FINITE ELEMENT ANALYSIS OF MONOPOLE TOWER FOR DOMESTIC WIND TURBINE

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Abstract—The trending demand and necessity towards renewable energy production has lead several challenges against engineering disciplines which are integrally associated with each other. One of its kinds is the wind energy sector in developing country like India. The associated disciples like mechanical, production, electrical and finally civil & structural engineering plays key role in development of sustainable and affordable solutions. The challenges lie in the cost and performance optimization of domestic wind turbines also counts from optimization of supporting tower system for holding the main assembly up above the ground. In this research paper, the authors have tried to demonstrate the comparative study of circular monopole towers between two widely used configurations -straight and tapered. For this study, the authors have also applied the latest finite element solution capability of general purpose software ANSYS® Workbench with integrated multiple simulation schematic environment to carry out static structural analysis along with modal analysis and linear buckling analysis. At the last, the comparative advantages of tapered configuration over straight are drawn.

Index Terms— FEM, Wind Turbine, Monopole Tower, ANSYS Workbench

I. INTRODUCTION

Universal access to clean, secure and sustainable energy systems is one of the biggest development challenges today. In a recent report released by International Energy Agency (IEA), more than 1.3 billion people in the world lack access to electricity; about 95% of them are from Asian developing countries and sub-Saharan Africa. To respond to energy poverty, the United Nations secretary general announced in “Rio20”, the United Nations conference on sustainable development, a major initiative, “Sustainable energy for all (SE4all)”, to provide electricity to all people by 2030. Among many renewable energy technologies, wind energy offers an immense potential to extract clean energy. In developing countries, such as India, wind energy technologies are not fully developed due to many barriers. The key barriers include lack of profitable markets and well-adapted technologies to end user needs, inability to manufacture and manage technologies, high capital and life-cycle costs, technological limitations, financing risks etc. Cliffton-Smith and Wood reported that the cost of manufacturing the towers could be 30 to 40% of the installation cost in the case of small wind turbines. Small wind turbines, which have rotor swept area smaller than 200 m^2 are increasingly relevant in rural or off-grid areas for generating cost-effective electricity. A wind turbine tower has two primary functions. First, it supports the wind turbine and accessories at a desired height. Second, it transfers the loads acting on the wind turbine and associate parts to the foundation.

There are mainly two types of towers:

(1) Monopole or tubular tower: The Monopole Towers were widely used from 1kW to 50kW wind turbines. Monopole tower has good appearance, reliable structure and easily to be installed. The survival wind speed is approx. 60 m/s. The design life time is 20 years for a monopole tower.

(2) Lattice tower: Lattice towers are cost effective since it requires only half as much material as tubular tower with a similar stiffness. Transportation is easy since small parts can assemble at site. The basic disadvantage of lattice towers is their visual appearance. It requires larger base area than monopole towers.

Finite Element Analysis is a good technique for the structures where the direct analysis is not possible.

ANSYS® Workbench is handy software for the FEM study. In ANSYS® Workbench project section various tools as Geometry, Static Structure, Linear Buckling, Modal, etc. are available. In this paper the FEM study using ANSYS® Workbench was done for tapered hollow monopole tower and straight hollow monopole tower for various results and the comparison were carried out.

II. MODELLING AND LOADING

For the accurate analysis, the general purpose Finite Element Software ANSYS® Workbench is used. The Highlights and details for modeling and Load application are explained here.

LOADING:

Unlike other structures, there are no specific guidelines available exclusively on domestic wind turbine supporting system for its structural analysis and design. There are only few guidelines available for wind turbine analysis and design such as ASCE-72, BSEN 61400-2:2006, RISØ Guidelines, etc. However, there are some indicative clauses pertaining to loading and supporting tower design.

