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Effect of Soil Structure Interaction on RC Chimneys with Different Heights Subjected To Sesimic Loads

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Abstract: *The actual behaviour of the structures under seismic load may significantly differ from what the analysis provides treating the structure to be on fixed base. There is a large difference in the foundation input motion during the earthquake for soft soils when compared to free field ground motion that exists in the absence of structure with the assumption of a fixed support. These interaction effects results in dynamic responses showing significant variation in frequency and amplitude values that were obtained. The present study focuses on the effect of soil flexibility of significant design variables in the seismic response of chimney structures with raft footing. The results show that, lateral displacements and support displacements decrease with increase in soil subgrade modulus, natural frequency decreases with increase in soil flexibility and percentage decrease in natural frequency decreases with increasing soil flexibility.*
Keywords*: chimney, interaction, frequency, soil flexibility, dynamic response.*

I. Introduction

The response of soil influences the behaviour of structure. The behaviour of the structure influences the response of soil and this process is termed as soil structure interaction (SSI). Research on effect of soil structure interaction of chimneys with greater height and other different slender structures has received attention in last few years. In recent times the need to built large structures at places with less favourable geotechnical consideration and in seismically active regions where the problem of soil structure interaction has become a significant topic of interest.

It was clear from 1994 niigat earthquake (M7.5), damage to structure depends on sub soil even not only on the super structure. Researchers studied the behaviour of soil under dynamic loading analytically, numerically, experimental investigations were done and it was observed that the response of soil to the dynamic loading has a great impact in the damage of structure. Several factors are to be considered as the behaviour of soil becomes more complex.

From the past there are many evidences that during major earthquake the damage of the structure is not only structural damage but also due the underlying soil even. In 1985 of Mexico earthquake partial bearing failures of underlying soil were observed in the damage of high rise buildings.

1.1 Objective

To perform linear dynamic analysis on three different heights of chimneys i.e., 75meter, 150meter, 250meter with fixed support and three different types of subgrade modulus i.e., 12000 kN/m^2/m , 36000 kN/m^2/m and 64000 kN/m^2/m at all seismic zones in india i.e., Zone-II, Zone-III, Zone-IV, Zone-V and to compare the lateraldisplacement, mode shapes and support displacements

II. Modelling of Structure

In STAAD PRO V8i software program the chimney model is generated

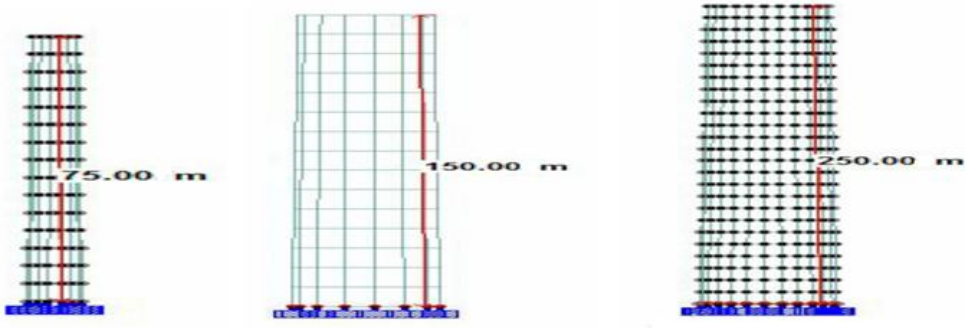


Fig no :2.1 generated Staad models

Table no 1:- Dimensions of chimney

Height of chimney	75m	150m	250m
Diameter of base	4.8m	12.0m	18.0m
Diameter of top	4.0m	11.0m	16.0m
Diameter of raft for12000 kN/m^2/m	12m	31.0m	38.0m
Diameter of raft for36000 kN/m^2/m	7.5m	20.0m	30.0m
Diameter of raft for64000 kN/m^2/m	5.5m	14.0m	22.0m

Chimneys are generated with required thickness and loads are assigned to the chimney, response spectrum method is used by calculating the acceleration. Load combinations of 1.5 DL+1.5 EQ(RS) and 0.9 DL + 1.5 EQ(RS) are assigned and Raft is created using surface meshing .

2.1Material properties

The following properties of the concrete are considered in the analysis

- Grade of Concrete, f_{ck} = M30
- Poisons ratio = 0.2
- Density =25 kN/m^3
- Modulus of Elasticity = 27386.13 MPa

2.2 Loads

The design loads considered are as per IS 875 (part 1, and part 2for dead and live loads respectively) and the earthquake loads considered are as per IS 1893 (part 1): 2002.

III. Results And Discussion

The seismic response of the chimney is compared for different earthquake intensities and soil types. The results are presented separately for all the above models for four different earthquake intensities confining to Zone – II, III, IV and V according to IS 1893: 2002. The seismic responses such as lateral displacements, support displacements, mode shapes, natural frequency and time period are evaluated.

3.1 Lateral Displacements

The lateral displacements are investigated for the studied chimney of 75m, 150m and 250m height with different sub grade modulus values of soil. The lateral displacements over the chimney height for different soil conditions along with the response of SSI model to that of fixed-base model are introduced in fig no 3.1 to 3.12.

