International Journal of Computer Applications (0975 – 8887)
International Conference on Quality Up-gradation in Engineering, Science and Technology (ICQUEST2015)

Analysis of Soil Structure Interaction in Framed Structure

Janardhan Shanmugam
Research student
Department of Civil Engineering
DMCOE, Airoli, Navi Mumbai

P. A. Dode
Assistant Professor
Department of Civil Engineering
DMCOE, Airoli, Navi Mumbai

H. S. Chore, PhD
Professor and Head
Department of Civil Engineering
DMCOE, Airoli, Navi Mumbai

ABSTRACT

The effect of soil-structure interaction on a four storeyed, two bay frame resting on pile and embedded in the cohesive soil is examined in this paper. For the purpose of the analysis, simplified idealizations made in the theory of finite elements are used. The slab provided for all storeys are idealized as three dimensional four nodded shell elements. Beams and columns of the superstructure frame are idealized as three dimensional two nodded beam elements. Pile of the sub-structure is idealized as three dimensional two nodded beam elements. The finite element based software program ANSYS is used for the purpose of analysis. The effect of different pile diameters on the response of superstructure is evaluated. The responses of the superstructure considered include storey displacements at respective storeys.

General Terms

Soil Structure Interaction, Single Pile, Ansys

Keywords

foundation - frame; piles, soil-structure interaction, superstructure

1. INTRODUCTION

Several studies have been made on the effects of soil structure interaction on the super structure to obtain realistic results. The interaction effects are found to be quite significant especially for the structures resting on highly compressible soils. The conventional procedure of analysis of framed structures normally assumes the bases to be fixed or hinged. However, the foundation can also deform due to the underneath deformable soils. Thus, the conventional procedure neglects the flexibility of the foundation and compressibility of the sub- soil. Soil Structure Interaction(SSI) is, therefore, necessary for the accurate assessment of the response of the superstructure. Many researches on Soil Structure Interaction (SSI) have been reported in the 1960-70s studies such as Chameski [1], Morris [2], Lee and Harrison [3], Lee and Brown [4], King and Chandrasekaran [5], Buragohain et al. [6], Subbarao et al. [7], Deshmukh and Karmarkar [8] and Dasgupta et al. [9]. Most of these analyses have been presented either for the interaction of frames with isolated footings or for the interaction of frames with raft foundation, whereas only a few of them were focused on the interaction of frames with combined footings. Much work is also done on pile foundation, but comparatively little work, except Buragohain et al. [6], was reported on the analysis of framed structures resting on pile foundations with soil-structure interaction effects. Buragohain et al. [6] work was based on simplified approach. The necessity of interaction analysis for building frames resting on pile foundation based on a more rational approach and realistic assumptions was reported by Ingle and Chore [10] and subsequently, Chore [11] reported the interaction analysis of a single storeyed building frame having two bays and supported on the group of piles. In accordance to this, Chore and co-authors [12-17] reported the interaction analyses for the building frame resting on pile foundation which included the coupled and uncoupled approaches. 3-D finite element idealizations were made for building frame and the sub-structure was idealized using 3-D as well as simplified idealizations based on the theory postulated by Desai et al. [18] which considered linear as well as non-linear behavior of the soil. Analysis of four storeyed building frame having two bays is reported in the present study. The effect of varying diameter of piles with Soil- structure Interaction (SSI) effects is evaluated on the displacement of the frame.

2. MODELING OF THE SUPER-STRUCTURE AND SUB-STRUCTURE

2.1 Super-structure

A finite element modelling is done for the superstructure along with the supporting system using finite element software ANSYS (Workbench 15). The slab of the frame is idealized as three dimensional four-nodded shell elements. Beams and columns of the superstructure frame are idealized as three dimensional two-nodded beam elements.

2.2 Sub-structure

Pile of the sub-structure is idealized as three dimensional six-nodded beam elements. Soil is modelled by using Drucker Prager model. A homogeneous deep sandy soil volume of 20m × 20m × 6m is considered for this study.

