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Investigation of nonlinear dynamic behavior of lattice structure wind turbines

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ABSTRACT

Wind turbines are kinds of electricity generators, proliferating nowadays due to their consistency with the environment. The rotation of the wind turbine blades duo to wind, burdens some frequencies on the wind turbine tower. Therefore, in addition to common design due to service loads, the wind turbine tower should be checked in the frequency analysis so that its natural frequencies do not coincide with the frequencies caused by blades rotation, resulting in the resonance of the tower and its failure. This makes the design of these structures to be complex. In this research, the frequency analysis of the lattice tower of a three-blade horizontal-axis wind turbine including different sources of nonlinearities, i.e., geometric, material and joint slip effect is carried out and the natural frequencies are obtained using the developed Nonlinear Analysis Software for Towers -NASTower-. It is observed that the joint slip effect can substantially reduce the natural frequencies of the lattice tower, which are significant in the design of these structures. In addition, the wind turbine displacements due to different design load cases are investigated, indicating that incorporating the joint slip effect into the analysis substantially increases the wind turbine displacements, which could affect on its performance.

1. Introduction

In recent years, the tendency to renewable energies has been increasing due to the environmental problem caused by the use of fossil fuels. Wind energy is one of renewable energies, extracted from wind, using wind turbines to produce electrical energy. Therefore, the analysis and design of the wind turbines is one of the structural and mechanical engineering problems. The wind turbines are mostly mounted on the tubular and lattice towers and it is an advantage to have a high tower, since wind speeds increase farther away from the ground. In the analysis and design procedure of the wind turbines it is necessary to avoid the coincidence of the blades rotation frequencies with the natural frequencies of the tower, which brings about the resonance of the tower and its failure. This makes the design of the wind turbine towers to be complex.

Many of researchers have devoted themselves to the study of the wind turbines. Gebhardt and Roccia presented an aeroelastic model intended for three-blade large-scale horizontal-axis wind turbines [1]. This model results from the coupling of an existing aerodynamic model and a structural model based on a segregated formulation derived in an index-based notation that enables combining very different descriptions such as rigid-body dynamics, assumed-modes techniques and finite element methods. Also, a novel design optimization model for placing frequencies of a wind turbine tower/nacelle/rotor structure in free yawing motion was developed and discussed by Karam and Maalawi [2]. The main aim was to avoid large amplitudes caused by the yawing-induced vibrations in the case of horizontal-axis wind turbines or rotational motion of the blades about the tower axis in case of vertical-axis wind turbines. This could be a major cause of fatigue failure and might severely damage the whole tower/nacelle/rotor structure. Jia presented a practical and efficient approach for calculating wind induced fatigue of tubular structures, the effects of the wind direction, across wind and wind grid size on the high cycle fatigue of the structure were addressed [3]. A grid is defined which covers the whole structure. For each node in the grid a time series is generated. This time series contains the mean wind speed and the statistical properties of the fluctuating part of wind components as defined by the one point wind spectra and the coherence functions. In each time step of the dynamic response calculation, the large deformation effects and the wind induced drag forces due to the

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updated structural deformations are taken into account. Moreover, a new design scheme of light weight structure for wind turbine tower was presented by Li and Lu [4]. This design scheme is based on the integration of the nanostructured materials produced by the Surface Mechanical Attrition Treatment (SMAT) process. The objective of this study was to accomplish the weight reduction by optimizing the wall thickness of the tapered tubular structure. Andersen et al. presented a probabilistic approach about the natural frequencies of wind turbines on monopile foundations in clayey soils [5]. A nonlinear stochastic p-y curve was integrated into a finite difference scheme for calculation of the monopole response in which p is the soil resistance and y is the absolute value of the pile deflection.