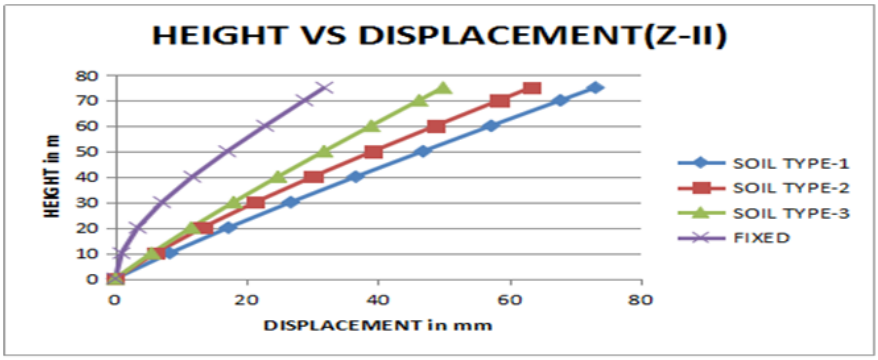


FIG NO: 3.1 Height vs Displacement for 75m in seismic zone-II

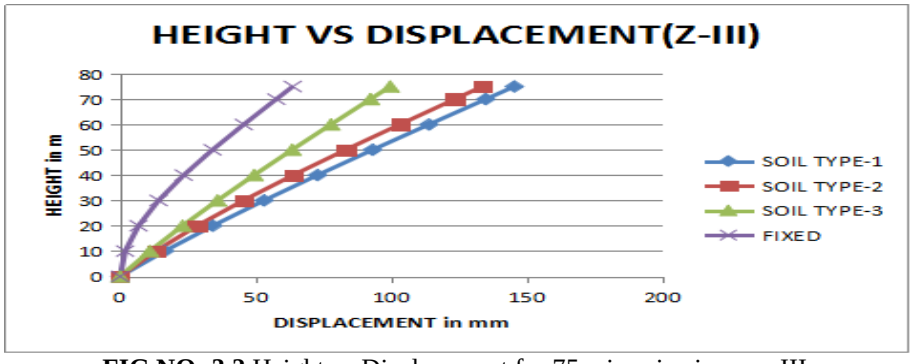


FIG NO: 3.2 Height vs Displacement for 75m in seismic zone-III

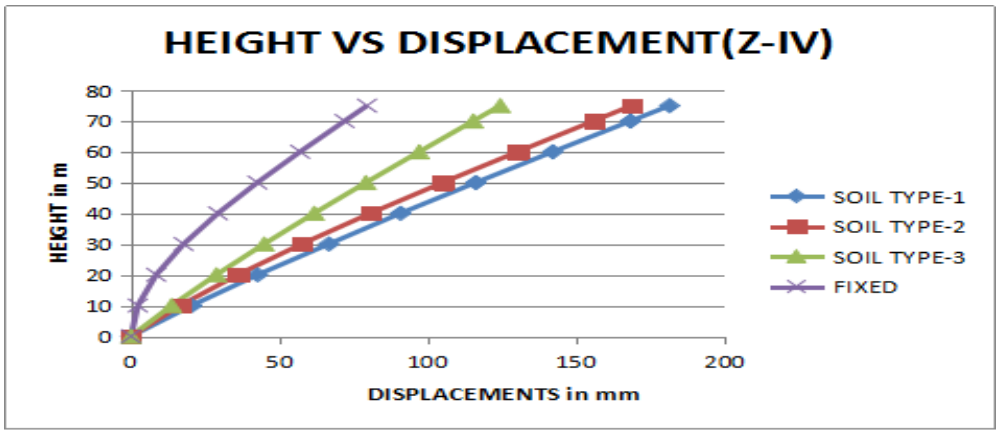


FIG NO: 3.3 Height vs Displacement for 75m in seismic zone-IV

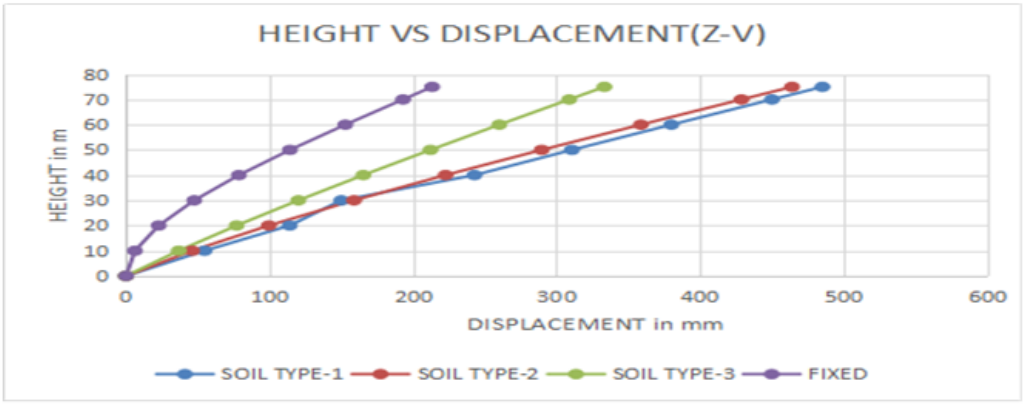
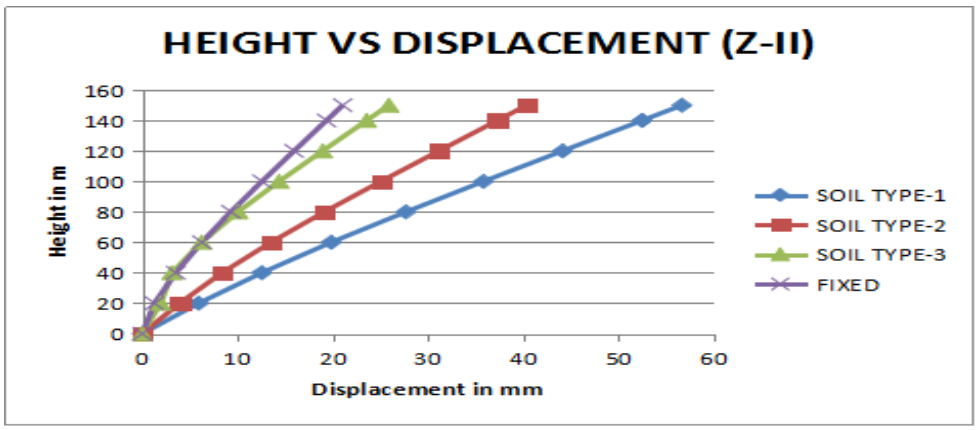


FIG NO: 3.4 Height vs Displacement for 75m in seismic zone-V

From the figures shown above, it is observedthat the displacements decrease with increase in soil subgrade modulus which may be due to increase in stiffness of the soil. Considering the 40m height of 75m chimney, the displacement for sub grade modulus of 12000 kN/m^2/m is 36.61mm, for subgrade modulus of 36000 kN/m^2/m is 30.032mm,for subgrade modulus of 64000 kN/m^2/m is 24.73mm, for fixed support is 11.73mm. The displacement for sub grade modulus of 36000 kN/m^2/mgetsdecreased by 18% when compared with sub grade modulus of 12000 kN/m^2/m. The displacement for sub grade modulus of 64000kN/m^2/m gets decreased by 32% when compared with sub grade modulus of 12000 kN/m^2/m.

Comparing the results with respect to seismic zone for sub grade modulus of 12000 kN/m^2/m the displacements are decreased by 85%, 70%, 62.5 for zone-III, zone-IV, zone-V respectively.

Considering the results of 150 meter height chimney, the lateral displacements over the chimney height for different soil conditions along with the response of the SSI model to that of fixed-base model are introduced in fig no 3.5 to 3.8.



