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Finite Element Analysis of Wind Turbine Tower by using Structural Steel

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ABSTRACT

The present work aims at the Static Structural Analysis of Wind Turbine Towers structural steel through Finite Element Modelling (FEM) Method using Ansys Workbench v16.1. Wind Turbine Towers are assumed to be cantilever beam which is fixed at the base and free to deflect at the top of the tower with uniformly varying cross-section along the height of the tower. The simulation results are then validated with the analytical results (using Simple Bending Equation) from directional deformation and bending stress. For the design of the Steel Tubular Tower with 80 meters hub height, base diameter is assumed to be the design parameter for the wind turbine tower. Finally, results from directional deformation and bending stress have extrapolated for higher wind turbine tower (120 meters and 150 meters).

Keywords: Structural steel, wind tower, finite element analysis

1 Introduction

Depending on the form of energy they supply, the classification of the energy sources as: Primary energy encompasses the forms of energy that are directly consumed as they are found in nature, without any processing. The various forms of coal, crude oil, natural gas, hydraulic energy and passive solar energy are among these forms, Secondary energy forms are used by the consumers in a refined, processed form. The liquid petroleum products derived from crude oil, such as gasoline, diesel and kerosene; fuel from biomass; biodiesel; solar collector energy; and thermal geothermal are among the secondary energy forms and Tertiary energy forms involve one or more transformations of energy. Electric energy, in any way it is produced, is a tertiary form of energy. Nuclear energy, wind power and most of the other renewable energy sources when they are used to produce electricity contribute to the supply of tertiary energy. Secondary and tertiary forms of energy must be produced from primary sources. The main primary energy sources that have satisfied the global energy demand since 1970 are shown in figure 1.1. These primary sources are classified as: a) The various forms of coal (anthracite, bituminous, lignite, peat), b) Crude oil/petroleum, c) Natural gas, d) Nuclear, e) Hydroelectric energy or water energy, f) Biomass and waste, which primarily comprises trees, and g) Other renewable forms such as solar, wind and geothermal.

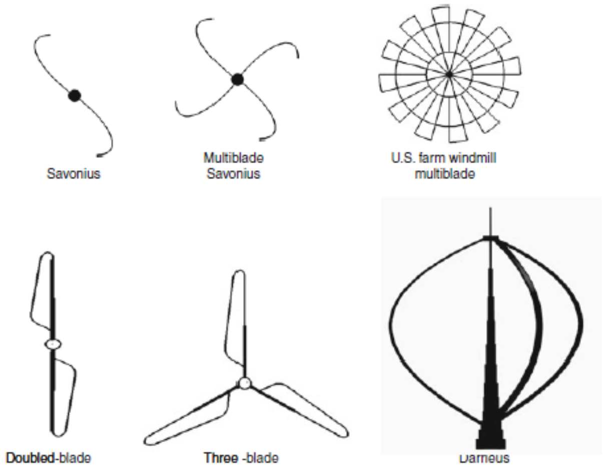


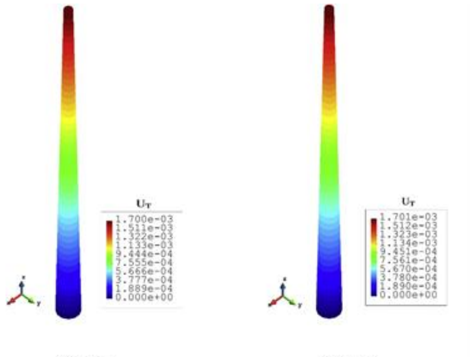
Figure 1: Types of common wind turbines

Angelina Jay et al. (2016) [8] studied the buckling strength and fatigue strength of a tapered tubular steel tower through on-site fabrication using spiral welding technique. This method removes the limitation on the tower with a diameter-to-thickness ratio up to 300 and enables easy installation of the very large turbine with a diameter-to-thickness ratio up to 500.Amlan Das et al. (2015) [9] studied both guyed wire and freestanding lattice towers. The lattice towers were modelled in three different shapes (triangular, rectangular and trapezoidal) and two different sections (Pipe and Angle). The entire tower divided into three parts, and models are designed and analyzed under static and dynamic conditions in STAAD Pro software. The values of section size were varied continuously to achieve the optimum shape and size.Alvarez Anton et al. (2016) [10] developed a new method (Hybrid Towers) for manufacturing tower with reduced weights. This new hybrid tower is composed of a concrete tower contain prefabricated quarter-circle elements of elements and steel tube at the top of the towerMeng Ran et al. (2014) [11] studied the comparison between steel tubular tower and concrete tower and developed an optimized design process for pre-stressed concrete towers. They created a pre-stressed concrete tower using a regular octagon cross-section with inner ribs on each side, which was optimized by comparing the natural frequency and stress difference under the same lateral load in different directions of the tower using ABAQUS software (FEM modelling).

