Effect Of Piled Raft Design On High-Rise Building Considering Soil Structure Interaction

R. R. Chaudhari, Dr K. N. Kadam

Abstract: Piled-raft foundations for important high-rise buildings have proved to be a valuable alternative to conventional pile foundations or mat foundations. The concept of using piled raft foundation is that the combined foundation is able to support the applied axial loading with an appropriate factor of safety and that the settlement of the combined foundation at working load is tolerable. Pile raft foundation behavior is evaluated with many researches and the effect of pile length; pile distance, pile arrangement and cap thickness are determined under vertical or horizontal static and dynamic loading. In the present paper the influence of pile length configurations on behavior of multi-storied are evaluated under vertical loading. In practice, the foundation loads from structural analysis are obtained without allowance for soil settlements and the foundation settlements are estimated assuming a perfectly flexible structure. However, the stiffness of the structure can restrain the displacements of the foundations and even tiny differential settlements of the foundations will also alter forces of the structural members. Hence, the interaction among structures, their foundations and the soil medium below the foundations alter the actual behaviour of the structure considerably than what is obtained from the consideration of the structure alone. In this work, analysis of pile soil structure interaction has been studied by finite element software ANSYS 11. The soil structure interaction has been found to be significantly affecting the performance of structure and it is discussed in this paper.

Key words: ANSYS, FEM, interface, high rise building, pile configurations, pile raft foundation, soil structure interaction

1 INTRODUCTION

According to the advanced numerical analysis, the interaction between a raft, soil and the structure is considered. The response of any system comprising more than one component is always interdependent. For instance, a beam supported by three columns with isolated footing may be considered (Fig.1). Due to the higher concentration of the load over the central support, soil below it tends to settle more. On the other hand, the framing action induced by the beam will cause a load transfer to the end column as soon as the central column tends to settle more. Hence, the force quantities and the settlement at the finally adjusted condition can only be obtained through interactive analysis of the soil–structure–foundation system. This explains the importance of considering soil–structure interaction. The three-dimensional frame in superstructure, its foundation and the soil, on which it rests, together constitute a complete system. With the differential settlement among various parts of the structure, both the axial forces and the moments in the structural members may change. The amount of redistribution of loads depends upon the rigidity of the structure and the load-settlement characteristics of soil. Generally, it may be intuitively expected that the use of a rigorous model representing the real system more closely from the viewpoint of mechanics will lead to better results. But the uncertainty in the determination of the input parameters involved with such systems may sometimes reverse such anticipation. Thus, to choose a detailed model, one should also be careful about the extent of accuracy with which the parameters involved with the model can be evaluated. In the present study, an attempt has been made to scrutinize the various approaches of modeling the soil–structure–foundation system and also compare the same highlighting their rigor and suitability for solving practical engineering problems with desired accuracy. In most of the civil engineering analysis, structure is assumed to be fixed at the base. Thus, the flexibility of foundation and the compressibility of the supporting soil medium are neglected. Consequently, the effect of uneven foundation settlements on redistribution of forces and moments in the superstructure is also neglected. Conventional structural design methods neglect the SSI effects. Neglecting SSI is reasonable for light structures in relatively stiff soil such as low rise buildings and simple rigid retaining walls. The effect of SSI, however, becomes prominent for heavy structures resting on relatively soft soils for example nuclear power plants, high-rise buildings and elevated-highways on soft soil. Hence, the attempt has been made to study the actual behavior of multi-storied building along with different types of soils. The building frame is considered under the gravity loading. Various pile length configurations are modeled and analyzed along with the building to study the optimum forces and moments in the building. Finally, different conclusions are drawn by studying the soil structure interaction.

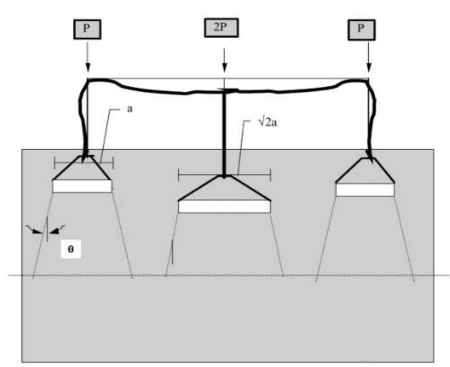

Fig.1: Redistribution of loads in a frame due to soil–structure interaction.

