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Analysis of Steel Tubular Wind Turbine Tower with Door Opening

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Abstract: ***With increasing demand of sustainable energy, the production of wind power by using wind turbines have become increasingly important over the last few decades. The tower is provided with a door for the inspection and maintenance of the equipment's inside the tower. The main objective of this paper is to investigate the stresses around the door opening of wind tower for the load case and to find out the best stiffener. The loading of the tower generates the stresses around the door opening and these stresses will analyze for static analysis using the FEM software ANSYS R15 as there is more probability of having crack near the door opening. Analysis of the opening with stiffeners are also carried out. For analysis wind load is considered along the side of the opening.***

Keywords: Wind tower, Stress, ANSYS R15, Static analysis.

1. Introduction

Wind turbines have been used for at least 3000 years, mainly for grinding grain or pumping water, while in sailing ships the wind has been an essential source of power for even longer. From as early as the thirteenth century, horizontal-axis windmills were an integral part of the rural economy and only fell into disuse with the advent of cheap fossil-fuelled engines and then the spread of rural electrification. The use of or wind turbines to generate electricity can be traced back to the late nineteenth century with the 12 kW DC windmill generator constructed by Brush in the USA and the research undertaken by LaCour in Denmark. However, for much of the twentieth century there was little interest in using wind energy other than for battery charging for remote dwellings and these low-power systems were quickly replaced once access to the electricity grid became available.

Commercial wind power generation in India began in 1986. Many of the older low-capacity (< 500 kW) wind turbines installed more than 10 to 12 years ago occupy some of the best wind sites in India. These turbines need to be replaced with more efficient, larger capacity machines. One of the immediate benefits after repowering the old wind turbines is that more electricity can be generated from the same site. A study on repowering potential conducted by WISE for the Ministry of New and Renewable Energy estimated India's current repowering potential at approximately 2,760 MW16. However due to a lack of policy guidelines and incentives for repowering, concerns are raised on a number of subjects including disposal of old machines, fragmented land ownership in existing wind farms, clarity on the feed-in tariff offered to newly repowered projects and constrained evacuation of the extra power generated.

Wind power is a mature and scalable clean energy technology where India holds a domestic advantage. India has an annual manufacturing capacity for over 9.5 GW of wind turbines today. The country is seeing about 3 GW in annual installations under the 12th Plan target. This modest pace of utilization of the country's wind power manufacturing and resource potential so far is attributable to several factors, including lack of an appropriate regulatory framework to facilitate purchase of renewable energy from outside the host state, inadequate grid connectivity, high wheeling and open access charges in some states, and delays in acquiring land and obtaining statutory clearances. The broader global economic slowdown has reduced expectations for the fiscal year 2012-13 from the wind sector, which is still coping with the reduction of the Accelerated Depreciation benefit from 80 percent to 35 percent in the first year of a wind turbine's operation.

2. Scope

To extract energy from wind, Wind turbines emerged as one of the most efficient ways of converting the kinetic energy in wind into mechanical power. Now a day's wind turbines are installed in many countries. Steel towers for multi megawatt turbine consist usually of several conical steel segments which are welded together to sections. These sections are connected by bolted flange connection. A typical feature of these towers is the presence of a manhole cut-out near the bottom, serving purposes of accessibility into the tower for maintenance of the electrical and mechanical equipment. This paper helps to increase the lifetime of wind turbine tower by reducing the effect of wind over the door openings.

3. Objective

1) To analyse the wind turbine tower with door opening
2) To analyse the wind turbine tower with different stiffeners around the door opening and to comparing the stresses

4. Methodology

Modelling of wind turbine tower with door opening and different stiffeners around the opening is carried out using ANSYS R15 software and the von mises stresses are compared.

4.1 Basic Assumptions

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- The basic structural model of the tower is represented by an equivalent long, slender cantilever beam built from segments (modules) having different but uniform cross-sectional properties. The tower is cantilevered to the ground, and is carrying a concentrated mass at its free end approximating the inertia properties of the nacelle/rotor unit. This mass is assumed to be rigidly attached to the tower top.
- Material of construction is linearly elastic, isotropic and homogeneous. The tower has a thin-walled circular cross-section.
- The Euler-Bernoulli beam theory is used for predicting deflections. Secondary effects such as axial and shear deformations, and rotary inertia are neglected.
- Distributed aerodynamic loads are restricted to profile drag forces. A two dimensional (2D) steady flow model is assumed.
- Nonstructural mass will not be optimized in the design process. Its distribution along the tower height will be taken equal to some fraction of the structural mass distribution.
- Structural analysis is confined only to the case of flapping motion (i.e. bending perpendicular to the plane of rotor disk).
- Under any load combination (including any load safety factors), the material of the load bearing structural elements of the tower should remain in the linear elastic region of its stress-strain diagram i.e. no plastic deformation has occurred.