Figure 2 A prototype-scale, hand-welded example of a tapered, spirally-welded wind turbine tower (Image provided courtesy of Keystone Tower Systems) [8]

Figure 3 Design of hybrid towers [10]

Mingyang Li et.al. (2020) [17] with the increasing popularity of wind energy, offshore wind turbines (OWTs) are currently experiencing rapid development. However, the tower will not only stand its own weight and weight of the top structure, but also be surrounded by harsh wave and wind loading conditions. Therefore, it is necessary to apply a structural health monitoring (SHM) system to monitor the health condition of the OWT towers in real-time. The total displacements and von Mises stresses obtained from iFEM analysis are compared against reference results and optimum sensor locations are determined



(a) FEM

(b) iFEM

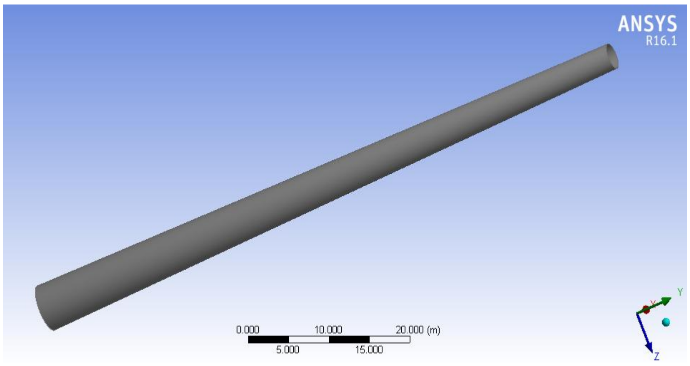
Figure 3 Contour plot of UT (unit: m) for static condition [17]

2. Modelling of wind tower

Problems on structure can be solved by using finite element computational analysis under the module of Ansys popularly known as Static Structural Analysis. The solution of structural problem in the module of static structural analysis is performed in steps. Firstly, the engineering data i.e. the properties of material like density, Young's modulus of elasticity, Poisson's ratio, etc. are considered for the material. After this, geometries were prepared in static structure design modular followed by mesh generation.The direction of the wind in the atmosphere is not certain. Therefore, in this case first the prevailing direction of the wind is determined with the help of commonly used method. The wind rose is a diagram which shows the percentage of wind blowing from each of the leading 12 points in compass and also shows the prevailing direction of the wind i.e. the direction of the wind blow most of the time. In this present work, wind turbine tower is assumed to be subjected horizontal wind shear and therefore it is important to know the prevailing wind direction. In the present analysis, +X-direction is assumed to be the prevailing direction of the wind i.e. it is assumed that the wind is blowing from east to west direction and all the loads are applied in +X-direction. Therefore, results such as direction deformation, bending stress are calculated in +X-direction. Geometry for the steel tubular tower, structured steel tower and aluminum based material tower is considered.

2.1 Geometry of wind turbine tower for S235 structured steel grades

The considered dimension for a wind turbine tubular tower for a hub height of 80 m. Based on this, the geometry for tubular tower with 80 meters hub height has been prepared on static structural design modular of Ansys (material considered is the grades of structured steel) shown in figure 4. The properties for structured steel material is discussed in the further chapters.



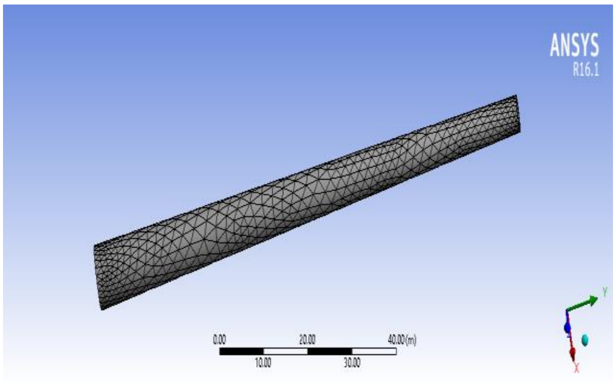


Figure 4 Isometric view of wind turbine towerFigure 5: Mesh generation for concrete based wind turbine tower

3. Results and Discussion

3.1 Directional deformation of wind turbine tower

The wind shear (horizontal wind load) has been calculated for the grades of structured steel material S235, S275, S355. S450 and concrete based wind turbine tower. This value of the wind shear is assumed to be subjected on the entire surface of the wind turbine tower and this causes a directional deformation on the tower in the applied direction of load. The variation of directional deformation on wind turbine tower has shown below