Due to Domestic wind turbine and its sizes and due to its limited capacity, it is hereby recommended to use simplified methods from several available methods described in RISØ Guidelines. For the considered case the loading explained as under:

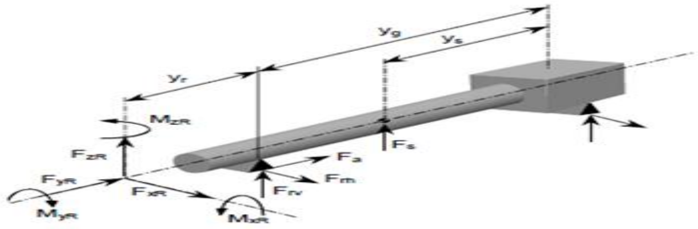


Fig.1: Loads acting on shaft

Where,
F_{xR} = side force on rotor and nacelle
F_{yR} = thrust on rotor
F_{zR} = weight of rotor
M_{xR} = tilting moment at rotor
M_{yR} = driving torque at rotor
M_{zR} = yaw moment at rotor
F_s = shaft mass

Simple Load Basis		
Gravitational acceleration(m/s^2)	9.81	m/s^2
Rotor Blade radius in meter(R)=	2.7	M
Rotor mass in kg(m)=	360	kg
Rotor frequency (n_r)=	2.6	Hz
Nominal Power of wind turbine(P_{nom})=	5000	
Nominal Efficiency (η)=	0.7	
Calculations:-		
a) A static horizontal airflow load (F_0)		
F_o= 300A where A= area of rotor =22.91143		
F_o= 6873.429 N		
b) A driving Torque ($M_{e,nom}$)		
$M_{e,nom}$= $P_{nom}/(2\pi*nr*\eta)$ = 437.0629		
eccentricity (e)= 0.45		

Load Components	**Symbol**		**Static Load**	**Dynamic Amplitude**	**Load**
Horizontal force in Rotor Plane(N)	F_x	0	0	0	0
Moment about Horizontal axis in rotor plane(N.m)	M_x	eF_o	3093.043	$0.25eF_o$	773.2607
Horizontal force along rotor axis(N)	F_y	F_o	6873.429	$0.25F_o$	1718.357
Moment about rotor axis(N.m)	M_y	$1.3M_{e,nom}$	568.1818	$0.25(1.3M_{e,nom})$	142.0455
Vertical force(N)	F_z	-mg	-3531.6	0	0
Moment about vertical axis(N.m)	M_z	eF_o	3093.043	$0.25eF_o$	773.2607

(Note: The figure in the dark yellow box requires the user input data. It is obtained from manufactures of domestic wind turbine solutions at Ahmadabad, Gujarat)

WIND LOADS
Wind loads are calculated by the IS-875(Part-ɯ) by force co-efficient method (clause-6.3)
Location - Ahmedabad
Wind Load = 574.64 N/m^2

MODELING:

ANSYS® Workbench provides very efficient interaction flowchart between several CAD design modules including geometry import from many supporting CAD design software with meshing import facility. Optimally, the in-built Design modular for generating geometry from scratch. Two models for monopole hollow tubular towers have been developed with same weight for straight and tapered configuration.

ANSYS® Workbench project schematic shown below can be developed for the analysis. General steps are as follows:
Step-1: Preparation of Geometry
Step-2: Meshing
Step-3: Boundary Conditions and Load Application
Step-4: Solutions and Results

