EXPERIMENTAL STUDY ON PILE FOUNDATION UNDER VERTICAL AND LATERAL LOADS

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Abstract - *In recent days, numerous earthquakes are emerging around the world. The seismic loads are generally dynamic in nature when they are subjected to lateral force. The structural responses due to earthquake are mainly depends upon the soil- structure interaction. It is very important to note the soil-structure interaction forces since it creates an impact to the structure. Due to this action, pile deformation occurs along with settlement. The seismic soil-structure interaction involves the investigation of the collective response of the structure, the fondation and its surroundings, to a pre-determined free-Field ground motion. In this investigation pile fondation is analyzed for earthquake loads. The piles are modeled in SOLIDWORKS software and analyzed in ANSYS workbench. The vertical and lateral load is applied on long pile. Due to impact of lateral force huge overturning and displacement occurred in long pile, combined with small ground displacements.*

Key Words: Pile Foundation, Soil – Structure Interaction, Pile Deformation, Settlement, Overturning, Displacement, ANSYS, Lateral Loads

1. INTRODUCTION

1.1 SOIL STRUCTURE INTERACTION

Since 1960's, soil-structure interaction (SSI) has been recognized as an important factor that may significantly affect the relative building response, the motion of base and motion of surrounding soil (Todorovska and Trifunac, 1990). In general, building-soil interaction consists of two parts; kinematic and dynamic (or inertial) interaction. The former is a result of wave nature of excitation and is manifested through the scattering of incident waves from building foundation and through filtering effect of the foundation that may be stiffer than the soil and therefore may not follow the higher frequency deformations of soil. This interaction depends on frequency, angle of incidence and type of incident waves, as well as shape of foundation and on the depth of embedment. It develops due to presence of stiff foundation elements on or in soil cause foundation motion to deviate from free-field motions. The latter is due to inertia forces of building and of the foundation which act on soil due to contact area. And it depends on the mass and height of the building and the mass and depth of foundation, on the relative stiffness of soil compared with the building and on the shape of foundation. It develops in structure due to its own vibrations which gives rise to base shear and base moment, which in turn cause displacements of the foundation relative to free field.

Dynamic analysis of soil-structure interaction can be done using

a. Direct Method

b. Substructure Method

1.1.1 Direct Method

Direct Method is one in which the soil and structure are modeled together in a single step accounting for both inertial and kinematic interaction. Inertial interaction develops in structure due to own vibrations give rise to base shear and base moment, which in turn cause displacements of the foundation relative to free field. Kinematic interaction develops due to presence of stiff foundation elements on or in soil cause foundation motion to deviate from free field motions. The earthquake ground motions are specified at the base and the resulting response of the interacting system is computed from the following equation of motion

1.1.2 Sub-Structure method or Multistep Method

Sub-Structure Method is one in which the analysis is broken down into several steps that is the principal of superposition is used to isolate the two primary causes of soil-structure interaction, inability of foundation to match the free field deformation and the effect of dynamic response of structure foundation system on the movement of supporting soil.

1.2 PILE FOUNDATIONS

Foundations provide support for structures, transferring their load to layers of soil or rock that have sufficient bearing capacity and suitable settlement characteristics. There are a very wide range of foundation types available, suitable for different applications, depending on considerations such as:

- The nature of the load requiring support.
- Ground conditions.

- The presence of water.
- Durability of the materials.
- Cost.
- Accessibility.
- Sensitivity to noise and vibration.
- Proximity to other structures.

Very broadly, foundations can be categorized as shallow foundations or deep foundations. Shallow foundations are typically used where the loads imposed by a structure are low relative to the bearing capacity of the surface soils. Deep foundations are necessary where the bearing capacity of the surface soils is insufficient to support loads imposed and so they are transferred to deeper layers with higher bearing capacity.

