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A STUDY ON WIND TURBINE TOWER SUBJECTED TO SOIL-STRUCTURE INTERACTION

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Abstract - ***Abstract Wind turbine design has progressed significantly in terms of its size and type in recent years. However, the design of the towers is commonly based on a fixed based structural model, and the soil-structure interaction is ignored even for soft soils. Soil-structure interaction is the process that involves the analysis of the relationship between the structure and the underlying soil, and how it affects the motion that the structure experiences during an earthquake. In structural engineering practice, soil-structure interaction is considered as a favorable effect to lessen the seismic response of the structure.***

Soil-structure interaction consists of two parts, namely, inertial and kinematic interactions in sub-structuring technique. In the present study, the seismic response of a wind turbine tower is examined with & without soil-structure interaction. The modelling and analysis of the tower is carried out using SAP2000 V14 software package. Soil is modelled as per Winkler formulation using spring constants.

The results in form of fundamental time period, lateral sway at the top and base shear are compared under various zones considered. It is observed that, the fundamental time period of the structure and the lateral sway or lateral displacement at the top of the structure considered increased when the effect of soil structure interaction was considered. Also the base shear values for the interaction case is found to be lower than that of non-interaction case. Based on the analysis, it was concluded that the seismic response of the wind turbine tower is greatly influenced by soil supporting its base. Disregarding them can significantly affect the performance of the wind turbine tower during an earthquake and result in devastating effects. The detailed results are described and shown in this report.

Key Words: *Wind mill, Soil-Structure Interaction, Seismic Analysis, Fixed Base, Spring Support.*

1. WIND MILLS

The name wind turbine is given for a device that converts kinetic energy coming from the wind to electrical energy. The correct suitable name for such type of machine would be aero-foil powered generator as there is technically no turbines used in the design. Today, due to rapid advancement & modern engineering, wind mills are manufactured in wide range of types. The small wind turbines are used for local applications like battery charging, while slightly larger wind turbines can be used for generating domestic power supply and large wind turbines, known as wind farms, are becoming a progressively significant source of renewable energy in many countries.

1.1 Types of Wind mills.

Wind turbines can rotate about either a vertical or a horizontal axis, the latter being both older and most common type. Horizontal-axis wind turbines (HAWT) have the electrical generator & the main rotor shaft at the top of tower, and should be pointed into the wind. Vertical-axis wind turbines (VAWT) have the main rotor shaft arranged vertically. One of the major advantage of this kind of arrangement is that the turbine need not to be necessarily pointed into the wind in order to be effective, which is a plus point on a location where the wind direction is exceedingly variable.

1.2 Efficiency of Wind mill

Not all the energy of blowing wind can be harvested, since conservation of mass requires that as much mass of air exits the turbine as enters it. Betz's law gives the maximal achievable extraction of wind power by a wind turbine as 59% of the total kinetic energy of the air flowing through the turbine. Further inefficiencies, such as rotor blade friction and drag, gearbox losses, generator and converter losses, reduce the power delivered by a wind turbine. Commercial utility-connected turbines deliver 75% to 80% of the Betz limit of power extractable from the wind, at rated operating speed. Efficiency can decrease slightly over time due to wear.

2. SOIL-STRUCTURE INTERACTION

Most of the civil engineering structures involve some type of structural element with direct contact with ground. When the external forces, such as earthquakes, act on these systems, neither the structural displacements nor the ground displacements, are independent of each other. The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is termed as soil-structure interaction (SSI). Usually, conventional structural design methods neglect the Soil Structure Interaction effects. Ignoring SSI is sensible for light structures in moderately stiff soil such as simple rigid retaining walls and low rise buildings. The consequence of SSI, however, becomes noticeable for dense structures which are resting on rather soft soils, for example nuclear power plants and high rise structures. The structure in response can considerably be influenced by the flexibility of soil. There are 2 primary matters involved in occurrence of soil structure interaction namely Kinematic interaction and Inertial interaction. Two different types of methods have been adopted in the past to investigate the problem of soil-structure interaction and incorporate the effect of soil compliance in the dynamic analysis which are Direct method & Multi step method.

