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Effect of internal stiffening rings and wall thickness on the structural response of steel wind turbine towers

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ABSTRACT

In this paper, the structural response of steel tubular wind turbine towers with various design configurations is analysed using FEM modelling. Towers of various heights between 50 and 250 m are considered and investigated with three different design options as follows: (i) thick walled tower with internal horizontal stiffening rings, (ii) thick walled tower without stiffening rings and (iii) thin walled tower with stiffening rings. Based on this analysis, weight reduction ratios are examined in relation to the horizontal sway and von Mises stress increase ratios in order to identify a more efficient design approach between reducing the wall thickness and adopting internal stiffeners. All studied design solutions satisfy the strength and serviceability requirements as specified by the design codes of practice. In the final part of paper, the dynamic characteristics of these three types of towers have been examined to obtain the natural frequencies and mode shapes. The studied model ignored the mass of nacelle-rotor system and the wind turbines, namely, only the isolated tower was included. Furthermore, the recommendations to avoid resonance for each height case are proposed.

1. Introduction

The use of renewable energy and in particular, wind energy, mitigates the rate of environmental deterioration as it minimises the emission of greenhouse gases. Wind energy appears as a clean and appropriate solution to cope with a great part of this energy demand. Currently, wind energy is extensively used and the underpinning technology is developing very rapidly. In Denmark, for example, 20% of electricity had produced from wind by 2007, and it is planned that 50% of Danish electricity needs will be met by wind generation by 2025 [1]. China's wind market has continued its high growth rates in the past few years, and an additional capacity of 6.3 GW of wind power has been installed in China, bringing the total capacity to 12.2 GW by 2008 [2]. Wind turbines are energy converters that convert kinetic energy from the moving air to electrical power; they are attached to supporting towers that also support the rotor and the power transmission and control systems. One of the most common design options for wind turbine towers is a tubular steel structure manufactured in sections of 20–30 m with flanges at both ends facilitating the bolting of these sections *in situ*.

Economic efficiency is a key parameter that needs to be considered in the design of a wind turbine tower. As a proportion of the total cost, the construction cost of the wind turbine accounts for a considerable percentage, i.e. approximately 15–20%. The materials used, and subsequently the weight of the system, determine the costs incurred during transport and erection. The height of a tower directly determines the energy yield, and hence will be determined before the design process commences [3].

A successful structural design of a tower should meet the design criteria of cost effectiveness, safety and functionality. Given the proportion of steel material cost in the total cost of the wind tower, a material efficient design with satisfactory performance becomes an important step in the wind turbine tower construction. Negm and Maalawi [4] considered the cross-sectional area, the radius of gyration and the height of each segment as the key design variables, and suggested five design options before reaching the final one. Bazeos et al. [5] analysed a prototype wind turbine steel tower with respect to its static and dynamic behaviour and other destabilizing effects. The refined and simplified models developed for static and seismic analyses are compared with each other and are in close agreement. Lavassas et al. analysed and presented the detailed design of a prototype of a tubular shaped 1 MW steel wind turbine tower, with a variable wall thickness along the height

