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Analysis of Pile Group under Lateral Load

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ABSTRACT

The pile group foundation is a geotechnical composite construction, consisting of the three elements - piles, pile cap and the soil, which is applied for the foundation of tall buildings in an increasing number. The behavior of the foundation system is determined by complex interaction effects between the elements and an understanding of these effects is essential for a reliable design. This study presents the three dimensional finite element analysis of pile group foundation under lateral load by using ANSYS software. The soil is modeled to be pure clay and is assumed as homogeneous and isotropic in the analysis. Elasto-Plastic behavior of the soil is numerically modeled to follow Drucker–Prager Yield criterion. The study does not take into account the development of pore water pressure in the soil since the load applied is instantaneous. A parametric study was conducted to study the behavior of pile groups under lateral load with various configurations. The effect of pile length, pile diameter and configuration of piles in the group were studied. In this study, the spacing of piles and length to diameter (L/D) ratio were altered.

KEYWORDS: Pile, group pile, lateral load, Drucker-Prager Yield criterion

INTRODUCTION

Many buildings and structures require the use of deep foundations to utilize the bearing capacity of stronger soil layers. Pile groups are one particular type of deep foundation commonly used for large structures [1-3]. In addition to vertical loads that must be sustained by the piles, significant lateral loads may be present and must be accounted for in design [4-8]. These lateral loads can come from variety of sources such as wind forces, collisions, wave or ice impact, earthquake shaking, liquefaction and slope failure [9-10].

Investigation of nonlinear response of pile groups is an important issue in the analysis and design of many civil engineering structures such as bridges, high rise buildings and towers etc. [2]. In past, many analytical/numerical methods for analysis of pile groups have employed simplified assumptions such as replacing the soil medium by Winkler springs, treating the soil medium as an elastic continuum [11-12], and neglecting the interaction between various components (namely, the pile-cap, the piles and the soil medium).

The present study was directed at understanding the response of piled group foundation subjected to lateral loads in clay soil. The analyses were performed to study the effect of pile length and pile diameter on the lateral load carrying capacity of the pile group with increasing spacing between the piles. The effect of pile group configuration was also studied here.

MODEL DESCRIPTION, MATERIAL PROPERTIES AND BOUNDARY CONDITIONS:

A three dimensional model of pile and soil was used for this study as shown in Fig. 1. The soil was modeled to be pure clay and was assumed as homogeneous and isotropic in the analysis. Elasto-Plastic behavior of the soil was used to follow Drucker-Prager Yield criterion. The study did not take into account the development of pore water pressure in the soil since the load applied was instantaneous.

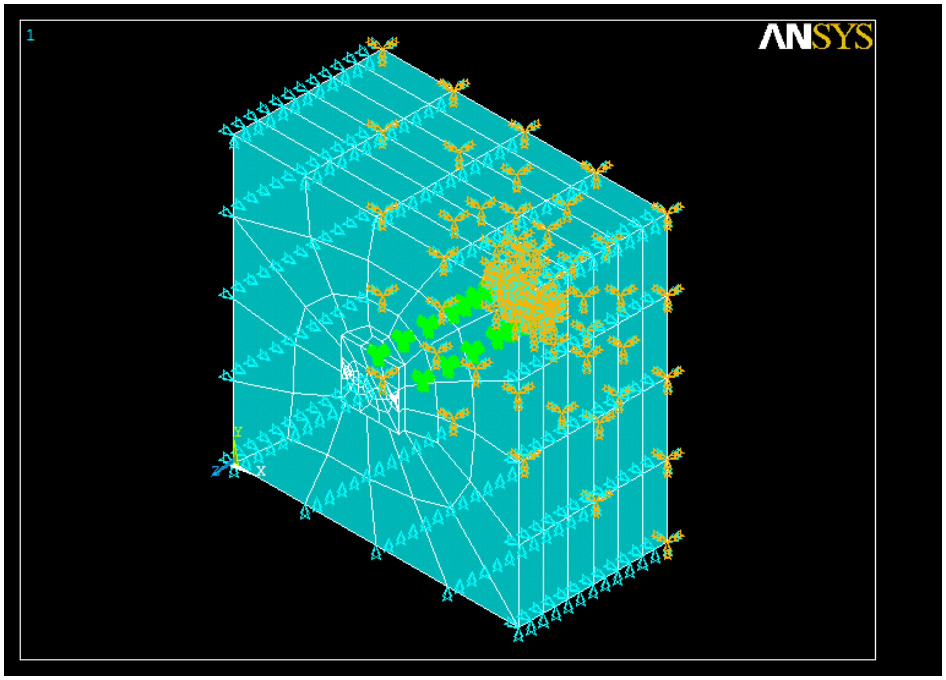


Figure 1: Three dimensional pile-soil model

Soil was first discretized 2-dimensionally by 4 noded plane 82 solid elements, which was later extruded with 20-noded brick element (ANSYS manual 4.2). Again, pile and pile cap were discretized 2-dimensionally by 4 noded plane 42 solid elements, which were extruded with 20-noded brick element.

