Evaluation Of Dynamic Response For Monopole And Hybrid Wind Mill Tower

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Abstract. The wind mill towers are constructed using monopoles or lattice type tower. As the height of tower increases it gives more power but it becomes uneconomical, so in the present research work innovative wind mill tower such as combination of monopole and lattice tower is analyzed using FEM software. When the tall structures are constructed on soft soil it becomes dynamically sensitive so 3 types of soil such as hard, medium and soft soil is also modeled and the innovative tower is studied for different operating frequencies of wind turbine. From study it is concluded that the innovative tower will reduce resonance condition considering soil structure interaction

INTRODUCTION

From the mid part of the 19th century to today, 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 becomes most popular and there is more advancement in the technology.

One of the important sources of power generation is wind mills. In India total wind power potential of 48,561 MW has been established, only three states of India have tapped about 75 per cent of the potential. The wind power capacity has been established mainly in Tamil Nadu, Gujarat, Maharashtra, Andhra Pradesh, Karnataka and Rajasthan. Tamil Nadu has even exceeded the estimated potential of 5500 MW and set up nearly 6000 MW of wind generators. Other states like Gujarat, Maharashtra and Rajasthan have seen significant growth in wind capacity over the last four to five years, also due to a stable policy and regulatory regime. The wide gap between the installed capacity and the assessed potential clearly indicates the opportunity in this space.

As stated earlier the wind energy is one of the sources for power production and there is 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 types of tower have its own advantages and disadvantages. As the height of the wind mill increases the thickness of the wall of the monopole towers are increasing and it untimely leads to increase in cost and uneconomical sections. While the lattice towers of wind mills are formed by connecting 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 so wind will pass between the members and wind loads are reduced significantly on the towers.

As the idea of taller towers has become more widespread, more wind resource data has been acquired to verify the potential increases in energy output. Data from the Iowa Energy Center shows that at 100 m, wind flows 4.5% faster than it does at 80 m. This would result in an increase in power output of approximately 14%.

So it is required to increase the height of wind mill turbine towers, there are basically 2 types of wind mill turbines such as monopoles and lattice towers are used. 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 become dynamically sensitive. So in this study a hybrid tower which is combination of monopole and lattice tower is proposed and the loads of earlier research works are applied on the hybrid tower and the dynamic analysis of the tower is carried out.

LITERATURE REVIEW

B. Gencturk and A. Attar and C. Tort [1] has studied the various bracing system for 24 meter high lattice tower and he has given the various design alternatives for the 24 meter high lattice tower and its dynamic properties. B. Song, Y. Yi and J. C. Wu [2] has studied the effects of the different earthquake on tall wind turbines and he has shown that dynamic response of structure is affected by height. When the height increases 177%, the maximum displacement in the top of the tower would increase 231% in 8-degree rare earthquake. Domenico Lombardi , Subhamoy Bhattacharya, David Muir Wood [5] has experimentally studied the effects of the soil structure interaction on the wind mills and he has shown that the clayey soils will make the tall structure dynamically sensitive. Hani M. Negma, Karam Y. Maalawi [7] has done optimization of 100 kw wind mill tower using different cross sectional areas radius of gyration and height of each segment and the optimum design obtained is applied to design of 100 KW horizontal axis wind turbine. Ian Prowell, P.E., M.ASCE, Chia-Ming Uang, M., Ahmed Elgamal, M. J. Enrique Luco, and Lanhui Guo [9] has carried out the full scale wind turbine testing for 65 KW 22.6 mt hub height. He has done the dynamic analysis of turbine and the frequencies are compared with earlier wok and after that he has applied the different earthquake on the full scale turbines and he has observed that due to earthquakes degradation of grout at the tower base, and loss of bolt torque at the connections between tower segments is possible. M. Harte , B. Basu , S.R.K. Nielsen [12] 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. Mohammad AlHamaydeh, Saif Hussain [13] 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. Remi Andre Kjorlaug, Amir M. Kaynia, Ahmed Elgamal [15] 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 he has concluded that soil must be modeled to study the response of the wind mill towers. S. Jerath1 and S. Austin [16] has modeled 3 different wind mill turbines of 65 KW, 1MW and 5 MW capacity in the FEM software he has performed dynamic analysis of the turbines and applied acceleration time history of 3 different earthquake and studied the peak acceleration and deformation Reponses at various levels of the tower and he has 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 Bhattacharya, James A. Cox, Domenico Lombardi David Muir Wood [17] has studied the dynamic properties of off shore wind turbine considering soil structure inter action and he concluded that the frequency of offshore turbines largely depends on the foundation type and soil type , so in analysis of turbines the effects of soil must be considered to avoid resonance conditions.