FIGNO : 3.5 Height vs Displacement for 150m in seismic zone-II

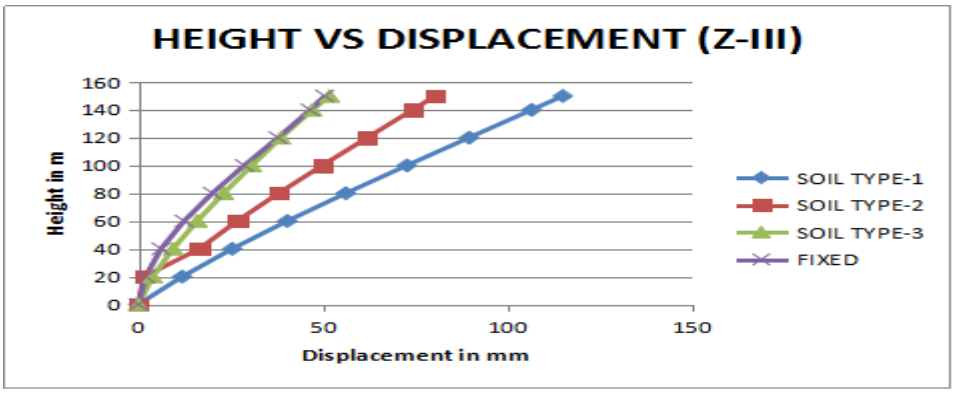
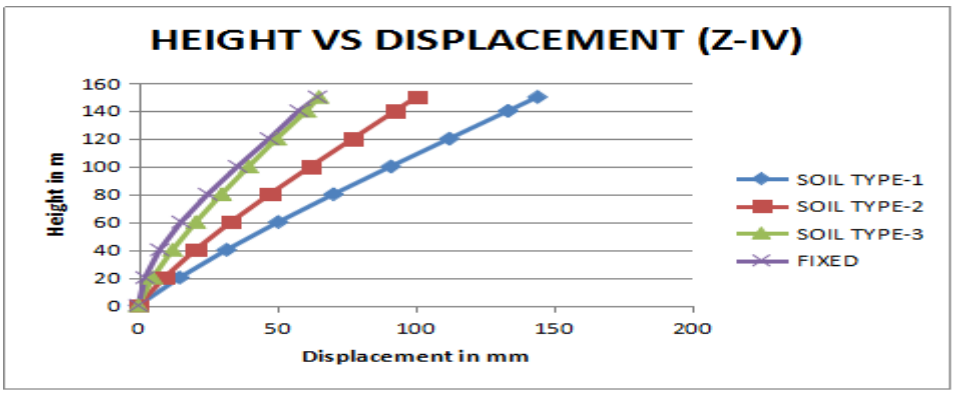


FIG NO : 3.6 Height vs Displacement for 150m in seismic zone-III



FIGNO : 3.7 Height vs Displacement for 150m in seismic zone-IV

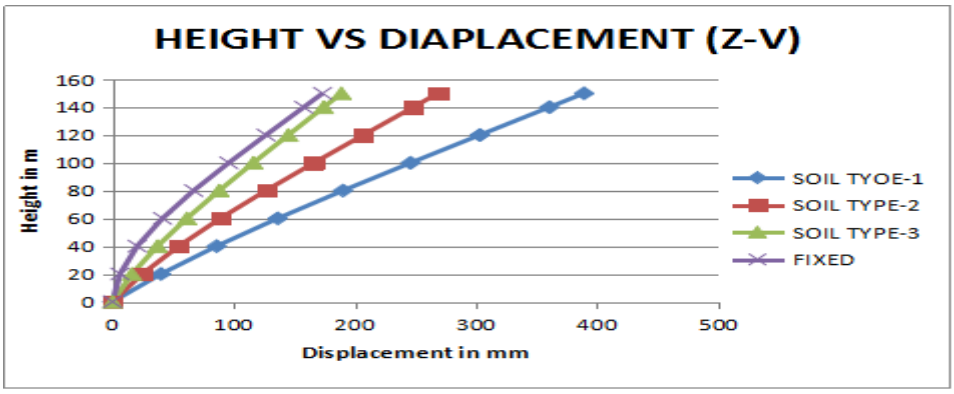


FIG NO: 3.8 Height vs Displacement for 150m in seismic zone-V

From the figures shown above, it is observed that the displacements decrease with increase in soil subgrade modulus which may be due to increase in stiffness of the soil. Considering 80m height chimney, the displacement for sub grade modulus of 12000 kN /m^2/m is 27.69mm, for sub grade modulus of 36000 kN /m^2/m is 19.12mm,for sub grade modulus of 64000 kN /m^2/m is 10.06mm, for fixed support is 9.31mm. The displacement for sub grade modulus of 36000 kN /m^2/m gets decreased by 30.94% when compared with sub grade modulus of 12000 kN /m^2/m. The displacement for sub grade modulus of 64000 kN /m^2/m decreased by 63.66% when compared with sub grade modulus of 12000 kN /m^2/m.

Comparing the results with respect to seismic zone for sub grade modulus of 12000 kN /m^2/m the displacements are decreased by 85%, 70%, 62.5 for zone-III, zone-IV, zone-V respectively. Considering the results of 250 meter height chimney, the lateral displacements over the chimney height for different soil conditions along with the response of the SSI model to that of fixed-base model are introducedFig. no 3.9 to 3.12.

