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Soil Structure Interaction on 100m Tall Industrial Chimney under Seismic Load

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Abstract - The response of a structure during an earthquake depends not only on the structure itself but also on the characteristics of the ground motion and the subsoil conditions. The actual behaviour of the structure under seismic load may significantly differ from what the analysis provides considering the structure to be fixed at base. Particularly for soft soils, the foundation input motion during the earthquake differs from the free-field ground motion that may exist in the absence of the structure. These interaction effects lead to dynamic responses that may differ considerably in amplitude and frequency content from that obtained, when a fixed support is assumed.

The present study focuses on the quantification of the effect of soil flexibility on the most important design variables in the seismic response of chimney structures with raft footing. For the analysis RC Chimney models are considered and the soil beneath the structure is modeled using both linear elastic soil models to represent the behavior of the soil. The soil structure interface is modeled with tied surface to surface contact. The time history analysis of the soil-structure model was carried out using the general FEM software SAP 2000 for ground motions BHUJ.

Based on the analysis results, it has been concluded that the effect of soil-structure interaction plays a significant role to decrease the natural frequency, raft displacement, radial and tangential moments in annular raft.

Keywords: ***Dynamic soil-structure interaction; seismic response; finite element method; SAP 2000; natural frequency.***

1. INTRODUCTION

Civil engineering is a system of structures most of them are direct contact with ground. When the external forces like Earthquake and Wind load act on these system, neither structure displaced, nor the ground displaced, 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).

The effects of SSI are ignored if the ground motion of the structure is same as free-field motion when the response is computed. Free-field motion is defined as the ground motion that would occur at the level of the foundation if no structure was present. Such idealization of base motion for a structure is true only if the supporting medium is rigid. Many design codes have suggested that the effect of SSI can reasonably be neglected for the seismic analysis of structures. Most of the design codes use oversimplified design spectrums, which attain constant acceleration up to a certain period, and thereafter decreases monotonically with period. Considering soil-structure interaction makes a structure more flexible and thus, increasing the natural period of the structure compared to the corresponding rigidly supported structure. Moreover, considering the SSI effect increases the effective damping ratio of the system. The smooth idealization of design spectrum suggests smaller seismic response with the increased natural periods and effective damping ratio due to SSI. With this assumption, it was traditionally been considered that SSI can conveniently be neglected for conservative design. In addition, neglecting SSI tremendously reduces the complication in the analysis of the structures which has tempted designers to neglect the effect of SSI in the analysis.

1.1 Characteristics of soil structure interaction.

The soil structure interaction is characterized by the following two major effects

- Flexibility of foundation soil directly increases fundamental period of fixed base structure.
- Change in effective damping of fixed base structure which is due to energy dissipation capacity of soil through radiation material types of damping.

1.2 Approach to soil structure interaction problems.

Two different approaches for interaction effects:

- Modify the given free-field motion and then compute response of given structure to modified motion of foundation.
- Modify the dynamic properties of structure and then compute response of structure to the prescribed free-field motion.

Both approach gives correct result, however second approach in easy to implement and therefore often specified in the most of design codes.

1.3 Types of soil structure interaction.

Soil structure interaction divided into two types

- Kinematic interaction.
- Inertial interaction.

1.4 Approach of soil structure interaction.

Two different approaches 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.

- The Direct approach
- The Sub-structure approach

1.4.1 The Direct Approach

In the direct method, the structure and a finite bounded soil zone adjacent to the structure (near field) are modeled by the standard finite-element method and the effect of the surrounding unbounded soil (far field) is analyzed approximately by imposing transmitting boundaries along the near-field/far-field interface. The soil is often discretized with solid finite elements and the structure with finite beam elements. Since assumptions of superposition are not required, true nonlinear analyses are possible. Many kinds of transmitting boundaries have been developed over the past two decades to satisfy the radiation condition, such as a viscous boundary, a superposition boundary, and several others. However, results from nonlinear analyses can be quite sensitive to poorly-defined parameters in the soil constitutive model, and the analyses remain quite expensive from a Computational standpoint.

1.4.2 The Sub-Structure Approach

The substructure method is more complex than the direct method in modeling the SSI system. In the substructure method, the soil–structure system is divided into two substructures: a structure, which may include a portion of non-linear soil or soil with an irregular boundary, and the unbounded soil.

