Dynamic Analysis of Pile Foundation with Footing in Different Foundation Soils

Jigyasu Chourasia[1], Umesh Pendharkar[2], Raghvendra Singh[3]

[1]*M.E. student, Ujjain Engineering College, Ujjain (MP),*
[2]*Professor, UEC, Ujjain (MP)*
[3]*Professor, Dept. of Civil Engineering, UEC, Ujjain, Madhya Pradesh, INDIA*

Abstract - *Several studies have done to obtain storey displacement to recognize the structural safety in various loading conditions. The types of soil, types of foundation and building frame form a complete structural system to resist the external loads. In earthquake prone areas the extensive damage is caused due to the failure of foundation (sub structure) that leads to the displacement of structure which causes loss of human life and economy. Types of foundations, footings and foundation soils have greater impact on stability and design criteria of structure. In this research, an attempt has been made to find the effect of deep foundation (single under-reamed friction pile) with or without square footing on the displacement behavior of a four storied, one bay frame resting on different types of soil under dynamic loading using the finite element analysis software ANSYS WORKBENCH (18.0). It is well known that the foundation failures during earthquake excitation are greatly influenced by the interaction effect between soil and foundation. Such interaction effect and foundation behavior are one of the important aspects and is also considered in this analysis. The results obtained from the finite element analysis, indicates that the addition of footing in single under-reamed friction pile significantly affects the dynamic response of structure as compared to the pile without footing. It is also observed that, the total displacement decreases for the foundation having single under-reamed friction pile with footing as compared to the single under-reamed friction pile without footing.*

Key Words: **Single under-reamed friction pile, ANSYS WORKBENCH, Isolated footing, Sub-structure, Super-structure, Storey displacement, Building frame.**

1.INTRODUCTION

As we know the complete load of the building or any superstructure lies on the sub structure that transfers safely to the ground, but if the foundation displaced, it affects the whole building and leads to the displacement of each storey. Several studies have been done (King and Chandrasekaran, 1974, Buragohain et al., 1977, Subbarao et al., 1985, Deshmukh and Karmarkar, 1991 and Dasgupta et al., 1998) to obtain the difference of displacement of multi storey frame structures by changing different parameters of deep foundation such as spacing of piles, diameter of piles and number of piles in a group etc. whereas only a few of them were focused on the interaction of frames with combined footings. A building frame is subjected to both vertical as well as horizontal loads and the structural designer who designs earthquake-resistant structures wants to know how exactly the soils behaves during an earthquake; not only is this important, seismic soil-structure interaction is an important part in the consideration of failure of the structure, but it is quite very complex to analyze.

The finite element method is used to carried out an analysis of framed structure resting on pile foundations using simplified approach counting the effect of soil-structure interaction between the soil and pile foundation. The requirement of interaction analysis for building frames resting on pile foundation are based on rational approach and realistic assumptions. The pile foundations are generally preferred when heavy structural loads have to moved through weak subsoil, though most of the analyses consider the action of soil as linear, in practical the soil behavior is non-linear. The non-linear behavior of soil can be represented by three dimensional constitutive models. The specific objectives of the research are to develop a finite element based 3D models to study performance of a four-story building frame on single under-ream friction pile and single under-ream friction pile along with the combination of pile and shallow footing in sandy soil under dynamic loading.

The response spectra of Bhuj earthquake 2001 (Patel et al. 2016) is used for the earthquake loading in this analysis. The methods of construction of shallow and deep foundation are not only different but also, they have induced distinctly changes in the soil. Shallow foundations are constructed in open excavations in a visible manner where as deep foundation are installed in the interior of the earth unaided by visible inspection. The extent of disturbance of soil is limited to a very small zone during the construction of shallow foundation. But in deep foundation irrespective of the method of construction a large zone of soil is affected extending over the entire length of deep foundation. Presence of loose soils beneath the foundation has the tendency to cause differential settlement of foundation. To avoid such conditions the foundation should be placed at a minimum required depth. Each part of the foundation soil is cut during modelling and then foundation is placed by providing necessary friction between foundation and soil.

2. MODELLING

Based on the finite element software ANSYS WORKBENCH (ver. 18.0), a model of four storied frame constructed over single under-reamed frictional pile with or without shallow footing is developed as shown in figure 1.

2.1 Geometry Modelling

Multistory frame model is developed with the consideration of beams, columns elements with line element i.e. BEAM188, it is based on Timoshenko beam theory therefore, shear deformation effects are considered during analysis. A single bay multi story frame of size 0.3 m X 0.3 m column and 0.3 m X 0.3 m beam are modelled with line elements. Slab of each floors are modelled with shell element i.e. SHELL181 and 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 is represented by Figure 1. The material properties of concrete of building frame and the pile are discussed 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 various types of soils is assessed. The models for friction pile with single under-reamed bulb and friction pile with single under-reamed bulb with shallow footing are developed with solid elements. 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. 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. In pile with footing, the square footing is taken as 2.0 m X 2.0 m in size. The models of pile and pile with square footing are presented in the Figure 1, (b) and (c).

