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NON-LINEAR SEISMIC ANALYSIS OF LATTICE- MONOPOLE TYPE WIND MILL TOWER ON DIFFERENT SOIL CONDITIONS

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ABSTRACT

The conventional wind mill towers are constructed using monopole or lattice type structure. we can get more power by increasing height of tower but by increasing height of tower the tower becomes uneconomical due to increased wall thickness. in the present research an innovative hybrid wind mill tower is proposed. the nonlinear time history analysis of proposed hybrid wind mill considering different soil is carried out and it is concluded that hybrid wind mill tower is more effective compared to conventional monopole tower.

Keywords: *Wind mill tower, Time History Analysis, Soil Structure Interaction.*

I. INTRODUCTION

From the mid part of the 19th century to till date, fossil fuels have provided the power necessary to complete many of society's most basic tasks worldwide. But in the recent years the renewable sources of energy have become most popular and there is more advancement in the technology.

One of the important sources of power generation is wind mills. According to details available from Government of India, the states like Gujarat, Karnataka, Kerala have utilized only 3 to 5 percent of their wind power potential. All states of India have total wind power utilization of only 26777 MW which is only 8.86 percentage of the total wind power potential available in major states of India. The wide gap between the installed capacity and the assessed potential in India clearly indicates the opportunity in this field. So, to utilize all available wind power potential there must have more advancement in the Wind Mill Technology. The height of the wind mills is increased in the recent years to extract more power at higher elevations. Basically, two types of tower system such as monopoles or lattice towers are used for the wind mill supporting towers. Each type of tower has its own advantages and disadvantages. As the height of the wind mill increases the thickness of the wall of the monopole towers is increasing and it untimely leads to increase in cost and uneconomical sections. On the other hand, the lattice towers are formed byconnecting the various angle or box sections by doing proper riveting at the site. The lattice towers will resist the loads by truss action of the members, so members of towers are subjected to axial forces only. As the lattice towers are open, wind will pass between the members and wind loads are reduced significantly on the towers.

The monopoles are used for lesser heights of the turbine while the Lattice tower can be used for turbines having lesser mass. If we increase the height of turbine it becomes single degree of freedom system and becomes dynamically sensitive particularly in soft soils. So, in present research an innovative hybrid tower which is combination of monopole and lattice tower is proposed and the loads of earlier research works are applied on the innovative hybrid tower and the dynamic analysis of the tower is carried out considering 3 different types of soil.

II. LITERATURE REVIEW

Gencturk[1] has studied the various bracing system for 24 meter high lattice tower and various design alternatives are given for the wind mill lattice tower. Song [2] has studied the effects of the different earthquake on tall wind turbines and has concluded that dynamic response of structure depends on height. When the height increases to 177%, the maximum displacement in the top of the tower would increase to 231% in 8-degree rare earthquake. Lombardi[3] has experimentally studied the effects of the soil structure interaction on the wind mills and has concluded that the clayey soils will make the tall structure dynamically sensitive. Hani[4] has done optimization of 100 kw wind mill tower using different cross-sectional areas. Author obtained optimum design trends through the use of the interior penalty function technique. Prowell[5] has determined the dynamic properties of 52-meter-high 900 KW wind turbine considering 3 different types of soil and has concluded that soft soil will influence dynamic properties of tower. In other research Prowell[6] has carried out the full-scale wind turbine testing for 65 KW having 22.6 m hub height. The different earthquake time histories are applied on the full-scale turbines and he has observed degradation of grout at the tower base, and loss of bolt torque at the connections between tower segments. Harte [7] has studied the effects of modeling the soil and foundation for the wind turbines and he has studied the effect of soil in terms of displacement, base shear, shear force and bending moment in the turbine and foundation system. According to the Ministry of New and Renewable Energy Government of India [8] total wind power potential of 302251 MW has been estimated at 100-meter height In India, and only 21 percent us used by India. Hamaydeh [9] has modeled the wind turbine of 2 villages located in alsaka considering the soil properties prevailing at site. He has investigated the pile foundation for given site. Researcher has changed the dimensions of pile and spacing of pile and given the foundation design at two different sites. Kjorlaug[10] has modeled 65 KW and 5 MW wind turbine and applied wind and earthquake forces on the wind mill tower. He has also modeled soil at the foundation and has concluded that soil must be modeled to study the response of the wind mill tower. Jerath[11] has modeled 3 different wind mill turbines of 65 KW, 1MW and 5 MW capacity in the FEM software and performed dynamic analysis of the turbines and applied acceleration time history of 3 different earthquakes and studied the peak acceleration and deformation Reponses at various levels of the tower and has also concluded that the change in the damping ratio will not affect much more in the response in two horizontal directions but change in damping has significant effect on the vertical direction response. Subhamoy [12] has studied the dynamic properties of off-shore wind turbine considering soil structure inter action and has concluded that the frequency of offshore turbines largely depends on the foundation type and soil type, therefore in analysis of turbines the effects of soil must be considered for avoiding resonance.