Usually a dynamic soil–structure interaction analysis by the substructure method can be performed in three steps as follows:

1. Determination of foundation input motion by solving the kinematic interaction.
2. Determination of the frequency dependent impedance functions describing the stiffness and damping characteristics of the soil-foundation interacting system. This step should account for the geometric and material properties of foundation and soil deposits and is generally computed using equivalent linear elastic properties for soil appropriate for the in-situ dynamic shear strains. This step yields the so called soil springs.
3. Computation of response of the real structure supported on frequency dependent soil springs and subjected at the base of these springs to the foundation input motion.

It should be noted that if the structural foundations were perfectly rigid, the solution by substructure approach would be identical to the solution by the direct method. Generally, the foundation input motion is assumed to be the same as free-field motion, i.e. the effects of kinematic interaction are neglected in SSI analysis for most of the common constructions. Kinematic interaction should invariably be considered if the structure and foundations to be constructed are very massive, rigid and very large.

PROPERTIES OF SOIL					
Designation	Soil	Shear wave velocity(m/sec)	Poisson's ratio υ	Density	Elastic modulus,
	type			(KN/m)	(KN/m2)
S1	Loose sand	100	0.4	16	45,668
S2	medium sand	300	0.35	18	4,45,872
S3	dense Loose	600	0.3	20	1,908,257
S4	rock	1200	0.3	20	7,699,028

Table 1.1 Shear wave velocities for different soil types.

2. METHODOLOGY

The analysis of super structure-substructure-soil system is carried out by applying time history function with the help of software SAP2000; Material-based damping is available for linear and nonlinear direct-integration for time-history analysis.SAP2000 is the most suitable stand-alone finite-element-based structural for the analysis and design of civil structures.

2.1 Modeling of soil contuinumm medium

It is well known that compared to the structural size in engineering practice, the Earth's crust is vast on the geometrical side, and therefore can be treated as an infinite medium on the mathematical analysis side. This poses a challenge problem for the conventional finite element method because the modeling domain must be finite in the conventional finite element analysis. However, in the present problem the soil is modeled with finite boundary by providing width of soil medium equal to the four times the width of annular raft and bed rock is assumed at 30m depth for all chimneys.

2.2 PROCEDURE OF SSI IN SAP2000

The Soil-Structure Interaction analysis under earthquake excitation may be carried out in SAP2000 as follows:

1. Geometrical modeling: The soil-structure model can be generated using SAP2000 software. The interface between soil and structure is defined by a tied surface to surface contact and a finite boundary is defined around the truncated domain where Soil and Structure defined as a Solid and Shell element respectively.

2. Static analysis: Carry out a static analysis of the soil-structure system with the structure only subjected to gravity loading. In order to record the static reactions at the base of the structure, which are to be used in subsequent dynamic analysis of the soil-structure system subjected to earthquake excitation.

3. Transient analysis: Here, the soil-structure system which is subjected to gravity loading are analyzed by time history analysis. In this method, incremental response of structure is evaluated at each time interval. Response obtained from this method is compared with conventional method (IS 11089:1984).