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2 SOIL STRUCTURE INTERACTION UNDER STATIC LOADING

Numerous studies have been made on the effect of soil structure interaction under static loading. These studies have considered the effect in a very simplified manner and demonstrated that the force quantities are revised due to such interaction. Several studies, experiments and research works have been carried out since a long time all over the world to understand and to evaluate the effect of pile soil interaction. References [1-3] have shown the load-settlement behavior of the soil using ANSYS software whereas Ref. [4] used PLAXIS software. Experimental work has been done [5] using pile with soil. Many other literatures were studied on the soil structure interaction. Many other literatures were studied on the soil structure interaction. All the paper [6-14] restrains their work upto the soil settlements behavior. Very few authors have done their research on behavior of high rise building along with the soil pile interaction. Hence, taking in view the above research the further study in this paper is carried out on high rise building. Therefore, the author is trying to find the actual behavior of the structure with the soil pile interaction in terms of forces, displacements and moments.

3 DIFFERENT TECHNIQUES OF SSI ANALYSIS

Many numerical techniques has been developed to solve SSI problem such as, transmitting or absorbing boundaries of different kinds, boundary elements, infinite elements and their coupling procedures. The following are the techniques used for the soil – structure analysis.

a) Analytical method – The use of analytical method to analyze soil structure interaction problem requires the assumption of linear elastic homogenous half space and a regular foundation form. However, soil properties are rarely elastic. The actual soil is layered in nature and thus it is anisotropic material. It is very difficult to express anisotropy and non linearity in the analytical model.
b) Finite element method – Finite element method is one of the versatile methods for analysis of structure, as it is capable of modeling any irregularities in the structure, complex boundary conditions and linear as well as nonlinear behaviors. FEM is now a day's one of the most frequently used computational method in solving scientific and engineering problems. This is mainly due to the fact that FEM is able to reflect the original mathematical model in a very natural way. However, using a mesh of finite extent to model soil strata of theoretical infinite horizontal extent as well as deep soil deposits would create factious box effect trapping the wave absorbing boundaries has been invented to reproduce radiation of waves in to outer region.
c) Boundary element method - Boundary element method is essentially a semi analytical method. As only the boundary of the model needs to be modeled. Boundary integral representation is an exact representation of the problem and only approximation is those due to numerical implementation of this integral equation. This method is especially suitable for the problems involving infinite or semi – infinite domains because the Green's function used in the foundation automatically satisfies the radiation condition at the far field.

4 MODELLING

The analytical models of the frame include all components that influence the mass, strength, stiffness and deformability of structure. The structure system frame consists of beams, columns and foundation. Beams and columns of frame are modeled as two noded BEAM3 elements. Each node on 2D frame is associated with three DOF. Pile and soil are modeled with the help of PLANE-183 with two DOF at each node. Brief descriptions about the elements used for modeling are discussed below.

a. BEAM3 (2-D Elastic Beam)

BEAM3 is a uniaxial element with tension, compression, and bending capabilities. The element has three degrees of freedom at each node, translations in the nodal x and y directions and rotation about the nodal z-axis. BEAM3 geometry shows the geometry, node locations and the coordinate system for this element (Fig.2). The element is defined by two nodes, the cross-sectional area, and the area moment of inertia.

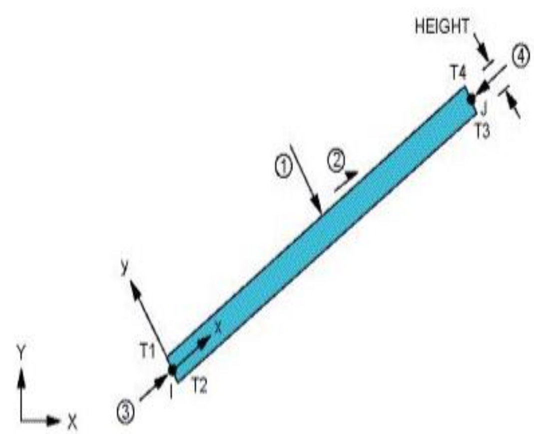


Fig.2: BEAM3 (2-D Elastic Beam) Geometry

b. PLANE183 (2-D 8-Node or 6-Node Structural Solid)

PLANE183 is a higher order 2-D, 8–node or 6-node element. It has quadratic displacement behavior and is well suited to modeling of irregular meshes and curved boundaries. This element is defined by 8 nodes or 6-nodes having two degrees of freedom at each node; translations in the nodal X and Y directions. The element may be used as a plane element (Plane stress, plane strain and generalized plane strain) or an axisymmetric element. This element has plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyper elastic materials. The geometry, node locations and the coordinate system for this element are shown in Fig.3.