3. NUMERICAL PROBLEM

A four storeyed (G+3) space frame resting on pile foundation as shown in figure 1 is considered for the purpose of the parametric study. The frame, 9 m high, is 10 m × 10 m in plan with each bay being of 5 m × 5 m. The height of each storey is 3 m. The slab, 0.2 m thick, is provided at the top as well as at the floor level. The slab at the top is supported by beams, 0.3 m wide and 0.3 m deep, which in turn rest on columns of size 0.3 m × 0.3 m. Figure 1 shows the arrangement of column and beams along with the fixed base condition. The fixed support is applied at the 9 nodes of the structure. While dead load is considered according to unit weight of the materials of which the structural components of the frame are made up. A lateral load of 100 kN is assumed to act at the joints of the frame in the specified direction shown in the figure at the 12 nodes excluding the nodes having fixed support condition. (Figure 1).

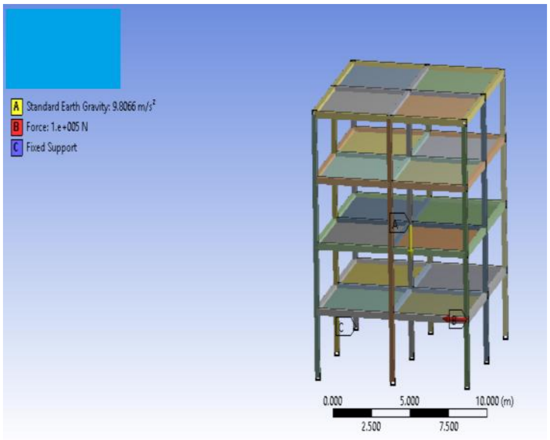

Figure 1: Extruded model of the building frame in fixed position

3.1 Elements and Material model selection in ANSYS-15

In ANSYS framed superstructure is modelled with 2D-Beam element BEAM188 and Piles with BEAM188, interface element with CONTA175 and TARGE170. Soil is modelled with SOLID 185 and Drucker–Prager nonlinear material model is for soil behaviour. The Drucker–Prager yield criterion is a pressure-dependent model for determining whether a material has failed or undergone plastic yielding. The criterion is introduced to deal with the plastic deformation of soils. The Drucker–Prager yield surface is a smooth version of the Mohr–Coulomb yield surface. The basic Drucker–Prager material model assumes perfectly plastic behavior (no strain hardening). BEAM188 is suitable for analysing slender to moderately thick beam structures. The element is based on Timoshenko beam theory which includes shear-deformation effects and element provides options for unrestrained warping and restrained warping of cross-sections. SOLID185 is eight noded 3-D element gives translations in 3-directions used for solid modeling. CONTA175 is ideal to use when there is sliding between two elements in contact (either node to node or line to line). Contact occurs when the element surface penetrates one of the target segment elements, TARGE170 on a specified target surface. Soil is modeled with SOLID 185. Material model Drucker–Prager for soil describes the non-linear plasticity behavior which depends on the engineering soil properties. The properties of the concrete for the superstructure elements and sub-structure element (according to Indian specification) are given in Table 1. The corresponding Young's modulus of elasticity and Poisson's ratio are also given in Table 1. A soft cohesive soil is considered in the analysis.

The classic Drucker- Prager model is applicable to granular (frictional) material such as soils, rock, and concrete and uses the outer cone approximation to the Mohr-Coulomb law. The input consists of only three constants:

- Cohesion value
- Angle of internal friction
- Dilatancy angle

The amount of dilatancy (the increase in material volume due to yielding) can be controlled via the dilatancy angle. If the dilatancy angle is equal to the friction angle, the flow rule is associative. If the dilatancy angle is zero (or less than the friction angle), there is no (or less of an) increase in material volume when yielding and the flow rule is non-associated.

