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Soil structure interaction effect on the dynamic analysis of wind turbine tower

Prasantagouda Bhagavantagoudra[1], Mamata Mogali[2]

[1]*P.G student, Dept. of Civil Engineering, SDMCET Dharwad, Karnataka, India*
[2]*Assistant professor, SDMCET Dharwad, Karnataka, India*

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Abstract – The wind turbine tower in the design in most of the cases is blindly considered as fixed case but it's not true in all the case as the base is placed on soft soil in most of the cases this alters the analysis result. In the present work the soft soil condition is modeled by the Winkler spring system values in the SAP2000 V14 software, the analysis elements which are determined for the comparison are natural frequency, top end displacements, base shear and the time period the analysis results are found to be the natural time period of the structure and top end displacements of the structure is more when the effect of soil structure interaction is considered, and the base shear value for the interaction case is found to be lower than that of the case where the soil structure interaction is absent by the result observation it is found that the soil structure interaction condition is greatly influenced the analysis results the detailed results are described and shown in this report.

Key Words: Turbine tower, Winkler spring, frequency, base shear, displacement, Interaction

1. INTRODUCTION

The Engineers for the dynamic analysis in most of the cases for the buildings or any tower structures is simply on the assumption that the base is hard or stiff type. This assumption is true only for the base which is having rock surface, where the transform of vibration from the structure to the foundation and back from the foundation to the structure is not existing. The case where the structure is placed on a soft base their absolutely the transform of vibration from the structure to the soil and back from the soil to structure is existed here the above Engineers assumption fails and design leads to reducing the safety factor and the structure become in danger zone, hence the topic arises called soil structure interaction (SSI), here the alterations which are to be done for the consideration of soil is done by using the soil assumption like spring constant and an attempt is being done similarity in the effect as that of the transmitted vibration from both the building and the base soil.

2. SOIL STRUCTURE INTERACTION

When a structure is subjected to dynamic loading the vibrations formed are of very large extent. The transform these vibrations from the building to the soil takes place for this vibrations the base soil responses. Then it transfers back the vibrations to the building for this vibrations the building responses for this response the building reacts and finds the variation in their characters like base shear, time period, natural frequency, top end displacements. This effect is called soil structure interaction, this effect absent in the structure where the soil structure interaction is not considered and the results obtained are also without soil structure interaction. The ignorance of this soil structure interaction is not having that great influence on the results of the small scale buildings which are light weight buildings, simple rigid walls having low rise buildings On all buildings which are placed very hard surface that is stiff soil, rock surface etc. But ignorance of this same Soil structure interaction effect on the high rise buildings, very high self weight building , buildings placed on soft soil have the very adverse effect

3. MODELLING AND ANALYSIS

The modeling and analysis of the wind turbine tower structure, foundation and the underlying soil is done using a universally accepted soil SAP (stands for Structural Analysis Programming) Version 14. The modeling details such as material properties, section properties, soil properties, modeling dimensions are as given below, Similarly, frame sections such as beams, columns etc are defined. Then the frame sections are to be modeled in case of normal building sections, but here the consideration is tall tower structure hence it is modeled by taking initially shell element like frame structure, then the member is modelled as continuous line that connects 2 points. Curved object can be divided into multiple straight line objects using the graphical user interface. Each elements local coordinate points for sectional property. the base diameter of the tower is 4.5m, the top end diameter of the tower is 4m, the height of the tower is 80m, thickness of the tower is 0.45m, load of the rotator part is taken as 80ton , the soil conditions considered are soft, medium and hard. In the material data property, the Material name, Weight per unit volume, Mass per unit volume, Poisson's Ratio, Elastic modulus and certain other things must be mentioned for all of the defined material. The self weight of the components in mass per unit volume needed for the calculation of whole structure. The grade of steel is Fe 415 and concrete strength is M25 is considered Super-structure of the tower as three dimensional frame is modeled The superstructure as space frame consists of frames as plinth beams at the base of the tower. Area objects have been chosen as a form of slab which is placed at the top of the tower and on which the loads are applied. Another area object has been chosen as the walls of the tower. The sectional and material properties of these objects were shown earlier in this chapter. The graphical image of the whole structure is as shown below.

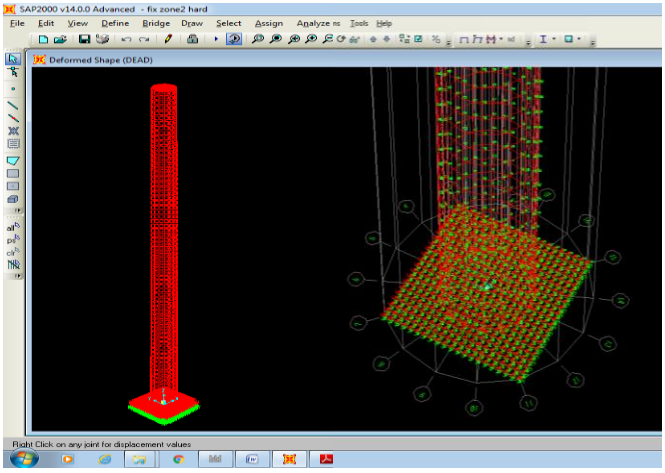

Fig -1: Wind turbine tower structure

The finite element modeling/idealization of Raft footing is done like a slab system, then the raft foundation slab is divided in both the x and y direction in equal number of nodes and at each node the fixed condition is given, in this case no spring constant values are to be given as the soil is assumed to be fixed to the above foundation base. One of all these detailing snapshot is given below.

