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Soil Structure Interaction Assessment of RCC Building with Shallow Footing

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Abstract*: The main purpose of this paper is to be the understanding soil structure interaction behavior of three stories RCC frame building constructed over shallow footing below a base of dense soil. The horizontal deformation and vertical deformation of the RCC building is estimated from the finite element based 3-D model under static and dynamic loading. In this study, the finite element method considering the direct method is applied to the model of the soil structure interaction analysis of shallow footing with a base of dense soil by using commercial software ABAQUS (ver. 6.13). The base of the footing is considered as fixed and the sides of the footing are considered as free in vertical direction. The interaction between soil base and base of the footing is considered as friction with hard contact. The Mohr's Coulomb perfectly elastic plastic soil model and solid element of RCC concrete beams and columns are used for the analysis. The static loading under gravity and 0.1g horizontal ground acceleration respectively is used for the analysis. The results obtained from the finite element analysis, the soil structure interaction between footing and soil is indicated that there is a clear difference is observed with shallow footing and soil base and without the soil base. Therefore this study indicates that the soil structure interaction has an important role to assess the behavior of any structure with the various base of footing or foundation.*

1. Introduction

The Soil-Structure Interaction (SSI) effects has become an important feature of Structural Engineering with the advent of massive constructions on soft soils such as nuclear power plants, concrete and earth dams. Buildings, bridges, tunnels and underground structures may also require particular attention to be given to the problems of SSI.

The seismic response of structure is influenced by the medium on which the structure is founded. The dynamic response of the superstructure founded on the rock is different from soil and even varies with the soil type and its state at that particular instant. Figure 1 represents the SSI influence diagram.

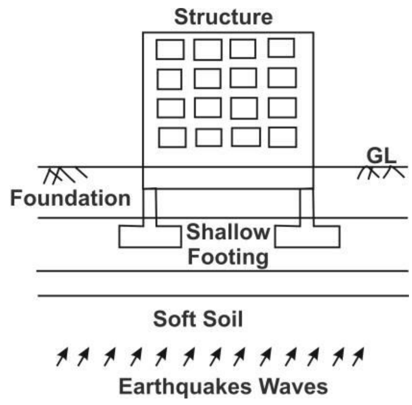

Figure 1. **Seismic soil structure interaction.**

When the interaction effect included in the analysis the responses of the superstructure is found to more than the fixed base analysis. If the structure is supported on soft soil deposit, the inability of the foundation to conform to the deformations of the free field motion would cause the motion of the base of the structure to deviate from the free field motion. Also the dynamic response of the structure itself would induce deformation of the supporting soil. These effects are more significant for stiff and/ or heavy structures supported on relatively soft soils. For soft and /or light structures founded on stiff soil these effects are generally small.

In order to understand the SSI effects properly, it is necessary to have some information of the earthquake wave propagation through the soil medium for two main reasons. Firstly, when the seismic waves propagate through the soil as an input ground motion, their dynamic characteristics depends on the modification of the bedrock motion. Secondly, the knowledge of the vibration characteristics of the soil medium is very helpful in determining the soil impedance functions and fixing the boundaries for a semi-infinite soil medium, when the wave propagation analysis is performed by using numerical techniques. The two types of interaction are generally accounts for the SSI analysis and are discussed in the following subsections. To understand the influence of local soil conditions in modifying the nature of free field ground motion it is very essential to understand the terminology of local site effect.

1.1. Kinematic Interaction

Generally the SSI effects are being estimated by the considering of three different modes of substructure and superstructure and their interaction between them during seismic loading. The soil structure interaction (SSI) effect which is related to the stiffness of the structure and it's known as kinematic interaction behavior as represented by the Figure 2.

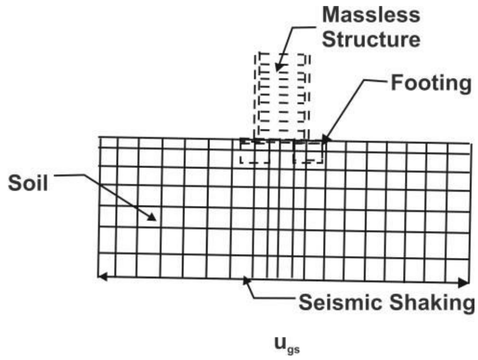

Figure 2. Kinematic interaction: Massless structure over shallow footing.

1.2. Inertial Interaction

The SSI effect which is associated with the mass of the structure is termed as inertial interaction as represented by Figure 3. It is purely caused by the inertia forces (seismic acceleration times mass of the structure) generated in the structure due to the movement of masses of the structure during vibration. The inertial loads applied to the structure lead to an overturning moment and a transverse shear. If the supporting soil is compliant, the inertial force transmits dynamic forces to the foundation causing its dynamic displacement that would not occur in case of a fixed-base structure.