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 of the size of pile length. The perfectly elastic plastic Mohr -Coulomb nonlinear material model is used for the analysis of soil behavior. As per the Mohr-Coulomb model, yielding occurs when the shear stress on any plane in the material reaches the criterion. 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

In this research work, to assess the performance of both the pile models the soil material of the foundation are varied and the behavior of pile models in the dense and loose sandy soil are tried to find from the FEM analysis. As we know cohesion-less soil (sand) is free running type of soil, whose strength depends on friction between particles also referred to as frictional soil. In such conditions, there are the major causes of shallow foundation failure due to unequal settlement of sub soil beneath the foundation. To distribute the load uniformly throughout the depth, a layer of gravel of 0.6 m is provided below the shallow footing. The geometry of soil model along with the pile and frame are presented in the Figure 2. The models are fixed at the base and restrained in the horizontal directions. For the contact between the pile and the soil or pile, soil and shallow footing, the contact property CONTA174 is assigned in the 3-D model geometry which is a 8-node element that is intended for general rigid-flexible and flexible-flexible contact analysis. The frictional coefficient of 0.9 is used between the pile surface and soil and the bonded contacts between beams, columns and foundations are provided.

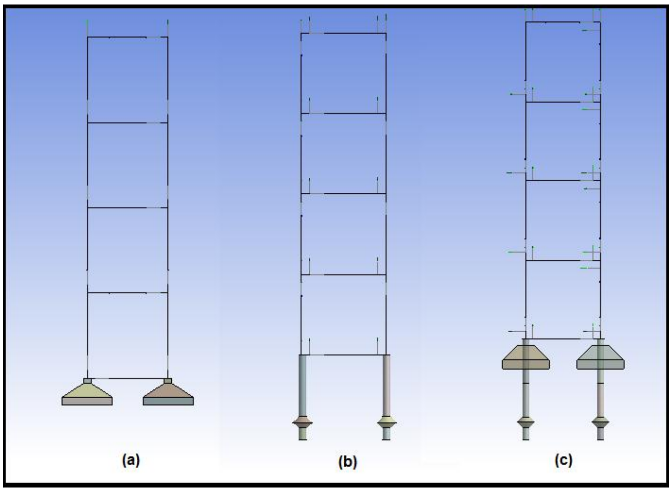

Fig -1: Geometry of frame and foundations

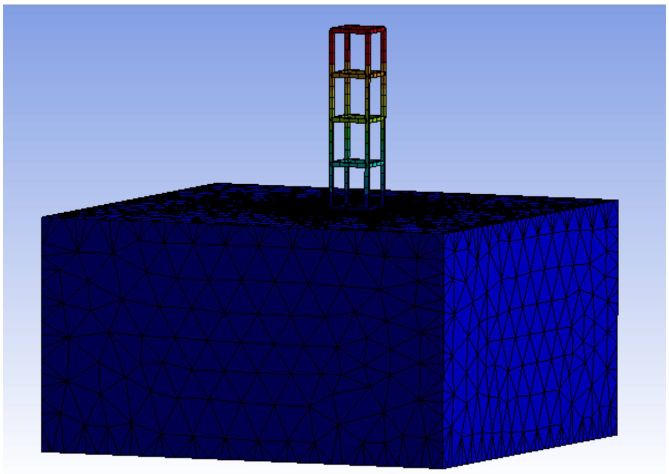

Fig -2: Geometry of soil and frame

2.2 Material Properties

The assignment of material properties and sections to all six developed finite element models are given through the option of material properties as inbuilt in the software itself. Parameters like modulus of elasticity, poisons ratio etc. are presented in the Table -1. The properties of soils are given in table 2

Table -1: Concrete material properties

S.N.	Properties	Concrete
1	Grade	M40
2	Young's Modulus	31622 (MPa)
3	Density	2400 (kg/m³)
4	Coefficient of thermal expansion	1.4E-05(/⁰C)
5	Poisson's ratio	0.2
6	Bulk modulus	1.7568 E10 (Pa)
7	Shear modulus	1.3176 E10 (Pa)

Table -2: properties of foundation soil

S.N.	Properties	Dense sand	Loose sand
1	Density	1800 (Kg/m3)	1650 (Kg/m3)
2	Young's modulus	9.40E+07 (Pa)	7.00E07 (Pa)
3	Poisson's ratio	0.3	0.3
4	Bulk modulus	7.83E+07 (Pa)	5.83E07 (Pa)
5	Shear modulus	3.61E+07 (Pa)	2.69E07 (Pa)
6	Initial inner frictional angle	45⁰	40⁰
7	Residual inner frictional angle	40⁰	35⁰
8	Dilatancy angle	15⁰	9⁰
9	Damping	5%	5%