FEM MODELLING AND VALIDATION

For validation purpose in present work the wind mill data of work done by researcher Ian Prowell, P.E., M.ASCE, Chia-Ming Uang, M., Ahmed Elgamal, M. J. Enrique Luco, and Lanhui Guo is considered.

In his research work author has done the experimental work on the wind mill tower. The tower is the 65 KW tower used in the Denmark for the wind farms. The tower consists of the three different hollow sections of the different diameters. The diameter is more in the bottom of the tower and to achieve the economy in the design the diameter is reduced at the top. Figure 1 shows the main parts of the wind mill structure. Based on this detail the tower is modeled in FEM software.

The various properties of the different material used to model the tower are shown in table 1. The tower was modeled using cylindrical shell property of steel and the nacelle of the tower was modeled as solid elements of a user-defined material with the correct mass.

Table 1. Material properties

Material	Mass Density KG/M3	E in N/MM2
Tower	9891	200000
Nacelle	1529	200000
Rotor	1101	210000
blades	1101	1000

The blades of the given towers are modeled as cylindrical sections of fiber glass reinforced polyester material defined through user-defined material In the FEM software. The turbine was assumed fixed to its base. The meshing of all the shell members of the tower has been done according to the requirements.

The blade is properly connected with the axle and then it is connected with the nacelle. Shell formulation will combines membrane and plate behavior. Each joint within a shell object has six. Since joints within frame objects also have six degrees of freedom, frames may connect directly to the joints of shell objects

As the blades are modeled as a frame element and it is connected with the solid. Joints within solid objects have only translational degree of freedom, therefore they provide no rotational resistance to interconnected frame and shell objects. A body constraint or rigid link should connect the end joint of a frame to the tributary joints of a solid such that a force couple is available to resist moment within the frame joint, so for this proper structural behavior and connection between solid and shell objects a body constraint is also provided to connect the elements with each other.