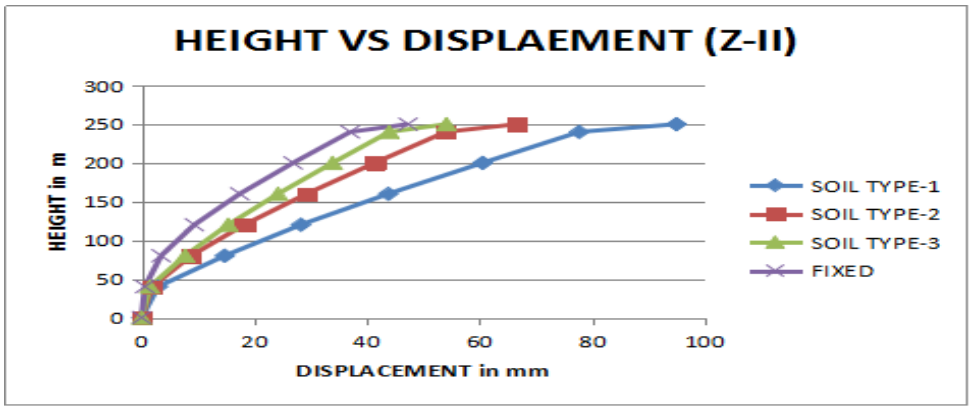


FIG NO: : 3.9 Height vs Displacement for 250m in seismic zone-II

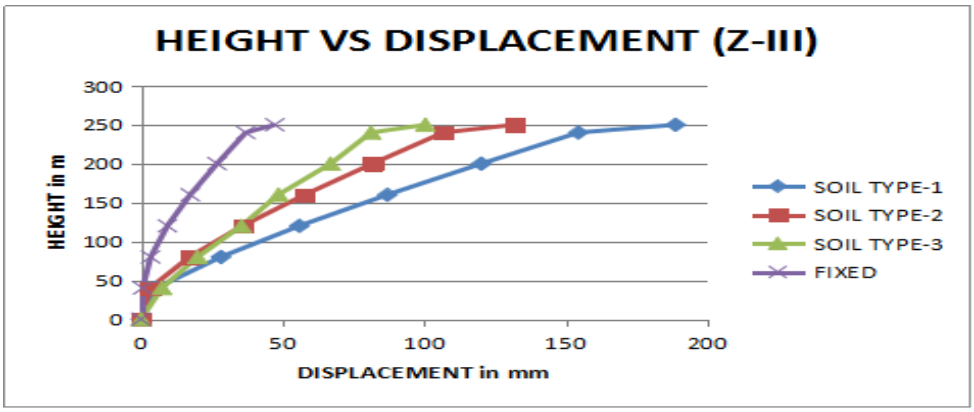


FIG NO:: 3.10 Height vs Displacement for 250m in seismic zone-III

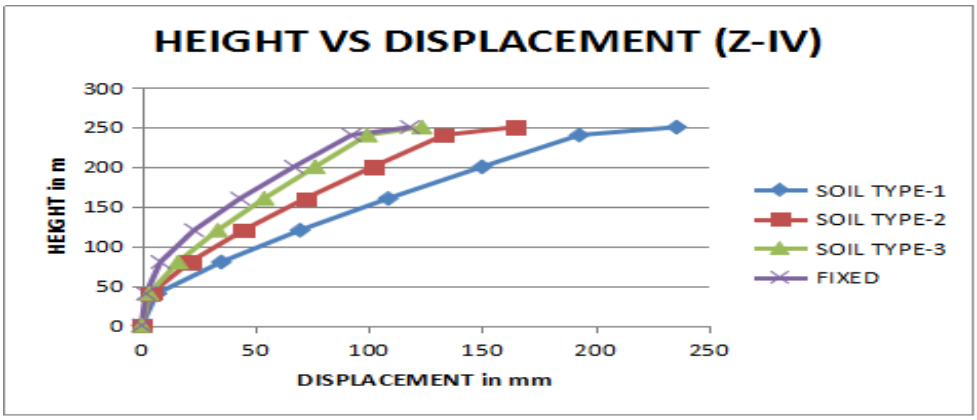


FIG NO: 3.11 Height vs Displacement for 250m in seismic zone-IV

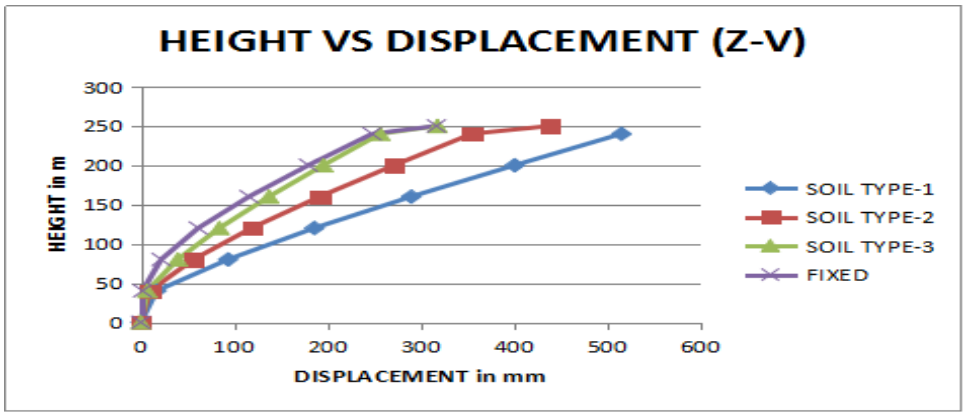


FIG NO: 3.12 Height vs Displacement for 250m in seismic zone-V

From the figure shown above, it is observed that the displacements decrease with increase in soil subgrade modulus which may due to increase in stiffness of the soil. Considering the 200m height chimney, the displacement for sub grade modulus of 12000 kN /m^2/m is 60.54mm,for sub grade modulus of 36000 kN /m^2/m is 41.40mm, for sub grade modulus of 64000 kN /m^2/m is 33.91mm, for fixed support is 26.90mm. The displacement for sub grade modulus 36000 kN/m^2/m gets decreased by 31.60% when compared with sub grade modulus of 12000 kN /m^2/m. The displacement for sub grade modulus of 64000 kN /m^2/m gets decreased by 43.98% when compared with sub grade modulus of 12000 kN /m^2/m.
Comparing the results with respect to seismic zone for sub grade modulus of 12000 kN /m^2/m the displacements are decreased by 85%, 70%, 62.5 for zone-III, zone-IV, zone-V respectively.

3.2 Support Displacements

The support displacements are investigated for the studied chimney of 75m, 150,250m with different sub grade modulus. The support displacements over the chimney height for different soil conditions along with the response of the SSI model to that of fixed-base model are introduced in figure no 3.13 to 3.24.

