The effect of soil-structure interaction on raft foundation

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Abstract - *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). Conventional structural design methods neglect the SSI effects. Neglecting SSI is reasonable for light structures in relatively stiff soil such as low rise buildings and simple rigid retaining walls. The effect of SSI, however, becomes prominent for heavy structures resting on relatively soft soils for example nuclear power plants, high-rise buildings and elevated-highways on soft soil. Damage sustained in recent earthquakes, such as the 1995 Kobe earthquake, have also highlighted that the seismic behavior of a structure is highly influenced not only by the response of the superstructure, but also by the response of the foundation and the ground as well. Soil-structure interaction makes a structure more flexible and thus, increasing the natural period of the structure compared to the corresponding rigid supported structure.*

Key Words: *soil-structure interaction, seismic analysis, foundation, natural period, flexibility*

1. INTRODUCTION

Earthquakes are the most destructive of all natural hazards. India has had a number of the world's greatest earthquakes in the last century. In fact, more than 50% area in the country is considered prone to damaging earthquakes as clearly illustrated by the Koyna (1967), Latur (1993), the Jabalpur (1997) and the Bhuj (2001) earthquakes. Earthquakes can trigger damage in a structure at different levels namely superstructure or sub-structural level or at the interface of the two. Raft foundations have shown better performance during past EQ and hence it is considered as an effective foundation system for multi storey structure. 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 interaction among structures, their foundations and the soil medium below the foundations alter the actual behaviour of the structure considerably than what is obtained from the consideration of the structure alone. It has conventionally been considered that soil-structure interaction (SSI) has beneficial effect on the seismic response of a structure. Many design codes have suggested that the effect of SSI can reasonably be neglected for the seismic analysis of structures which is a myth [2]. Soil-structure interaction makes a structure more flexible and thus, increasing the natural period of the structure compared to the corresponding rigid supported structure [3]. The present study makes an effort to understand the effect of earthquake on soil-foundation-structure system of a typical building by considering different soil types. For this purpose, various RC frames (16 frames) was selected and analyzed and its foundation supported over different ground conditions (hard soil and medium soil).

2. SYSTEM IDEALIZATION

2.1 *Structural idealization*

To analyze the dynamic behaviour of building frames with the effect of soil–structure interaction, buildings have been idealized as three-dimensional space frames consisting of two nodded frame elements. Slabs at different storey-level and the slabs of the raft foundation are modelled with the help of four-nodded plate elements with consideration of adequate thickness of these slabs. Each node of this element is considered to have six-degrees-of-freedom. For the purpose of design, the buildings are analyzed as bare frames with the help of computer software Etabs ignoring the presence of in-fill brick walls. To study the effect of soil-structure interaction 16 RC frames (2bay x 2bay x2story, 2bay x 2bay x 3story, 2bay x 2bay x 4story, 3bay x3bay x 3story, 3bay x 3bay x 4story, 3bay x 3bay x 5story,4bay x 4bay x 3story, 4bay x 4bay x 4story, 4bay x 4bay x5story, 5bay x 5bay x 4story, 5bay x 5bay x 5story, 6bay x2bay x 4story, 6bay x 2bay x 5story, 6bay x 2bay x 6story) are considered to be resting on medium soil and hard soil. The foundations which are provided to these frames are flat-raft type and are designed according to the Indian code IS2950:1981. The dimensions of columns, beams and slabs are arrived at on the basis of the design following the respective Indian Design Code.

2.2 *Idealization and modelling of soil*

The seismic load acts during a very small interval of time. Hence, during the action of such loads, instead of consolidation settlement, the instantaneous settlement is expected to occur. This behaviour of soil can be conveniently simulated by modelling the same with a set of linear elastic springs.

To analyze the soil–foundation–structure systems under dynamic loading, the impedance functions associated with a rigid massless foundation are often used. Translations of foundations in two mutually perpendicular principal horizontal directions and vertical direction are considered in the present study. The stiffnesses of this centrally placed spring for raft type of foundation resting on homogeneous elastic half-space have been computed on the basis of the guidelines prescribed in a well-accepted literature [4] formed on the basis of an extensive literature survey and study based on boundary element method. These expressions were developed in such a form that the single spring located at the centroid of the raft, in each of the said six degrees of freedom, can account for the flexible behaviour of soil below the entire raft in the equivalent sense. In the present study it is assumed that there is no rotation restrict.

