Vertical Displacement of Pile Foundation with Footing in Various Soil Conditions

Jigyasu Chourasia[1] Dr. Umesh Pendharkar[2] Dr. Raghvendra Singh[3]
[1]M.E. Student [2,3]Professor
[2,3]Department of Civil Engineering
[1,2,3]Ujjain Engineering College, Ujjain, Madhya Pradesh, India

Abstract— The deep foundations are generally preferred when heavy structural loads have to be transferred through weak sub soils which have low bearing capacity. Generation of excessive stresses may cause failure of foundations but it is mainly caused by excessive displacement and this results in the failure of structure. In this paper vertical settlement is estimated in three different foundations in sandy and clayey soil. Three different models, in which four storied framed structure rests on column footing, single under-reamed friction pile and single under-reamed friction pile with square footing are taken and vertical displacement is estimated on the basis of dead load and live load of the structure. 3D finite element software ANSYS Workbench is used for the modelling and analysis. The aim of this research is to identify the enhancement in the performance of pile foundation by adding a shallow trapezoidal footing along with the single under-reamed friction pile in loose soil strata in static condition. It is observed that the single under-reamed pile which have footing with it has lower vertical settlement as compared to the pile without footing.

Key words: Single Under-Reamed Friction Pile, Isolated Footing, Sub-Structure, Super-Structure, Vertical Settlement, Building Frame, ANSYS Workbench

I. Introduction

Several studies have been conducted on the effects of soil structure interaction and effect of foundation settlement on the super structure to obtain accurate results of story displacement. For the super structures resting on highly compressible clayey and sandy soils, the effects of foundation interaction with soil are found to be quite significant. Displacement of sub structure and super structure occurs due to many reasons but mainly it occurs by the settlement of foundation which is caused by the soil deformation beneath the foundation. This foundation settlement leads to the displacement of structure. Most of these analyses of structures are carried out and published in the literature either for the interaction of frames with isolated footings or for the interaction of frames with raft foundation (King and Chandrasekaran, 1974, Buragohain et al., 1977, Subbarao et al., 1985, Deshmukh and Karmarkar, 1991 and Dasgupta et al., 1998), whereas only a few of them were focused on the interaction of frames with combined footings. Several researches have concluded on the complex soil structure relationship Chore and Ingle (2008) worked on interaction analysis of building frame supported on pile group in his comprehensive interactive analysis it is observed that the displacement is less for fixed base condition and increases in the range of 55 to 165% with SSI. Displacement at the frame decreases with increase in number of piles in a group, increase in pile spacing, Increase in diameter. Rasal et al. (2015) analyzed the effect of soil structure interaction on response of the three-storied building frame supported on pile foundation they observed that the Soil- Structure interaction effect increases the displacement in each story of the frame and with increase in pile diameter, the displacement decreases at the corresponding stories. Hosamani et al. (2015) assessed the soil structure interaction using RC frame irregular building with shear wall, it is observed that Storey displacement and storey drifts are maximum in case of frame building with soil structure interaction and building has maximum response acceleration coefficient causing higher base shear values. Shanmugam et al. (2015) conducted an analysis of soil structure interaction in framed structure and it is observed that displacement is less for the fixed base condition and increases in the range of 210 – 441 % when the effect of SSI is taken into consideration and the displacement at top of frame decreases with increase in pile diameter. The percentage increase in displacement is found to be 441% and 304% for 400 mm diameter piles and 211% for 500 mm diameter piles. In this research work, the finite element approach is used to solve the sub structure problem therefore 3-D model is developed using the FEM theory.

II. Modelling

In ANSYS workbench (ver. 18.0), there are many sample materials that are used in different types of analysis, they are categorized in various categories such as solid elements, beam elements, shell elements, contact and target elements. In this research work, during the formation of the different models (i.e. Frame, pile and soil), different elements are used such as SOLID187, SOLID186, BEAM188, SHELL181, CONTACT174 and TARGET170 depending upon the model requirement.

A. Geometry Modelling

In the finite element analysis, beams and columns of the superstructure frame are modeled with the help of three dimensional two-nodded beam elements. The slab of the frame is idealized as four-nodded shell elements. Four storied frame models are developed by considering beams and columns with line element i.e. BEAM188 and slab of each floors are modelled with shell element i.e. SHELL181. The columns and beams of frame are of size 0.3 m X 0.3 m and modelled with line elements. The thickness of slab is considered as 0.12 m. The dimension of frame is taken as 3.22 m X 3.22 m X 3.4 m (each height) and it is single bay four story frame represented by Figure 2. The material properties of concrete of building frame and the pile are given in table in the material property section. In this research project, the influence of the deep foundation such as pile foundation with or without shallow foundation in two different soils (sandy and clayey) is evaluated.