3. MODELLING AND ANALYSIS

The modelling and analysis of the wind turbine tower structure, foundation and the underlying soil is done using a universally accepted software SAP (stands for Structural Analysis Programming) Version 14. The different soil types considered in the study are hard (stiff), medium and soft soil. These classifications are based on dynamic shear modulus (Bowles). The specifications of the wind tower is as follows- Height-75m, bottom radius-4m, top radius-2.5m, wall thickness-400mm, slab thickness-500mm, footing depth-1.5m. The grade of concrete is M35 and of the reinforcement steel is FE500. The loads of the rotor, blades and nacelle assembly is applied on the slab at the top of the tower. The load combinations are defined as per IS456:2000(Table 18).

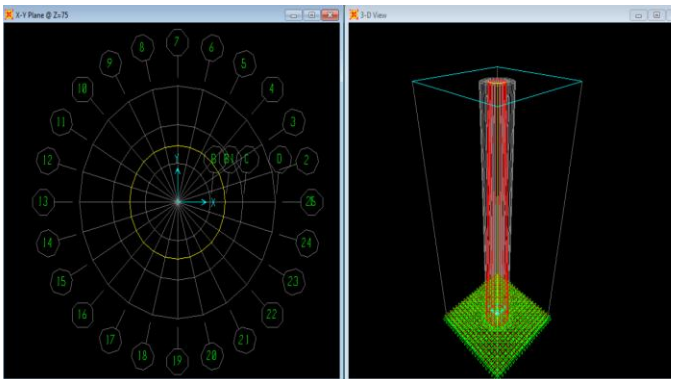

Fig -1: Modelling of wind mill tower.

The finite element modelling/idealization of Raft footing is carried out in the same way as that of the soil, that is, by using Modified Winkler Model. The raft foundation considered is discretized and modelled as shell-thin with 4 noded plate elements that are having 6 degrees of freedom at each and every node.

The soil is modelled by making use of spring constants as per Winkler formulation. Here, 3 translation and 3 rotational springs about 3 directions which are mutually perpendicular with each other have been considered to mimic the effect of flexibility of the soil. The Stiffness of equivalent soil springs along various degrees of freedom is calculated using the formulas provided by Gazetas (ATC-40) for raft foundations for soft, medium and stiff soil.

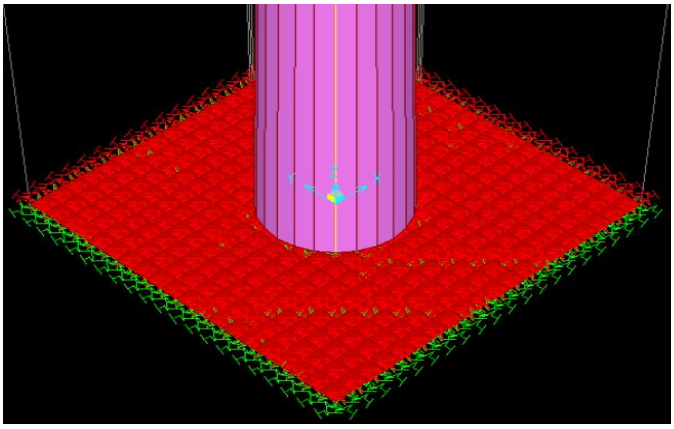

Fig -2: Soil equivalent spring stiffness assigned at the foundation

Linear dynamic analysis is performed by response spectrum method. The seismic and wind parameters are taken on the basis of the site location present in Belgaum, Karnataka. The analysis is carried out on the models considering fixed support and spring supports.

3. RESULTS AND DISCUSSION

The analysis is carried out for the towers (RC & STEEL) for different soil-structure system (Winkler's model) by the method of response spectrum presented in IS 1893:2002, using SAP2000 v14 software. The comparisons of various responses for the set parameters between the case of fixed boundary condition and with considering the soil-structure interaction case have been shown. Graphs are plotted for relevant tables and the results obtained are discussed in detail.