2.3 Loadings

All the three FEM models (1) a four-story framed structure constructed over single under reamed bulb friction pile (2) a four-story frame structure constructed over single under reamed bulb friction pile with shallow footing (3) four storey frame rests on footing only are analyzed for two different type of foundation soil (Dense and loose sand) under gravity loading (acceleration due to gravity i.e. 9.8 m/s²), dead load, live load or earthquake loading. The earthquake of Bhuj 2001 in terms of response spectra (Patel et al. 2016) are used for this analysis. The response spectra of Bhuj 2001, earthquake is presented in the Figure 3. 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.

In the absence of design recommendations, the following may be taken as a general guidance as per (NBC): (1) Dead load alone (2) Dead load + partial or full live load whichever causes the most critical condition in the structure. (3) Dead load + wind or seismic load (Kaniraj SR, 2002).

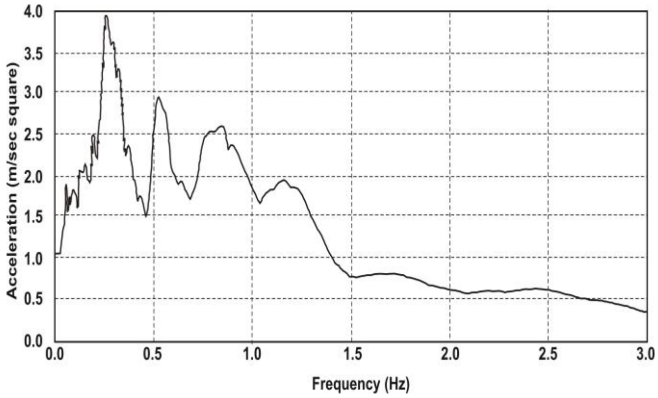

Fig -3: Response spectra of Bhuj 2001 earthquake

3. RESULTS AND COMPARISONS

The results obtained from the finite element analysis in terms of displacements of multi storey frame under dynamic loading for all the Models in dense and loose sandy soil is represented Figure 4 and Figure 5 respectively.

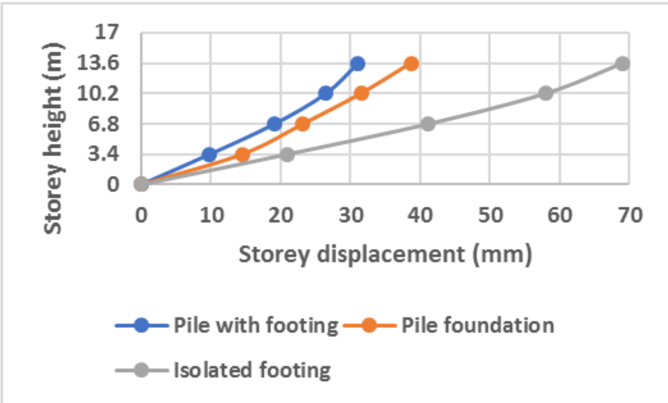

Fig -4: Storey displacement in dense sand

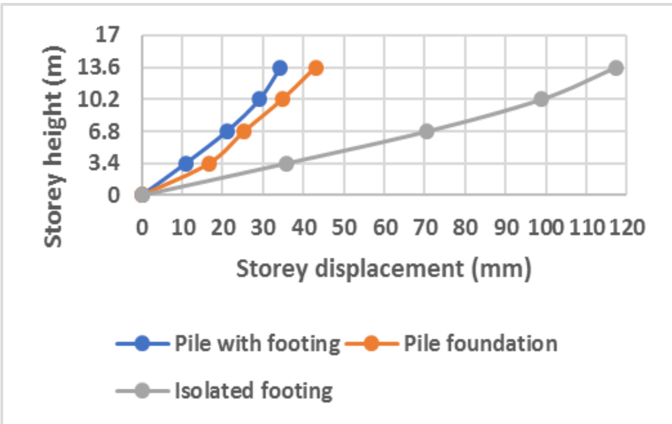

Fig -5: Storey displacement in loose sand

Figure 4 represents the variation of storey displacement with respect to storey height (3.4, 6.8, 10.2, 13.6 m) in dense sand for all the three models (1) Frame resting on pile with footing

(2) Frame resting on pile foundation only and (3) Frame resting on isolated footing

Table -3: Storey displacement in dense sand

Storey height (m)	Storey displacement (mm)		
	Pile with footing	pile foundation	Isolated footing
3.4	9.8546	14.5	20.984
6.8	19.146	23.267	41.248
10.2	26.5	31.547	57.994
13.6	31.115	38.726	69.128

Figure 5 represents the variation of storey displacement with respect to storey height (3.4, 6.8, 10.2, 13.6 m) in loose sand for all the three models (1) Frame resting on pile with footing (2) Frame resting on pile foundation (3) Frame resting on isolated footing. Values of storey displacement are given in table 3 and table 4.