2.3 ANALYSIS OF ANNULAR RAFT FOUNDATION

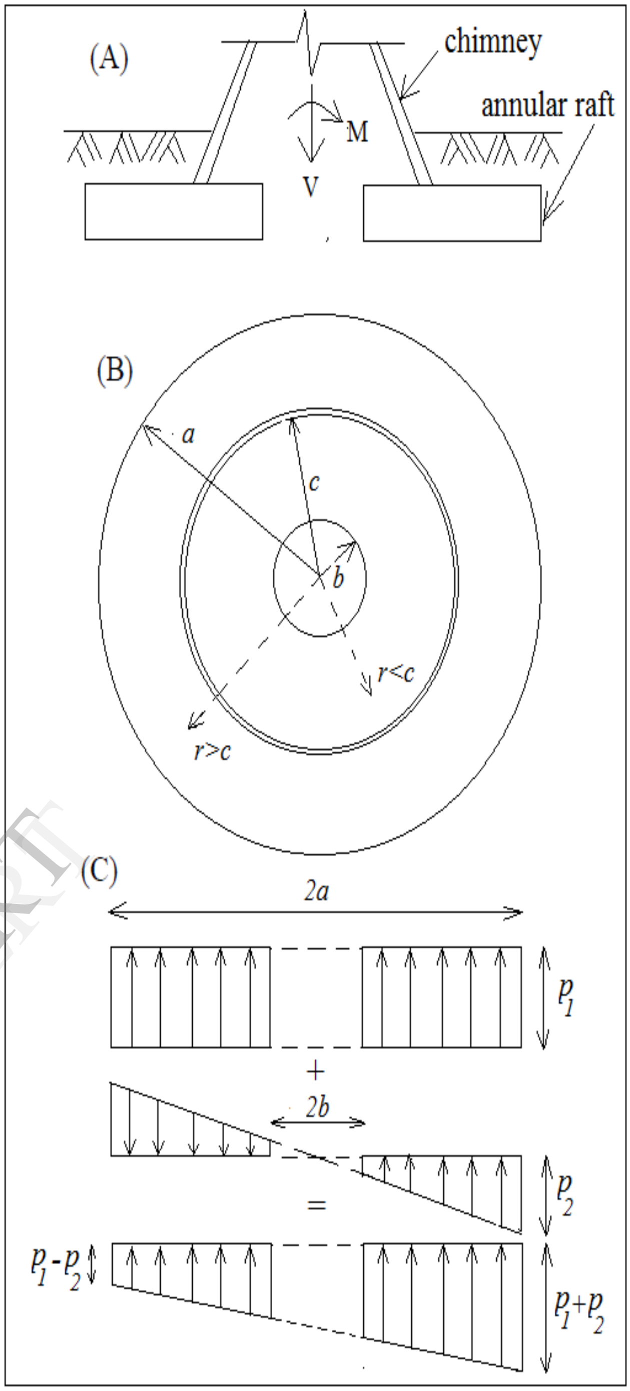
The foundation is analyzed using conventional method as per IS: 11089 – 1984. This is based on the assumption of linear distribution of contact pressure. The basic assumptions of this method are

- The foundation is rigid relative to the supporting soil and the compressible soil layer is relatively shallow
- The contact pressure distribution is assumed to vary linearly throughout the foundation

The ring annular raft is analyzed from approximately non-uniform pressure distribution to uniform pressure distribution.

The modified pressure intensity p is given by $p_1+0.5p_2$, where p_1 is uniform pressure due to dead loads (W) and p_2 is pressure due to bending (M) effects.

The formulae for circumferential and radial moments Mt and Mr respectively are given below.



For r < c

$$Mt = pa^2/16\left[\left\{4\left(1+\frac{b^2}{r^2}\right)\left(\log_e\frac{a}{c}+\frac{1}{2}-\frac{c^2}{2a^2}\right)\right\}+\frac{r^2}{a^2} - 4b^2/a^2\left\{\log_e\frac{r}{a}+\frac{3}{4}\left(\frac{1}{3}+\frac{a^2}{b^2}+\frac{a^2}{r^2}\right)-\frac{a^2+b^2}{a^2-b^2}\cdot\frac{b^2}{r^2}\log_e a/b\right\}\right]$$

equation (1)

$$Mr = pa^2/16\left[\left\{4\left(1-\frac{b^2}{r^2}\right)\left(\log_e\frac{a}{c}+\frac{1}{2}-\frac{c^2}{2a^2}\right)\right\}+\frac{3r^2}{a^2} - 4b^2/a^2\left\{\log_e\frac{r}{a}+\frac{3}{4}\left(\frac{1}{3}+\frac{a^2}{b^2}-\frac{a^2}{r^2}\right)+\frac{a^2+b^2}{a^2-b^2}\cdot\frac{b^2}{r^2}\log_e a/b\right\}\right]$$

equation(2)

For r>c

$$Mt = (Mt)\, r < c + pa^2/16\left[\left\{4\left(1+\frac{b^2}{a^2}\right)\left(\log_e\frac{c}{r}+\frac{1}{2}-\frac{c^2}{2r^2}\right)\right\}\right]$$

equation (3)

$$Mr = (Mr)\, r < c + pa^2/16\left[\left\{4\left(1-\frac{b^2}{a^2}\right)\left(\log_e\frac{c}{r}-\frac{1}{2}+\frac{c^2}{2r^2}\right)\right\}\right]$$

equation(4)

Where

a = outer radius of annular raft

b = inner radius of the annular raft

c = center line radius of chimney shell

r = radial distance

3 PRESENT STUDIE.

In the present study, soil-structure interaction effect on 100m tall industrial chimney under seismic load is investigated. Chimney resting on different types of soil with different slenderness ratios and different raft thicknesses are considered. The time history analysis of these chimneys has been done by subjecting the whole system to earthquake ground motion, using SAP2000 software.