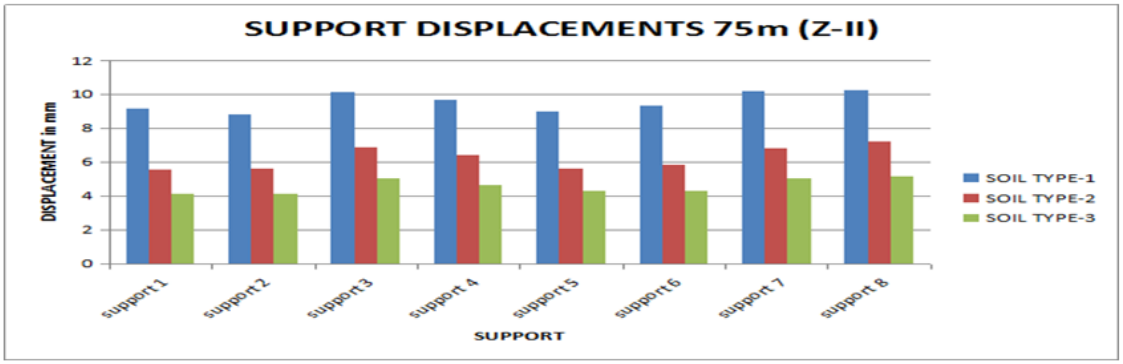


FIG NO: 3.13 Support Displacement for 75m for seismic Zone-II

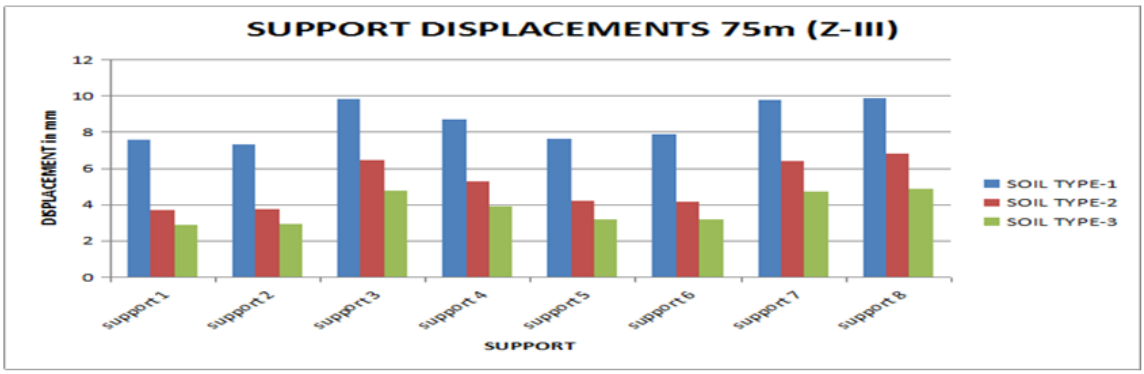


FIG NO: 3.14 Support Displacement for 75m for seismic Zone-III

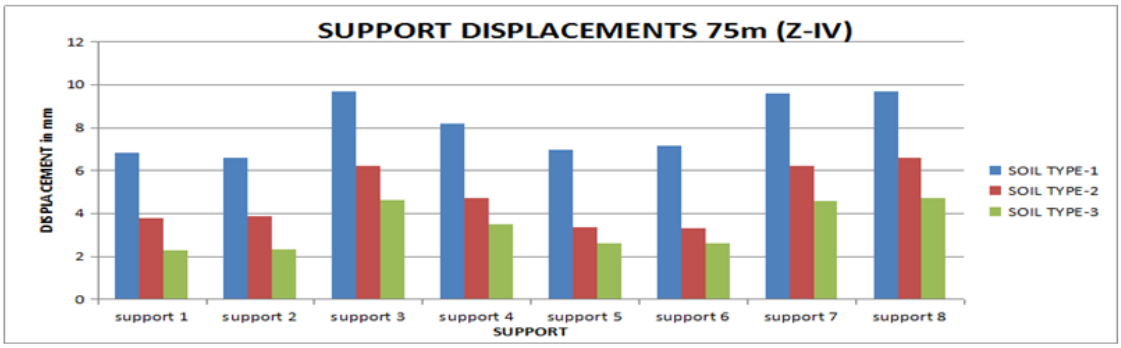


FIG NO: 3.15 Support Displacement for 75m for seismic Zone-IV

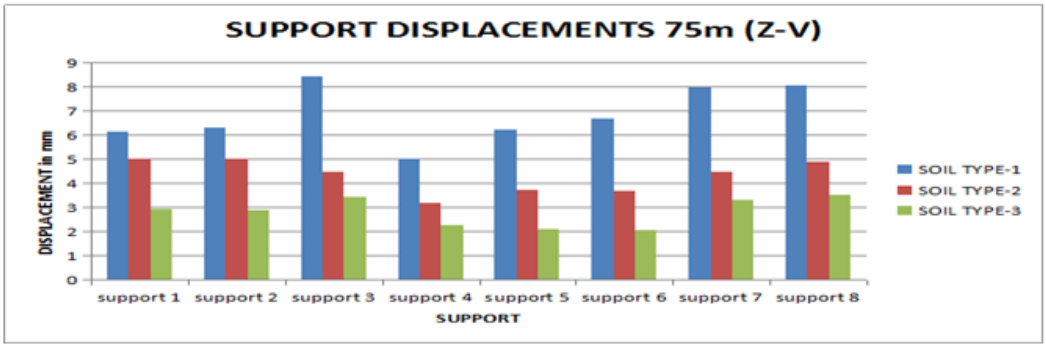


FIG NO: 3.16 Support Displacement for 75m for seismic Zone-V

From the figure shown above, it is observed that the support displacement decreases with increase in soil subgrade modulus which may be due to increase in stiffness of the soil. Considering the 75m height chimney, the support displacement for sub grade modulus of 12000 kN /m^2/m is 10.13mm,for sub grade modulus of 36000 kN /m^2/m is 6.83mm, for sub grade modulus of 64000 kN /m^2/m is 5.05mm. The support displacement for sub grade modulus of 36000 kN/m^2/m gets decreased by 32.60% when compared with sub grade modulus of 12000 kN /m^2/m. The displacement for sub grade modulus of 64000 kN /m^2/m gets decreased by 50.15% when compared with sub grade modulus of 12000 kN /m^2/m.

Considering the results of 150 meter height chimney, the lateral displacements over the chimney height for different soil conditions along with the response of the SSI model to that of fixed-base model are introduced in figure no 3.17 to 3.20.