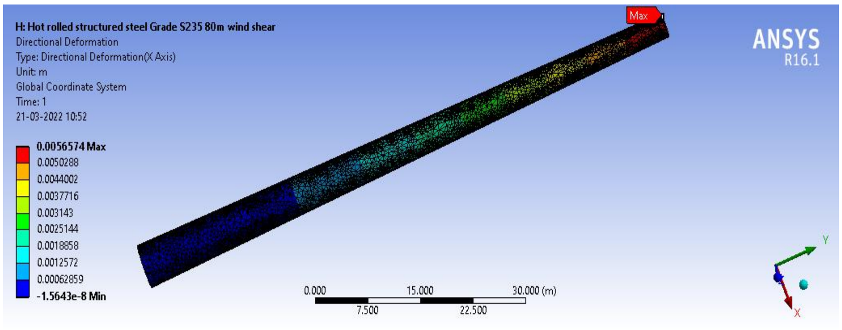

H: Hot rolled structured steel Grade S235 80m wind shear
Directional Deformation
Type: Directional Deformation(X Axis)
Unit: m
Global Coordinate System
Time: 1
21-03-2022 10:52

Figure 6 Contour of directional deformation for S235 structured steel wind turbine tower

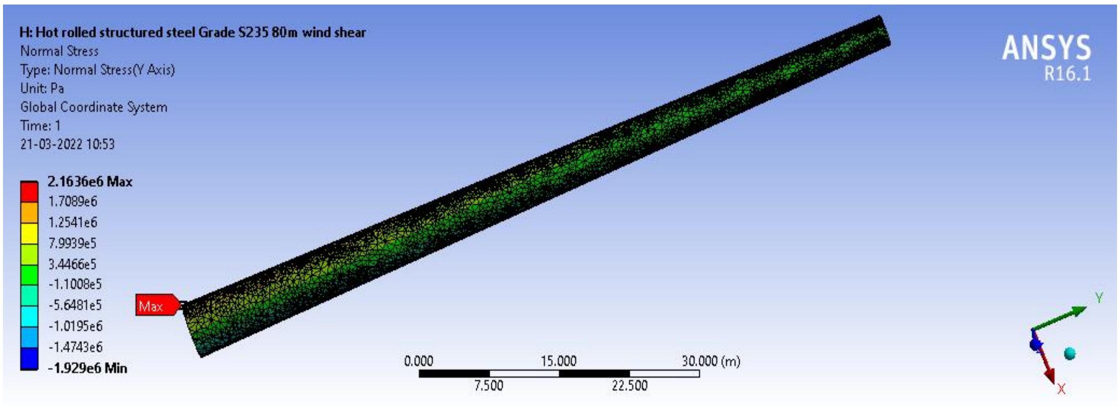


Figure 7 Variation of bending stress on wind turbine tower for S235 structured steel (maximum at the bottom and minimum at the base of the tower)

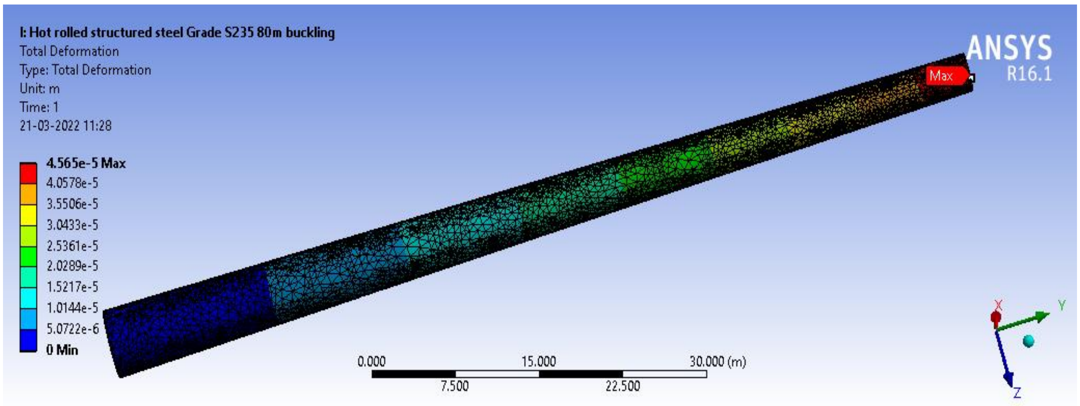


Figure 8 variation of vertical deformation due to buckling load on S235 structured steel wind turbine tower

4. Conclusions

The maximum values of directional deformation and bending stress on structured steel material grades S235 material based on numerical simulations matched well with that from the analytical approach. Thus, finite element method could be used for the design purpose of quick calculation of directional deformation and bending stress on wind turbine tower.

Directional deformation and bending stress on the wind turbine tower (for the considered materials) increases as wind pressure increases with hub height.

Directional deformation for all the cases of considered material is found maximum at the top of the wind turbine tower and minimum at the base of the wind turbine.

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