3.1 Geometric parameters

For the present study 100m chimney, of slenderness ratio 7, 12 and 17 are considered (Menon 1997) and the taper ratio (Dt/Db) of 0.6, base diameter to base thickness ratio (Db/tb) of 35 and top thickness of 0.4 tb are considered.

The base of chimney is supported on annular raft foundation with uniform thickness. The outer diameter of the foundation has been taken as approximately twice that of base diameter of chimney. The thickness of raft has been varied to check the effects of soil structure interaction, for different ratios of 15, 17.5, 20, 22.5 and 25. Table 4.1 gives the dimensions and other geometric parameters of chimneys considered in this study.

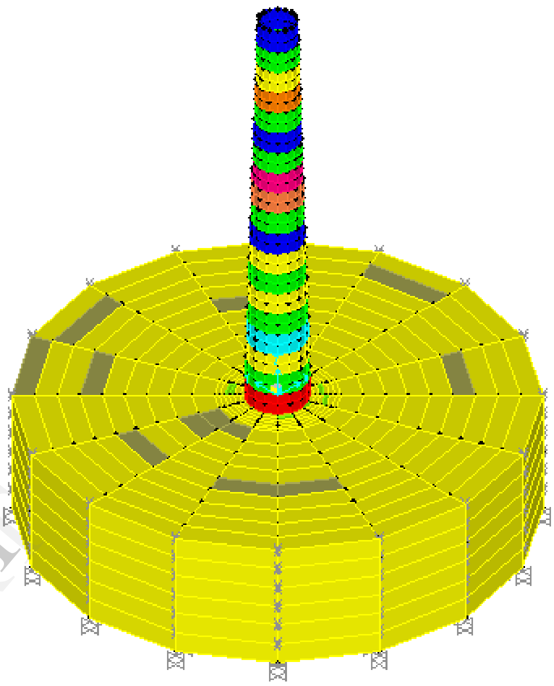
The structures are assumed to be founded on different soil types varying from lose sand to very dense sand. They are represented by elastic continuum; the elastic continuum method is based on elastic modulus of soil. The soil has been considered as lose sand, medium dense sand and dense sand, the modulus of sub grade reaction (Ks) in (kN/m^3) are 10E3, 40E3 and 100E3 respectively.

Height of Chimney (H) in (m)	Slenderness ratio (H/D_b)	Diameter at base (D_b) in (m)	Taper ratio (D_t/D_b)	Diameter at top (D_t) in (m)
100	7	14.5	0.6	8.7
100	12	8.5	0.6	5.1
100	17	6	0.6	3.6

Base diameter to base thickness Ratio (D_b/T_b)	Thickness at base (T_b) in (m)	Thickness at top T_t=0.4T_b or 0.2m	Raft external diameter (Do) in (m)	Raft internal diameter (Di) in (m)
35	0.5	0.2	28	6
35	0.3	0.2	18	4
35	0.2	0.2	13	2

Raft thickness (t) in (m)				
Do/t 15	Do/t 17.5	Do/t 20	Do/t 22.5	Do/t 25
1.867	1.6	1.4	1.244	1.12
1.2	1.02	0.9	0.84	0.72
0.867	0.742	0.65	0.578	0.52

Table 4.1



Elastic 3D Continuum Model.

4 RESULTS AND DISCUSSIONS

A study of three dimensional 100m chimney structure models with different slenderness ratio, with different raft thickness of annular raft and resting on three types of soils ranging from vary soft to stiff has been carried out. The structure is subjected to acceleration time history of Bhuj earthquake ground motion. Here, the soil is idealized as an elastic model and the prescribed ground motion is used for SSI analysis. The variation of natural frequency, deflection of raft and structural response for various parameters like tangential and radial moments of annular raft on different types of soil is studied. Comparisons are made with those obtained from the analysis of conventional method (IS11089:1984).