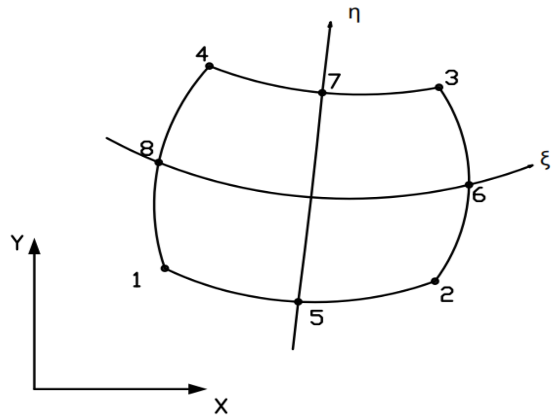


Fig.3: PLANE183 Geometry

c. Interface element

When the system of two different materials is to be analyzed, the stresses on the face of either element at their interface are unequal. This discrepancy is attributed to material incompatibility. Hence, it is necessary to introduce 'interface elements' between the two materials, such that the actual interface stresses are obtained as the stresses in the elements. Interface elements are in the form of very thin membranes. Such interface elements are primarily used to simulate 'perfectly smooth' or 'perfectly rough' interfaces. A very high value of E is assigned to the elements in the direction normal to the contact surface and negligible values in the tangential directions, whereas the latter is obtained by assigning very high values of E to the elements in both directions. It may be noted that whereas tangential component of contact pressure can develop to any magnitude, the theoretical limit being infinity, in the case of a perfectly rough interface (no slip), no tangential component can exist in the perfectly smooth case (slipping). While these two are theoretical extremes, all practical cases fall under conditions of finite roughness where the tangential component (of force) can develop but not exceed the value of the normal component multiplied by the coefficient of friction.

5 FINITE ELEMENT ANALYSIS

To study the contribution of pile length configurations with different soils on the behavior of building considering SSI, the parametric study with various soil types is done. The plan of the building with piles position is as shown in Fig.4. Simplified 2D finite element modeling and analysis is done for the pile raft system with structure. For this reason a strip i.e., section A-A is selected. Symmetrical four bay G + 11 storey frame having one pile supported under each column subjected to gravity load is modeled and analyzed using different cases i.e., changing the raft thickness, pile diameter and soil types. Depth of soil considered in the analysis is 41 m and the horizontal dimension is 63 m. Sizes of beam and column and the material parameters used in the analyses are tabulated in Table 1.

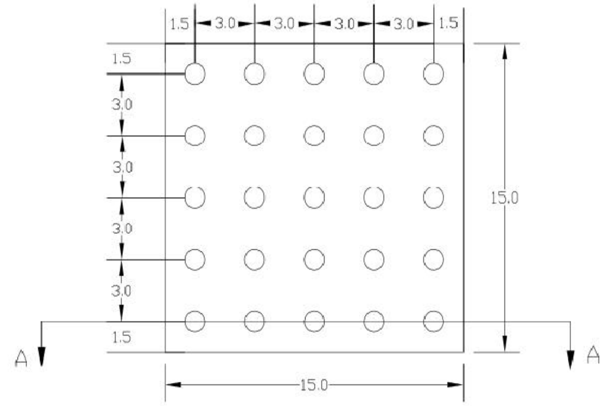


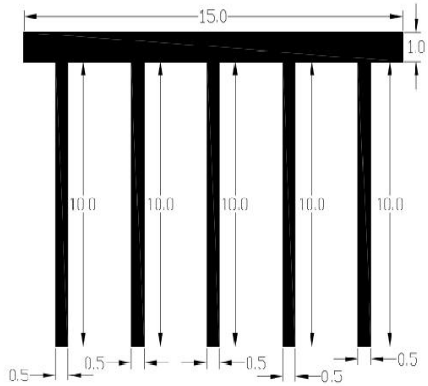
Fig.4: Plan of the building along with piles (All dimension are in m)