Pile foundations are deep foundations. They are formed by long, slender, columnar elements typically made from steel or reinforced concrete, or sometimes timber. A foundation is described as 'piled' when its depth is more than three times its breadth (Atkinson, 2007). Pile foundations are principally used to transfer the loads from superstructures, through weak, compressible strata or water onto stronger, more compact, less compressible and stiffer soil or rock at depth, increasing the effective size of a foundation and resisting horizontal loads. They are typically used for large structures, and in situations where soil is not suitable to prevent excessive settlement.

Pile foundation is a popular method of construction for overcoming the difficulties of foundation on soft soils. But, until nineteenth century the design was entirely based on experience (Poulos and Davis, 1980). It is only too convenient for an engineer to divide the design of major buildings into two components: the design of the structure and the design of foundations. But in reality, the loads on foundation determine their movement, but this movement affects the loads imposed by the structure; inevitably interaction between structure, foundation and soil or rock forming the founding material together comprise one interacting structural system (Poulos and Davis, 1980). Significant damage to pile supported structures during major earthquakes (such as 1906 San Francisco earthquake, 1964 Niigata and Alaska earthquakes) led to an increase in demand to reliably predict the response of piles. Since then, extensive research has been carried out and several analytical and numerical procedures have been developed to determine the static and dynamic response of piles subjected to horizontal or vertical loads. Also, full scale experimental observations on the pile's behavior and numerous model testing have been carried out. Details of the same are given in the following sections of this thesis. Observations of damage to pile foundation of buildings in recent major earthquakes also indicate substantial instances of the damage at deeper part of the piles.

Generally, such damages tend to be common at interfaces of soil layers with prominent stiffness contrast. It is evident that the damages occurring at deeper part of piles are inherently difficult to detect and practically impossible to repair. Consequently, adequate provision in the design is indispensable to make such damages as unlikely as possible. Reports on the investigation of buildings with pile foundations affected by the Hyogoken-Nambu earthquake of 1995 indicate reoccurrence of the nature of damage to PHC (Prestressed High Strength Concrete) piles observed in the Miyagiken-oki earthquake of 1978. In addition, another distinctive nature of the damage to relatively long piles were observed, where the failure was seen at deeper parts of relatively long piles and at locations close to distinct soil layer interfaces. Such failure to piles seems to result due to the existence of lateral stiffness contrast between adjacent soil layers, including the liquefaction and loss of strength at an intermediate layer (Sugimura et al, 2001). A number of approaches have been formulated for the analysis of dynamic soil-pile interaction in the past years. The research work carried out in the area of seismic soil-pile foundation structure interaction could be most generally classified into determination of kinematic seismic response that is determination of pile-head impedance and determination of superstructure seismic response. Challenges involved in soil-structure interaction are given in the following section.

1.3 OBJECTIVES

The major objective of this study is to understand the SSI that take place in long and short pile which embedded in sand

The aim of the work is

1. To investigate the substructure behavior by varying the L/d of the pile & the lateral load.
2. To study the substructure properties by providing vertical and lateral loading for long and short pile.
3. Numerical stimulation models are to be taken for testing the behaviour of long and short pile under the dynamic lateral loading.

2. PROPERTIES OF MATERIALS

2.1 GENERAL

The general properties and characteristics of soil and concrete have been used for defining the soil continuum and pile are analytically determining those have been discussed in this chapter.

2.2 PROPERTIES OF SOIL

The type of soil that has been selected for this study sandy soil.

Table -2.1: Properties of Soil

S. No	Properties of Soil	
1	Density	1700 kg/m³

2	Young's modulus	4.0417E+07
3	Poisson's ratio	0.3
4	Bulk modulus	7.83E+07
5	Initial inner frictional angle	25^0
6	Residual inner frictional angle	7.5^0
7	Initial cohesion	5000 pa

Table -2.2: Properties of Concrete

S. No	Properties of Concrete	
1	Density	2300 kg/m^3
2	Young's modulus	3E+10
3	Poisson's ratio	0.18
4	Bulk modulus	1.5625E+10
5	Shear modulus	1.2712E+10
6	Density	2300 kg/m^3
7	Young's modulus	3E+10

3. MODELING PARAMETER

3.1 GENERAL

The analysis of response of pile is a complexity involved intricate process which is time consuming. This makes the entire process cumbersome. The simulation of a model using is used analyze the behavior of system of configuration.

