The Effect of Soil Structure Interaction in the Dynamic Behavior of Group of Structures

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Abstract - *Numerous studies show that Soil Structure Interaction (SSI) has a significant impact in the dynamic characteristics of structures resting on soft soil, which may lead to unexpected seismic responses and/or failure. When more than one structure is present in the medium, because of the interference of radiation energy emitted by the vibrating structure it evolves to be a cross-interaction problem between multiple structures. The response of structures may increase or decrease tens of percent depending on the distance between them. Thus, the interactions between neighboring buildings have to be investigated.*

In this thesis, a numerical study is conducted to find out the dynamic behavior of group of structures resting on a soft soil deposit. The general purpose finite element software ANSYS 17.0 is used to model the soil structure system to investigate its behavior under seismic excitation. Numerical studies were conducted to study the group effect of structures - like group of two structures with and without soil. A significant change is observed in the time period, displacement and acceleration of the buildings due to group effect under Soil Structure Interaction.

Key Words: **Soil structure interaction, Dynamic behaviour, Geometric nonlinearity, Piled – Raft foundation, ANSYS workbench 17.0**

1. INTRODUCTION

Soil Structure Interaction (SSI) is an interdisciplinary field of endeavor. It lies at the intersection of soil and structural mechanics, soil and structural dynamics, earthquake engineering, geophysics and geomechanics, material science, computational and numerical methods, and other diverse technical disciplines [1]. Every important structure, including nuclear power plant and multistorey buildings, founded on the soft strata need to be analysed by considering the interaction effect. SSI is usually neglected in the design because of the assumption that flexible base will lead to reduced response in the structure. But as per literature, by comparing conventional code design spectra to actual response spectra, it was shown that an increase in fundamental natural period of a structure due to SSI does not necessarily lead to smaller response, and that the prevailing view in structural engineering of the always-beneficial role of SSI, is an oversimplification which may lead to unsafe design [2]. Also, when more than one structure is present in the medium interaction effect may increase or decrease depending on the distance between them. With rapid development and economic growth, the construction of closely spaced buildings are on the rise due to lack of space thus giving great importance for study of group interaction due to SSI. This thesis studies the dynamic behaviour of single and group of two buildings with and without considering substructure.

2. MODELLING

2.1 Geometry of Structure and Soil

Since SSI is predominantly seen in midrise building ranging from 5 to 15 storeys, a base model of 10 storey is selected. The cross-sectional elements are selected and designed as per IS codal provisions. A simple geometry of story height 3m, base area 8m x 8m, cross-sectional properties of superstructure elements as, column 300x600mm, beam 300x450mm and floor slab thickness – 150mm is modelled. Piled raft foundation is adopted because of the low bearing capacity of the soil. A raft slab of 250mm with piles of 750mm diameter and 20m length along with a soil dimension of 120x120x60m constitutes the substructure of the model. Building model with and without soil is shown in Figure-1 and Figure-2.

2.2 Finite Element Modelling

Finite element modelling is done for both superstructure and substructure together using the finite element software ANSYS 17.0. It is modelled using the concept of elastic half space theory. Soil structure interaction problem can be modelled in two ways, first is direct method in which both soil and structure is modelled together and second is substructure method in which soil and structure is modelled separately. Direct method is used for modelling in this study. Mesh size of 400mm is used for structural elements and 8000mm is used for soil after conducting mesh convergence study.