4.2 Description of Structure

We have model wind turbine towers for 3MW. The dimension of the uniform thickness tower is at the base the outer diameter is 4.5m and the inner diameter is 4.462m at the top the outer diameter is 3.8m and the inner diameter is 3.762m and the thickness is 38mm throughout. The height of the tower is 100m. (Table 1). Door opening dimension is seen in Figure 1. Door opening with different stiffeners seen in Figure 2.

4.3 Material Used

S355 is most commonly used material in wind turbine tower. S355 is a high strength, low alloy steel that finds its best application where there is need for more strength per unit of weight. Less of this material is needed to fulfill given strength requirements than is necessary with regular carbon steels.

In addition, S355 is noted for its increased resistance to atmospheric corrosion.

It is commonly used in structural applications, heavy construction equipment, building structures, heavy duty anchoring systems, truck frames, poles, liners, conveyors, boom sections, structural steel shapes, and applications that require high strength per weight ratio.

Table 1: Dimension of the Tower

	Dimension of uniform tower with opening	*Dimension of uniform tower with stiffeners around the opening*
Outer diameter at base	4.5 m	4.5 m
Inner diameter at base	4.462 m	4.462 m
Outer diameter at top	3.8 m	3.8 m
Inner diameter at top	3.762 m	3.762 m
Thickness at base	38 mm	38 mm
Thickness at top	38 mm	38 mm
Height	100 m	100 m

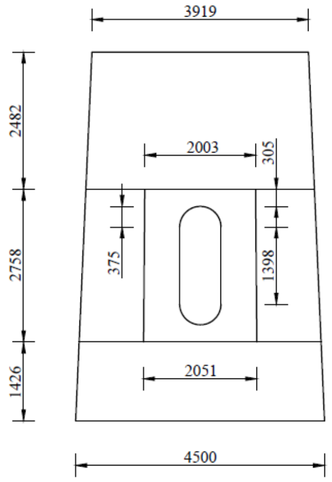

Figure 1: Door Opening Dimension

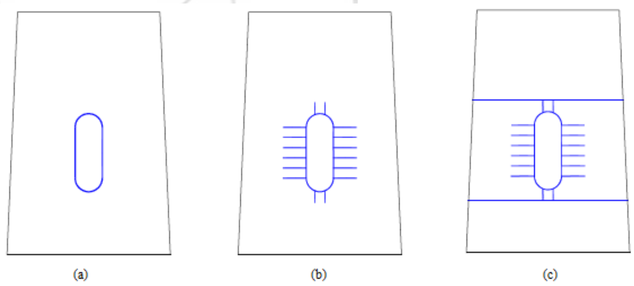

Figure 2: Type 1, Type 2, Type 3 Stiffeners

4.4 Load Calculation

4.4.1 Basic Wind Speed

Basic wind speed is based on peak gust velocity averaged over a short time interval of about 3 seconds and corresponds to mean heights above ground level in an open terrain. Basic wind speed for some important cities/towns is also given in IS Code [3].

4.4.2 Design Wind Speed

The basic wind speed (Vb) for any site shall be obtained from IS code [3] and shall be modified to include the following effects to get design wind velocity at any height (Vz) for the chosen structure:

a) Risk level
b) Terrain roughness, height and size of structure; and
c) Local topography.

It can be mathematically expressed as follows:

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$$Vz = Vb\ k1\ k2\ k3 \qquad (1)$$

Where,
Vz = design wind speed at any height z in m/s
k1 = probability factor (risk coefficient)
k2 = terrain, height and structure size factor and
k3 = topography factor

4.4.3 Design Wind Pressure (Pz)

The design wind pressure at any height above mean ground level shall be obtained by the following relationship between wind pressure and wind velocity:

$$Pz = 0.6\ Vz^2 \qquad (2)$$

Where, Pz = design wind pressure in N/m^2 at height z, and Vz = design wind velocity in m/s at height Z.