The following results of the wind turbine tower with raft foundation are studied, as a function of following parameters namely Base Shear due to seismic excitation, Lateral sway at the top due to earthquake excitation & Fundamental natural time period.

Base shear - Zone III - 75m RC tower				
Soil type	Direction	Fixed	Spring	% Variation
Hard	x	212.28	210.42	0.8762012
	y	212.24	210.35	0.8905013
Medium	x	288.7	272.35	5.6633183
	y	288.65	272.05	5.7509094
Soft	x	354.5	300.11	15.342736
	y	354.44	299.86	15.398939

Table -1: Variation of Base Shear of RC tower in zone III.

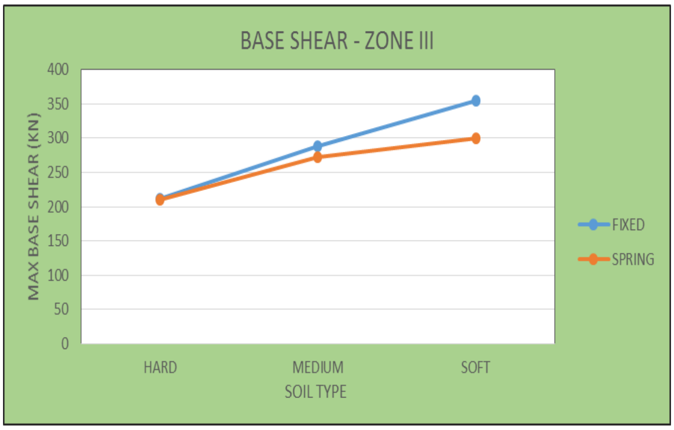

Chart -1: Graph showing variation of Base Shear in zone III.

The above figure and table shows the values of base shear in kN with respect to shear modulus. Percentage variation of base shear values from fixed to spring, obtained considering different soil types are shown. It can be seen that, in comparison to fixed support, the interaction analysis substantially decreases by a percentage of 0.89 in case of hard soil, 5.75 % in case of medium soil and 15.3% in case of soft soil. It can also be seen that as the foundation soil system is rendered flexible, base shear increases.

Lateral sway at top - Zone III - 75m RC tower				
Soil Type	Direction	Fixed	Spring	% Variation
Hard	x	22.77	22.97	0.8707009
	y	22.78	22.98	0.8703220
Medium	x	30.95	32.81	5.6690033
	y	30.96	32.84	5.7247259
Soft	x	38	53.76	29.315476
	y	38.01	53.54	29.006350

Table-2: Variation of Displacement of RC tower in zone III.

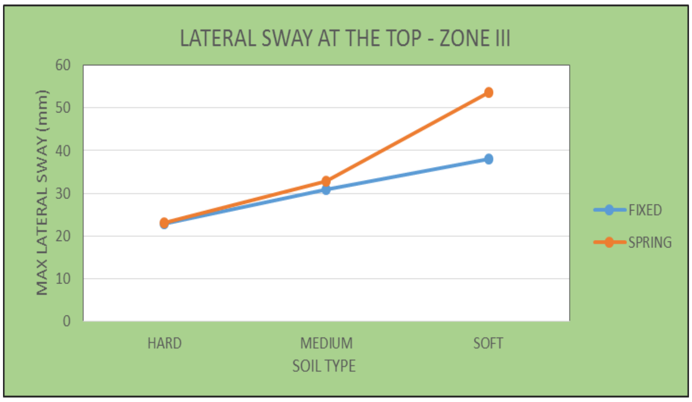

Chart -2: Graph showing variation of Displacement at top in zone III.

The above figure and table shows the values of lateral sway at the top in mm with respect to shear modulus. Percentage variation of displacement values from fixed to spring, obtained considering different soil types are shown. It can be seen that, in comparison to fixed support, the interaction analysis substantially decreases by a percentage of 0.87 in case of hard soil, 5.72% in case of medium soil and 29.3% in case of soft soil. It can also be seen that as the foundation soil system is rendered flexible, displacement increases.