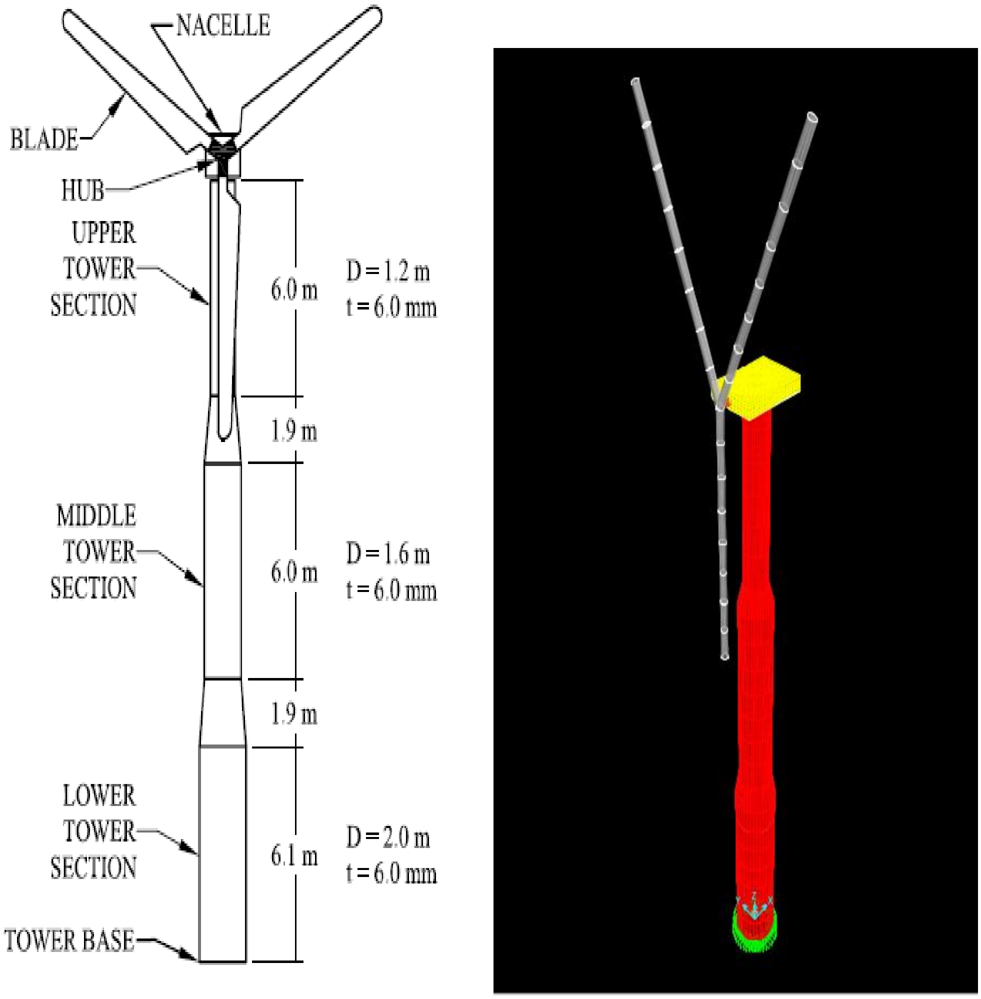

Figure 1. Dimensions of tower and its FEM model.

RESULTS OF MODEL VALIDATION

The dynamic analysis of tower is carried out in the FEM software using Eigen value analysis. The number of modes are selected in such a way that modal mass participation ratio is more than 90 percentage so that maximum mass of tower will participate in dynamic analysis. The frequency of the tower in various modes is obtained. The results obtained by present research work is almost same with previous work and it is shown in the table 2

Table 2. Dynamic properties of tower

Direction	Frequency by Ian Prowell's work Hz	Frequency by present work Hz
Fore Aft	1.70	1.86
Side to side	1.71	1.86
Fore Aft	11.9	11.00
Side to side	12.4	11.59

DYNAMIC RESPONSE ANALYSIS OF THE MONOPOLE AND INNOVATIVE HYBRID TOWER CONSIDERING VARIOUS TYPES OF SOIL

In order to study the influence of dynamic response in different site conditions, FEM software SAP 2000 is used. In the previous work the towers are modeled as monopoles having height of 22.0 meter. But as discussed earlier if the height of tower is increased we may get more wind at particular place and more power can be generated, as we know that the wind mill tower system is single degree of freedom system, so by increasing the height of tower the tower becomes dynamically sensitive and during operation conditions of the wind mill the resonance condition may occur. In order to study the effect of increasing height of the monopole towers on dynamic properties of the soil monopole tower of 32 meter height is modeled in the FEM software. After studying the monopole tower a hybrid tower which is combination of monopole tower and lattice tower is modeled having I.e. 32 meter height in finite element software. The height of Hybrid tower is also considered 32 meter with bottom 17.4 meter is modeled as lattice tower and remaining 14.6 meter height is modeled as monopoles. In the hybrid bottom portion of tower is lattice tower so main leg of lattice tower is modeled as beam element and the internal bracing systems are modeled as truss elements. For the analysis of the tower various loads given in the data such as self weight of the tower, nacelle, blade etc are considered.

It is not possible that wind mill towers are always constructed on hard soils, the soil may be medium or soft soil, so depending on soil the dynamic properties of the tower such as natural frequency, time period of the tower will change. To study the effect of soil on dynamic properties of tower this monopole and hybrid tower is modeled using 3 types of different soil condition. It is modeled considering tower on hard soil, medium soil and soft soil. The properties of the soil considered in FEM modeling are shown in table 3

Table 3. properties of soil

Type of soil	Shear modulus (G) KN/M2	Elastic modulus (E) KN/M2	Poission's ratio
Hard	30000	72000	0.20
Medium	20000	50000	0.25
Soft	10000	26000	0.30

Modeling of soil as FEM

Soil is assumed to be an isotropic, homogeneous, linearly elastic soil medium, the behavior of this tyoe of soil can be idealized and represented using solid models for modeling of the soil as solid it is required to give shear modulus, elastic modulus and poisons ratio in the FEM software. Soil is modeled using eight nodded element such as solid element having three degrees of freedom of translation and rotation in the respective co ordinate directions at each node.