For dynamic analysis, the geophysical methods utilizing seismic wave velocity measuring techniques with absolutely no disturbance of natural site conditions. Therefore they may yield relatively more realistic results than those of the geotechnical methods, which are based primarily on bore hole data and laboratory testing. The shear wave velocities for this SPT values were obtained from Engineering Properties of Materials. [5] Primarily, the study attempts to see the effect of soil–structure interaction on buildings resting on different types of soil, viz., medium and hard soil .To obtain the values of the stiffness's of the springs for these varieties of clayey soil, values of shear modulus (G) of soil have been estimated using the relationship $G = \rho V_s^2$

Table -1: STIFFNESS OF EQUIVALENT SOIL SPRINGS

Degrees of freedom	Stiffness of equivalent soil spring
Vertical	$[2GL/(1-\mu)](0.73+1.54\chi^{0.75})$ with $\chi = A_b/4L^2$
Horizontal (lateral direction)	$[2GL/(2-\mu)](2+2.50\chi^{0.85})$ with $\chi = A_b/4L^2$
Horizontal (longitudinal direction)	$[2GL/(2-\mu)](2+2.50\chi^{0.85})-[0.2/(0.75-\mu)]GL[1-(B/L)]$

Where, Ab –Area of the foundation considered.
B and L—Half-width and half-length of a rectangular foundation, respectively

TABLE-2: SOIL PROPERTIES

For medium soil	For hard soil
N=10-30	N = >30
$G= \rho V_s^2$	$G= \rho V_s^2$
ρ = 1900kg/m^3	ρ = 2000kg/m^3
Vs = 390m/s	Vs = 1900m/s
G= 2.834 X 10^6 kN/m^2	G= 70.8 X 10^6 kN/m^2
Es=2G(1+μ) Es=6.518X10^{6}kN/m^2	Es=2G(1+ μ) Es=162.84X10^{6}kN/m^2

Where, N- standard penetration value
Vs- shear wave velocity in m/s
G- shear modulus in kN/m^2
Es- soil modulus in kN/m^2
ρ- Density in kg/m^3

2.3 ANALYSIS METHODOLOGY:

Finite element method is adopted to formulate the mass and stiffness matrices for the building frames. Consistent mass matrix approach is used to make the formulation as accurate as possible. The eigen value problem corresponding to the free vibration condition is solved by subspace iteration method to obtain the natural periods of the building frames under consideration. Seismic analysis of building frames accounting for the effect of soil–structure interaction is carried out with the help of the design spectrum provided in IS 1893:2000.

Five percent of critical damping is reasonable for concrete structures. Thus, 5% of critical damping in each mode was considered irrespective of the fixed base condition or support flexibility.

Finally, due to incorporation of the effect of soil-flexibility, the variations in the natural period are obtained.

2.4 RESULTS AND DISCUSSION:

This section presents the change in lateral natural period as a function of soil type parameter. Table 3 and Table 4)

TABLE 3: % change in natural period for medium soil

Frames	Natural period at fixed condition (secs)	Natural period at flexible condition (secs)	%change in the natural period
2bayx2bay x 2storey	0.46	0.59	29
2bayx2bay x 3storey	0.70	0.85	22.15
2bayx2bay x 4storey	0.94	1.05	11.05
3bayx3bay x 3storey	0.75	0.98	30.6
3bayx3bay x 4storey	1.01	1.25	15.59
3bayx3bay x 5storey	1.28	1.45	13.3
4bayx4bay x 3storey	0.75	0.98	30.58
4bayx4bay x 4storey	1.01	1.21	19.68
4bayx4bay x5storey	1.28	1.29	3.9

Table- 4: % change in natural period for hard soil

Frames	Natural period at fixed condition (secs)	Natural period at flexible condition (secs)	%change in the natural period
2bay x 2bay x 2storey	0.46	0.49	6.18
2bay x 2bay x 3storey	0.70	0.73	4.3
2bay x 2bay x 4storey	0.94	0.98	3.9
3bay x 3bay x 3storey	0.75	0.78	4.24
3bay x 3bay x 4storey	1.01	1.04	3.1
3bay x 3bay x 5storey	1.28	1.29	0.46
4bay x 4bay x 3storey	0.75	0.86	14.78
4bayx4bayx 4storey	1.01	1.03	4.19
4bay x 4bay x5storey	1.28	1.30	1.19

The change in fundamental lateral natural period due to the effect of soil–structure interaction is studied for various RC frames with raft foundation resting on hard soil and medium soil. For buildings supported on soft soil requires practically infeasible size of raft foundation and a piled raft may be necessary. The present study is confined to hard and medium soil. Various RC frames like 2bay x 2bay x 2storey, 2bay x 2bay x 4 storey, 3bay x 3bay x 4storey, 3bay x 3bay x 3storey 4bay x 4bay x 3storey, 4bay x 4bay x 4storey, 6bay x 2bay x 5storey, 6bay x 2bay x 6storey. These frames are resting on hard and medium soil. Graphs are plotted depicting the change in the natural period due to different soil considerations.