III. VALIDATION OF EARLIER RESEARCH WORK

For Present Research the wind mill data of 78-meter-high tower is collected from research paper published by Elena Nuta at el, titled"Methodology for seismic risk assessment for tubular steel wind turbine towers, application to Canadian seismic environment" published in Canadian journal of civil engineering (2011).

In his Research work author has modeled 78-meter-high tower and various loads are applied on the tower and push over analysis is carried out. The details of 78-meter-high tower are shown in the figure 1. Based on these details the monopole tower is modeled in FEM software.

The loads applied on the tower are self-weight of tower, the mass of Nacelle and mass of the blade. The details of the load are shown in table 1. The mass of the tower is calculated based on the geometry and density given in FEM software.

Table 1Mass of Various Components on tower.

Sr no	Component	Mass	Eccentricity
1	Tower	108 ton	--
2	Nacelle	52 ton	80 mt level
3	Rotor	43 ton	3.447mt from C/L

The nacelle is located at 80-meter height from ground level while blades are located at an eccentricity of 3.447 meter from the center line of tower. The masses are applied at top of tower and it is connected using rigid links given in FEM software with the tower.

After applying all loads on the tower, the tower is analyzed and dynamic properties of the tower are evaluated. The frequency of the tower in different modes are evaluated and it is compared with earlier research work. The frequency obtained in present research and earlier work are shown in table 2

Table 2 .Time period obtained in present research work.

Direction	Time period by Nuta at el work	Time Period by our work	% Difference
Fore Aft	3.17 sec	3.24 sec	2.16
Side to side	0.38 sec	0.38 sec	0
Bending	0.15 sec	0.14 sec	0.06