Time period & Frequency - 75m RC tower				
Soil type		Fixed	Spring	% Variation
Hard	Time period	1.2346	1.2457	0.8910652
	Frequency	0.8099	0.8028	0.8766514
Medium	Time period	1.2346	1.3101	5.7629188
	Frequency	0.8099	0.7633	5.7537967
Soft	Time period	1.2346	1.7599	29.848286
	Frequency	0.8099	0.5682	29.843190

Table-3: Variation of time period & frequency in RC tower.

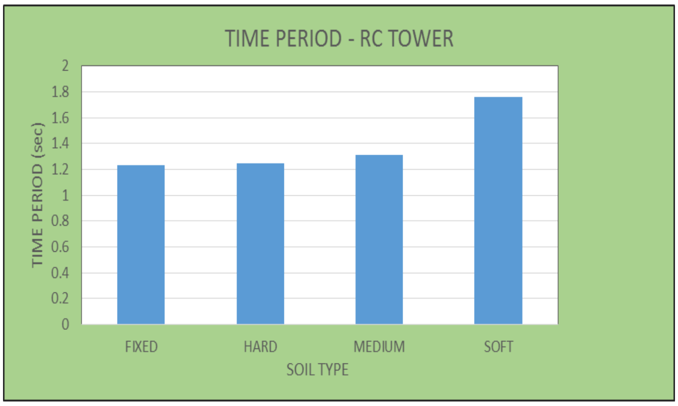

Chart -3: Graph showing variation of Time Period in RC tower.

The above figure and table shows the values of time period in sec with respect to shear modulus. Percentage variation of time period values from fixed to spring, obtained considering different soil types are shown. It can be seen that, in comparison to fixed support, the interaction analysis substantially increases by a percentage of 0.89 in case of hard soil, 5.76% in case of medium soil and 29.84% in case of soft soil. It can also be seen that as the foundation soil system is rendered flexible, time period increases.

4. CONCLUSIONS

This dissertation extends to evaluate the effect of soil flexibility on certain important structural characteristics namely, maximum displacement, fundamental period and also seismic base shear. The study leads to the following broad conclusions.

4.1 FUNDAMENATAL NATURAL PERIOD

- The fundamental natural period is more in the structure where soil-structure interaction is considered compared to non-interaction.

- With increase in the shear modulus of soil, the fundamental natural time period of a particular structure decreases.
- The fundamental natural time period of a particular structure remains almost same with the changes from zone II to zone V.

4.2 BASE SHEAR

- The values of Base shear for the SSI case is found to be lower than that of non-interaction case which can be seen predominantly.
- Along any direction, the base shear values for a particular structure decreases as the soil becomes stiff, i.e, when there is increase in shear modulus of soil.
- The base shear values for a particular structure increases with the changes from zone II to zone V.

4.3 LATERAL SWAY

- The values of maximum lateral displacement resulting from a fixed base analysis are considerably enhanced when interaction analysis of the system is considered.
- As the flexibility of the of soil decreases, i.e, shear modulus increases, the displacement results alongside any of the horizontal directions for a particular structure decreases.
- The lateral sway values for a particular structure increases with the changes from zone II to zone V.

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REFERENCES

[1] Dr. Narayana G & Priyanka S (2013), "Dynamic soil-structure interaction behavior of asymmetric 3D building frames with raft footing"
[2] Geetha P M et al, "Soil structure interaction of an irregular building considering the effect of brick infills".
[3] Bowles.J.E-"Foundation Analysis and Design", McGraw-Hill, Singapore-1974.
[4] Gazetas G (1991) "Formula and charts for impedance of surface and embedded foundations" Journal of Geotechnical Engineering, ASCE 117(9)1363-1381.
[5] ATC-40 (Applied Technology Council) "Seismic evaluation and retrofit of concrete buildings".
[6] IS: 456-2000, "Code of Practice for Plain and Reinforced Concrete", Bureau of Indian Standards, New Delhi, India.
[7] IS:1893 (Part 1)-2002 Criteria for Earthquake Resistant Design of Structures, part 1-General provisions and buildings, fifth revision, Bureau of Indian Standards, New Delhi, India.

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