The classic Drucker- Prager model is assigned to the soil by inserting APDL (ANSYS Parametric Design Language) command. The command of classic Drucker- Prager model is as follows:

```
MP,EX,1,19E6

MP,NUXY,1,0.3

TB,DP,1

TBDATA,1,23,32,0
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Here,

EX command is used to define Young's modulus for the (MAT) Material ID,

NUXY command is used to define Poisson's ratio,

TB command is used to define drucker prager model,

TBDATA command is used to define three constants C1 (cohesion value), C2 (Internal friction), C3 (Dilatancy) and assign it to MAT (material) ID.

Figure 2 shows the extruded model of the building frame resting on piles in contact with the soil. The piles aren't visible but are embedded in the soil of dimension 200m x 200m x 60m. The piles are of length 3m and have diameter 0.3m, 0.4m and 0.5m set to run for each case of analysis.

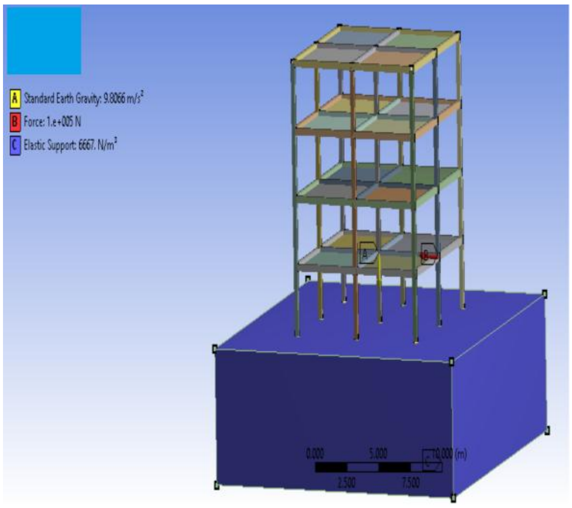

Figure 2: Extruded model of the building frame resting on piles in contact with the soil

Table 1. Material properties

Material Properties	Corresponding Values
Grade of Concrete used for the Frame Elements	M-40 (Characteristic Comp Strength: 40 MPa)
Young's Modulus of Elasticity for Frame Elements	0.3×10^8 kPa
Grade of Concrete Grade used for Pile	M-40
Young's Modulus of Elasticity for Foundation Elements.	0.3×10^8 kPa
Poisson's ratio (μ_c) for concrete	0.18
Poisson's ratio (μ_s) for steel	0.3
Modulus of subgrade reaction (K_h)	6667 kN/m^3.

Table 2. Soil properties

Soil Properties	Corresponding Values
Soil Type	Sandy clay
Young‟s modulus of elasticity (E_s)	19000 kPa
Posson's ratio (η)	0.3
Cohesion (C)	23kPa
Internal friction angle (Ø)	32

4. RESULT AND DISCUSSION

In the parametric study conducted for the specific frame presented here, the response of the superstructure considered for the comparison include the horizontal displacement of the frame at the storey level, for both fixed base and soil-structure interaction (SSI) cases. The displacements of frame evaluated in respect of various pile diameter and the fixed base condition is shown in Table 3. The effect of change in pile diameter on the storey displacements of the super structure is reported. The effect of pile diameter on the storey displacement is significant when they are calculated on the premise of fixed base approach and that soil- structure interaction (SSI). The corresponding change in storey displacement with respect to the storey displacement obtained considering fixed column is discussed below in Table 3.

Table 3. Values of storey displacement with fixed base condition and considering Soil Structure Interaction (SSI)

Storey Height (m)	Storey Displacement (mm)			
	Fixed	Pile Diameter		