In pile with footing, the size of footing is taken as 2.0 m X 2.0 m having gravel fill of 0.6 m under the footing.

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The dimensions of the single under-reamed bulb friction pile are taken in accordance with IS: 2911 (Part III). The diameter of pile is 0.3 m, length of pile is 3.6 m, diameter of under ream is 0.76 m, and length of under ream is 0.46 m. The models of pile and pile with square footing along with the dimensions are presented in the figure.1 and figure.2 respectively. The soil layer around and below the pile foundation is modelled with solid element having a dimension of 36.0 m X 36.0 m X 18.0 m which is approximately 10 times the size of pile length. The Mohr - Coulomb nonlinear material model is used for the analysis of soil behavior. As per the Mohr-Coulomb model, it defines yielding when the combination of pressure and shear stress reaches the cohesion of the material particles. Yield Surface is the Mohr-Coulomb property and includes the physical properties such as initial inner friction angle, initial cohesion, dilatancy angle, residual inner friction angle, residual cohesion. The frictional coefficient of 0.9 is provided between soil and foundation.

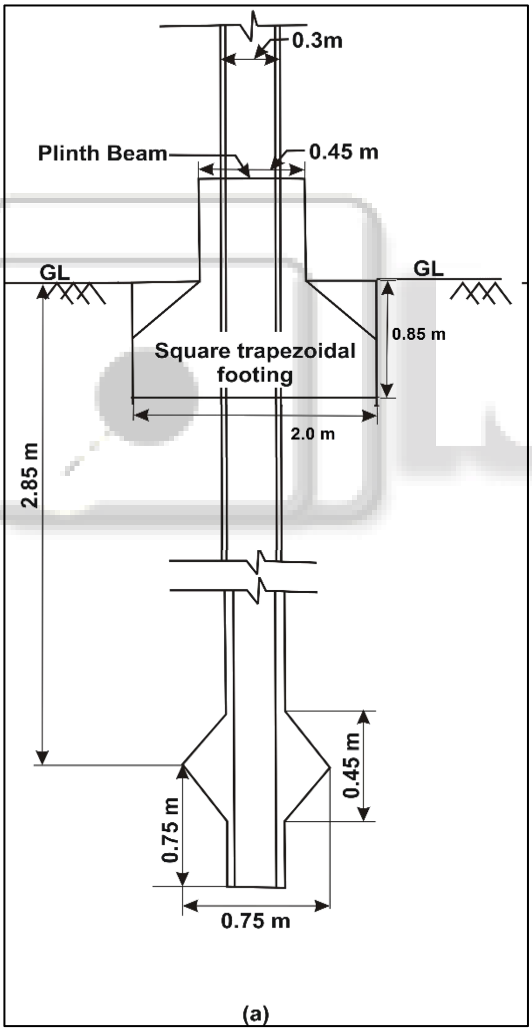

Fig. 1: Geometry of Single Under-Reamed Pile with Footing

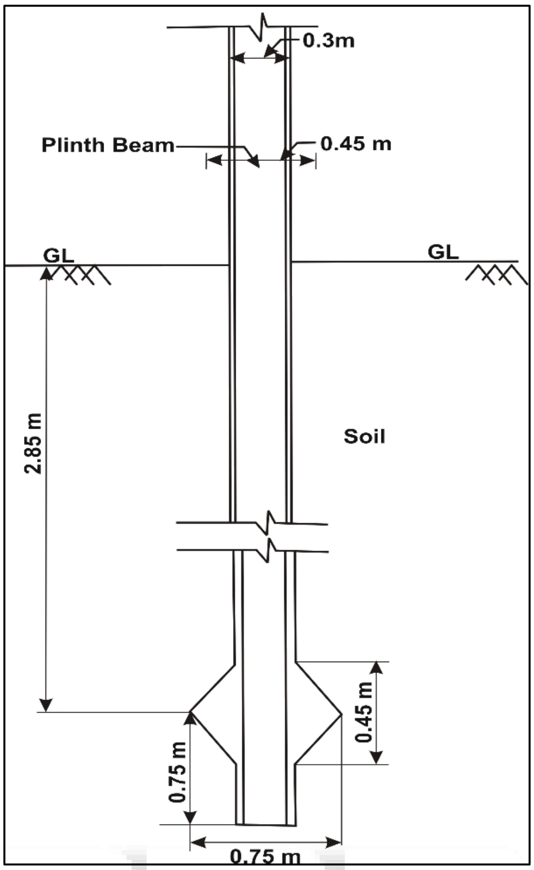

Fig. 2: Geometry of Single Under-Reamed Pile

B. Material Properties

After assigning the sections for all the geometries of these models, the material properties for frame and concrete pile is assigned. The material properties for frame and concrete pile are listed in the Table.1. The soil properties of clayey and sandy soil taken for the analysis are given in Table 2. Reinforcement is provided by using APDL (Ansys Parametric Design Language) command option. The diameter of bars is taken as 12 mm. 6 mm diameter rings of size 256 mm are provided at 204 mm c/c spacing.