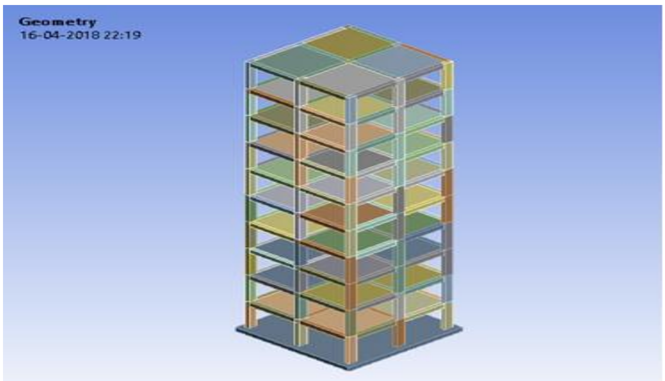

Figure-1: Single Building with fixed base

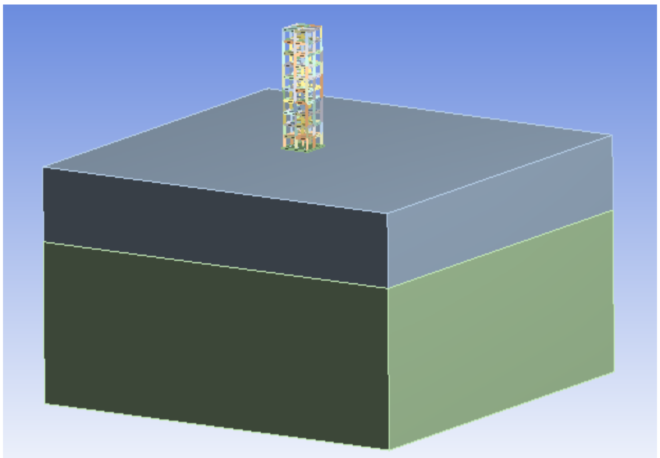

Figure-2: Single Building with soil

2.3 Material properties

Structure and soil are modelled as linear and nonlinear isotropic elements. Same grade of concrete is considered for all the structural elements. Two different type of soils are considered, one is soft and the other is relatively stiffer with a Standard penetration value more than 50 so that the end bearing pile can rest on it. Material properties considered for the study are Young's Modulus (E), Density (ρ) and Poisson's ratio(ν) and are given in Table1.

Table -1: Material properties of concrete and soil

Concrete	
Density	2500 kg/m³
Young's modulus	2.5×10^{10} Pa
Poisson's ratio	0.15
Soil 1	
Density	1798 kg/m³
Young's modulus	5×10^{7} Pa
Poisson's ratio	0.3
Soil 2	
Density	1850 kg/m³
Young's modulus	1×10^{8} Pa
Poisson's ratio	0.25

2.4 Boundary conditions and loading

We need to simulate the transmitting boundary (sometimes called absorbing boundary) conditions at the boundaries of the model to ensure that wave propagate outward and doesn't come back into the model, i.e. energy is not trapped. In short, we need boundary conditions at the far field with infinite elements. Symmetry boundary condition is the one in which it assumes the soil to be continuous and the waves are not going to come reflecting back as in the case of fixed boundary condition. Thus, symmetry boundary condition is applied to the corresponding direction at lateral side of soil solid element.

3. TRANSCIENT DYNAMIC ANALYSIS

Transcient dynamic analysis is done by giving NS component of El Centro earthquake as the input. Due to the complexity and time consumed for the analysis, only the first 5seconds of the earthquake data is given as input. Analysis is done for both fixed case and flexible case and the results are compared.

3.1 Single Building

Modal analysis of the soil structure model gives the time period of fundamental mode as 1.01s and fixed base model as 0.89s showing an increase in time period by a factor of 1.13 for flexible base when comparing to the fixed base model. Figure-3 shows the variation of time period in fixed and flexible base. A reduction in acceleration value from 12.141 m/s² to 10 m/s² is observed which conforms to the theory of soil structure interaction that SSI reduces the acceleration of buildings. Figure-4 shows the variation of acceleration by plotting the ratio of spectral acceleration (Sa) to acceleration due to gravity (g) in the y-axis and time (t) in the x-axis. Also there is an increase in the absolute top storey displacement of the building from 19.554mm to 35.669mm when SSI is considered. Figure-5 shows the variation in top storey displacement with and without SSI by plotting the ratio of displacement to building height in the y-axis and time(t) in the x-axis.

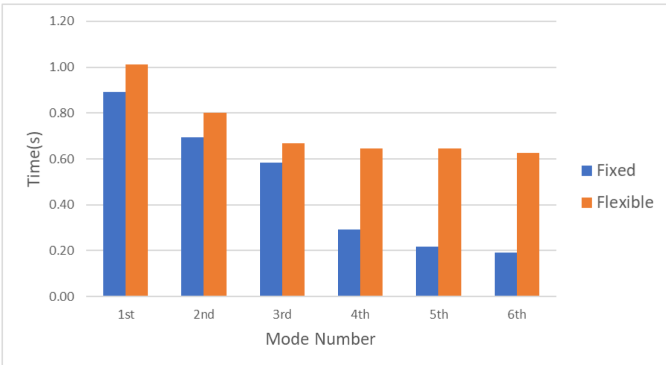

Figure-3: Variation in time period for single building (Fixed base and with SSI).