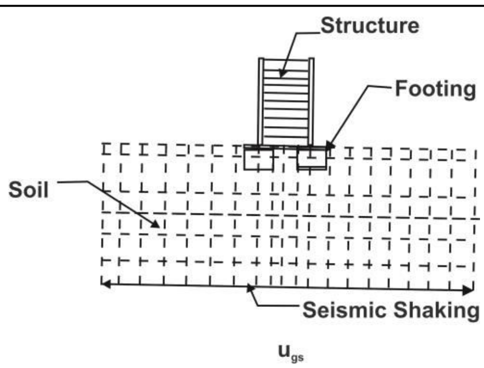

Figure 3. Inertial interaction.

1.3. Direct Method

In the direct method the soil, structure and foundation is modeled together using finite element method (FEM) and analyzed in single step as represented by Figure 4. The ground motion is specified as free field motion and is applied at all boundaries. The soil domain with some material damping is limited by a fictitious exterior boundary, which is placed so far away from the structure that during the total earthquake excitation, the waves generated along the soil-structure interface does not reach it.

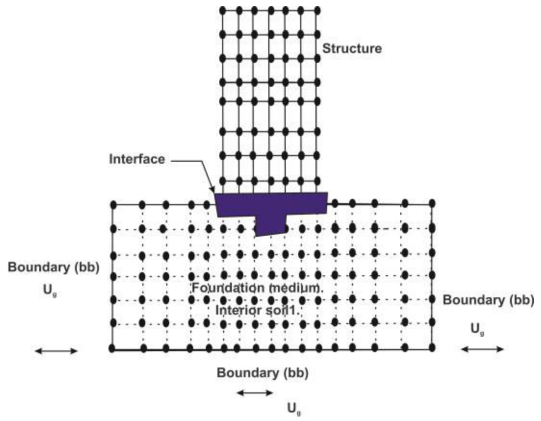

Figure 4. Direct method.

2. Finite Element Modeling

With the development of these numerical tools, there are advanced techniques employed for addressing the behavior of structure and soil. Although there are common techniques for structural and geotechnical modeling, the distinct demands of the two fields meant that modeling has evolved differently in each domain, thus leading to two modeling disciplines with distinctive high-level features.

The finite element method is a special form of matrix analysis, where the whole continuum is discredited into a finite number of elements connected at different nodal points. The general principles and use of the finite element method are well documented (e.g. Desai and Abel [1], Zienkiewicz et al. [7]).

In structural analysis, nonlinear modeling using finite element analysis has evolved to address complex issues of various structural forms (Izzuddin [2], Zienkiewicz et al. [7]). In fact, due to the universal nature of the finite element method in modeling real-life complex conditions including geometric and material nonlinearity in the response (Izzuddin [2]), this numerical technique has been widely used in design and assessment of complex structures (Smith and Coull [3], Rombach [6]).

Although the application of numerical methods in geotechnical design is not as widespread as in structural design, recent work by Gaba et al. [4] and Ravaska [5] has demonstrated that the use of numerical analysis, as opposed to other conventional methods, can lead to more accurate and economical design. As a result, the use of this type of analysis in design applications is bound to increase in the future, where a single simulation can provide all required information for design purposes.

There are numerous problems in Civil Engineering construction that require the use of realistic models for the structure, the supporting soil and the soil-structure interface.

Examples include the assessment of various structures under earthquake loading, the analysis of offshore jack up structures under extreme wave loading and the evaluation of the structural damage due to excavations to name but a few. This interaction can sometimes modify the stresses and deflections of the whole structural system significantly. In fact, the structure with its loading conditions imposes stresses and forces on the ground, which in turn deforms and as a consequence transmits back additional forces and deformation to the structure. This process continues until full equilibrium of the whole soil-structure system is satisfied, or until both the soil and the structure fail in the case of excessive loading and deformations of the system.

Numerical analysis, typically using the finite element or finite difference method, is currently the most advanced tool available to facilitate soil and structure analysis.

Finite element modeling of concrete column with longitudinal and stirrups reinforcement and soil is developed using ABAQUS (ver. 6.13) commercial software. The step by step modeling procedure is used in the analysis. From the geometry to the job creation in the software, the step-by-step model is prepared for the analysis. The meshing, boundary condition and interaction is also included in the given model. The material property of concrete is represented in the Table 1.

Table 1 Concrete material properties

Density	Mass Density (kg/m^3)	2.43E-009
Elastic	Young's Modulus (N/mm^2)	20000
	Poisson's Ratio	0.18
Concrete Damaged Plasticity	Plasticity	
	Dilation Angle (Degree)	31
	Eccentricity (mm)	0.1

The properties of steel and soil are used for the analysis are given Table 2, and Table 3 respectively.

Table 2. Steel properties

Density	Mass Density (kg/m^3)	7.85E-009
Elastic	Young's Modulus (N/mm^2)	210000
	Poisson's Ratio	0.3
Plastic	Yield Stress (N/mm^2)	350
	Plastic Strain	0

Table 3. Soil properties

Density	Mass Density(kg/m^3)	1.8E-009
Elastic	Young's Modulus (N/mm^2)	250000000
	Poisson's Ratio	0.32
Mohr's Coulomb plasticity model	Plasticity	
	Frictional Angle (Degree)	42
	Dilation Angle	0

3. Results

The soil structure interaction assessment of three story building constructed on concrete shallow foundation over soil base containing dense material is analyzed in this research work. The three story building finite element models with footing and without footing are developed with the help of ABQUS (ver. 6.13). After the analysis of these models, the horizontal, vertical deformations are presented in the following subsections. The finite element model with concrete footing over dense soil base is presented in the Figure 5.