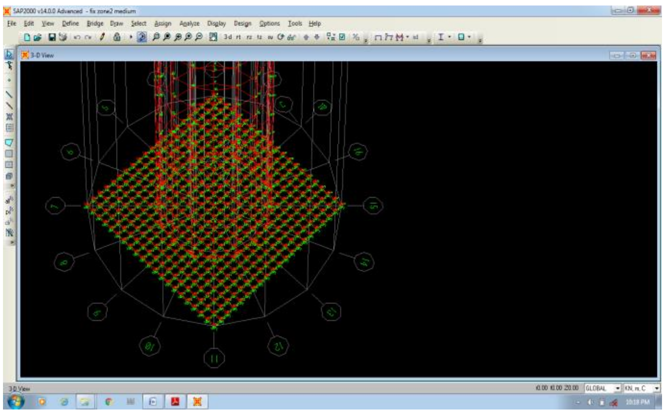

Fig –2: Raft Foundation with fixed restraints

The soil is modeled by making use of spring constants as per Winker formulation. Here both rotation and translation are in three numbers hence total number of rotation and translation are six, this is represented by three number springs are placed in orthogonal to each other in 6 paths, just to mimic the soil flexibility character.

The purpose of foundation is to withstand the force acting at base of wind mill tower to it. At the time of vibrations caused due to seismic activity, rigid base will be put under displacement of 6 DOF and the opposition caused acting by soil might have been expressed by the six corresponding resultant force component. Therefore the flexible nature is characterized fully by a set of forced displacement relationship which are well defined for these DOF. To fake the static behavior of structure soil system it is obvious that the below foundation model can be set of six linear springs that are acting in rigid base degrees of freedom. By the method of continuum mechanics suitable static spring constants can be assessed. Under dynamic loading to analyze the foundation soil system the impedance functions which are in relation with stiff mass less foundation are most commonly used. In present work three number of force acting at the base are considered along with 2 number of translation and one torsion or the rotation is taken into account.

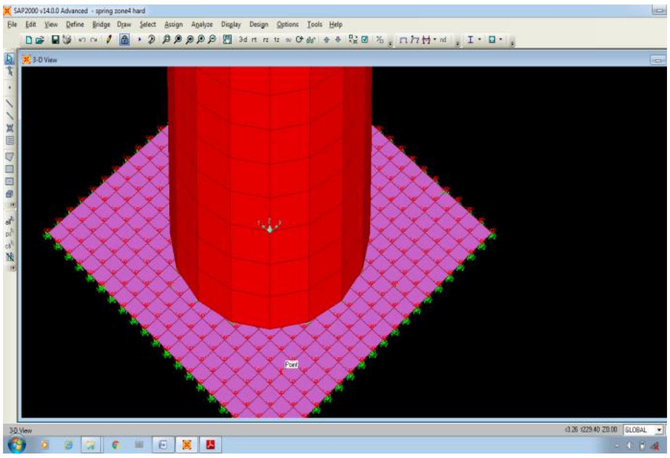

Fig -3: Soil equivalent spring stiffness assigned at the foundation

4. RESULTS AND DISCUSSIONS

The present chapter displays the results of linear dynamic analysis that is carried out with & without SSI. The analysis is carried out for the tower 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.

Table-1:Base shear percentage variation for zone II

BASE SHEAR - ZONE II				
		FIXED	SPRING	%VARIATION
HARD	X	56.62	56.01	1.07
	y	56.62	56.01	1.07
MEDIUM	X	76.99	70.62	8.27
	Y	76.99	70.62	8.27
SOFT	X	94.55	80.26	15.11
	Y	94.55	80.26	15.11

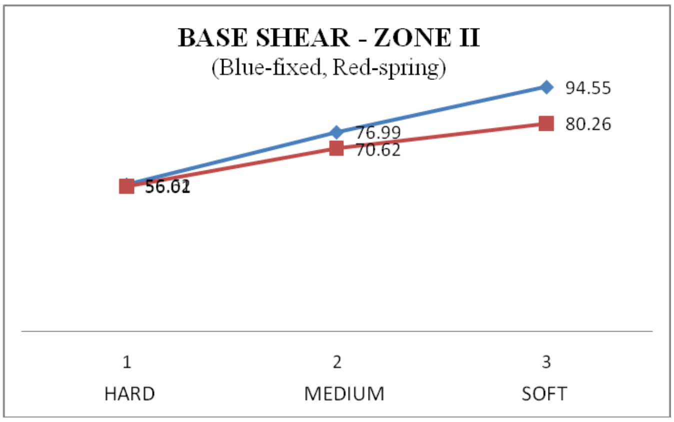

Fig -4: Base shear - Zone II

The above figure and table shows the values of base shear in kN with respect to shear modulus. Percentage variation of base shear value 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 1.07% in case of hard soil, 8.27 % in case of medium soil and 15.11% in case of soft soil. It can also be seen that as the foundation soil system is rendered flexible, base shear increases.