3.2 NEED FOR 3D MODELLING

As vertical and lateral load is applied, an enormous eccentricity is developed. The problem cannot be simplified to a 2d plain strain problem. Hence a 3D modelling was required and ANSYS workbench was as a tool to analyze the model.

3.3 MODELLING

The pile foundation system is modelled using the software package SOLIDWORKS. The major feature of this package is simplified part creation and assembly which was intricate in ANSYS.

3.3.1 PART

The part created were the soil continuum and group of pile. The parts were 3D, deformable and extrude-able solid in nature. The size of the pile was 500mm.the depth of the soil is taken to be 1.5 times the length of the pile shaft. The width was taken to be 10 times the width of the the raft in order to eliminated the effect boundary in presence of pile. The international system of units (SI) were taken.

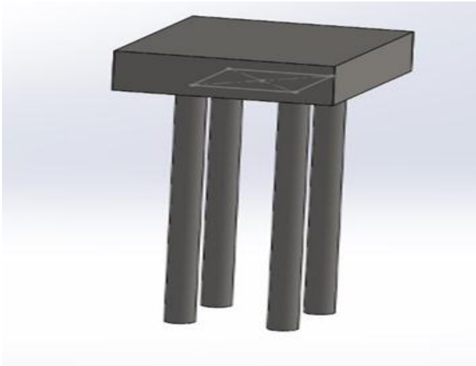


Fig 3.1. part-pile with cap

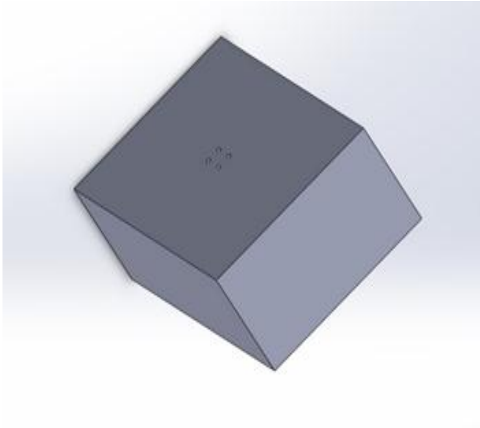


Fig 3.2. part-soil continuum

3.3.2 ASSEMBLY

The parts were imported in .prt format. These parts created were rotated, moved and assembled by simple mating process. The entire element was moved to the origin of the global system and were saved as IGS file. This IGS file served as a common file format to be imported in ANSYS.

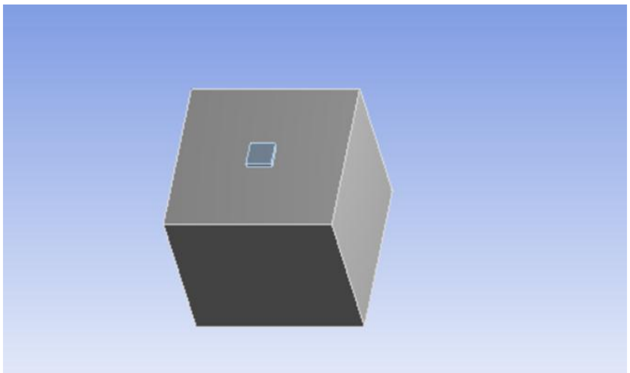


Fig 3.3-Assembled System

3.4 MODEL INTERFACE

The model was setup and material were assigned from the existing engineering data. The interface between the pile and the hollow soil shaft was provided with contact of part to part frictional with coefficient of 0.3.the contact body was the pile and target body was taken as soil continuum.

3.5 BOUNDARY CONDITION

The boundary condition was allowed to be simulated in the initial step itself. The bottom boundary must be arrested vertical translation while the vertical boundary must be arrest against lateral translation. All surface of soil continuum except the top and left side surface were restrained mechanically by providing fixed supports.in order to eliminated the effect of boundary conditions, a large soil continuum was necessary.