The boundary conditions were considered as a proper restrain on the mesh. The nodes belonging to the periphery of the mesh were fixed against displacement in both horizontal directions; yet remain free to have displacement vertically. The nodes constituting the bottom of the mesh were fixed against displacement in both horizontal and vertical directions as shown in Fig. 2

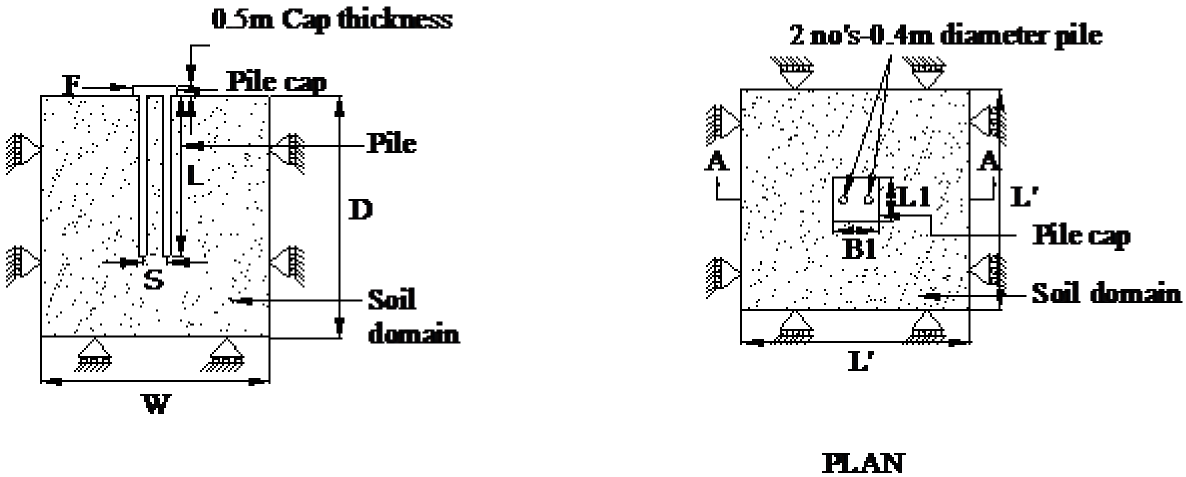


Figure 2: Pile-soil system with (1x2) pile group

Two types of material were considered in the pile-soil model. The property of concrete was assigned for the pile, while soil properties (Clay) were assigned for the soil. The details of the different properties were given in Table 1.

Table 1: Material properties of pile and soil

Material properties	**Pile**	**Soil**
Modulus of elasticity, E (kN/m²)	$2x10^7$	25000
Poisson's ratio, μ	0.3	0.45
Unit weight, γ_{soil}(kN/m³)	25	17
Cohesion, c (kN/m²)	-	60
Friction, ϕ	-	0

Table 2: Specification of pile group for case 1

Pile diameter (m)	0.4
Pile length (m)	6.0, 8.0 and 12.0
Pile cap thickness (m)	0.5
Spacing between piles	3d, 5d and 7d
Permissible horizontal deflection (mm)	5

RESULTS AND DISCUSSION

Though there are many factors which affect the response of the pile behavior, only three major factors were considered in this study. These are divided into three cases as mentioned below.

Case 1: lateral load capacity of 1x2 pile group under varying length and fixed diameter.

Case 2: Lateral load capacity of 1x2 pile group under fixed length and varying diameter.

Case 3: Effect of pile group configuration on lateral load capacity.

Here, the pile length (L) and diameter (D) are chosen in such a way that the L/D ratio remains same for both Case 1 and Case 2. Each of the above mentioned case has been discussed separately below.

Case 1: lateral load capacity of 1x2 pile group under varying length and fixed diameter.

The arrangement of the pile for this case is shown in Fig. 2 with detail specification as mentioned in Table 2. It was observed from Fig. 3 that lateral load carrying capacity remains almost same with increase in length of pile in the pile group. Again, for all the three lengths of the pile (6.0m, 8.0m and 12.0m), the lateral load carrying capacity increases with increase in spacing between the piles. This is due to the fact that as the spacing increases gradually, the overlap of stress zone of of the individual pile in the group decreases, which results in an increase in load carrying capacity of the pile group.