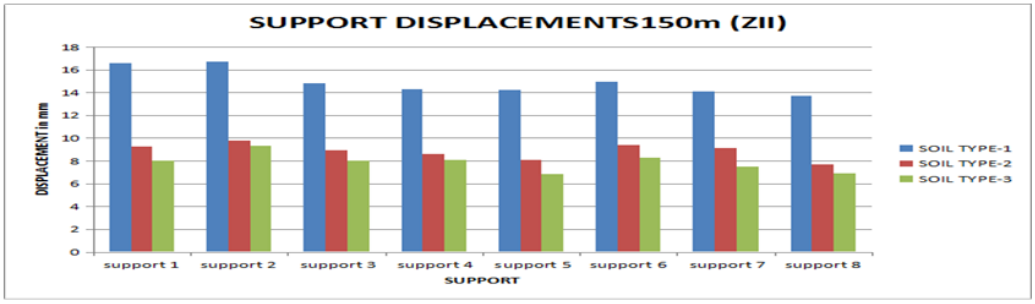


FIG NO: 3.17 Support Displacement for 150m for seismic Zone-II

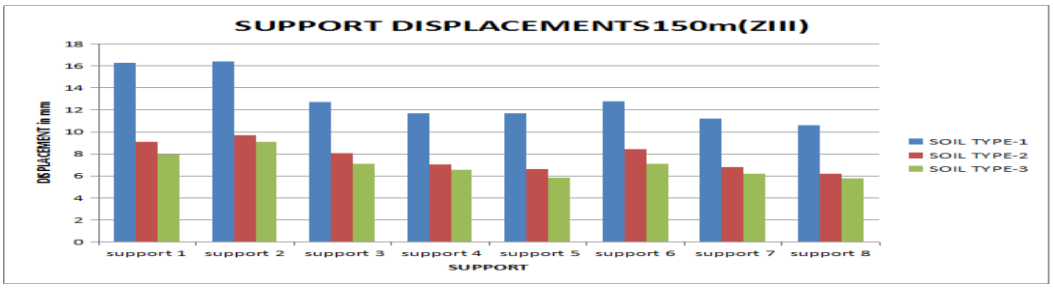


FIG NO: 3.18 Support Displacement for 150m for seismic Zone-III

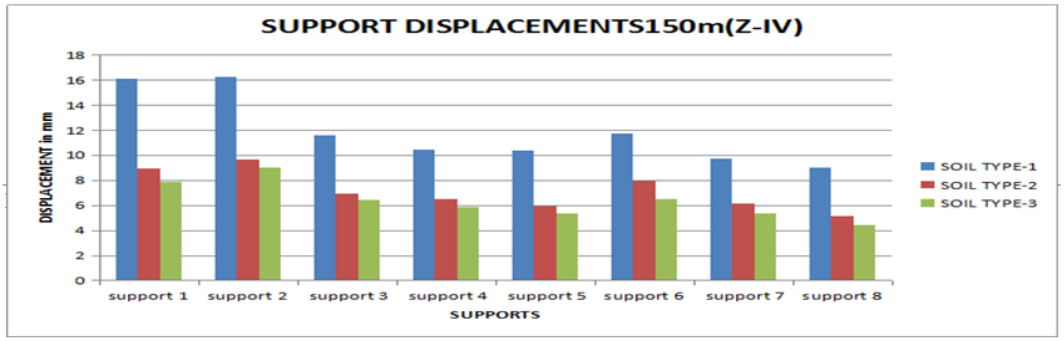


FIG NO: 3.19 Support Displacement for 150m for seismic Zone-IV

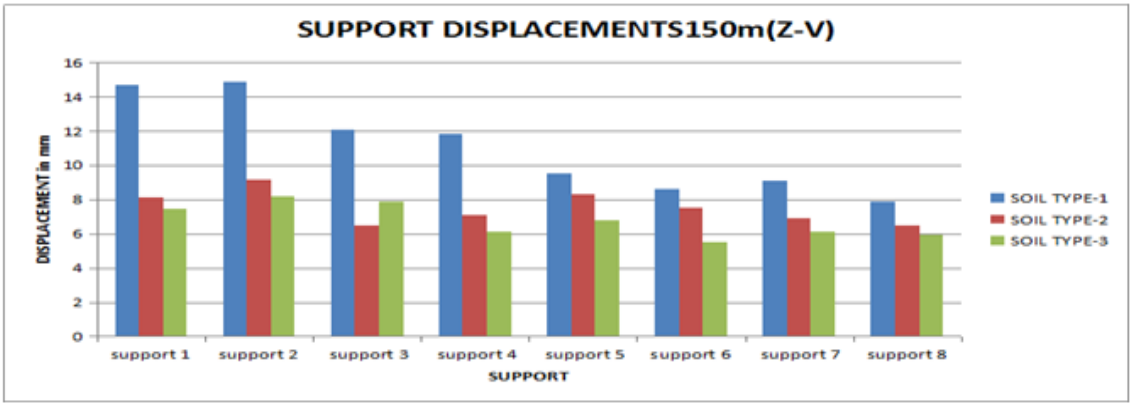


FIG NO: 3.20 Support Displacement for 150m for seismic Zone-V

From the figures shown above, it is observed that the support displacements decrease with increase in soil subgrade modulus which may be due to increase in soil stiffness of the soil. Considering the 150m height of chimney, the support displacement for sub grade modulus of 12000 kN /m^2/m is 14.23mm, for sub grade modulus of 36000 kN /m^2/m is 8.08mm, for sub grade modulus of 64000 kN /m^2/m is 6.82mm. The support displacement for sub grade modulus of 36000 kN/m^2/m gets decreased by 43.21% when compared with sub grade modulus of 12000 kN /m^2/m. The displacement for sub grade modulus of 64000 kN /m^2/m gets decreased by 47.93% when compared with sub grade modulus of 12000 kN /m^2/m.

Considering the results of 250 meter height chimney, the lateral displacements over the chimney height for different soil conditions along with the response of the SSI model to that of fixed-base model are introduced in figure no 3.21 to 3.24.