4.1 Variation in natural frequency

The variation in natural frequency due to the effect of soil flexibility, slenderness ratio and thickness of raft are studied for 100m chimney models, modeled with annular raft. The structure is assumed to be resting on three different soil conditions with modulus of sub grade reaction Ks 10E3, Ks

40E3 and Ks 100E3, modeled using elastic model, and the results are shown in Table 4.2 and 4.3

4.1.1 Effect of soil flexibility

It is observed here that natural frequency decreases by the incorporation of the soil flexibility. In the case of 100m chimney with slenderness ratio of 7 and raft thickness Do/t 15, a decrease of 36.04% in natural frequency is observed for soil with Ks 10E3, and this decrease gradually reduces with increase in stiffness of soil. i.e., 14.08% for Ks 100E3.

4.1.2 Effect of slenderness ratio of chimney

It is observed here that natural frequency decreases by the increase of slenderness ratio of chimney. In the case of 100m chimney with soil Ks 10E3 and raft thickness Do/t 15, a decrease of 36.04% in natural frequency is observed for chimney slenderness ratio of 7, and this decrease gradually reduces to 15.76% with the increase in slenderness ratio of 17. As the stiffness of soil increases i.e., for Ks 100E3, a decrease of natural frequency 19.63% and 8.40% is observed for slenderness ratio 7 and 17 respectively, when compared with fixed base condition.

4.1.3 Effect of thickness of raft

It is observed that natural frequency decreases by the decreases of raft thickness. In the case of 200m chimney with soil Ks 5E3 and slenderness ratio of 7, a decrease of 36.04.00% in natural frequency is observed for thickness of raft Do/t 15 and this decrease gradually increase to 44.59% with the decrease in raft thickness Do/t 25. As the stiffness of soil increases i.e., for Ks 100E3, a decrease of natural frequency of 19.63% and 26.56% is observed for thickness of raft of Do/t 15 and Do/t 25 respectively, when compared with fixed base condition.

4.2.1 Variation of radial moment in raft

The variation in radial moment due to the effect of soil flexibility is studied on 100m chimney, modeled with annular raft. The structure is assumed to be resting on very soft to stiff soils, modeled using elastic model, and the percentage variation in radial moment with conventional method are tabulated in Table 4.4. The variation is plotted in Figure 4.1

Soil type	Mode no.	Frequency (Hz)				
		H/Db = 7				
		Do/t= 15	Do/t= 17.5	Do/t= 20	Do/t= 22.5	Do/t= 25
Fixed base	1	1.9064	1.9064	1.9064	1.9064	1.9064
	2	1.9064	1.9064	1.9064	1.9064	1.9064
	3	7.119	7.119	7.119	7.119	7.119
	4	7.119	7.119	7.119	7.119	7.119
	5	7.3948	7.3948	7.3948	7.3948	7.3948
Ks10E 3	1	1.2193	1.1707	1.1279	1.0804	1.0428
	2	1.2193	1.1708	1.1279	1.0804	1.0429
	3	4.1434	4.1755	4.189	4.2178	4.2323
	4	4.1442	4.1762	4.1898	4.2185	4.2331
	5	4.5069	4.5349	4.6915	4.5696	4.5812
Ks 40E3	1	1.3902	1.3376	1.2937	1.2515	1.2189
	2	1.3902	1.3377	1.2937	1.2515	1.2189
	3	5.4983	5.5076	5.5273	5.5068	5.5035
	4	5.4988	5.508	5.5277	5.5072	5.5038
	5	6.2771	6.3142	6.3878	6.3627	6.3789
Ks 100E3	1	1.532	1.4884	1.4525	1.4235	1.3999
	2	1.532	1.4884	1.4525	1.4235	1.3999
	3	6.2084	6.1514	6.106	6.0705	6.0425
	4	6.2085	6.1514	6.1061	6.0705	6.0425
	5	7.1012	7.0969	7.0929	7.0892	7.0861

Table 4.2 Modal frequencies of chimney

It is observed here that radial moment decreases by the incorporation of soil flexibility. In the case of slenderness ratio of 7 and raft thickness Do/t 15, a decrease of 40.01% in radial moment is observed for soil with Ks 10E3. The radial moment gradually reduces with increase in stiffness of soil i.e., 58.8% for Ks 100E3.