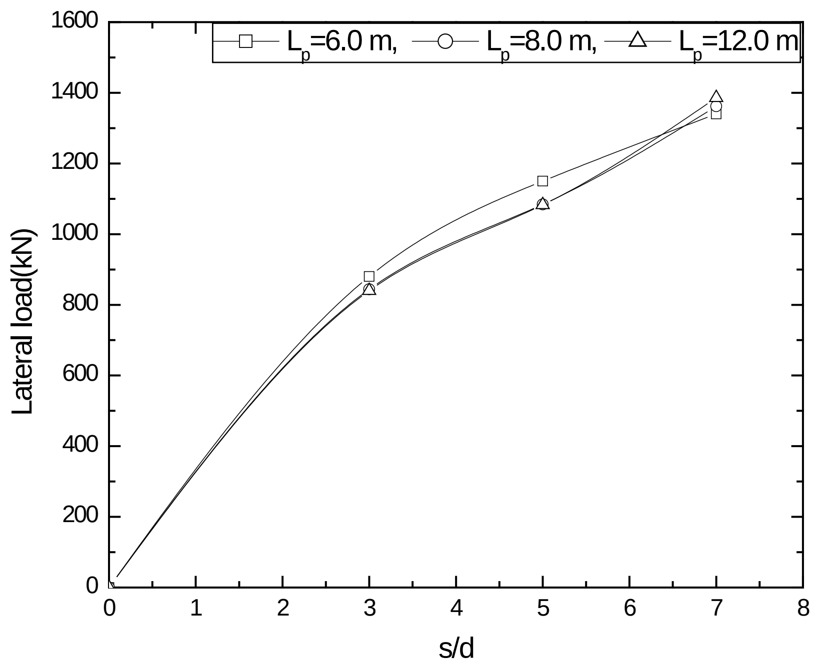


Figure 3: Lateral load Vs spacing for (1x2) pile group with varying length and fixed diameter

Case 2: Lateral load capacity of 1x2 pile group - Length fixed and diameter varying

Fig. 4 shows the arrangement of the piles in the group for the second case. The specifications are listed in Table 3 below and the results obtained are shown in Fig. 5. In this case, the lateral load carrying capacity of the pile group increases considerably with the increase in diameter of the piles. As the diameter increases, the surface area of the piles increases which gives more resistance to the lateral load.

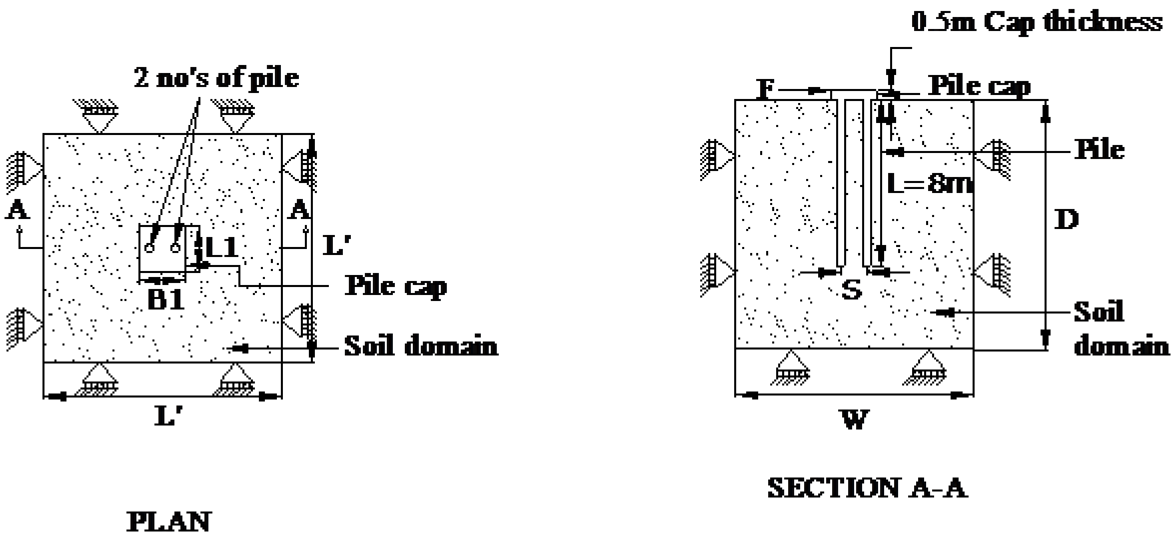


Figure 4: (1x2) pile group with fixed length and varying diameter of pile.