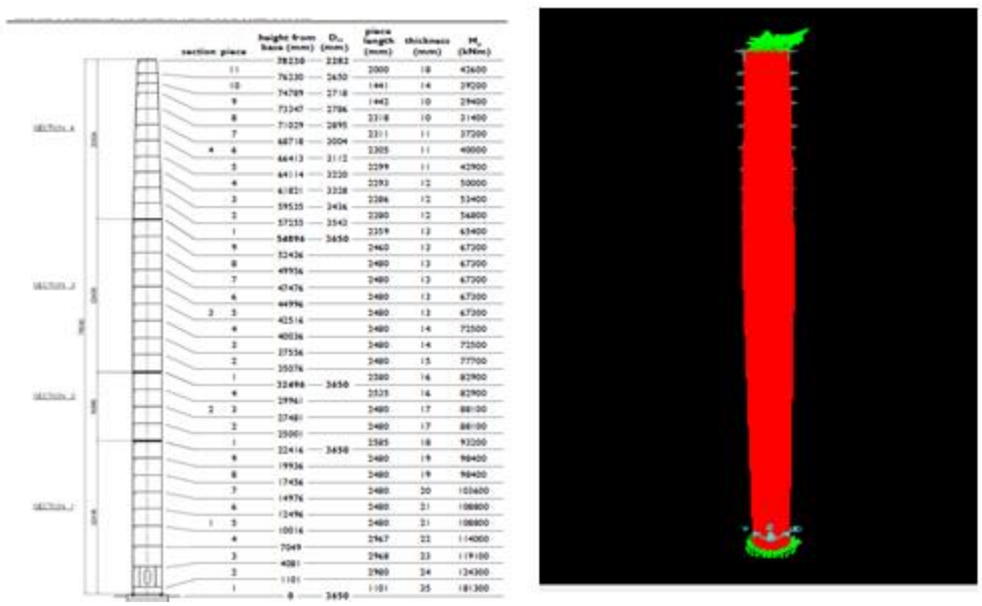

Fig. 1. Details Of 78-meter-high tower and its FEM model

IV. DYNAMIC ANALYSIS OF 125-METER-HIGH MONOPOLE AND HYBRID TOWER CONSIDERING DIFFERENT SOIL.

As discussed earlier, it is observed that if turbine is located at higher elevations, we may get more power from wind turbine. In order to study the effect of increased height of turbine the structural height of tower is increased from 78 meters to 125 meters. To compare the behavior of monopole and innovative hybrid tower, first 125-meter-high monopole tower is modelled in FEM software and same 125-meter-high tower is modelled as hybrid tower which is combination of monopole and lattice tower. In hybrid tower bottom 68-meter portion is taken as lattice tower and remaining 57-meter tower is modeled as monopole. The width of the tower at the base is considered as 16 meter which is reduced to 4.1 meter at 68-meter level. In order to keep the lattice and monopole portion as single structure proper connection between the monopole and lattice element is required. The FEM software has given the 2 joint link elements, which will connect the 2 joints rigidly and transfer all the loads and moments to other joint. In the lattice portion of the tower M type bracing is given toincrease the stiffness of the tower and to reduce the unsupported length of bracing of tower.

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V. MODELING OF SOIL STRUCTURE INTERACTION

Normally the structures are analyzed considering fixed support at the base but for tall structures like wind mill tower the effect of soil is predominant on dynamic properties of tower. In the present study 3 different types of soil such as hard soil, medium soil and soft soil is assumed, and the properties of the soil are considered shown in table 3. The soil is modelled as 8 nodded solid element in FEM software. The Soil is assumed to be an isotropic, homogeneous, linearly elastic. The behavior of such soil can be idealized and represented using solid elements in FEM software. For modeling the soil as solid element it is required to give shear modulus, elastic modulus and poisons ratio as input parameters in the FEM software.

Table 3properties of soil

Type of soil	(G) kn/m2	(E) kn/m2	Poission's ratio
Hard	30000	72000	0.20
Medium	20000	50000	0.25
Soft	10000	26000	0.30

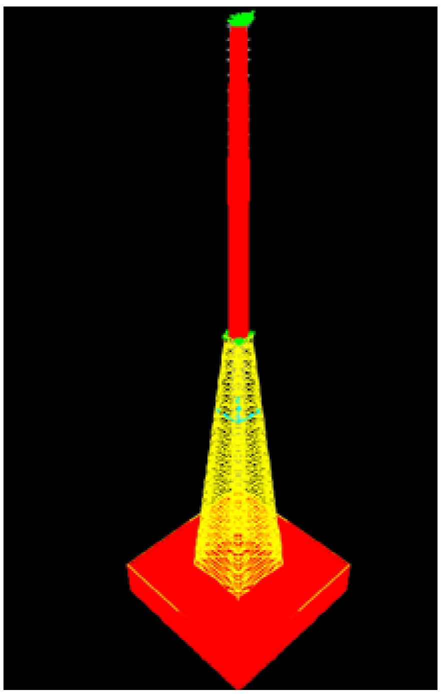
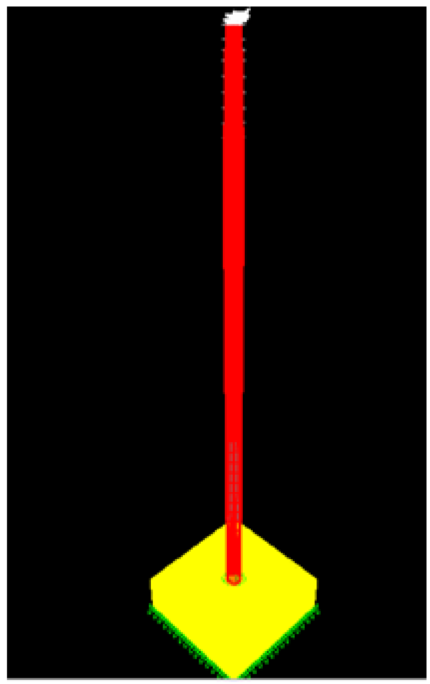