TABLE 1
Material and geometric properties of beam, column, raft, pile and soil

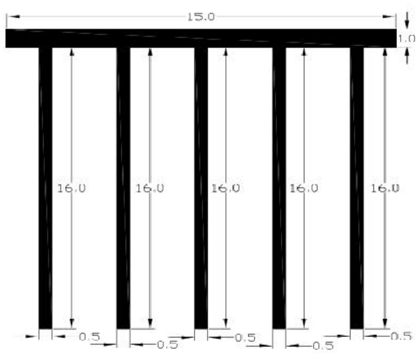
Sr.no.	Structure	Component	Details
1.	Frame	Storey height	3 m
		Bay width	3 m
		Beam size	0.35 m x 0.60 m
		Column size	0.35 m x 0.80 m
2.	Pile	Diameter	Varying
		Length	Varying
3.	Concrete	Young's modulus	2.4×10^{10} N/m^2
		Poisson's ratio	0.15
		Density	25000 N/m^3
4.	Clay	Young's modulus	16.5×10^6 N/m^2
		Poisson's ratio	0.45
		Density	16.4×10^3 N/m^3
5.	Stiff clay	Young's modulus	60×10^6/m^2
		Poisson's ratio	0.35
		Density	20.0×10^3 N/m^3
6.	Silty sand	Young's modulus	205×10^6 N/m^2
		Poisson's ratio	0.30
		Density	21.0×10^3 N/m^3

6 RESULTS AND DISCUSSIONS

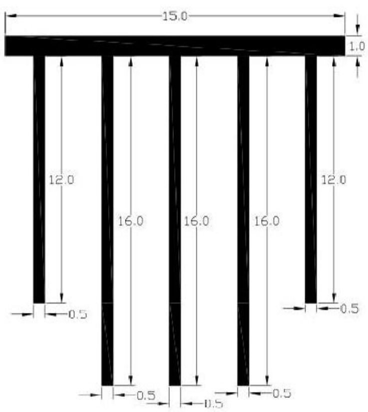
Different Pile length configurations are taken for analysis with raft thickness and pile diameter as 1 m and 500 mm respectively. Different grouping are done using various pile length along with soil and building. Over all four types combination are taken such as equal length, U-type, zig-zag, V-type and T-shape type. Different analyze are done using various models graphically represented in Fig.5. The different model with various pile length configurations along with raft are as shown below.



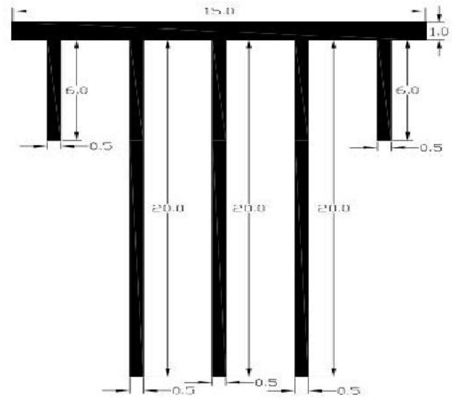
(a) E1 – All length of pile – 10 m



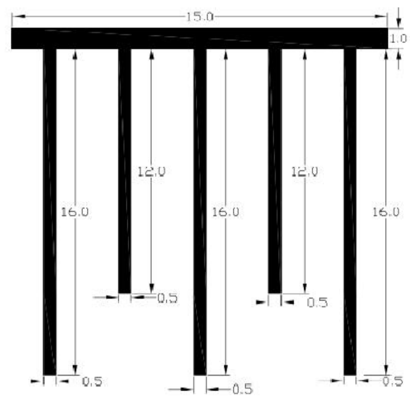
(b) E2 – All length of pile - 16 m



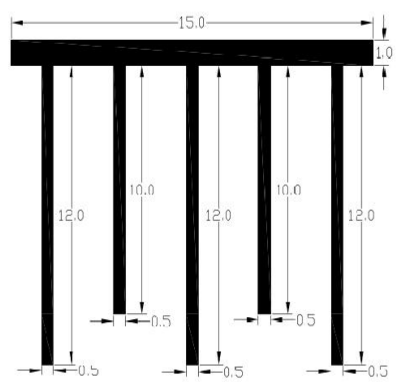
(c) U1 – Exterior and interior pile length 12 m and 16 m respectively