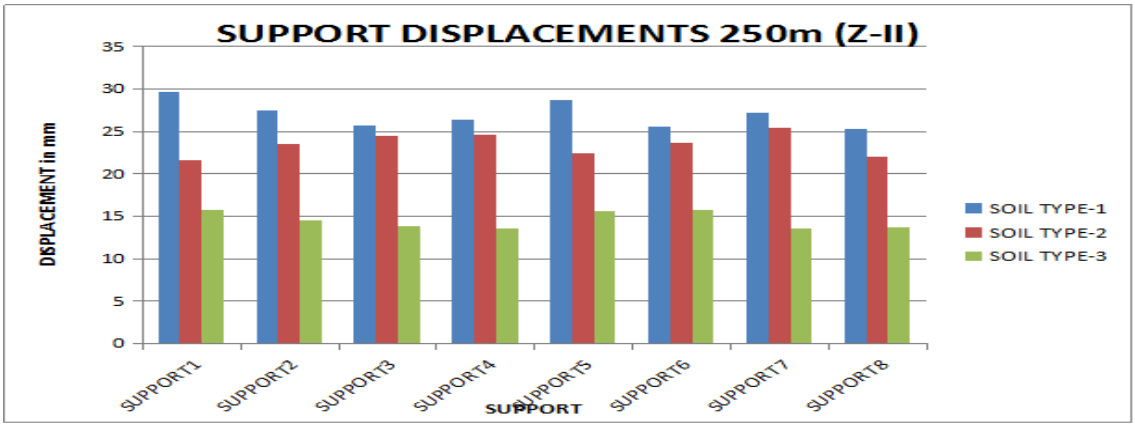


FIG NO: 3.21 Support Displacement for 250m for seismic Zone-II

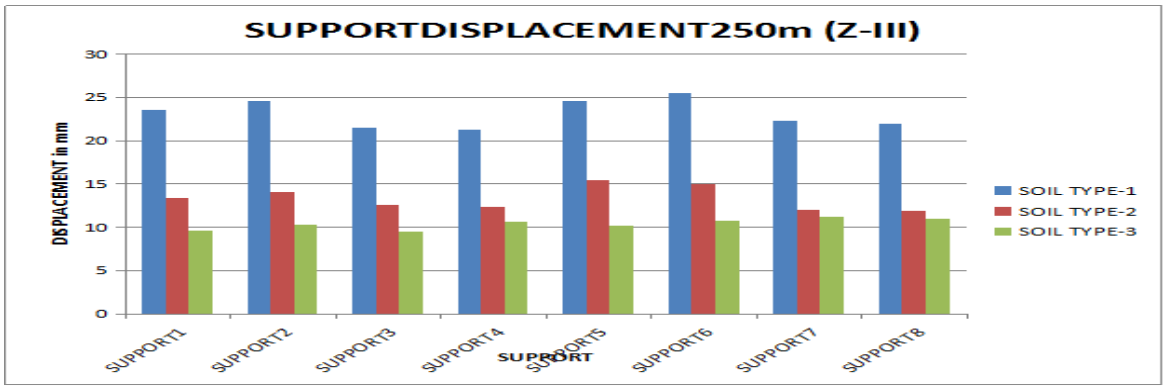


FIG NO: 3.22 Support Displacement for 250m for seismic Zone-III

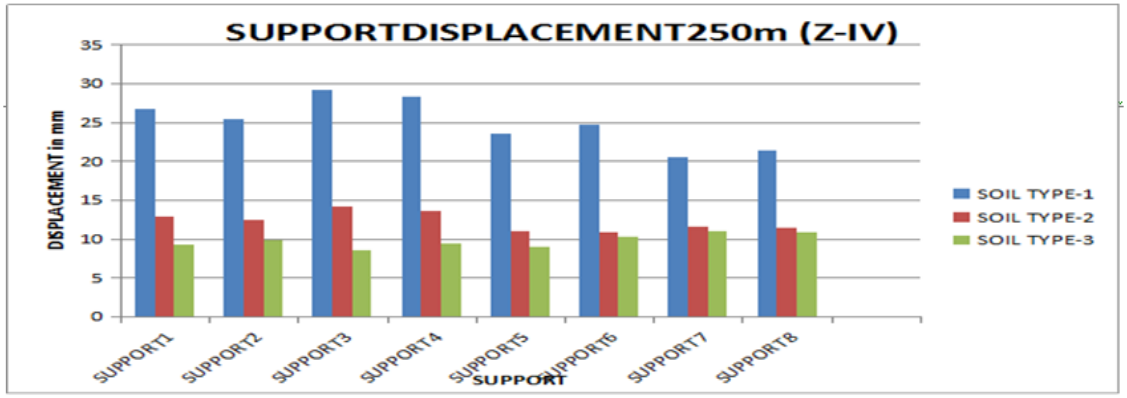


FIG NO: 3.23 Support Displacement for 250m for seismic Zone-IV

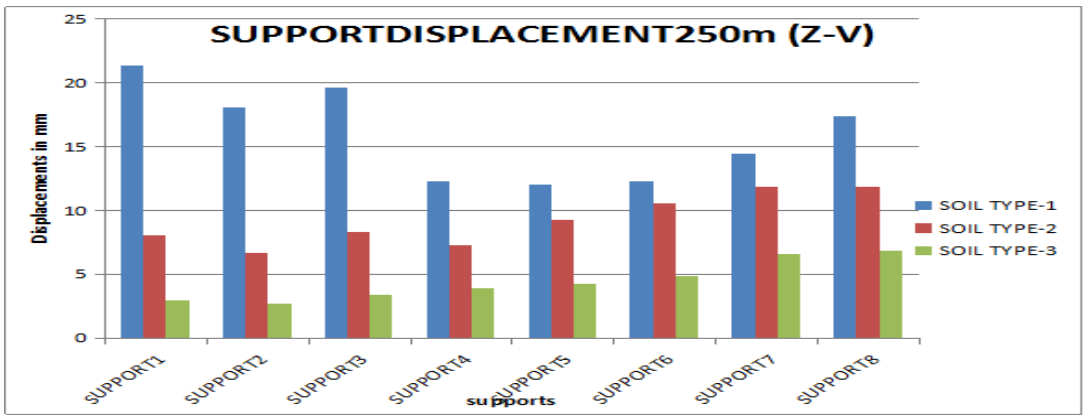


FIG NO: 3.24 Support Displacement for 250m for seismic Zone-V

From the figures shown above, it is observed that the support displacements decrease with increase in soil subgrade modulus which may be due to increase in stiffness of the soil. Considering the 250m height chimney, the support displacement for sub grade modulus of 12000 kN /m^2/m is 26.38mm, for sub grade modulus of 36000 kN /m^2/m is 24.56mm, for sub grade modulus of 64000 kN /m^2/m is 13.46mm. The support displacement for sub grade modulus of 36000 kN /m^2/m gets decreased by 6.89% when compared with sub grade modulus of 12000 kN /m^2/m. The displacement for sub grade modulus of 64000 kN /m^2/m gets decreased by 48.96% when compared with sub grade modulus of 12000 kN /m^2/m.

3.3 Frequency

Natural frequency is the frequency at which a system tends to oscillate in the absence of any driving or damping force. A period T is the time needed for one complete cycle of vibration to pass a given point. As the frequency of a wave increases, the period of the wave decreases.

The frequency values are plotted as shown below corresponding to their mode shapes from figure no3.25 to 3.30.