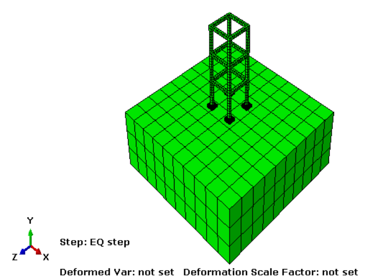

Figure 5. FEM Model.

3.1. Horizontal deformation

The results from the analysis of the finite element models with concrete footing over dense soil base and without footing are obtained and the estimated horizontal displacements for these two cases are presented in the Figure 6 and Figure 7 respectively. The horizontal displacement estimated for concrete footing over dense soil base model is 2.50 mm and the horizontal displacement estimated for without concrete footing and soil base is 3.30 mm which is comparable with the results and also indicated that the soil structure interaction effects are influencing the deformation behavior of the building. The dynamic force of unit 100000 mm/sec^2 or 0.1g horizontal ground acceleration is applied at the base of the footing for the analysis.

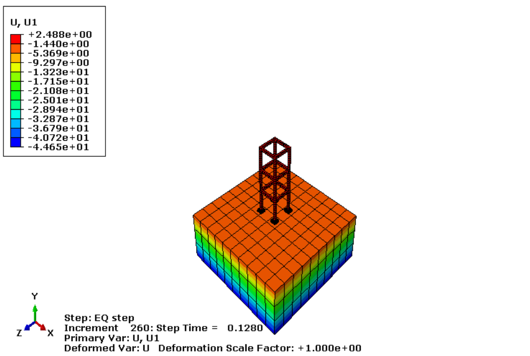

Figure 6. Horizontal Displacement with footing.

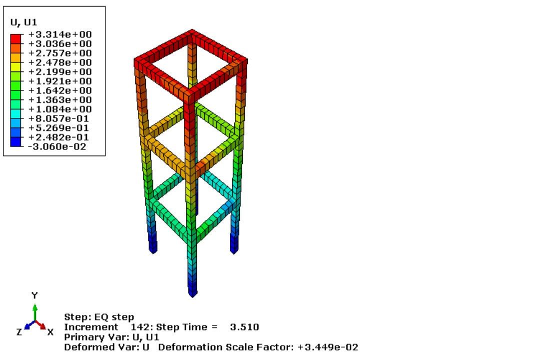

Figure 7. Horizontal Displacement without footing.

3.2. Vertical Deformation

The results from the analysis of the finite element models with concrete footing over dense soil base and without footing are obtained and the estimated vertical displacements for these two cases are presented in the Figure 8 and Figure 9 respectively. The vertical displacement estimated for concrete footing over dense soil base model is 27.0 mm and the vertical displacement estimated for without concrete footing and soil base is 25.0 mm which is comparable with the results and also indicated that the soil structure interaction effects are influencing the deformation behavior of the building. The horizontal acceleration of unit 100000 mm/sec^2 is applied at the base of the footing for the analysis.

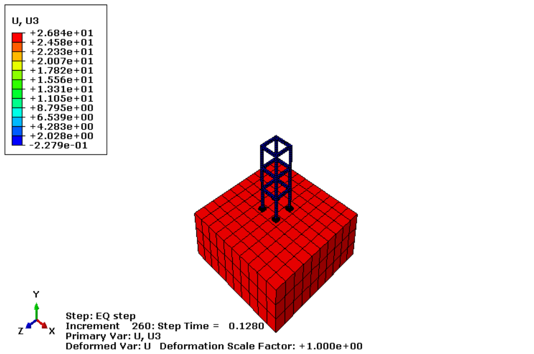

Figure 8. Vertical Displacement with footing.

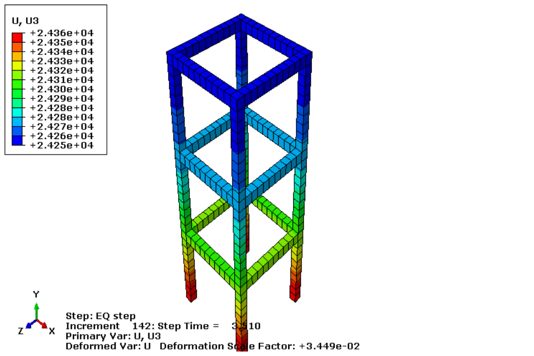

Figure 9. Vertical Displacement without footing.

4. Conclusions

The soil structure interaction influence of three story building rested over concrete shallow footing below a soil base of dense soil are assessed by developing models with the help of finite element based commercial software ABAQUS (ver. 6.13). The horizontal and vertical displacements are estimated after the static and dynamic analysis of the model. The horizontal ground acceleration of unit 100000 mm/sec^2 are applied at the base of the footing. The estimated horizontal and vertical displacements are clearly indicated that the soil structure interaction influence the deformation behavior of the structure. A comparison with and without footings are also discussed.

5. References

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