Table 3.1: Specification of Models

S. No	Description	Condition	Model
1	Long pile	L/d >15	Pile length=7.5m Pile dia =500m Pile cap size=3mx3m Soil continuum=20mx20mx18.5m
2	Short pile	L/d<15	Pile length=3m Pile dia =200mm Pile cap size=2mx2m Soil continuum=10mx10mx7.5m

4. VALIDATION OF WORK

4.1 GENERAL

There are number of literatures that project the response of pile foundation under various soil medium and loadings statically and dynamically. Hence, its essential to substantiate the model that is created with the help of existing literature to audit the fidelity of the work. After validating the model it's imperative to arrive the critical parameters for the models from the earlier studies for arrival of integrated results.

4.2 VALIDATION OF MODEL

The model was validated using Three-dimensional modeling of laterally loaded pile groups resting in sand by Amr Farouk Elhakimet al. (2012) [1]. The soil was modeled as Mohr's-coulomb model and the three-dimensional PLAXIS was used to analysis the laterally loaded piles embedded in sand. But in this study three-dimensional model is analyzed by ANSYS workbench and moreover, the loading parameter is validated by R. Ayothiraman et al.(2012).

4.3 MODELING PARAMETER

The critical parameters are those which show the most optimized responses for a particular model. From the earlier study, the parameters shown in table are found to be critical and used in this study.

Table 4.1 Parametric Configuration

Diameter of pile (mm)	500
Thickness of pile cap(mm)	500
Length to diameter ratio (L/d)	15
Size of pile cap	3m x 3m
Mass of floors	16801 kg

Table 4.2 Parameters of Pile

Density	2300 kg/m^3
Young's modulus	3E+10 pa
Poisson's ratio	0.18
Bulk modulus	1.56525E+10 pa
Compressive strength of concrete in the pile	M25

Table 4.3 Parameters of Soil

Density	1700 kg/m^3
Young's modulus	4.014E+10
Poisson's ratio	0.3
Bulk modulus	3.36E+10
Mohr's coulomb parameters	
Initial inter friction angle	25^0
Initial cohesion	5000 pa
Distance angle	7.5^0

5. RESULT AND DISCUSSION

5.1 GENERAL

The numerical investigation of pile foundation and parametric study across all the configuration that were modelled are discussed in this chapter. The response of pile foundation and the influence of direction of the pile are investigated by numerical simulation. The analysis study carried out is reported.

5.2 EFFECTS OF VERTICAL LOAD AND LATERAL FORCES TO LONG PILES

The ultimate lateral capacities of piles installed in sandy soils with density were evaluated by applying horizontal velocities at the soil continuum and monitoring the piles loads variation with their settlements in soil. The lateral load of 7 Richter scale is applied. And vertical load of 16802 KN were applied on the pile in vertical load. Further monitoring the displacement, shear stress, response of pile, settlement, pile displacement, pile head displacement, ground displacement.