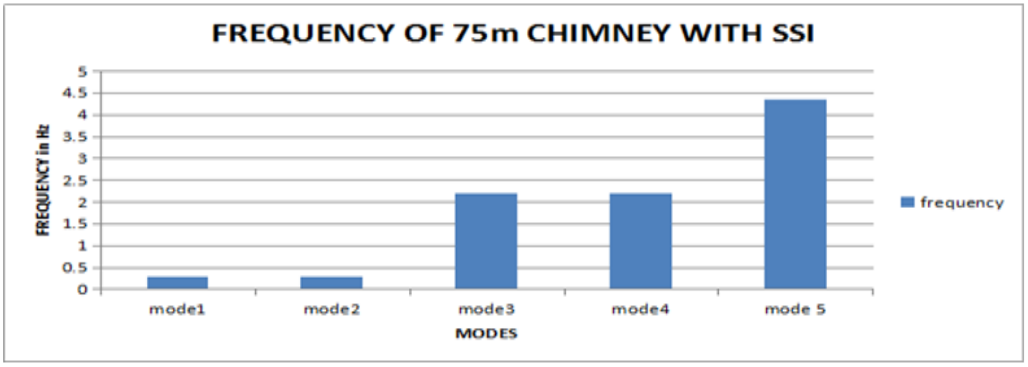


FIG NO: 3.25 Frequency for 75 m chimney with SSI

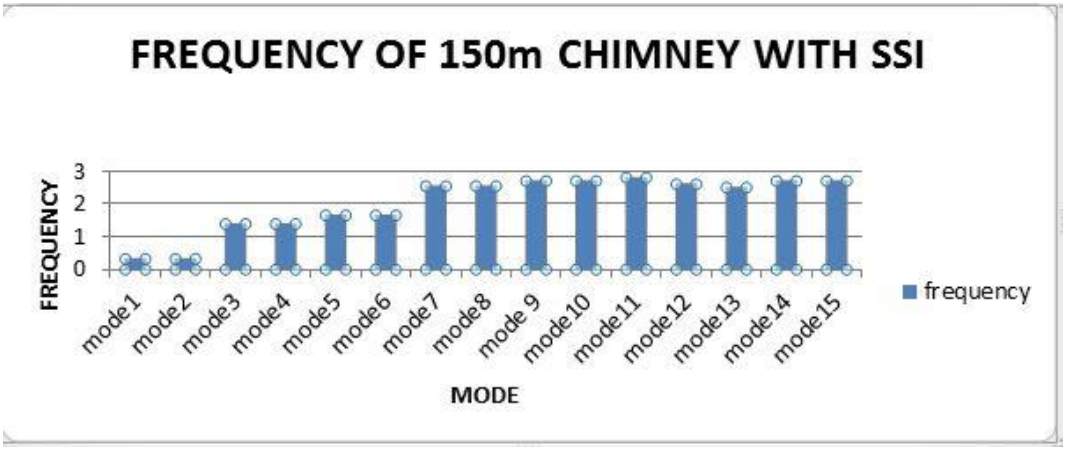


FIG NO: 3.26 Frequency for 150 m chimney with SSI

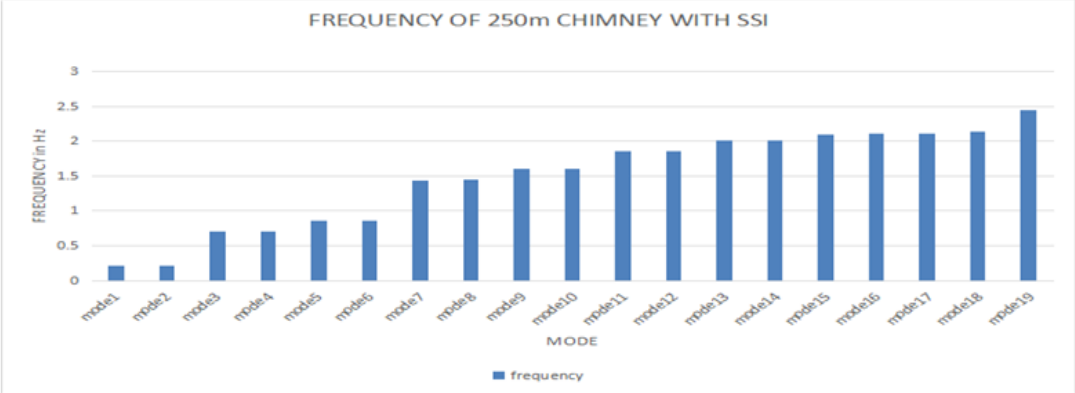


FIG NO: 3.27 Frequency for 250 m chimney with SSI

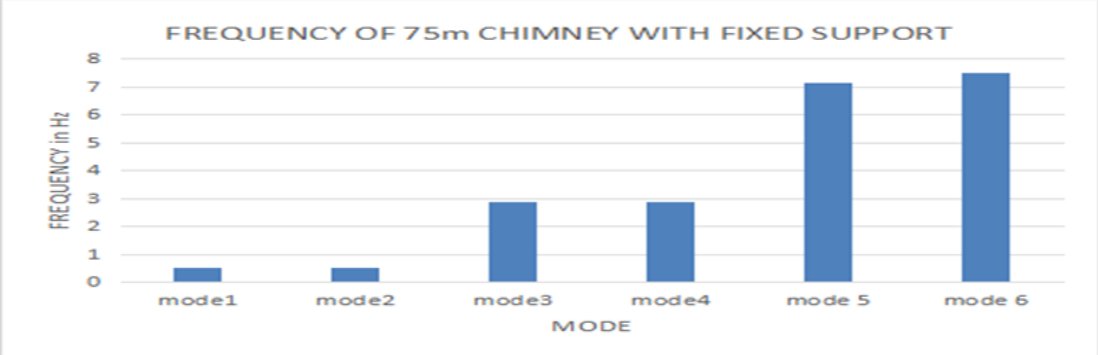


FIG NO: 3.28 Frequency for 75 m fixed chimney

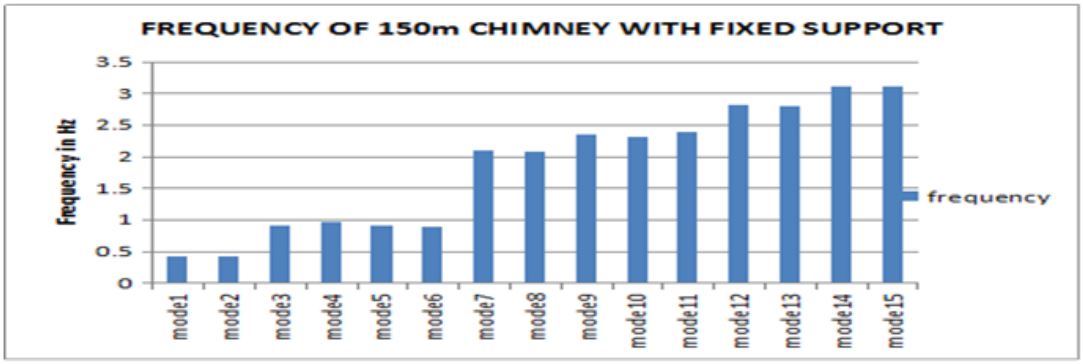


FIG NO: 3.29 Frequency for 150 m fixed chimney

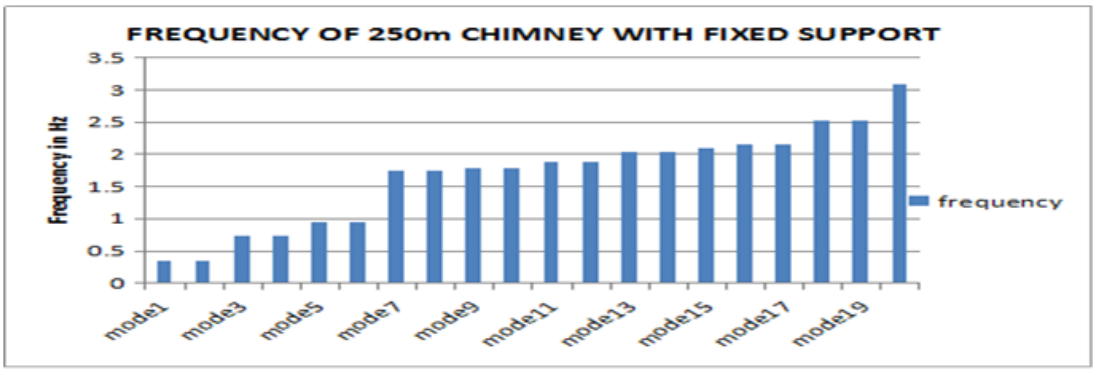


FIG NO: 3.30 Frequency for 250 m fixed chimney

The study shows that natural frequency decreases with increase in soil flexibility and percentage decrease in natural frequency decreases with increasing soil flexibility.

IV. Conclusions

- Lateral displacements decreases with increase in soil subgrade modulus i.e, for 75m height chimney the lateral displacements decreases by 18% for sub grade modulus of 36000 kN/m^2/m when compared to sub grade modulus of 12000kN/m^2/m and 32% for sub grade modulus of 64000 kN/m^2/m.
- Lateral displacements decreases with increase in soil subgrade modulus i.e, for 150m chimney lateral displacements decrease by 30.94% for sub grade modulus of 36000 kN/m^2/m and 63.66% for sub grade modulus of 64000 kN/m^2/m when compared with sub grade modulus of 12000 kN/m^2/m.
- Lateral displacements decreases with increase in soil subgrade modulus i.e, for 250m chimney lateral displacement decreases by 31.60% for sub grade modulus of 36000kN/m^2/m and 43.98% for sub grade modulus of 64000 kN/m^2/m when compared with sub grade modulus of 12000 kN/m^2/m
- At a seismic zone with same sub grade modulus with increase in height of chimney there is an increase in lateral displacements
- With increase in soil subgrade modulus, the fixity of the structure and stiffness are being increased
- Support displacements are decreased by 50% with increase in the soil subgrade modulus
- The actual behaviour of the structure under seismic load significantly differ from what the analysis provides considering the structure to be fixed at base.
- The natural frequency decreases with increase in soil flexibility and percentage decrease in natural frequency decreases with increasing soil flexibility.
- For Raft deflection criteria, it is concluded that the Deflection reduces as the stiffness of soil is increased, i.e, the hard soil medium leads to good seismic response of a chimney structure.

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