4.4.4 Wind Force (Fz)

When calculating the wind load on individual structural elements such as roofs and walls, and individual cladding units and their fittings, it is essential to take account of the pressure difference between opposite faces of such elements or units. For clad structures, it is, therefore, necessary to know the internal pressure as well as the external pressure. Then the wind load, F, acting in a direction normal to the individual structural element or cladding unit is:

$$F = (cpe - cpi)\ A\ Pz \qquad (3)$$

Where, cpe = 0.95
The wind force comes out as 670.250 KN and wind pressure comes out as 1915 N/m_2 with the design wind speed as 56.47 m/s and basic speed 44m/s for Vadodara. Also k_1 is taken as 1.07 for tower with design life 100 years, k_2 is taken as 1.20 for 100 m height for terrain category-1 and for class-c and k_3 is taken as 1.0.

5. Finite Element Analysis

The static analysis is performed by using three-dimensional (3D) finite element models created with Finite Element Analysis (FEA) program ANSYS. In static analysis the loads which are not varying with time is calculated which includes displacement analysis, principal stress and Von Mises stresses.

Fixed boundary conditions are assumed at the lower end of the tower for all analyses. Quadrilateral tetrahedron shell elements (4-node element) are used for the tower wall. High strength structural steel grade S355 with yield stress of 355 MPa is used for all structures. Beam element are used for stiffeners. Figure 3 shows the area model of the tower.

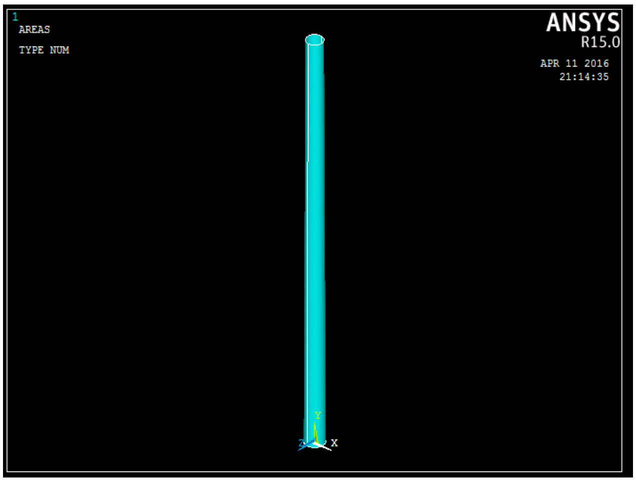

Figure 3: Area Model of the Tower in ANSYS

6. Results & Discussions

6.1 Tower with Door Opening

The maximum stress at the door opening when load is applied along the side of door opening was to be 123N/mm^2.

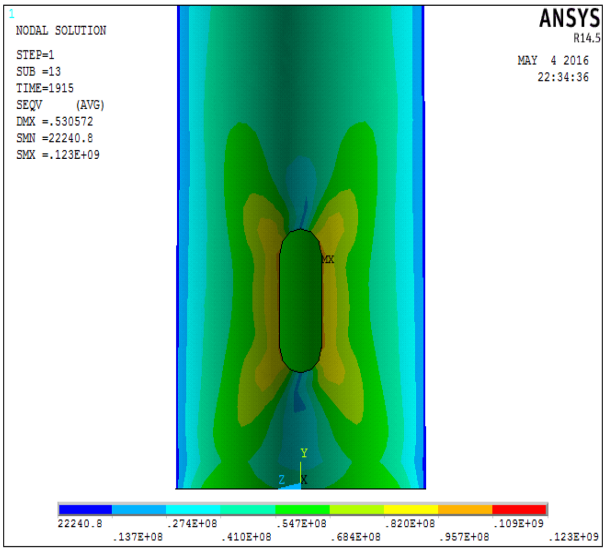

Figure 4: Von Mises Stress Diagram of Tower with Door Opening

6.2 Door Opening with Type 1 Stiffener

When the door opening is provided with ring stiffener the stress is found to be 86.5 N/mm^2.