Also, comparison between Do/t 15, 17.5 ,20 22.5 and 25 are made for each H/Db ratios resting on soil having stiffness Ks 10E3, Ks 40E3 and Ks 100E3 and it is observed that Radial moment decreases with the decrease in raft thickness. The variation is plotted in Figure 4.2

From the variations of moments in the raft it is observed that, when the value of sub grade reaction of soil increases the radial moment decreases. This is due to the fact that for low values of Ks the raft behaves as a rigid plate, whereas for high values of Ks the raft behaves as a flexible plate.

Soil type	Mode no.	Frequency (Hz)									
		H/Db =12					H/Db = 17				
		Do/t= 15	Do/t= 17.5	Do/t= 20	Do/t= 22.5	Do/t= 25	Do/t= 15	Do/t= 17.5	Do/t= 20	Do/t= 22.5	Do/t= 25
Fixed base	1	0.91956	0.91956	0.91956	0.91956	0.91956	0.60741	0.60741	0.60741	0.60741	0.60741
	2	0.91956	0.91956	0.91956	0.91956	0.91956	0.60741	0.60741	0.60741	0.60741	0.60741
	3	4.196	4.196	4.196	4.196	4.196	3.0197	3.0197	3.0197	3.0197	3.0197
	4	4.196	4.196	4.196	4.196	4.196	3.0197	3.0197	3.0197	3.0197	3.0197
	5	10.268	10.268	10.268	10.268	10.268	7.6935	7.6935	7.6935	7.6935	7.6935
Ks10E3	1	0.72149	0.69143	0.66623	0.65213	0.62141	0.51165	0.49482	0.46395	0.45094	0.45094
	2	0.72149	0.69143	0.66623	0.65213	0.62141	0.51165	0.49482	0.46395	0.45094	0.45094
	3	3.4509	3.3936	3.3491	3.3257	3.2778	2.6148	2.5677	2.4913	2.4624	2.4624
	4	3.4509	3.3936	3.3491	3.3257	3.2778	2.6148	2.5677	2.4913	2.4624	2.4624
	5	5.4009	5.4096	5.4151	5.4178	5.4232	4.6997	4.7032	4.7077	4.7093	4.7093
Ks 40E3	1	0.77207	0.74667	0.72673	0.71596	0.69307	0.53666	0.52337	0.51139	0.4918	0.4918
	2	0.77207	0.74667	0.72673	0.71596	0.69307	0.53666	0.52337	0.51139	0.4918	0.4918
	3	3.6147	3.5506	3.504	3.4801	3.4322	2.7061	2.662	2.6249	2.5691	2.5691
	4	3.6147	3.5506	3.504	3.4801	3.4322	2.7061	2.662	2.6249	2.5691	2.5691
	5	7.5099	7.5205	7.5274	7.5307	7.536	6.6205	6.6254	6.629	6.6337	6.6337
Ks 100E3	1	0.81311	0.79551	0.72673	0.77524	0.76029	0.55675	0.595	0.54039	0.52835	0.52835
	2	0.81311	0.79551	0.72673	0.77524	0.76029	0.55675	0.595	0.54039	0.52835	0.52835
	3	3.7553	3.7012	3.504	3.643	3.6028	2.7855	2.9563	2.7246	2.6833	2.6833
	4	3.7553	3.7012	3.504	3.643	3.6028	2.7855	2.9563	2.7246	2.6833	2.6833
	5	9.3136	9.2454	7.5274	9.1748	9.1276	7.1653	7.5425	7.0596	6.992	6.992