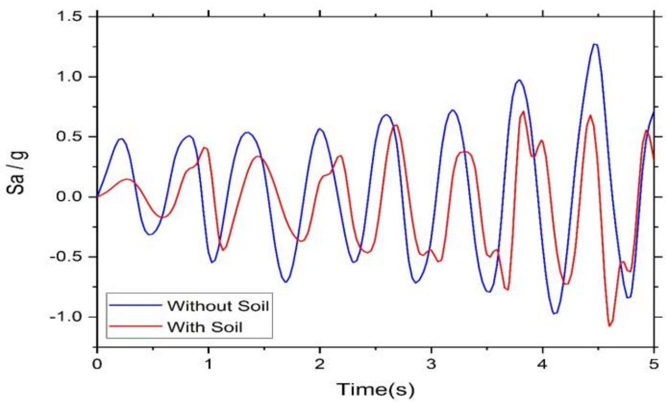

Figure-4: Acceleration response for single building (Fixed base and With SSI).

To have more insights on the effects of change in displacement due to SSI, the variation of storey drift is also studied for both fixed and flexible base building. It is understood that even though SSI increases the inter storey drift, its value falls with in the acceptable limits of 0.4% given by IS 1893(Part I):2016. Figure-6 shows the variation of storey drift by plotting floor level in the y-axis and storey drift (%) in x-axis.

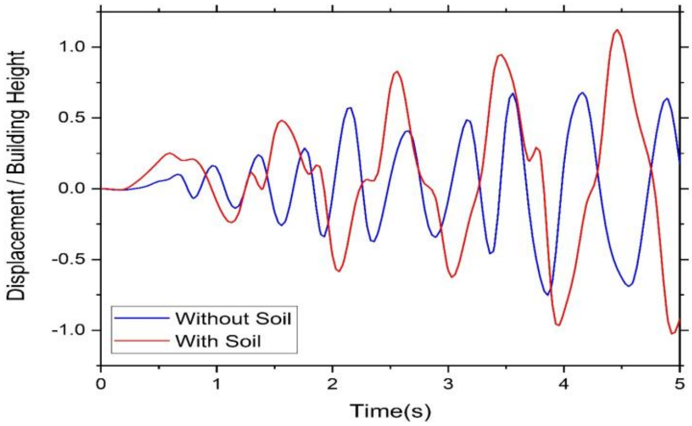

Figure-5: Displacement for single building (Fixed base & with SSI).

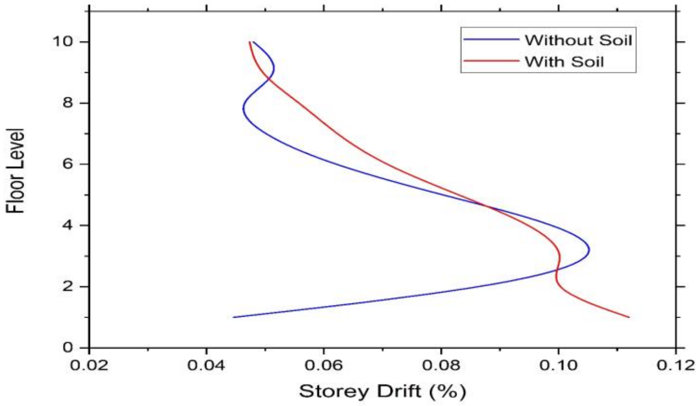

Figure-6: Storey Drift for Single Building (Fixed base and With SSI).

3.2 Group of Two Buildings

The two buildings under consideration are kept at a distance 8m from each other which is equal to the width of the buildings. Modal analysis of the soil structure model shows that there is a shift in period by 1.43 times as shown in Figure-7 An increase in acceleration value from 12.141 m/s^2 to 14.329 m/s^2 is observed which is contrary to the theory of soil structure interaction that SSI reduces the acceleration of buildings giving important insights to the detrimental effect of group effect due to SSI. Figure-8 shows the variation of acceleration for group of two buildings. Also there is an increase in the absolute top storey displacement of the building from 19.554mm to 136.49mm and 120.04mm for left and right building respectively. This increase in displacement increases the ductility demand of the buildings causing serious damages. Figure-9 shows the variation in top storey displacement for group of two buildings.

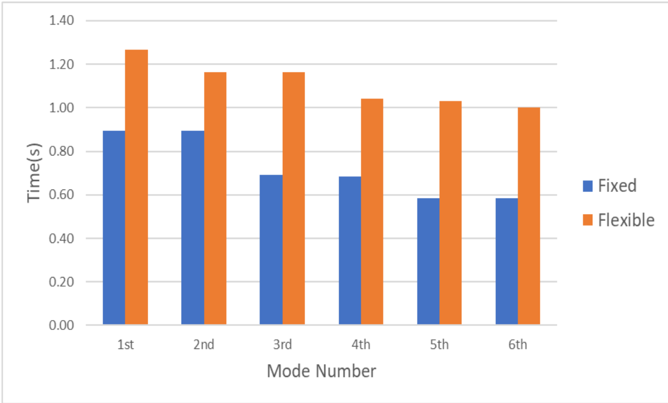

Figure-7: Variation in time period for group of two buildings (Fixed base & with SSI).

