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Wind forces on circular steel tubular lattice structures with inclined leg members

Yan Li[a], Zhengliang Li[a], Bowen Yan[a,*], Zhitao Yan[a,b,*]

[a] Key Laboratory of New Technology for Construction of Cities in Mountain Area (Ministry of Education), School of Civil Engineering, Chongqing University, Chongqing, China

[b] School of Civil Engineering, Chongqing University of Science and Technology, Chongqing, China

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ABSTRACT

The wind forces on the steel lattice structures have drawn increasing concerns in the structural design of high-rise and long-span buildings and structures due to their low damping, light self-weight, and high flexibility. The aim of this paper is to assess the aerodynamic forces on circular steel tubular lattice structures with vertical and inclined leg members using the wind tunnel tests. In order to elucidate the underlying mechanism of wind loads contributed by the individual members of lattice structures, a new type of rigid experimental model for High-frequency force balance (HFFB) wind tunnel tests is proposed in the study. And the individual member of lattice structures can be sequentially removed until remaining vertical or inclined leg members, which is referred to as "member subtraction". The experimental results reveal that with the same solidity ratio, the drag coefficient of lattice structure with inclined leg members is approximately 9% smaller than that with vertical ones. This indicates that the configuration of steel lattice structures, such as inclined leg members, might exert indispensable effects on the drag forces, which has yet been considered in the current wind codes and standards. In addtion, in order to clarify the interference mechanism between the leg and diagonal members, the wind tunnel tests of a three-cylinder model are performed and the wind tunnel results indicate that the presence of diagonal members in lattice structures would increase the overall drag coefficients in the scenario of small separation distances. Finally, the advantages and disadvantages of structural configuration (with and without horizontal or diagonal members) and their implications on structural design are discussed.

1. Introduction

In the past decade, with the advances in innovative constructional technologies and high-strength materials, the steel lattice structure has been increasingly incorporated in the construction practice of high-rise and spatial steel structures such as power transmission towers and long-span roof. The high-rise or long-span steel lattice structures, however, is significantly susceptible to lateral loads such as winds due to its light self-weight, high flexibility, and low damping [1,2]. And the structural damages and progressive collapses of the power transmission towers have been often reported under extreme wind events [3,4]. It has been well recognized by the policy-maker, project managers, and structural designers that the wind-resistance is one of the primary concerns during the structural design of high-rise steel lattice structures.

The evaluation of wind loads on buildings and structures mainly relies on the available wind codes and standards, whose specifications are generally based on the wind tunnel tests of downscaled models of generic shapes and layouts. However, it has been highlighted by several researchers that the geometric shapes and layouts of steel lattice structures in the realistic environments may be considerably different from those specified in the available wind codes. The horizontal or diagonal members in the spatial lattice structures might either decrease or increase the flow-induced forces on a structure, mainly depending on the configuration of lattice structures, their orientation with respect to the direction of flow, and tilt angle of the leg member. Most of the existing studies concerning the wind forces on the lattice structures were conducted by HFFB tests in the wind tunnel to measure the global aerodynamic forces. Bayar [5] proposed that the maximum effective wind forces on the lattice tower structures occurred at the wind incidence angle of 45°. Carril et al. [6] studied the wind forces on a lattice communication tower considering the effects of antennas and indicated that the shielding effect of the antenna increased with the tower solidity ratio. Mara et al. [7] experimentally investigated the effects of the vertical wind components in the upstream flow on two typical lattice

* Corresponding authors at: Key Laboratory of New Technology for Construction of Cities in Mountain Area (Ministry of Education), School of Civil Engineering, Chongqing University, Chongqing, China (Z. Yan).
E-mail addresses: bowenyancq@cqu.edu.cn (B. Yan), yanzhitao@cqu.edu.cn (Z. Yan).

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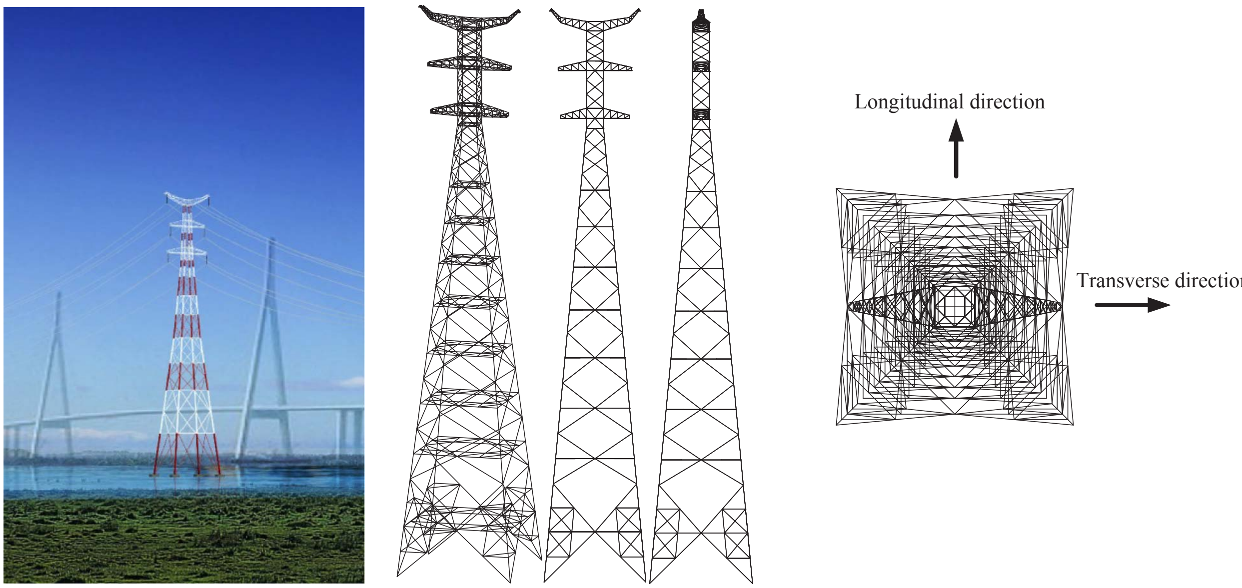