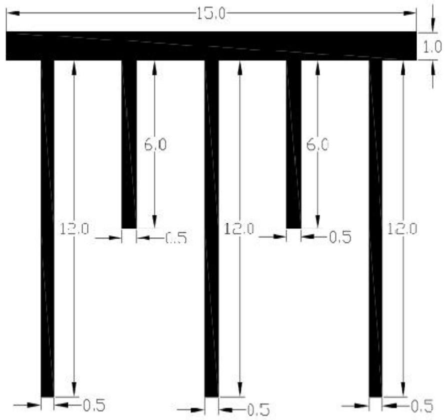
(d) U2 -- Exterior – 6 m and other pile length – 20 m



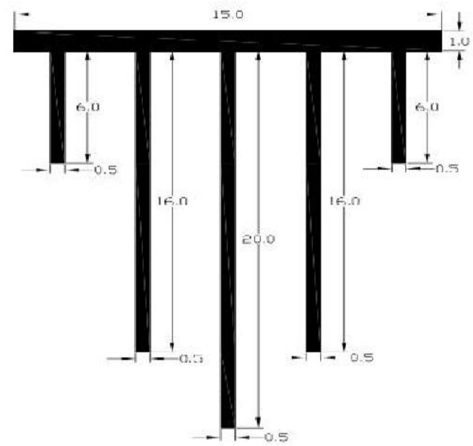
(e) Z1 – Alternate 16 m and 12 m pile length



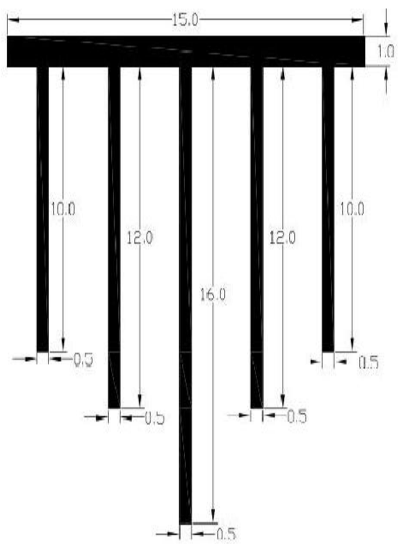
(f) Z2 – Alternate 12 m and 10 m pile length



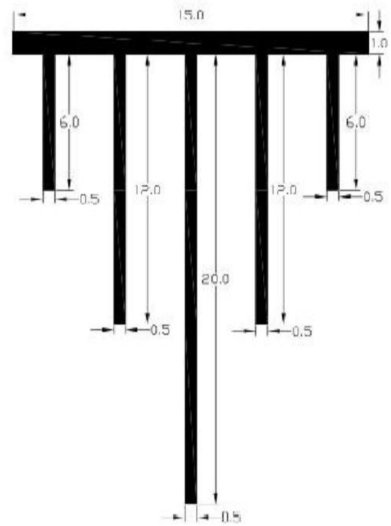
(g) Z3 – Alternate 12 m and 6 m pile length



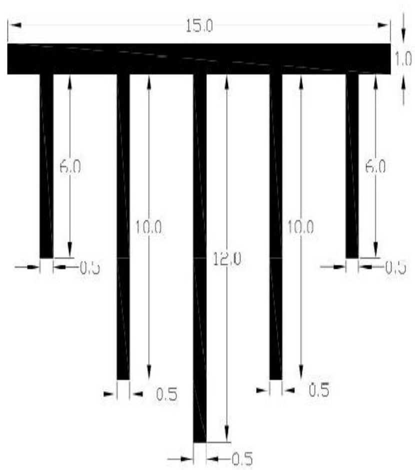
(j) V3 -- Exterior – 6 m, interior – 16 m and middle pile length – 20 m



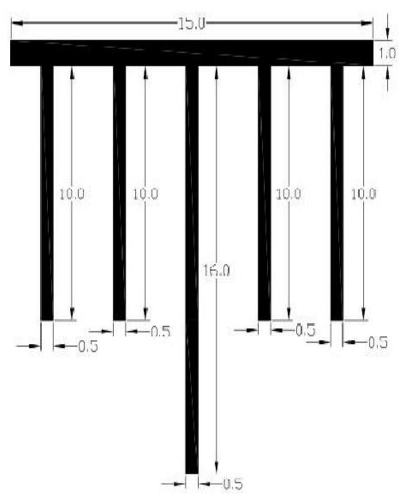
(h) V1 – Exterior – 10 m, interior – 12 m and middle pile length – 16 m