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 work 20 mt X 20 mt X 10 mt size soil is considered below tower. The FEM model of hybrid tower is shown in Figure. 2

Dynamic loads on wind turbine

The wind mills are subjected to the dynamic loads due to vibrations and rotation of the blades which is fixed at the top of nacelle. It is generally given in terms of frequency. The loads applied on towers are due to the vibrations caused by blade rotations which are known as 1P frequency the other dynamic load is blade passing frequency, which are known as 2P/3P frequencies. The blades of the wind turbine passing in front of the towers will 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 or two times (2P) the rotational frequency of the turbine for a two bladed turbine. The 2P/3P frequency of the turbine is simply obtained by multiplying the limits of the 1P band by the number of the turbine blades.

In present case the 1p frequency of the turbine under study is 45 to 55 RPM so it is 0.75 Hz to 0.92 Hz and from this the 3p frequency is 1.72 Hz to 2.25 Hz

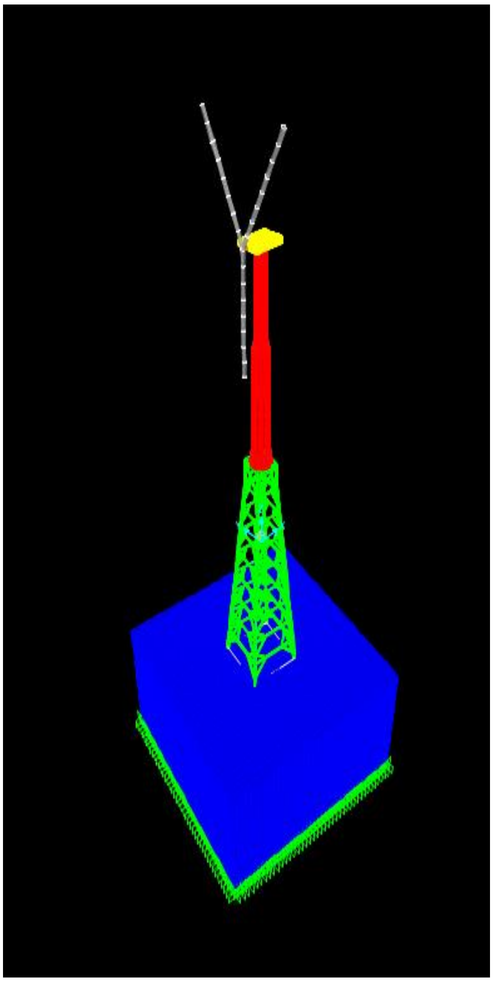

Figure 2. FEM model of hybrid tower with soil

RESULTS AND DISCUSSION

The loads applied on the tower is the dynamic loads due to rotors, it is observed that to avoid the resonance condition in the system, the designed frequency of overall system must be kept away from the frequency of applied loads.