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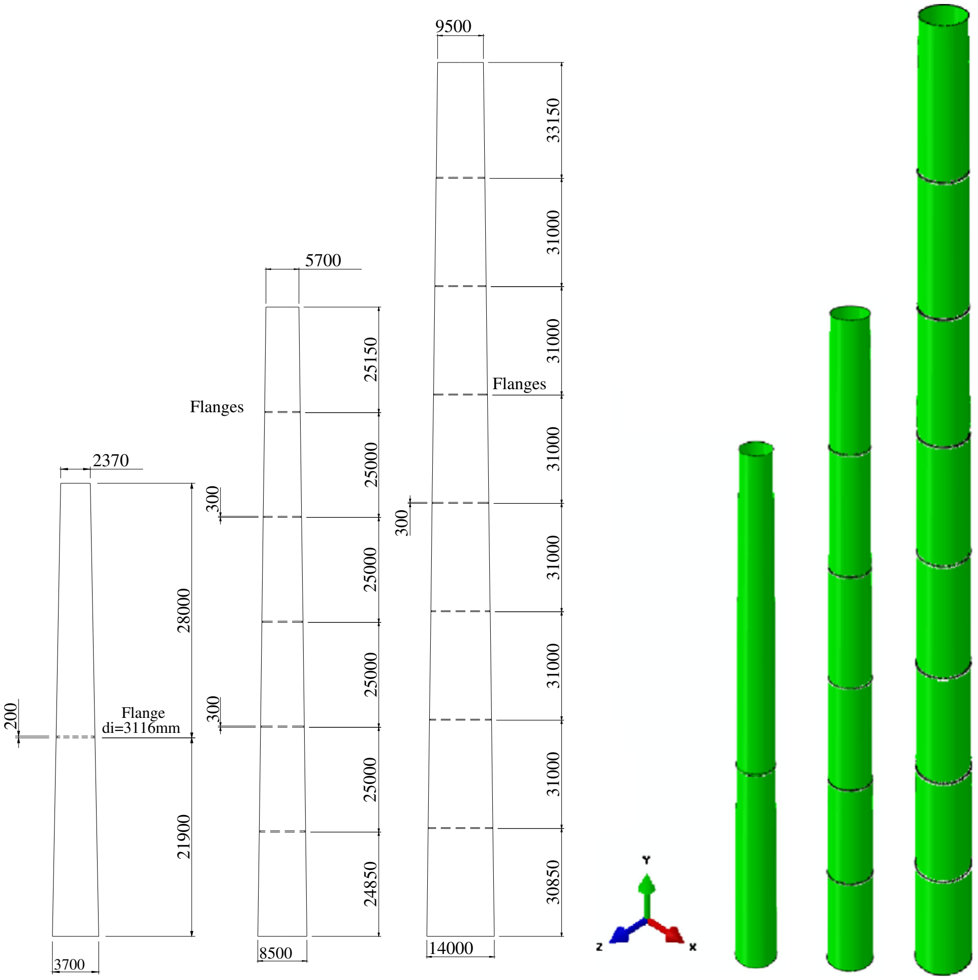

Fig. 1. Tower prototypes of three different heights: geometrical data and FEM models.

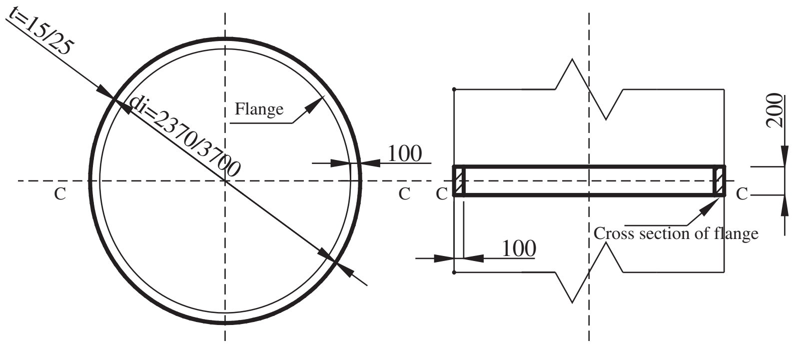

Fig. 2. Typical cross-section of the 50 m height tower (in mm).

Table 1
Material properties of structural steel of the wind turbine tower.

Material property	Elastic modulus (GPa)	Density (g/cm^3)	Poisson's ratio
Steel	205	7.85	0.3

of the tower [6,7]. Uys et al. [7] undertook a cost minimisation study for a steel tower where the cost function was formulated by including material and manufacturing cost. Jiang et al. [8] numerically simulated the welded joints between the tower and bottom flanges in a wind turbine by taking the residual stress into consideration. Results show that complex residual stresses are generated in the fillet weld. Recently Chou and Tu [9] investigated the collapse mechanism of a large wind turbine tower, and reviewed similar accidents in other countries to identify potential risk factors affecting the lifecycle of wind turbines. Li et al. [10] proposed some advice, in terms of economic efficiency, for designing a typhoon-resistant wind turbine for use in countries where tropical cyclones often occur. Perelmuter and Yurchenko [11] reported a parametric study procedure which employs steel conic shell towers for high capacity wind turbines. Dimopoulos and