Table-2: Lateral sway percentage variation for zone II

LATERAL SWAY AT TOP - ZONE II				
SOIL TYPE		FIXED	SPRING	%VARIATION
HARD	X	11.83	12.02	1.58
	y	11.83	12.02	1.58
MEDIUM	X	16.09	17.19	6.39
	Y	16.09	17.19	6.39
SOFT	X	19.75	27.34	27.72
	Y	19.75	27.34	27.72

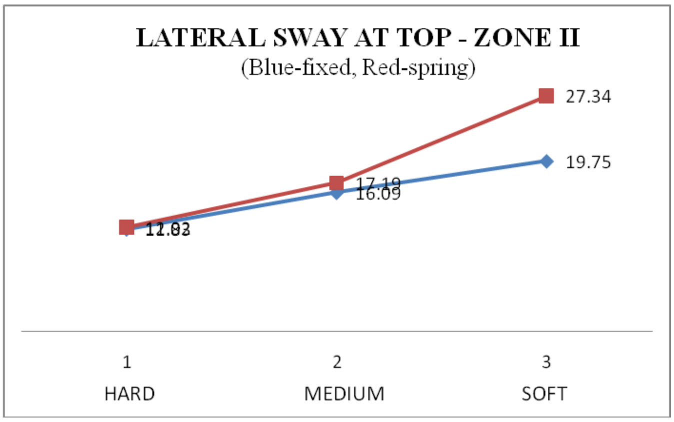

Fig -5: Lateral sway at top - Zone II

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 1.58% in case of hard soil, 6.39% in case of medium soil and 27.72% in case of soft soil. It can also be seen that as the foundation soil system is rendered flexible, displacement increases.

Table-3: Time Period percentage variation

TIME PERIOD & FREQUENCY				
SOIL TYPE		FIXED	SPRING	%VARIATION
HARD	Time Period	1.811	1.826	2.26
	Frequency	0.552	1.876	2.26
MEDIUM	Time Period	1.81	1.99	9.04
	Frequency	0.552	1.99	9.04
SOFT	Time Period	1.811	2.53	28.41
	Frequency	0.552	2.53	28.41

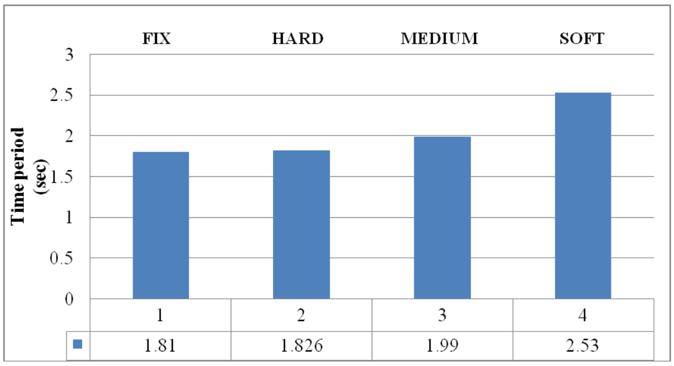

Table -6: Sample Table format

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 for fixed condition the time period is 1.811sec for all zones. in comparison to fixed support in the spring condition the interaction analysis substantially increases by 2.26% in case of hard soil, 9.04% in case of medium soil and 28.41% in case of soft soil. And also it can be seen that as the foundation soil system is rendered flexible, time period increases

5. CONCLUSIONS

The current study made a sincere attempt to gauge the effect of SSI on seismic response of a wind turbine tower on various seismic zones on soft, medium and hard soils which is resting on Raft foundation. This dissertation also extends to evaluate the effect of SSI certain parameters which are primary data to be collected for the design they are namely, maximum displacement, fundamental period the base shear. The study leads to the following broad conclusions.

5.1 NATURAL TIME PERIOD

The fundamental natural period is more in the structure where soil structure interaction is considered compared to non-interaction. With decrease in the shear modulus of soil, the fundamental natural time Period of a particular structure increases. The fundamental natural time period of a particular structure remains almost same in fixed condition with the changes from zone II to zone V.

5.2 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 wind turbine tower increases with the change in earthquake zone from II to V.

5.3 LATERAL SWAY

The magnitude of maximum top end horizontal displacement obtained by the fixed end condition are considerably increased when the soil flexibility analysis results 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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