(k) V4 -- Exterior – 6 m, interior – 12 m and middle pile length – 20 m



(i) V2 – Exterior – 6 m, interior – 10 m and middle pile length – 12 m



(l) T1 – Middle pile length – 16 m and other pile length - 10 m

Fig.5: Different models using various pile length configurations

Finite element analysis using ANSYS 11 software is carried out for all the 12 models of different pile configurations. After the analysis, the quantity of concrete is plotted against the different models to find the optimize combination of the pile length with the required economy. Fig.6 shows the graph of total pile length against all the different pile configurations.

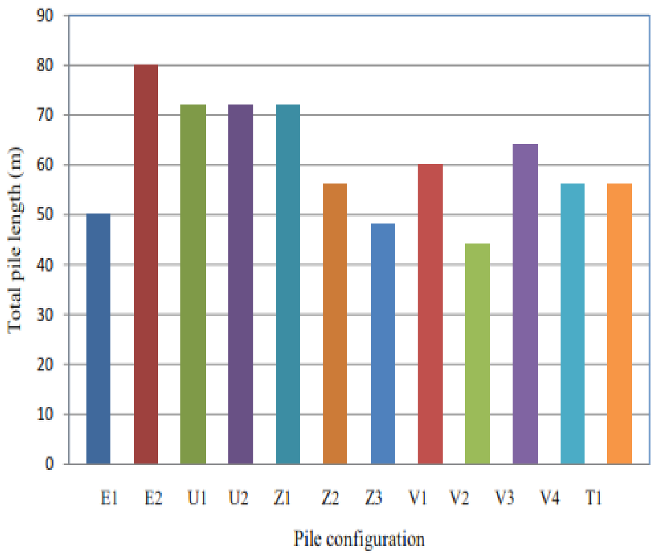


Fig.6: Total pile length for all the different pile configurations

From the Fig.6, it is observed that the quantities of concrete required for the zig-zag shape and for E1 model and V-shape are less than the other models. After that, the results are plotted in the graphs in terms of maximum moments (Mz) and the maximum vertical displacements (Uy). Fig.7 to Fig.9 shows the comparison of the maximum moments of all models with all the three soils viz., soft clay, stiff clay and silty sand. Fig.10 to Fig.12 presents the maximum vertical displacements in frame for each pile length combination.