It was observed that the %change in the natural period for a 2bay x 2bay x 2storey resting on hard soil was about 6% whereas, when the same frame rested on medium soil the % change in natural period was about 29%. It was observed that the %change in the natural period for a 2bay x 2bay x 3storey resting on hard soil was about 4% whereas, when the same frame rested on medium soil the % change in natural period was about 23%. It was observed that the %change in the natural period for a 6bay x 2bay x 6storey resting on hard soil was about 6% whereas, when the same frame rested on medium soil the % change in natural period was about 34%.

It has been observed that the %change in the natural period decreases with the hardness of the soil.

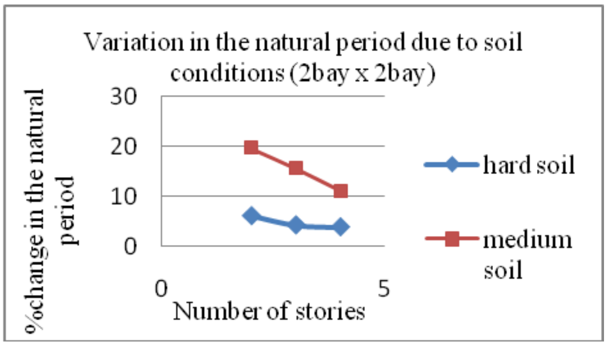

Chart -1: Variation in natural period due to soil conditions(2bay x 2bay)

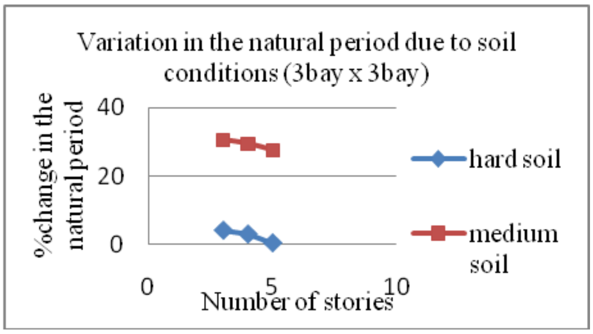

Chart -2: Variation in natural period due to soil conditions(3bay x 3bay)

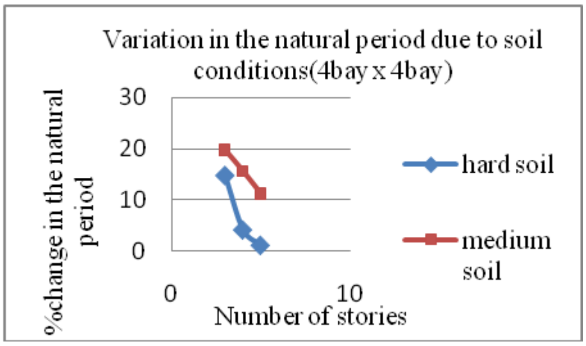

Chart-3: Variation in natural period due to soil conditions (4bay x 4bay)

3. CONCLUSIONS

1. Many design codes have suggested that the effect of SSI can reasonably be neglected for the seismic analysis of structures. This myth about SSI apparently stems from the false perception that SSI reduces the overall seismic response of a structure, and hence, leads to improved safety margins.
2. The effect of soil-flexibility may appreciably change the lateral natural periods of any building. This parameter primarily regulates the seismic lateral response of the building frames. Hence, the buildings maybe seismically vulnerable if the effect of Soil–structure interaction is not considered in the process of design.
3. The effect of soil-flexibility on lateral natural period of buildings is pronounced with decreasing hardness of soil in general. Hence, this effect needs to be considered very seriously at least for buildings of this category.

4. REFERENCES:

1. *Sekhar Chandra Dutta, Rana Roy "A critical review on idealization and modelling for interaction among soil-foundation-structure system", Computer and Structures 80 PP 1579-1594, Elsevier Science Ltd, 2002.*
2. *G.Gazetas "Seismic design of foundation and soil-structure interaction", First European Conference on Earthquake Engineering and Seismology, Geneva, Switzerland, 3-8 September, Paper Number: Keynote Address K7, 2006.*
3. *Koushik Bhattacharya, Sekhar Chandra Dutta, Suman Dasgupta, "Effect of soil-flexibilityon dynamic behaviour of building frames on raft foundation", Journal of Sound and Vibration 274 PP111–135, Elsevier Science Ltd, 2004.*
4. *G. Gazetas, "Formulas and charts for impedances of surface and embedded foundations", Journal of Geotechnical Engineering, American Society of Civil Engineers 117 (9) 1363–1381, 1991.*
5. *Engineering Properties of Materials (Geologic and Otherwise) GEOL 615*