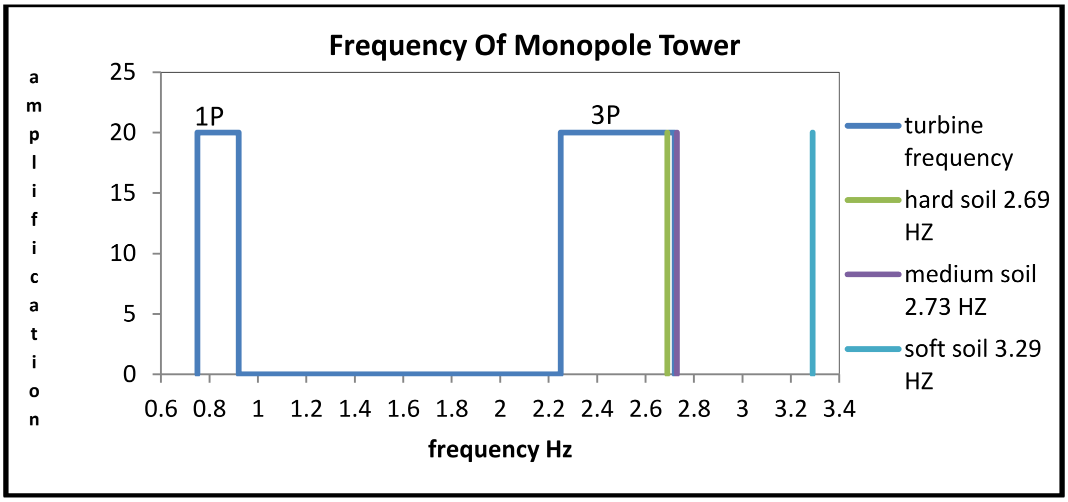

Figure 3. 1P and 3P Frequency of Monopole Tower

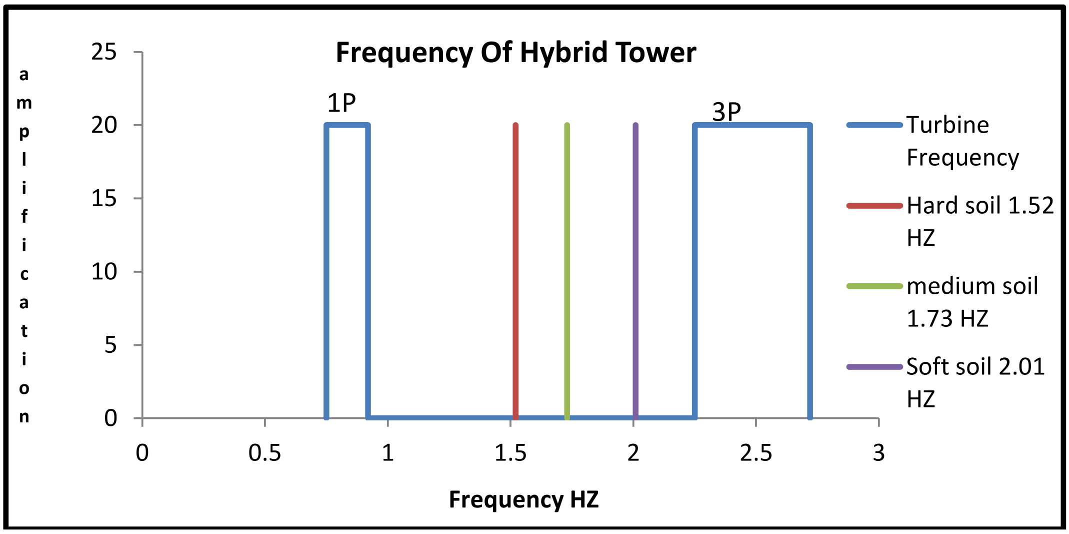

Figure 4. 1P and 3P Frequency of Hybrid Tower

There are 3 possible ranges in which the natural frequency of whole system may fall, which is soft- soft (natural frequency < 1P), soft- stiff (Natural frequency between 1P and 3P) and stiff-stiff (Natural frequency > 3P). It is required to do accurate evaluation of natural frequency of whole system, this natural frequency also depends on the stiffness of the foundation on which the towers are constructed. Figure 3 shows the frequency of the 32 meter high tower considering stiffness of the soil for monopoles and figure 4 shows the frequency of the hybrid tower considering stiffness of the soil. As mentioned in the data, the 1p frequency of the turbine under study is 0.75 Hz to 0.92 Hz and from this the 3p frequency is 2.25 Hz to 2.76 Hz. This range of 1P frequency and 3P frequency is plotted in the figure 3 and figure 4.

From figure 3 we can observe that we are getting 2.69 Hz and 2.72 Hz frequency for hard soil and medium soil for the monopole towers considering stiffness of soil, these natural frequencies are coinciding with 3P frequency of the applied loads so it may result in the resonance conditions during the operations of the tower.

From Figure 4 we can observe that the frequency of the hybrid tower considering the stiffness of all the 3 types of soil is between 0.92 to 2.25 Hz so we are not getting resonance condition in the hybrid towers. We are also getting soft-stiff design for all 3 types of soil and there are no chances of resonance in tower due to rotation of blades during operation and other loads applied on it.