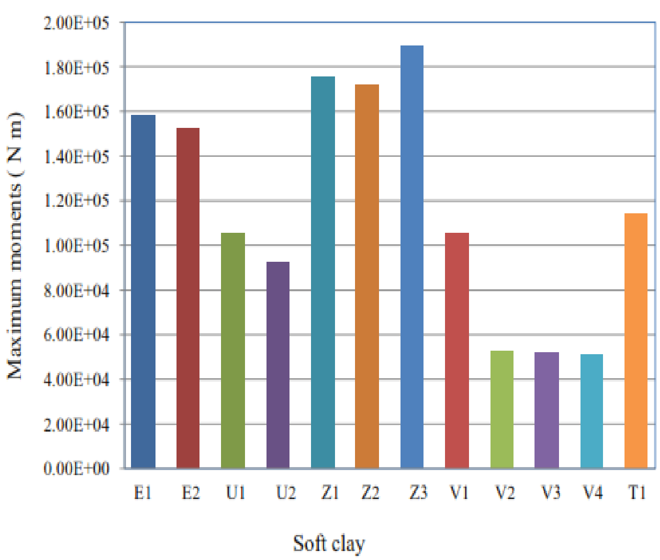


Fig.7: Maximum moments on frame along with soft clay

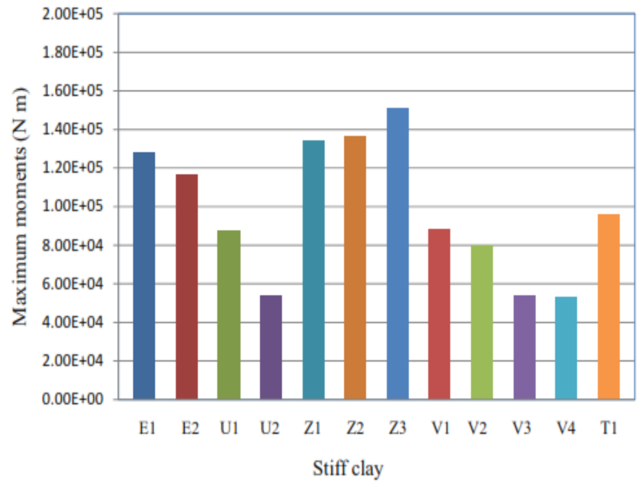


Fig.8: Maximum moments on frame along with stiff clay

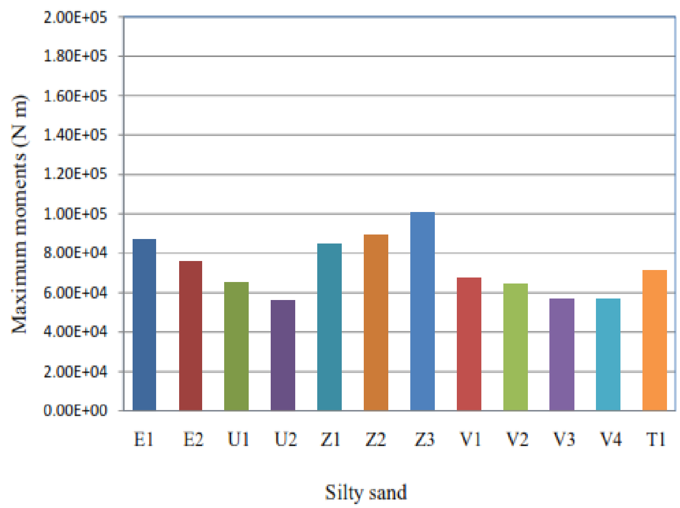


Fig.9: Maximum moments on frame along with silty sand

From Fig.7, Fig.8 and Fig.9, it is found that the values of maximum moments are large in soft clay as compared with silty sand and stiff clay. Also, it is clearly seen that the values of maximum moments are less for the V-shape and U-shape models than the other models for all the soil types. Hence, the V-shape and U-shape models are optimize combination of pile length in terms of moments and also in terms of concrete quantity. It is also observed that the optimum configuration of pile is soil dependent. The best configuration varies from soil-to-soil.