S.N.	Properties	Concrete
1	Grade	M40
2	Young's Modulus	31622 (MPa)
3	Density	2400 (kg/m^3)
4	Coefficient of thermal expansion	1.4E-05(/^{0}C)
5	Poisson's ratio	0.2
6	Bulk modulus	1.7568 E10 (Pa)
7	Shear modulus	1.3176 E10 (Pa)

Table 1: Concrete Material Properties

S.N.	Properties	Sandy soil	Clayey soil
1	Density	1800 (Kg/m^3)	1700 (Kg/m^3)
2	Young's Modulus	8.00E+07(Pa)	7.00E+07(Pa)
3	Poisson's ratio	0.3	0.3
4	Bulk modulus	6.67E+07(Pa)	5.83E+07(Pa)
5	Shear modulus	3.08E+07(Pa)	2.69E+07(Pa)
6	Initial inner frictional angle	41^0	6^0

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7	Residual inner frictional angle	36^0	4^0
8	Initial cohesion	0	80000 (Pa)
9	Residual cohesion	0	60000 (Pa)
10	Dilatancy angle	15^0	0
11	Damping	5%	5%

Table 2: Properties of Foundation Soil

C. Loadings

The models (a) single bulb friction pile without shallow footing and (b) single bulb friction pile with shallow footing (c) isolated footing are analysed for the gravity loading (acceleration due to gravity i.e. 9.8 m/s2), dead load and live load. In ANSYS live load is applied in form of pressure as a uniformly distributed load and it is taken as 3 KN/m2 from IS: 875 (part 2) -1987. On the behalf of such loading conditions the displacement behavior of all the three models in sandy and clayey soil are estimated.

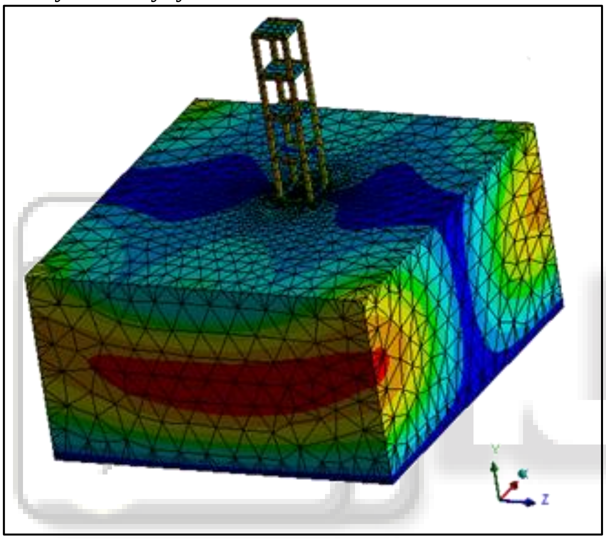

Fig. 2: Soil and Frame Geometry

III. Results and Comparisons

In this research six models were made, in which three of them have sandy soil in contact with foundation and other have clayey soil in which frame and foundation rests.

Vertical displacement or settlement of all the three types of foundations that is only column footing, pile foundation and pile foundation with footing is given in table 3, in both sandy and clayey soil.

Type of soil	Type of Foundation	Vertical displacement (mm)
Clayey soil	Isolated Footing	18
	Pile foundation	5.83
	Pile with footing	5.43
Sandy soil	Isolated Footing	16.9
	Pile foundation	5.30
	Pile with footing	4.50

Table 3: Total Vertical Displacement of Foundations

IV. Conclusion

In this paper the influence of adding column footing with pile foundation is estimated in sandy and clayey soil in static condition.

1) It is observed that footing displaces 51.57% in clayey soil and 48.42% in sandy soil.
2) The vertical displacement of pile in clayey soil is 52.38% and 47.61% in sandy soil.
3) The vertical displacement of Pile with footing is 54.68% in clayey soil and 45.31% in sandy soil.
4) It is also observed that the displacement of pile in sandy soil is 4.77% less as compared with clayey soil.
5) The displacement of pile with footing in sandy soil is 9.37% less as compared with clayey soil.
6) It is observed that, in static condition pile which have footing with it displaces 4% less in clayey soil and 8.17% less in sandy soil as compared with pile without footing.

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