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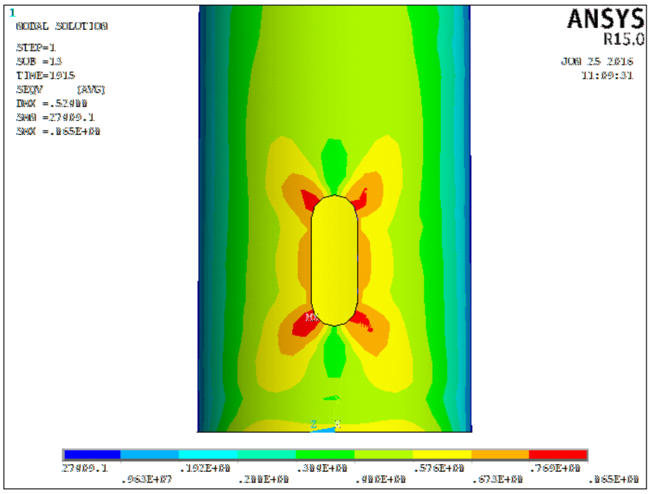

Figure 5: Von Mises Stress Diagram of Door Opening with Type 1 Stiffener

6.3 Door Opening with Type 2 Stiffener

Opening is provided with a set of horizontal and vertical stiffeners locally around the ring the stress is found to be 96 N/mm^2.

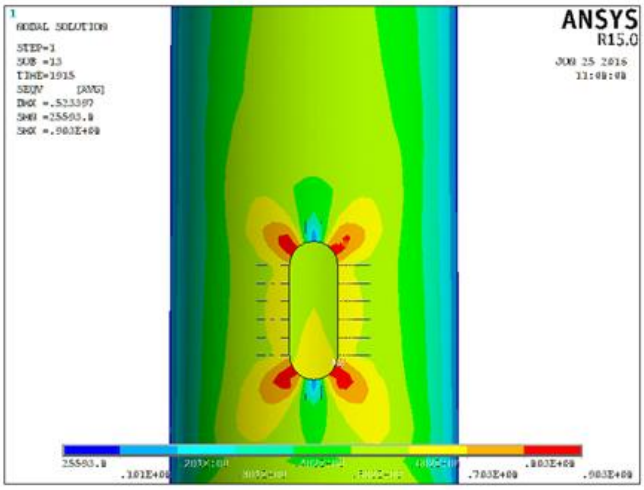

Figure 6: Von Mises Stress Diagram of Door Opening Type 2 Stiffener

6.4 Door Opening with Type 3 Stiffener

Opening is provided with a set of horizontal and vertical stiffeners locally around the ring and two circumferential rings above and below the door the stress is found to be 89 N/mm^2.

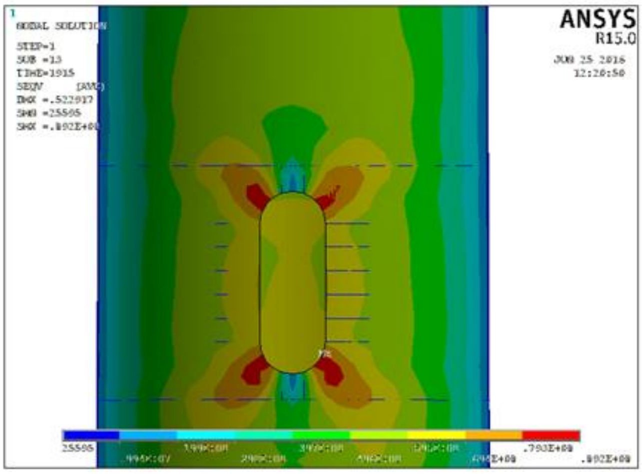

Figure 6: Von Mises Stress Diagram of Door Opening Type 3 Stiffener

7. Conclusions

Initially the turbine tower with door opening was considered to check the stresses near the door opening and to compare it with the other options. Tower with door opening the stress is 123 N/mm^2 and the opening is provided with ring stiffener the stress is 86.5 N/mm^2. Opening is provided with a set of horizontal and vertical stiffeners locally around the ring the stress is found to be 96 N/mm^2. Opening is provided with a set of horizontal and vertical stiffeners locally around the ring and two circumferential rings above and below the door the stress is found to be 89 N/mm^2.

From this it is to be concluded that opening with ring stiffener is better to reduce the stress around the opening when the tower is subjected to wind load along the side of the door opening.

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