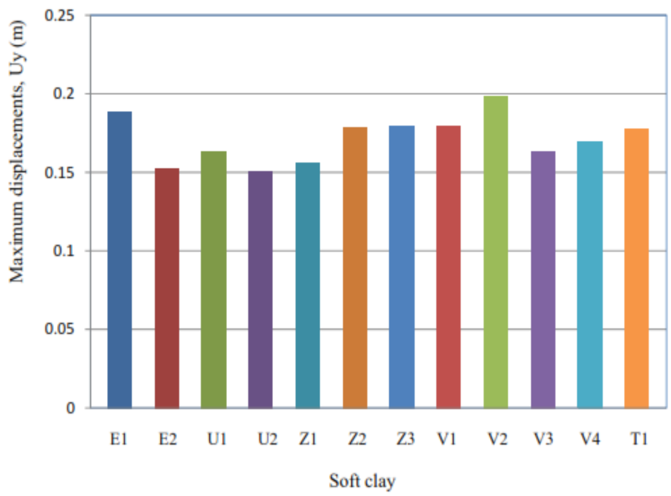


Fig.10: Maximum displacements on frame along with soft clay

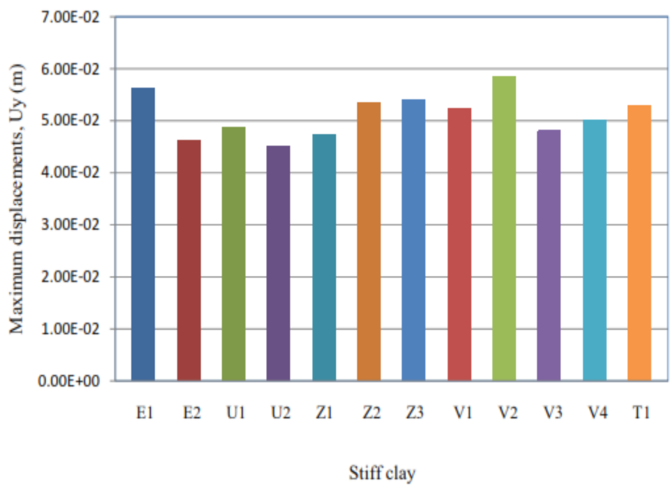


Fig.11: Maximum displacements on frame along with stiff clay

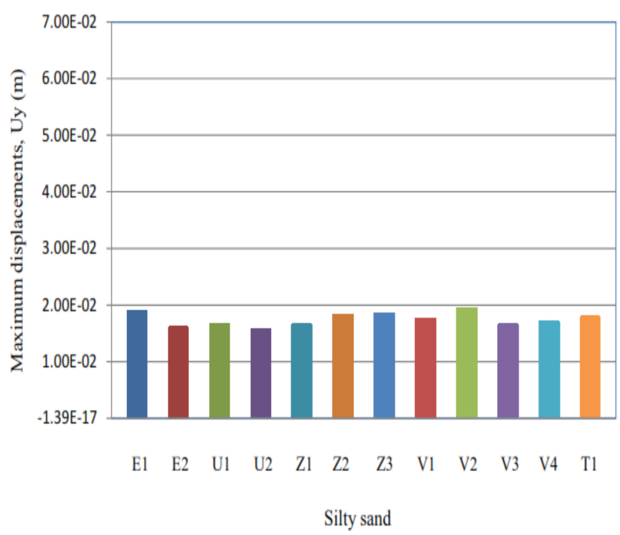


Fig.12: Maximum displacements on frame along with silty sand

From Fig.10, Fig.11 and Fig.12, it is found that the values of maximum displacements are large in soft clay than silty sand. Also, it is clearly seen that the values of displacements for all the models are nearby same for all types of soils individually. After studying all the models, the V-shape, U-shape and T-shape models give optimum results in terms of moments and displacements. Hence, Fig.13 presents total pile length for each V-shape, U-shape and T-shape pile length configuration.

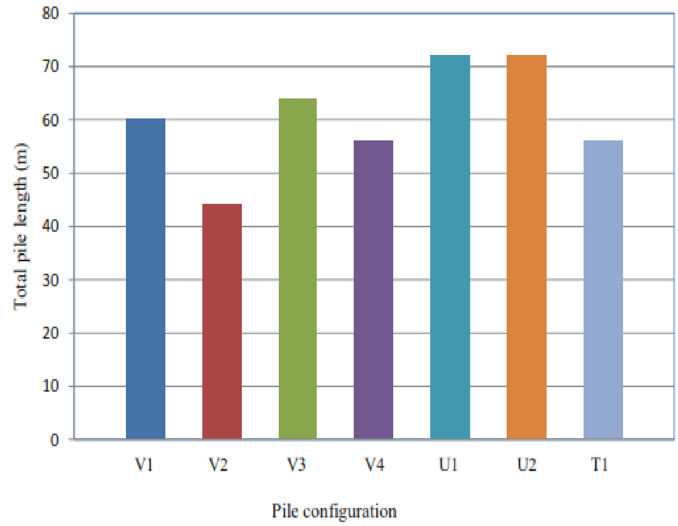


Fig.13: Total pile length for V-shape, U-shape and T-shape pile configurations

7 CONCLUSIONS

i. Due to the material discontinuity at the interface of the two different surfaces, the structure has to be modelled using the interface element.

ii. The maximum moments of soft clay are much larger than that of silty sand and stiff clay in all the cases.

iii. The maximum settlements are less affected by soil types.

iv. Moment carrying capacity of soil pile structure system is a function of-
   a) Soil type
   b) Pile diameter
   c) Pile configuration
   d) Quantity of concrete

iv The values of maximum moments are less for the V-shape and U-shape models than the other models for all the soil types. Hence, the V-shape and U-shape models are optimum combination of pile length in terms of moments and also in terms of concrete quantity.

v It is also observed that the optimum configuration of pile is soil dependent. The best configuration varies from soil-to-soil.

Piled raft foundations have the potential to provide economical foundation systems, under the appropriate geotechnical conditions. Hence, the design philosophy should be based on both ultimate load capacity and settlement criteria, with the key question to be answered being: “what is the optimum pile length configurations required to be added to the raft such that the ultimate load, settlement and differential settlement criteria are satisfied?” Use of some of the results outlined in this paper can be used to assist the foundation designer to provide a rational answer to this question.

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