Table 4.3 Modal frequencies of chimney

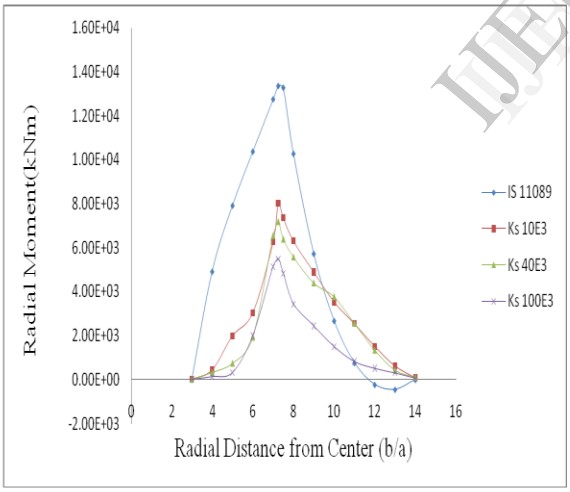


Figure 4.1

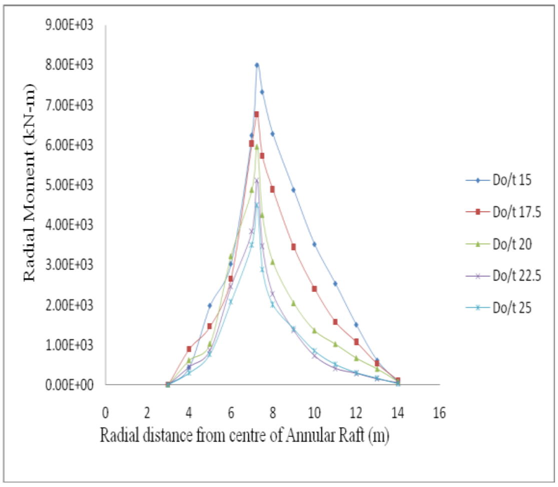


Figure 4.2

The radial moment decrease by incorporating of soil flexibility. The decrease ratio of 40.01%, 46.22% and 58.8% is observed for the soil with ks10E3, ks40E3 and ks100E3 respectively. When compared with conventional method.

Height of chimney	Soil Description	Percentage variation radial Moment (%)				
		H/Db=7				
		Do/t=15	Do/t=17.5	Do/t=20	Do/t=22.5	Do/t=25
100m	Ks 10E3	-40.01	-49.32	-55.27	-61.68	-66.21
	Ks 40E3	-46.22	-55.29	-62.99	-69.22	-82.81
	Ks 100E3	-58.8	-67.46	-73.88	-78.92	-82.81

Height of chimney	Soil Description	Percentage variation radial Moment (%)				
		H/Db=12				
		Do/t=15	Do/t=17.5	Do/t=20	Do/t=22.5	Do/t=25
100m	Ks 10E3	-44.4	-51.05	-48.4	-58.38	-63.5
	Ks 40E3	-51.8	-59.93	-62.01	-64.65	-69.15
	Ks 100E3	-59.69	-65.17	-68.95	-70.86	-74.76

Height of chimney	Soil Description	Percentage variation radial Moment (%)				
		H/Db=17				
		Do/t=15	Do/t=17.5	Do/t=20	Do/t=22.5	Do/t=25
100m	Ks 10E3	-49.99	-55.92	-60.99	-65.07	-68.4
	Ks 40E3	-57.87	-63.48	-67.81	-71.21	-73.3
	Ks 100E3	-66.12	-85.12	-73.5	-76.32	-78.5

Table 4.4

4.2.2variation of tangential moment in annular raft

The variation in tangential moment due to the effect of soil flexibility is studied on 100m chimney modeled with annular raft. The structure is assumed to be resting on very soft to stiff soils, modeled using elastic model, and the percentage variation in tangential moment with conventional method are tabulated in Tables 4.5. The variation is plotted in figure 4.3

The maximum moments predicted from SSI method is high at the chimney shell location in the direction ground motion, where as in conventional method the maximum moment value is predicted at the innermost radius of raft. It is observed here that tangential moment decreases by the incorporation of soil flexibility. In the case of slenderness ratio of 7 and raft thickness Do/t 15, a decrease of 66.2% in tangential moment is observed for soil with Ks 10E3. The tangential moment gradually reduces with increase in stiffness of soil i.e., 80.6% for Ks 100E3.

Also, Comparisons between Do/t 15, 17.5, 20, 22.5 and 25 are made for each H/Db ratio (i.e., H/Db 7, 12, 17) resting on soil having stiffness Ks 10E3, Ks 40E3 and Ks 100E3 and it is observed that tangential moment reduces with the decrease in raft thickness. The variation is plotted in figure 4.4

From the variations of moments in the raft it is observed that, when the value of sub grade reaction of soil increases the tangential moment decreases. This is due to the fact that for low values of Ks the raft behaves as a rigid plate, whereas for high values of Ks the raft behaves as a flexible plate.