Fig 5.1: Total Deformation of Long Pile

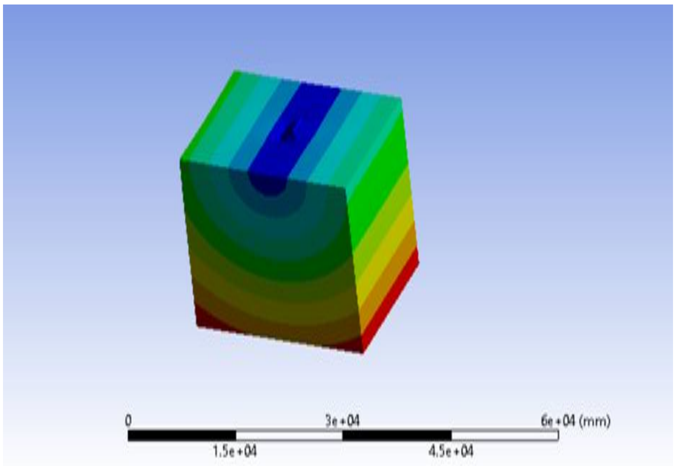


Fig 5.2: Total deformation of long pile

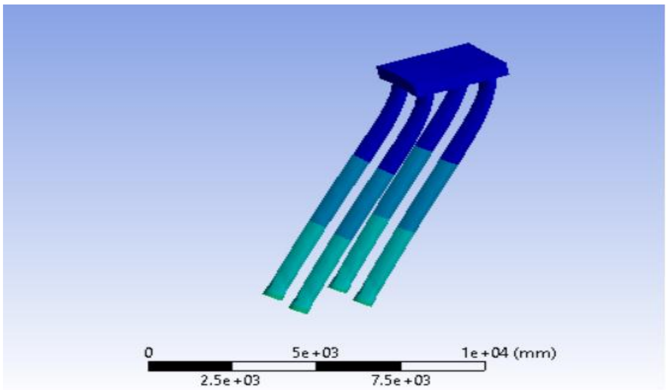


Fig 5.3: Directional Deformation of Long Pile

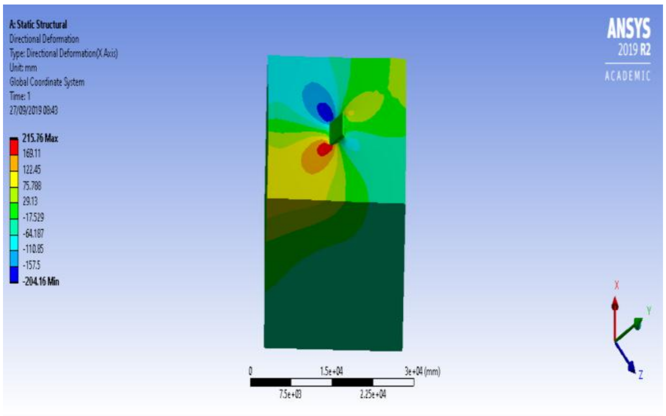
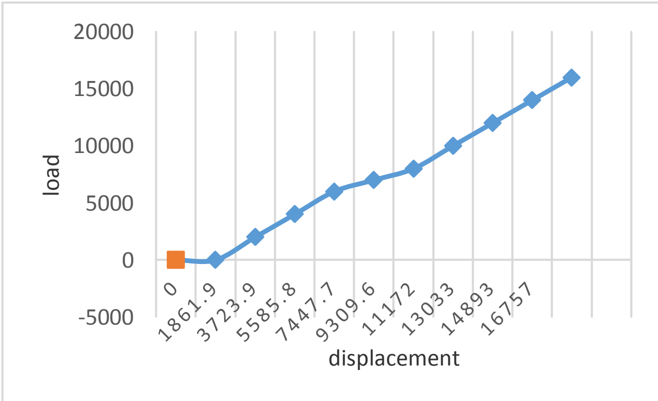


Fig 5.4: Load vs Displacement graph for long pile



From this analysis, as an impact of lateral force overturning of pile is observed, small ground displacement is occurring, pile is large displaced in long pile its shown in fig 6.1 and the Directional Deformation is shown in fig6.3. Then the effect of length to diameter ratio as load-carrying capacity holds good only up to a certain amount of settlement. The sandy soil the effect of area of the shaft as pile group behavior. Hence the system to bearing the lateral forces compulsory.

6. CONCLUSIONS

6.1 GENARAL

A complex foundation system comprising of long and short pile has been simulated and analyzed using ANSYS as these possess 3D stresses and deformation. The existing literatures shown the frontiers of the researches in the response of pile foundation.

6.2 CONCLUSION

From the study it was concluded that,

- In the impact of lateral force, the pile is displaced and then lets to overturning.
- The shear stress in long pile gradual changing (i.e.) decrease to increase but in short pile uneven changing develop.
- The L/d ratio increases, the settlement is decreases. Because the settlement in long pile depreciate and in short pile increment.
- The pile cap is dislocated and small ground misshaping by cause of lateral force.

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