		300mm	400mm	500mm
12	11.879	52.407	36.063	25.061
9	9.9952	48.583	33.114	22.533
6	5.8537	38.604	25.269	16.581
3	2.1352	24.632	15.382	9.4032
0	0	0	0	0

It is observed from the values of the displacements mentioned in the afore-mentioned table that with increase in pile diameter, the displacement at the respective storey level is found to decrease. At the top storey (12 m height), the storey displacement is 52.4 mm for 300 mm piles, 36.1 mm for 400 mm piles and 25.1 mm for 500 mm piles.

Figure 3 shows variation in storey displacements (for height of 0, 3, 6, 9, 12m) for the building frame under fixed base condition

Figure 4 shows variation in storey displacements (for height of 0, 3, 6, 9, 12m) for 300mm diameter piles in contact with soil.

Figure 5 shows variation in storey displacements (for height of 0, 3, 6, 9, 12m) for 400mm diameter piles in contact with soil.

Figure 6 shows variation in storey displacements (for height of 0, 3, 6, 9, 12m) for 500mm diameter piles in contact with soil.

Figure 7 shows comparative variation in storey displacements (for height of 0, 3, 6, 9, 12m) for fixed base condition and 300mm, 400mm and 500mm diameter piles in contact with soil.

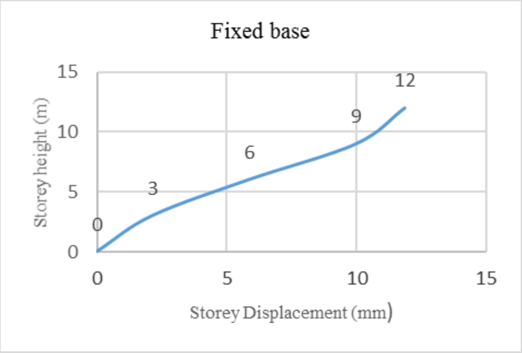

Figure 3: Graph showing variation of storey dispacement for specified storey under fixed base condition

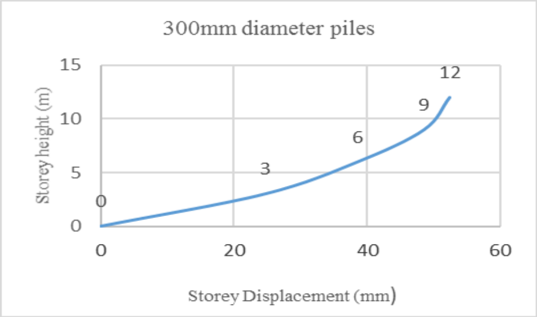

Figure 4: Graph showing variation in storey displacements for 300mm piles in contact with soil

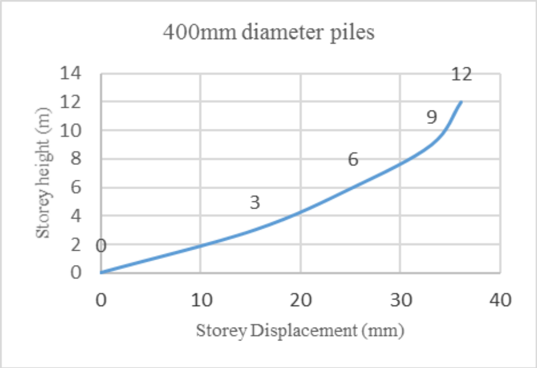

Figure 5: Graph showing variation in storey displacements for 400mm piles in contact with soil

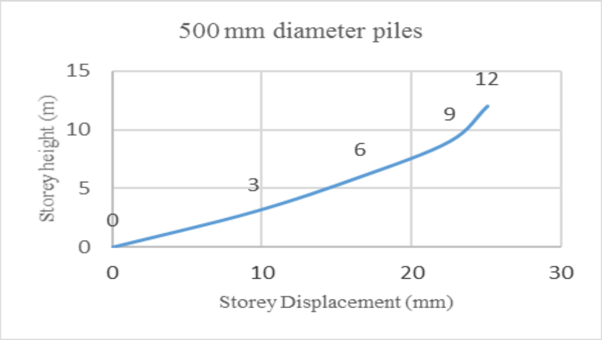

Figure 6: Graph showing variation in storey displacements for 500mm piles in contact with soil

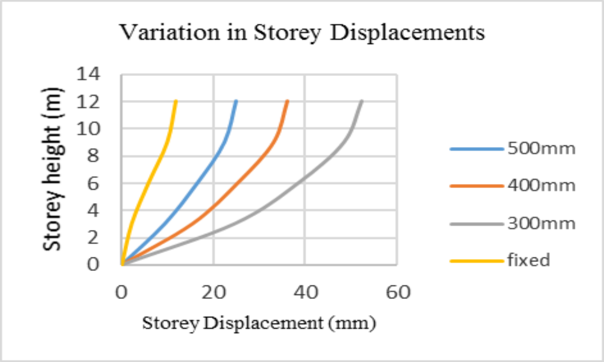

Figure 7: Graph showing variation in storey displacements

5. CONCLUSION

The broad conclusions emerging from the interaction analysis are given below.

1. The effect of soil- structure interaction on top displacement of the frame is quite significant. Displacement is less for the conventional analysis, i.e., fixed base condition and increases in the range of 210 – 441 % when the effect of SSI is taken into consideration

2. The displacement at top of frame decreases with increase in pile diameter.

3. The general trend observed for all the pile diameters considered in this investigation is that horizontal displacement is on higher side when the effect of soil structure interaction (SSI) is considered. For 300 mm pile diameter, at top of the subsequent storeys, the percentage increase in displacement is found to be 441% and 304% for 400mm diameter piles and 211% for 500mm diameter piles.

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