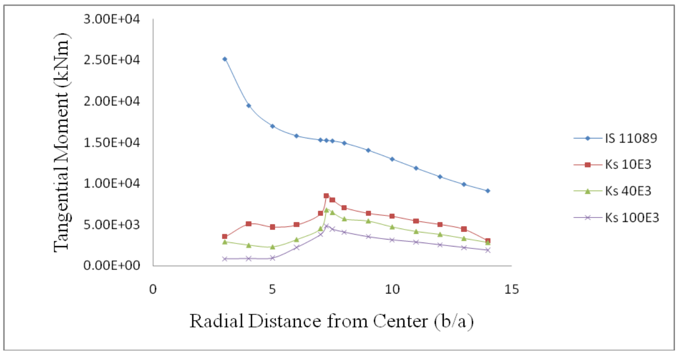


Figure 4.3

The Tangential moment decrease by incorporating of soil flexibility. The decrease ratio is 66.20%, 73.08% and 80.60% observed for the soil with ks10E3, ks40E3 and ks100E3 respectively. When compared with conventional method.

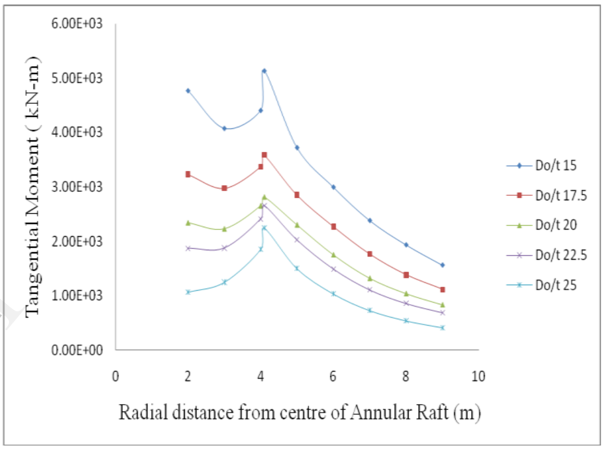


Figure 4.4

Height of chimney	Soil Description	Percentage variation radial Moment (%)				
		H/Db=7				
		Do/t=15	Do/t=17.5	Do/t=20	Do/t=22.5	Do/t=25
100m	Ks 10E3	-66.2	-73.3	-78.2	-82.26	-82.3
	Ks 40E3	-73.08	-79.6	-83.6	-87.11	-89.5
	Ks 100E3	-80.6	-85.88	-88.9	-91.33	-93.1

Height of chimney	Soil Description	Percentage variation radial Moment (%)				
		H/Db=12				
		Do/t=15	Do/t=17.5	Do/t=20	Do/t=22.5	Do/t=25
100m	Ks 10E3	-75.98	-81.96	-85.7	-86.6	-88.68
	Ks 40E3	-82.61	-86.51	-88.51	-89.33	-90.88
	Ks 100E3	-87.81	-89.56	-92.3	-91.48	-92.56

Height of chimney	Soil Description	Percentage variation radial Moment (%)				
		H/Db=17				
		Do/t=15	Do/t=17.5	Do/t=20	Do/t=22.5	Do/t=25
100m	Ks 10E3	-65.5	-72.11	-78.07	-80.05	-82.66
	Ks 40E3	-73.9	-78.95	-82.06	-84.25	-85.89
	Ks 100E3	-80.37	-91.79	-85.79	-89.77	-94.22

Table4.5

5 CONCLUSION

The thesis attempts to study the effect of soil-structure interaction under transient loading for tall chimneys with annular raft. This study has been mainly carried out to determine the change in various seismic response quantities due to consideration of flexibility of soil, slenderness ratio of chimney and thickness of annular raft.

Following conclusions were drawn from the present study:

1. The study shows that natural frequency decreases with increase in soil flexibility.
2. For Raft deflection criteria, it is concluded that the Deflection reduces as the stiffness of soil is increased, in other words it is observed that vertical displacement is not linearly varying which shows the maximum vertical displacement below the chimney shell for all the cases.
3. The effect of soil-structure interaction plays a significant role in decreasing the radial and tangential moments of annular raft when compared with conventional method.
4. The study shows that increase in slenderness ratio of chimney decreases tangential and radial moment of annular raft.
5. It is observed that decrease in radial and tangential moments when decrease in thickness of annular raft.

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