superior to linear analysis for modelling the stress state and the failure mode of the truss structure.

Ahmed et al. [12] carried out a study on the influence of the slippage of bolted joints on the behaviour of transmission towers. The research indicated that the tower-leg joint slippage has a significant influence on tower behaviour by either reducing the load carrying capacity or significantly increasing the deflections under working loads. Yang et al. [13] developed a finite-element model by using the software ANSYS for modelling of a typical 1000 kV transmission tower under different load cases, which included foundation settlement, slip, and inclination combined with normal design loads. The research indicated that the foundation deformations have considerable impacts to reduce load carrying capacity of the transmission towers.

At present, the majority of full scale tests for the transmission tower focused on the validation of the resistance of the tower structure under typical design loading conditions, such as normal working condition, wind condition, and ice covering condition. The full scale tests are very expensive and require a larger testing space and loading equipment. Also in the test, it is difficult to take into account the special undermining conditions. Fortunately, previous researches indicated that through scaled model tests and FE analyses, the deformation and failure mechanism of the transmission tower under different conditions can be reasonably assessed. Moona et al. [14] showed that half-scaled test model and FE analysis could reasonably reflect the structural response and deformation rule of the 152 kV transmission tower. Xie and Sun [15] conducted two half-scaled test tower models for a 500 kV transmission tower to investigate the deformation and failure of the tower structure under equivalent ice loading. In addition, the tests of scaled tower test model and FE analyses conducted in Refs. [7–9] also confirmed the feasibility of utilising scaled test tower models in structural analysis. Therefore, the tests on the scaled test tower model make it possible to study the deformation resistance of transmission towers in mining areas.

From the authors' knowledge, there is no any full scale test (for considering the structural resistance of the transmission tower subjected to the ground surface movements due to undermining) has been conducted. Hence, the main objectives of this research are:

- Develop a FE model using ANSYS for modelling the 110 kV single-circuit power transmission tower subjected to the horizontal support's movements. Based on the FE analyses, two half-scaled test tower models to represent a typical 110 kV single-circuit power transmission tower are designed and fabricated.
- Conduct two tests on the half-scaled test tower model to investigate the behaviour of the 110 kV single-circuit power transmission tower subjected to horizontal support's movements under normal working condition. The corresponding failure modes, stress states in the structural members and the relationship between the deformations and support movements are studied in detail.
- Validate the developed FE model, using the test data, for modelling the full-scale 110 kV single-circuit power transmission tower subjected to ground surface deformations.

2. Design and fabrication of the scaled test tower model

2.1. Design of the scaled test tower model

The prototype of the scaled test tower model is a typical 110 kV single circuit Cat-head like 1B-ZM3 transmission tower. As shown in Fig. 1, the tower is 26.7 m high; the support spaces are 4.035 m perpendicular to the line direction and 3.125 m along the line direction. In order to design the scaled test tower model (substructure) which is a good representation of the full-scale tower, a FE model by using ANSYS was developed for modelling the full-scale tower subjected to horizontal supports' movements. The predicted overall deformations and stress states of the tower structure were analysed in detail to identify the influence scope within the tower, caused by the horizontal deformations of ground surface.

The results of FE analyses showed that the truss members within the bottom part of the tower were most susceptible to horizontal relative movements in the supports. The influences deceased upwards along the tower height. At above the second diaphragm member (8 m up from the support's level, in Fig. 1) the influence due to ground surface deformations is negligible. According to the results of the FE analyses, the selection of steel angle members for the scaled test tower model, and available loading equipment in the lab, only part of the tower below the second diaphragm member was selected as the substructure for the scaled test tower model (in Fig. 1). The scale of the test tower model was set to be half-scaled (1:2), so the cross section area of the truss members for the scaled test tower model was 1/4 of the cross section of the truss members for the original full-scale tower. As shown in Fig. 2, the height of the scaled test tower model was 4 m, and the sizes of the top and bottom sections of the scaled test tower model were 2018 × 1563 mm and 1530 × 1200 mm, respectively.

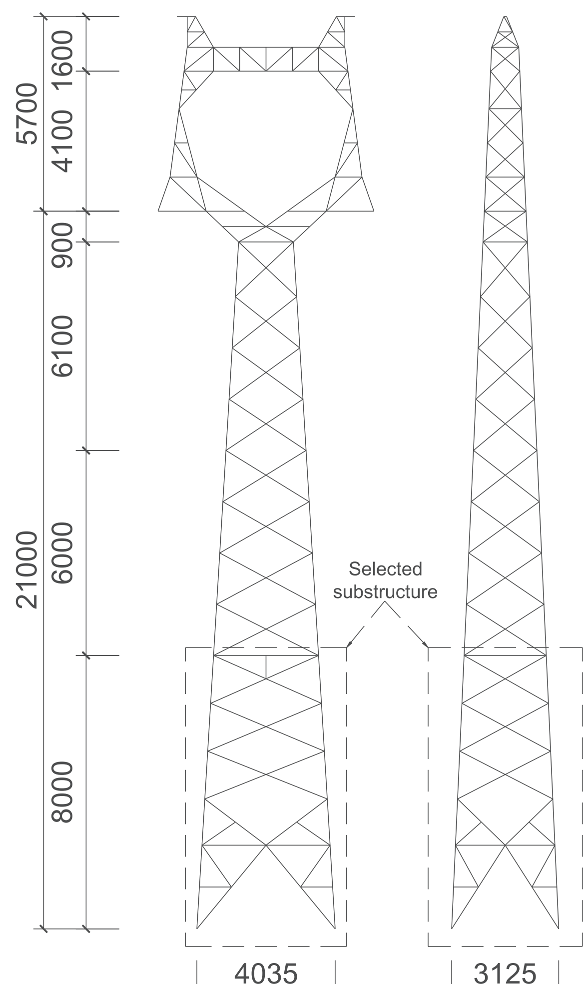

Fig. 1. A prototype of 110 kV single circuit transmission tower (all dimensions in mm).