Fig. 2. FEM model of 125-meter-high monopole and hybrid tower with soil

Normally the width and depth of soil is kept in such a way that it affects the behavior of the superstructure. So, to represent the soil as Continuum model it is represented by considering breadth equal to twice the width of the foundation along the plan dimension and thrice the width of foundation along the depth of foundation. So, in present research work 40 m X 40 m X 10 m size soil is considered below tower. The FEM model of 125-meter-high monopole and innovative hybrid tower including soil modeled at its base is shown in Figure. 2. The size meshing of soil is kept as 1mt x 1mt x 1mt. The meshing size of solid elements is selected in such a way that it resembles the actual soil condition of the site.

VI. DYNAMIC LOADS ON WIND TURBINE

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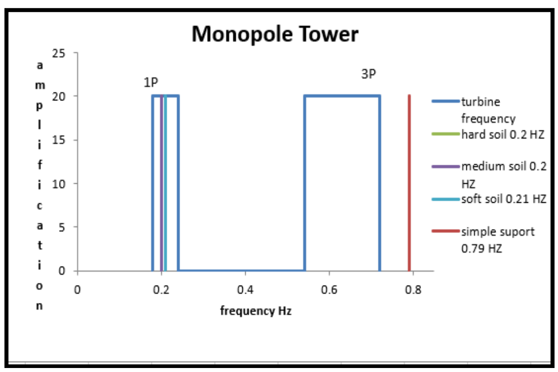
The wind mill turbines are subjected to dynamic loads due to rotation of blades atthe top of wind turbine tower. This load is generated by the vibration at the hub level because of the mass and aerodynamic imbalances of the rotor. This load has a frequency equal to the rotational frequency of the rotor which is referred to as 1P loading. Since most of the industrial wind turbines are variable speed machines, 1P is not a single frequency but it is a frequency band between the frequencies associated with the lowest and the highest rpm (revolutions per minute).

Loads in the tower because of the vibrations caused by blade shadowing effects is known as 2P (for 2 blade turbine) or 3P (for 3 blade turbine). The blades of the wind turbine passing in front of the tower cause a shadowing effect and produce a loss of wind load on the tower. This is a dynamic load having frequency equal to three times the rotational frequency of the turbine (3P) for three bladed wind turbines and two times (2P) the rotational frequency of the turbine for a two-bladed turbine. The 2P/3P frequency is simply obtained by multiplying the limits of the 1P frequency by the number of the turbine blades.

The wind mill tower is resembling a cantilever beam and the natural frequency of tower structure must be compared with wind turbine frequencies at operational states.as discussed earlier the 1P frequency signifies the rotational frequency of the turbine, and the 3P frequency signifies the blade-passing frequency. In the present research work the1P frequency of the tower is 0.18 to 0.24 Hz and 3P frequency of tower is 0.54 to 0.72 Hz as given by designer.

VII. RESULT AND DISCUSSION

Fig 3 shows the comparison of frequency of 125-meter-high monopole tower and hybrid tower in different soil.



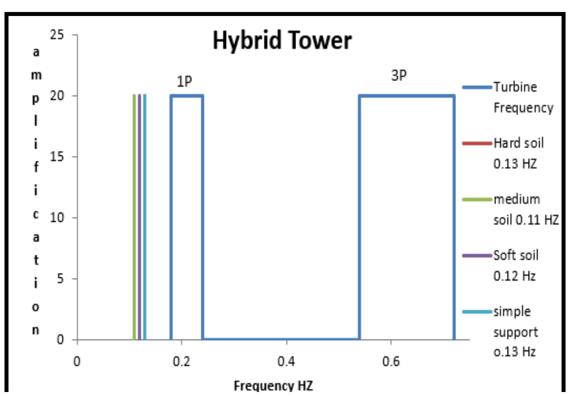


Fig. 3. Comparison of frequency in monopole and hybrid tower for different soil conditions