Table -4: Storey displacement in loose sand

Storey height (m)	Storey displacement (mm)		
	Pile with footing	pile foundation	Isolated footing
3.4	10.849	16.688	35.83
6.8	20.988	25.379	70.61
10.2	29.064	34.844	98.909
13.6	34.222	43.058	117.36

3.CONCLUSIONS

The broad conclusions emerging from the finite element analysis are given below.

1) The effect of adding footing with single under-reamed friction pile on the displacement of the frame is quite significant. Storey displacement is less for the frame resting on pile with footing.

2) Displacement varies in the range of 22.12 – 27.86% for the frame resting on pile foundation.

3) Storey displacement varies in the range of 17-22% for the frame resting on pile with footing.

4) For the frame resting on isolated footing the displacement varies in the range of 49-60%.

5) The general trend observed for all the models in this investigation is that the horizontal displacement is on higher side for the frame resting on isolated footing. For the frame resting on pile with footing the displacement decreases by22% as compared with the frame on pile foundation only.

REFERENCES

[1] IS 2911(part 3) "Code of practice for design and construction of pile foundation", under ream pile foundation, Bureau of Indian standard.

[2] Kaniraj SR (2002) "Design aids in soil mechanics and foundation engineering", Tata McGraw-Hill publishing company limited.

[3] Murthy VNS (1996) "Soil mechanics and foundation engineering in SI units", UBS publisher's distributers Ltd.

[4] Deshmukh AM and Karmarkar SR (1991) "Interaction of Plane Frames with Soil, In: Proc. Indian Geotechnical Conference", (IGC- 1991), Surat, India, 1, 323-326.

[5] Dasgupta S, Dutta SC and Bhattacharya G (1998) "Effect of Soil- Structure Interaction on Building Frames on Isolated Footings", Journal of Structural Engineering, SERC, Chennai (India), 26(2), 129-134.

[6] Subbarao KS Shrada Bai H and Raghunatham, BV (1985) "Interaction Analysis of Frames with Beam Footing", In: Proc. Indian Geotechnical Conference, Roorkee (IGC-1985), India, 1, 389-395.

[7] Buragohain DN, Raghavan N and Chandrasekaran,VS (1977) "Interaction of Frames with Pile Foundation", In: Proc. Int. Symposium on Soil- Structure Interaction, Roorkee (India).

[8] King GJW and Chandrasekaran VS (1974) "Interactive Analysis of a Rafted Multistoreyed Space Frame Resting on an Inhomogeneous Clay Stratum", Proceedings International Conference on Finite Element Methods, Australia, 493-509.

[9] Thangaraj DD and Ilamparuthi K (2012) "Parametric study on soil - raft - frame interaction, on the interaction and the non-interaction analyses", International Conference on Advances in Architecture and Civil Engineering, GET111, Vol. 1, 378-383.

[10] Chore HS and Ingle RK (2008) "SSI analysis of pile supported building frame", AJSTD, 25(2), 457-467.

[11] Dasgupta S, Dutta SC and Bhattacharya G (1998) "Effect of Soil- Structure Interaction on Building Frames on Isolated Footings", Journal of Structural Engineering, SERC, Chennai (India), 26(2), 129-134.

[12] Shah SJ and Swathy KG (2015) "Dynamic soil structure interaction effects on modeled building frame supported by pile foundation" International Journal of Research in Advent Technology, 172-177.

[13] Reddy C Sameer S and Reddy PS (2016) "A study on the behavior of multi storied building with soil structure

interaction'' ARPN Journal of Engineering and Applied Sciences, 11 (3), 13760-13765.

[14] Yumnam S and Mayengbam S (2017) ''Dynamic soil-structure interaction of RC frame structure", National Conference on Innovations in Science and Technology (NCIST-17), 126-131

[15] Pujitha LV and Rao CH (2017) ''Soil structure interaction on plane building frame supported on pile group embedded in cohesive soil'', International Journal of Civil Engineering and Technology, 8(1), 841-846.

[16] Patel KU, Sindal SK, Patel SH and Patel TN (2016) ''Response Spectrum analysis for Bhuj earthquake recorded at Ahmedabad station'', International Journal of Computer & Mathematical Sciences, 5(1), 4-11

[17] ANSYS WORKBENCH (ver. 18.0). Finite element based commercial software for design.