(a) Design sketch (b) Schematic picture (c) Projection drawing from the bottom

Fig. 1. Power transmission tower in Huainan - Nanjing – Shanghai UHVAC transmission line.

sections for a guyed transmission tower. Furthermore, they [8] discussed the influence of solid area layout on the drag force for a two-dimensional lattice section. Moreover, the aerodynamic loads on simplified lattice structures with angle members were evaluated through integrating the wind forces on each individual member by Prud'homme et al. [9]. Lou et al. [10] obtained the wind pressure distribution of leg, diagonal and auxiliary members using the Synchronous Multiple Pressure Sensing System (SMPSS) in the wind tunnel. In addition, the wind loads on the conductor support arm of a transmission tower have been studied [11,12]. The aforementioned research efforts have laid a solid foundation for the wind-resistant design of lattice towers in constructions.

In the various codes and standards for wind loads on the lattice structures [13–16], the drag coefficients are usually evaluated with respect to their solidity ratio and geometric shapes of leg members. It is worth noting that the presence of accessory members such as horizontal and diagonal bars and inclined leg member is quite common in the actual practice of steel lattice tower structures as shown in Fig. 1(a). Nevertheless, there is significantly inadequate research on the effects of inclined leg members, horizontal members and diagonal members on the overall wind loads of lattice structures. The main reasons seem to explain the lack of a comprehensive and generalized set of guidelines on these aforementioned critical factors. First, the problem is rather complex even for a simplified lattice structure with both leg and diagonal members. And there are a large number of variables involved, including the size and shape of individual members, the layout of lattice section, wind direction, and tilt angle of leg members. Secondly, there is short of available experimental data. Thirdly, the adverse effects due to the auxiliary members such as horizontal and diagonal bars on wind loads of lattice structures are grossly underemphasized.

The paper firstly aims to experimentally investigate the aerodynamic loads of circular steel tubular lattice structures with inclined leg members and elucidate the underlying mechanism of wind loads contributed by the individual members of lattice structures. To the best knowledge of the authors, such an experimental study has rarely been in detail conducted in the accessible documents. In this study reported herein, two types of lattice sections were designed and tested to quantitatively assess wind loads on the lattice structures with inclined leg members. And a new type of the rigid experimental model of lattice structures was adopted in the HFFB wind tunnel tests to study the influences of individual members on the overall drag forces of lattice structures. The second objective is to analyze the aerodynamic interference effects between the leg and diagonal members of lattice structures. And the wind tunnel tests of a three-cylinder model were performed to qualitatively assess the interference mechanism between the leg and diagonal members. Thirdly, since removal or addition of horizontal and diagonal members is dictated by structural analysis and strength considerations, this study further discussed the advantages and disadvantages of either structural configuration (with and without horizontal or diagonal members) and its relation to the current design practice for this type of structures.

2. Wind tunnel tests

2.1. Test models

(1) Lattice sections

In order to study the effects of inclined leg members on the drag forces of lattice structures, two types of lattice sections are designed and tested for comparison purposes. The prototype of lattice section with the inclined leg member (Model A) is fabricated according to the design sketch of a super high-rise power transmission tower in Huainan - Nanjing – Shanghai UHVAC transmission line as shown in Fig. 1. The tilt angle of leg member is of 5° as shown in Fig. 2(a) of Model A and the scale ratio is of 1:30. The second type of lattice section (Model B) as presented in Fig. 2(b) is composed of vertical leg members with the same solidity ratio as Model A. Both test specimens in the wind tunnel tests were made of circular steel tubes. The outer diameters of the leg, diagonal and horizontal members are 57 mm, 20 mm and 17 mm, respectively. The overall heights of both Models A and B are both 474 mm. The center-to-center distance (B) of the adjacent leg members divided by the diameter of the leg member (D) is defined as the spacing ratio (B/D). And the width of both Models A and B at the middle height is 570 mm, corresponding to the B/D of 10.

The models were mounted vertically on the HFFB using the base-plate. An end-plate was fixed at the top to diminish the end effects. To investigate the influences of individual members of lattice structures on the drag forces, a new type of rigid experimental model of lattice structures was proposed and adopted in the HFFB tests reported herein.