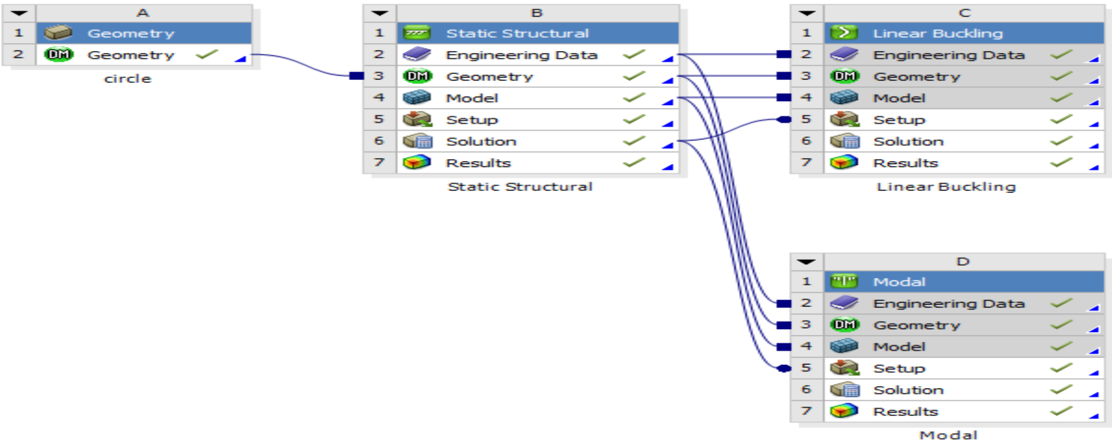


Fig.2: Schematic chart of work

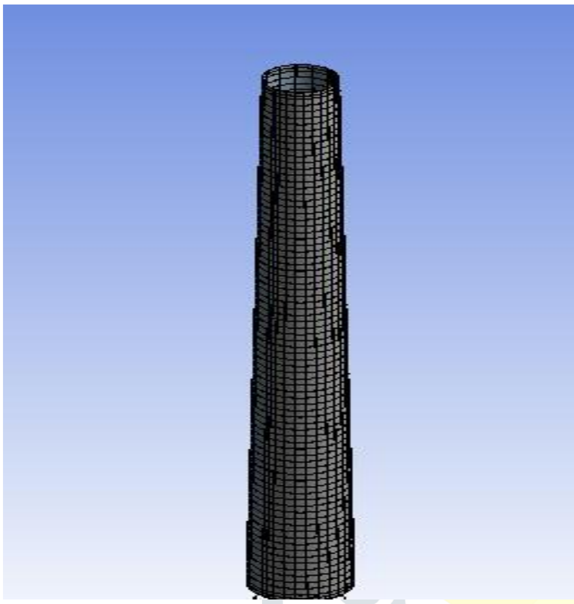


Fig.3: Typical meshing of Structure

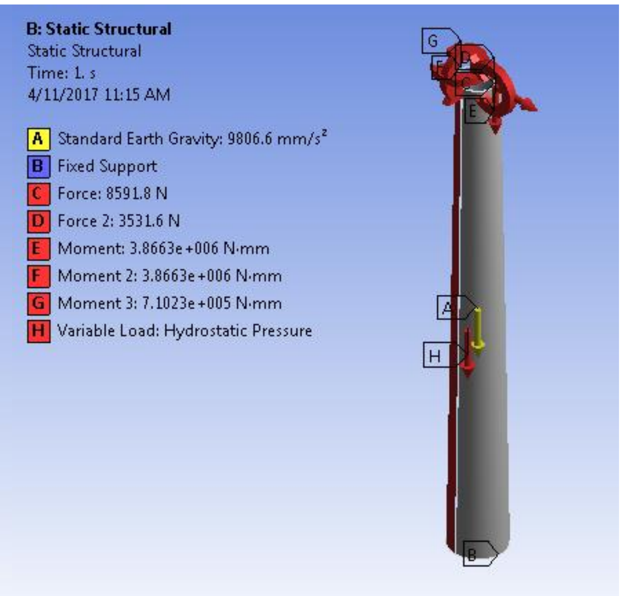
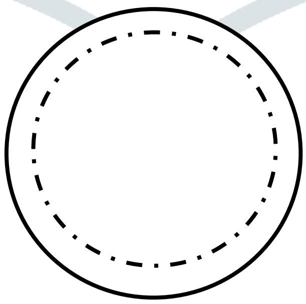


Fig.4: Support condition and Loads

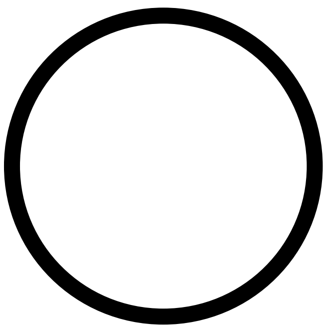
Basically, we can create required geometry in design modeler with more than one alterative, which generally affects our output either in terms of output quantity values or in terms of output computational cost and required computational time.

There are mainly two types of modeling methods in the ANSYS® Workbench:

Shell element: In the ANSYS software if the geometry is set up as a thin surface with outer diameter and the value of thickness is to be given as shown in fig., than it is called as shell element.



Solid element: In the ANSYS software if the geometry is set up as a non-thin surface with outer and inner diameter given in the sketch itself than it is called as solid element.