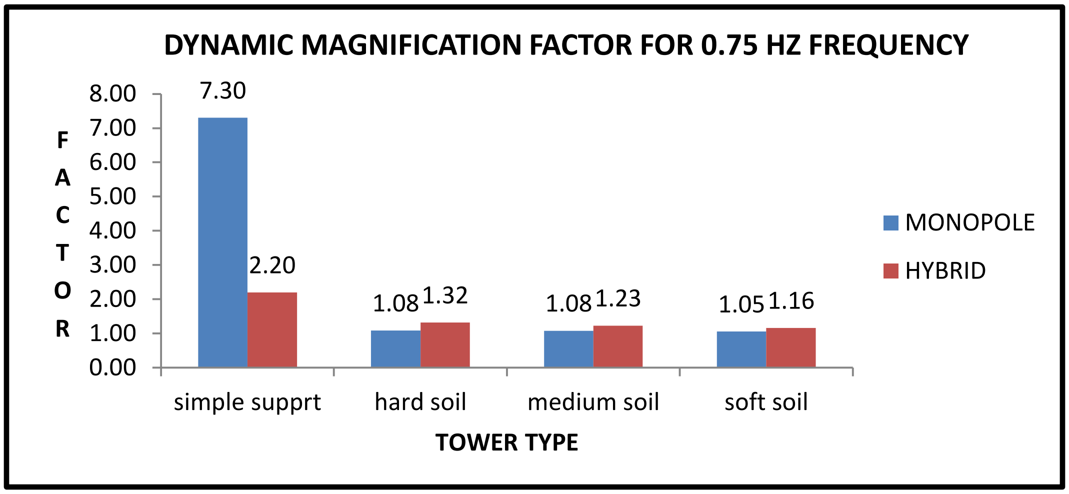

Figure 5. Comparison of DMF for 0.75 Hz Frequency

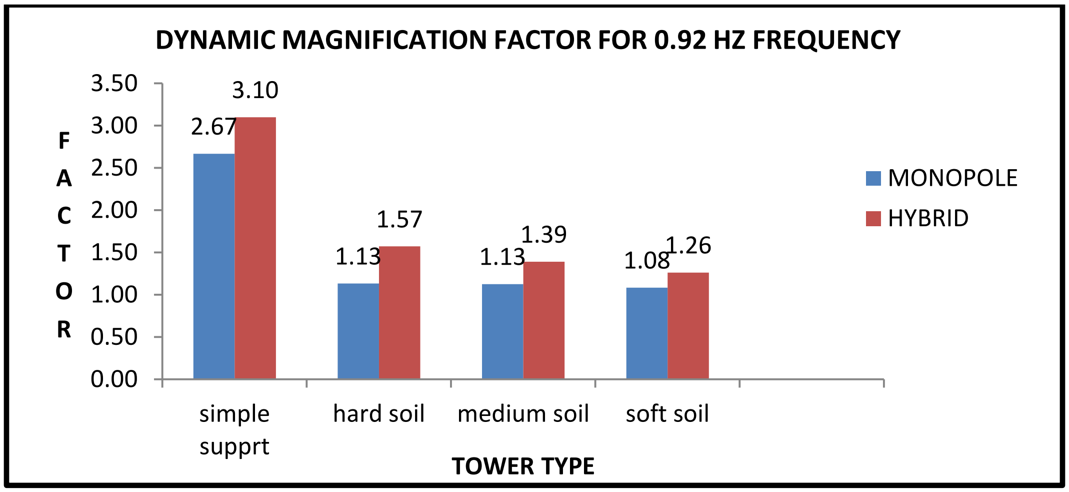

Figure 6. Comparison of DMF for 0.92 Hz Frequency

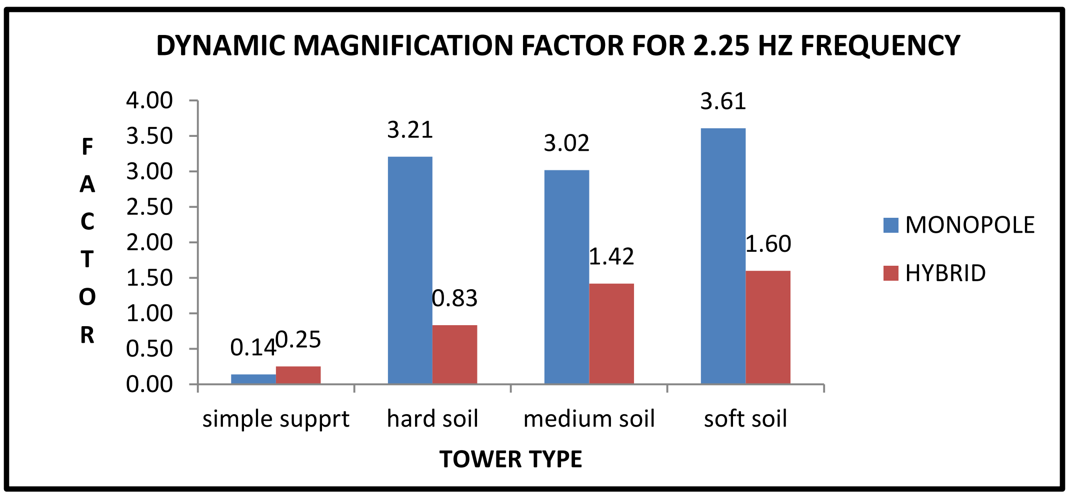

Figure 7. Comparison of DMF for 2.25 Hz Frequency

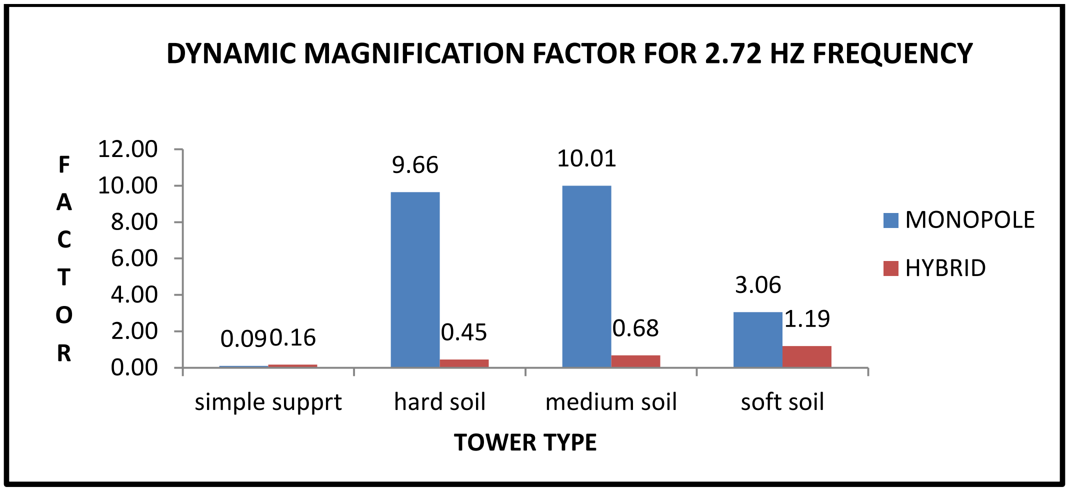

Figure 8. Comparison of DMF for 2.72 Hz Frequency

In case of dynamic loads the dynamic magnification factor is important parameter to study the effect of dynamic loads on any structure. It is the ratio of steady state amplitude to the static deflection of the structure. In our case the natural frequency of the structure depends on the mass and stiffness of the structure and also depends on stiffness of the soil. On the other hand, the operating frequency of the wind mill turbine varies and it depends on the wind blowing at the site, so to study this effects the dynamic magnification factor for different soils and different forcing frequencies are calculated and it is plotted in the figure no. 5 to 8.

We can observe that we are getting more dynamic amplification factor in case of monopoles as compared to the hybrid towers because monopole will behave as single degree of freedom system while hybrid tower has wider base compared to the monopoles so it will reduce vibrations and resonance conditions are avoided even for soft soils.

CONCLUSIONS

From the above study we can conclude that

1. The effect of the soil is more predominant in case of tall wind mill structures constructed on the soft soil and it can result in resonance conditions during the operation of wind mill towers so stiffness of soil must be considered for dynamic analysis of tower.
2. By increasing the height of monopole tower it results in the resonance conditions for different types of soil, but the innovative hybrid tower will eliminates the resonance conditions during dynamic loading.
3. The dynamic magnification factor also reduces in the hybrid tower compared to the conventional monopole towers
4. Hybrid towers are less sensitive to dynamic loads and can be used very efficiently for tall wind mill structures.

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