The natural frequency of monopole tower is between 0.2 to 0.21 Hz for different soil condition such as hard soil, medium soil or soft soil, so we can observe that the natural frequency of tower is within the with 1P frequency range of the turbine. which results in the resonance condition for monopole type tower

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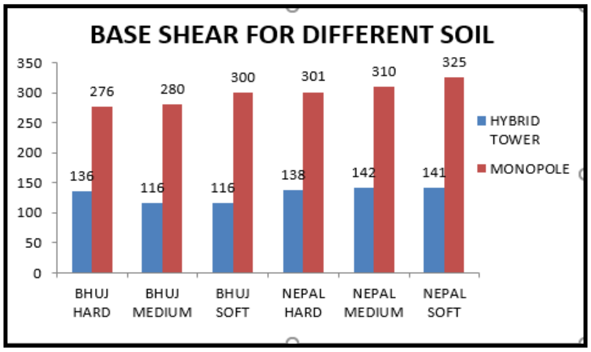
Fig 3 shows the frequency of tower for 125-meter-high hybrid tower we can see that natural frequency of hybrid tower is between 0.11 to 0.13 Hz which is outside the 1P range of 0.18 to 0.24 Hz so looking to this graph we can observe that there is no resonance condition of tower considering 3 different types of soil and we can use innovative hybrid tower for more height to obtain more wind power at higher elevations.

After performing dynamic analysis of tower, the acceleration time history of bhuj earthquake and Nepal earthquake is applied at the base of tower. The acceleration time history is applied in 2 horizontal direction and vertical component of acceleration is neglected. The nonlinear analysis of monopole and hybrid tower with different soil conditions are carried out in FEM software.



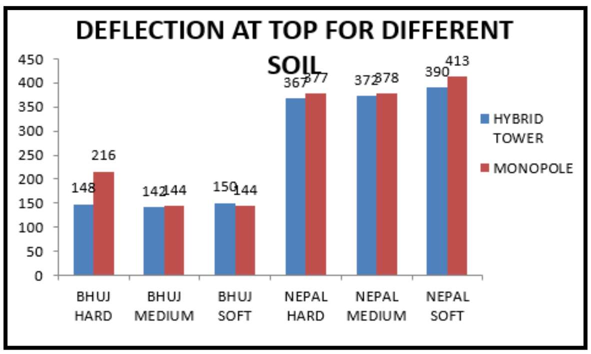


Fig. 4. Comparison of base shear and displacement for monopole and hybrid tower in different soil conditions

Fig.4 shows the base shear obtained from analysis of the bhuj and Nepal time history for both tower considering different soil conditions. We are getting 100 to 150 percent higher base shear for monopole tower compared to hybrid tower in case of bhuj earthquake for different soil conditions. While for the Nepal earthquake we are getting 115 to 130 percent higher shear in monopole tower compared to new innovative hybrid tower for different soil conditions.

The displacement at the top joint is also 6 mm to 68 mm high in case of monopole tower compared to hybrid tower for bhuj earthquake considering different soil conditions at site. The displacement is also 10 to 23 mm higher for Nepal earthquake in monopole tower compared to hybrid tower for different soil conditions.

VIII. CONCLUSIONS

From the present research we can conclude the following points.

(a) The conventional monopole tower gives resonance condition during operation of wind mill tower for more heights in different soil conditions on the other hand the innovative hybrid tower avoids resonance condition for tall tower in different soil condition, so we can use this innovative hybrid tower for more heights.

(b) The base shear obtained at the base of hybrid tower is less compared to the conventional monopole tower because the hybrid tower is made by lattice truss in the bottom portion and this 3D truss resists large earthquake forces produced in bottom portion of tower by axial action.

(c) The displacement of the top portion of tower under 2 severe earthquakes are also less in the hybrid tower compared to the monopole tower of same height.

So, we can conclude that the innovative hybrid towers can be used instead of conventional monopole towers to reduce the resonance conditions and to produce more power form turbine at higher elevations

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