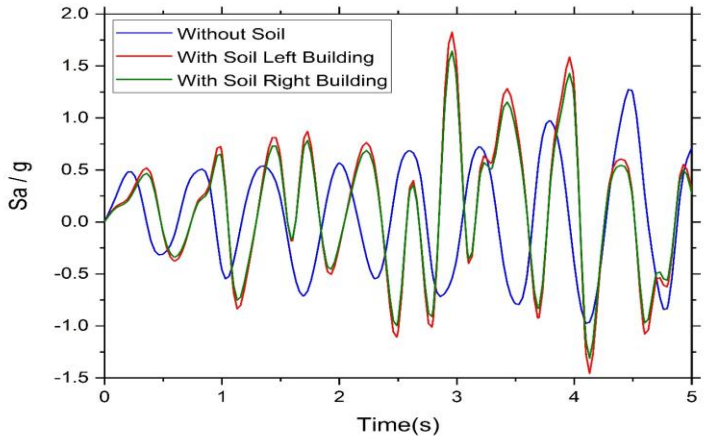

Figure-8: Acceleration response for group of two identical buildings (Fixed base and with SSI).

It is also observed that group effect due to SSI increases the inter storey drift and value (0.7%) exceeds way beyond acceptable limits mentioned in the design codes. Figure-10shows the variation of storey drift for group of two buildings.

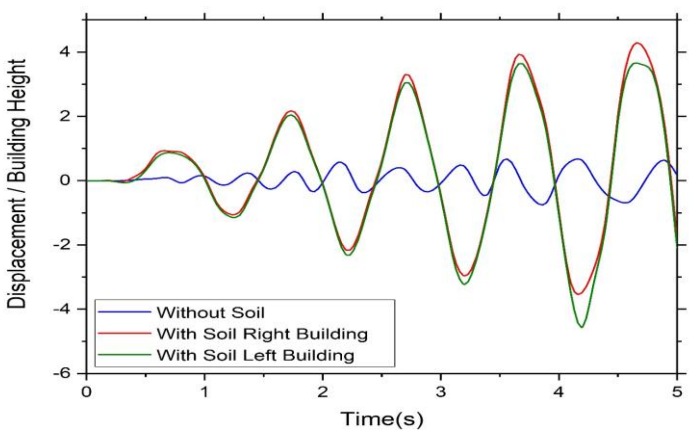

Figure-9: Displacement for group of two identical buildings (Fixed base & with SSI).

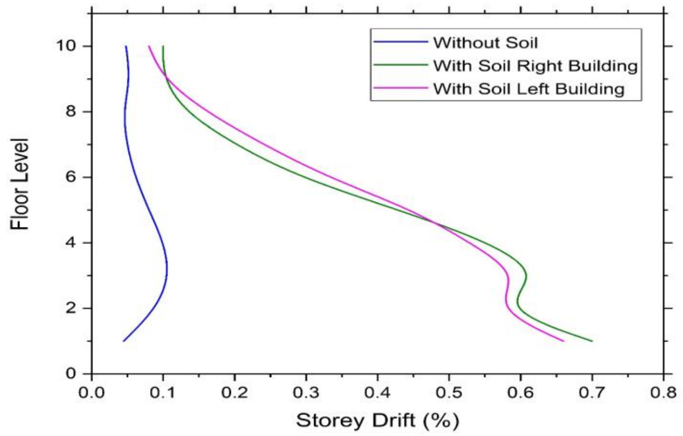

Figure-10: Storey Drift for group of two identical buildings (Fixed base & With SSI).

4. CONCLUSIONS

On the basis of the above results and discussions, following conclusions are drawn:

1) The soil structure interaction effect increases the time period of vibration of structures. This increase in time period is considerably large when group interaction effect is concerned.

2) Spectral acceleration response is a decreasing function of time period in the case of single building and the trend varies with group interaction effect.

3) There is a significant change in the lateral displacement of the structure due to the presence of a neighboring structure which inturn increases the ductility demand which may lead to unexpected seismic responses or failures.

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