The results obtained by above two methods for same section are as follows:

	Shell element	Solid element
Total Deformation(max) in mm	0.012369	0.012369
Normal Stress(max) in Pa	$9.5662*10^6$	$9.5662*10^6$
Normal Stress(min) in Pa	$-9.5662*10^6$	$-9.5662*10^6$

Time required to solve the solid element is much higher than the time required for solving the shell element. From the above results it is clearly shown that the results from the shell element are completely match with the results of solid elements. Hence, to minimize the computational efforts without compromising output, it is hereby recommended to use shell type modeling while creating geometry in Design Modeller.

PROBLEM DATA:

As described, the goal of the study is to explore the effect of tapering cross section on various structural analysis output quantities such as displacements, Normal stress, von-misses stress, natural vibrational frequency and linear buckling load factor.

We have considered two sections here for the analysis as per following properties:

(1) Straight hollow circular:

Height = 12.5 m
Outer Diameter = 1.2 m
Thickness = 5 mm
Weight = 1842 kg

(2) Tapered hollow circular:

Height = 12.5 m
Bottom Outer Diameter = 1.4 m
Top Outer Diameter = 1 m
Average Diameter = 1.2 m
Thickness = 5 mm
Weight = 1842 kg

The ANSYS® WORKBENCH project schematic is prepared to carry out interconnected several type of analysis simulation related to static structural analysis, modal analysis and linear buckling analysis. Fig.3 and Fig.4, represents the typical meshing and boundary conditions applied for each of modal study.

III. RESULTS AND COMPARISION

Several output predefined quantities are readily available in ANSYS results tabs within each simulating analysis type. The main focus was the Total Deformation, Normal Stress in the vertical direction, Von-misses Stress, Linear Buckling Load Multiplier and the natural Frequency. The various graph plotted for the above solutions are shown below:

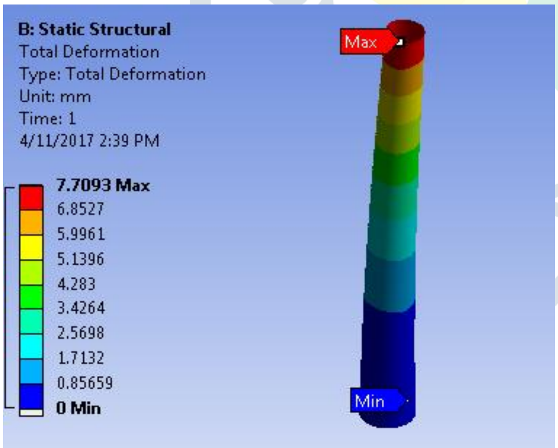


Fig.5: Total Deformation of Tapered monopole

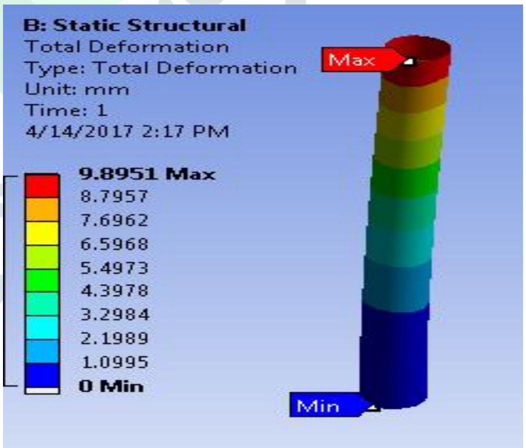


Fig.6: Total Deformation of Straight monopole

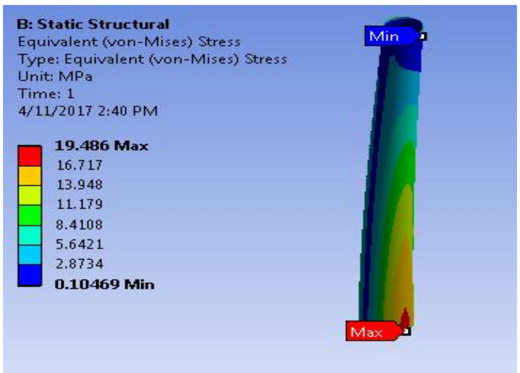


Fig.7: Von-Misses Stress of Tapered monopole

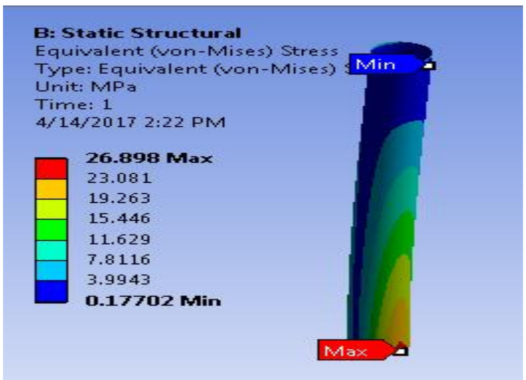


Fig.8: Von-Misses Stress of Straight monopole

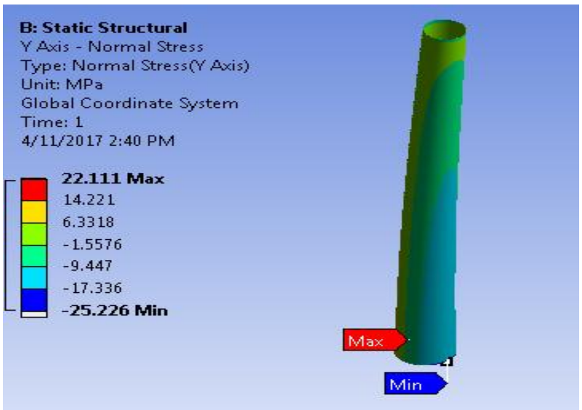


Fig.9: Normal Stress of Tapered monopole

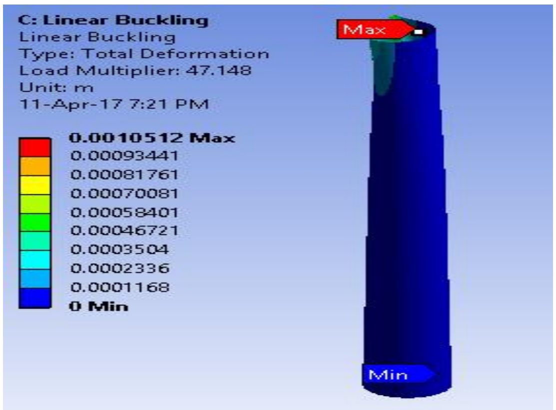


Fig.10: Linear Buckling of Straight monopole

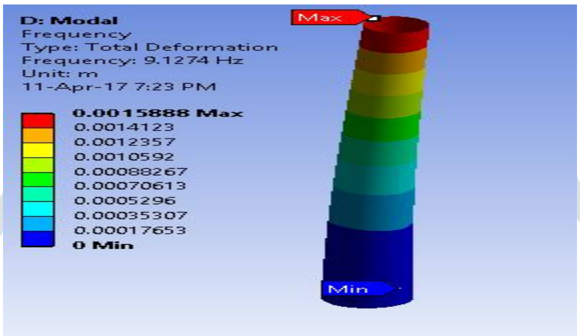


Fig.10: Frequency of Tapered monopole

The results obtained are as follows:

	Tapered hollow monopole	**Straight hollow monopole**
Total Deformation max (mm)	7.709	9.895
Normal Stress max (MPa)	22.111	31.858
Normal Stress min (MPa)	-25.226	-34.596
Von-misses Stress max (MPa)	19.486	26.898
Von-misses Stress min (MPa)	0.105	0.177
Linear Buckling Load Multiplier	47.148	44.515
Natural Frequency (Hz)	9.127	7.514
Weight (Kg)	1842	1842

IV. CONCLUTION

From the detailed study, it is thus concluded that there will be no difference in the result if we use shell element or solid element. Using of the shell element is more beneficial as they require less time and computational cost in static structural as well as in modal and linear buckling

For two circular hollow monopole towers with identical thickness and weight with tapered and with straight configuration. The detailed finite element analysis with several integrated analysis system is carried out to compare various structural response in ANSYS® Workbench. From the results, as shown in the table, it can be said that tapered circular section is more useful as compared with straight circular section. For the tapered section there is a less total deformation as well as lesser amount of Normal Stress and Von-misses Stress. The Load Multiplier for Linear Buckling higher in case of tapered compared to straight configuration. As the natural frequency increases there will be less chances of Resonance in the structure. Tapered section would also gives the higher value of frequency compared to Straight section, so it is beneficial with regards to overall performance.

V. REFRENCES

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