Furthermore, the investigations on the nonlinear behavior of lattice structures are frequently observed in the literature. Al-Bermani and Kitipornchai presented a nonlinear analytical technique for simulation of the ultimate structural behavior of self-supporting transmission towers, incorporating both geometric and material nonlinearity effects. Modeling of material nonlinearity for angle members is based on the assumption of lumped plasticity coupled with the concept of a yield surface in force space. Several transmission towers were modeled and analyzed in developed AK TOWER, which stands for incorporating the presented technique, to simulate their behavior in the full-scale experiments [6–10]. Moreover, Chan and Cho proposed a practical second-order analysis and design method for trusses composed of angle sections. Realistic modeling of semi-rigid connections associated with one- and two-bolt end-connections with flexible gusset plate and member imperfections such as initial curvatures and residual stresses is made and load eccentricity is also simulated [11]. Also, Ungkurapinan studied the behavior of such joints, incorporated 36 joint tests, generated joint slip data and developed mathematical expressions to describe slip and load-deformation behavior. In this study, it was concluded that joint slip effect cannot be eliminated and incorporation of the reported joint slip data or mathematical expressions in the tower analysis software will refine their results [12]. Afterwards, Ungkurpinan joint slippage models were employed by Jiang et al. in the modeling of a transmission tower, which resulted in improvement in the displacements results, coinciding with the full-scale test results [13]. In other research, the nonlinear finite

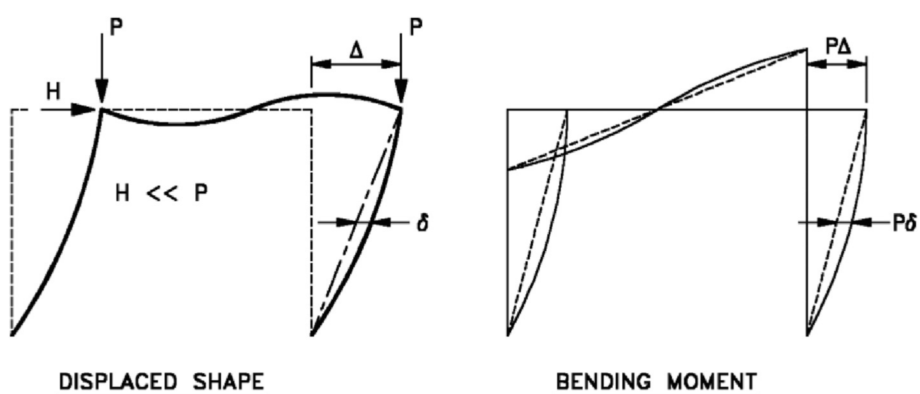

Fig. 1. Nonlinear effects: P-Δ and P-δ

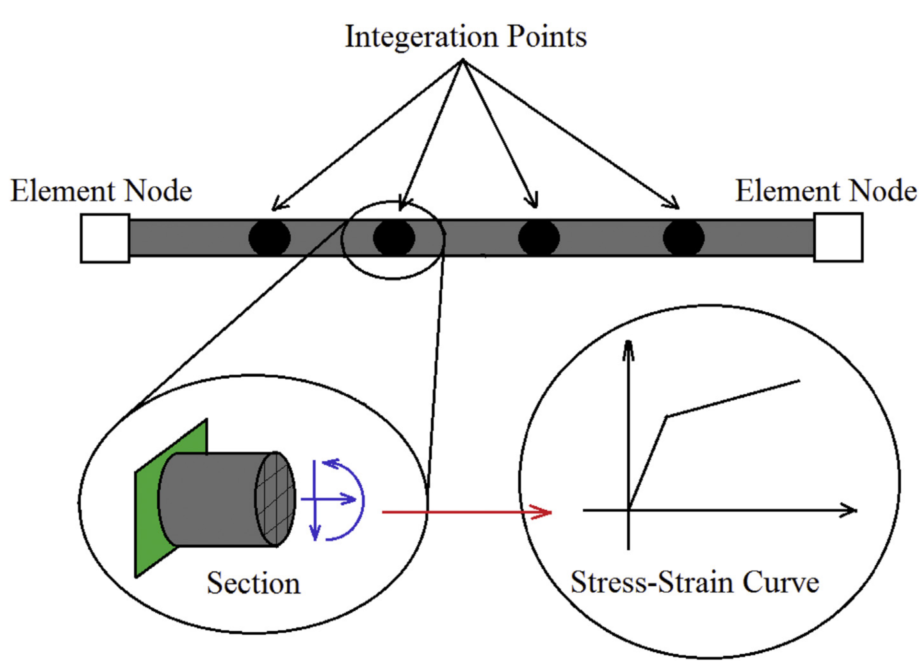

Fig. 2. The detail of a element with fiber section.