Table 3: Specification of pile group for case 2

Pile diameter (m)	0.53, 0.4 and 0.27
Pile length (m)	8.0
Pile cap thickness (m)	0.5
Spacing between piles	3d, 5d and 7d
Permissible horizontal deflection (mm)	5

Based on the results of *Case 1* & *Case 2*, it can be concluded that increasing L/D ratio simply did not increase the the load carrying capacity. It depends on the diameter of the piles which is the main factor in increasing the lateral load carrying capacity.

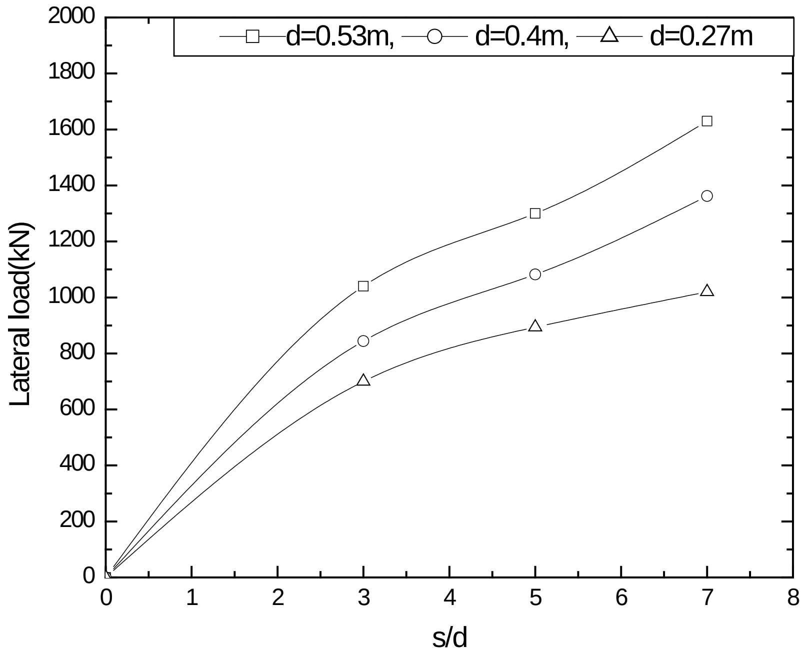


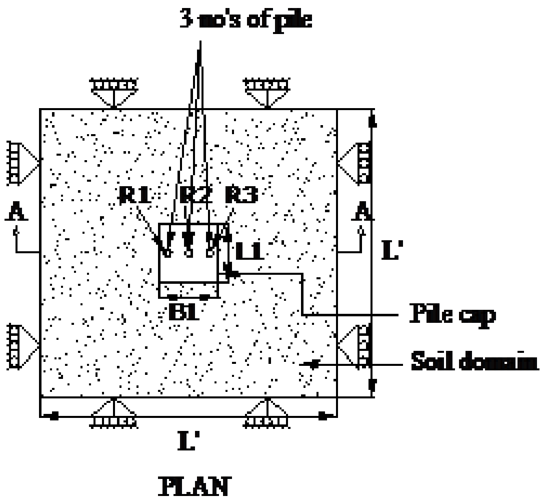
Figure 5: Lateral load Vs spacing for (1x2) pile group with fixed length and varying diameter

Case 3: Effect of pile group configuration on lateral load capacity

The effect of pile group configuration was studied by considering 1x2, 2x2 and 1x3 pile groups as shown in Fig. 1, 6 and 7 respectively. The specifications are listed in Table 4.

Table 4: Specification of pile group for case 3

Pile diameter (m)	0.4
Pile length (m)	6.0
Pile cap thickness (m)	0.5
Spacing between piles	3d



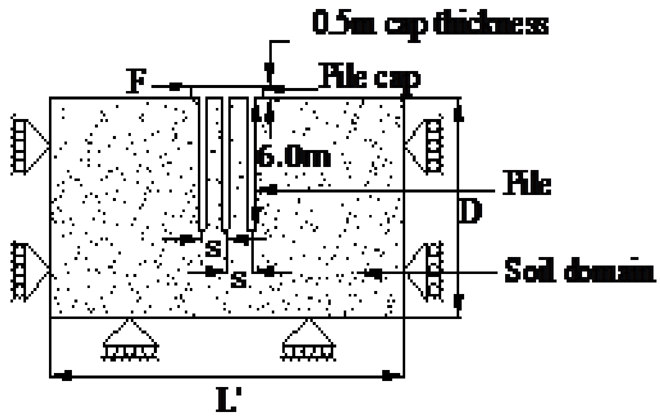
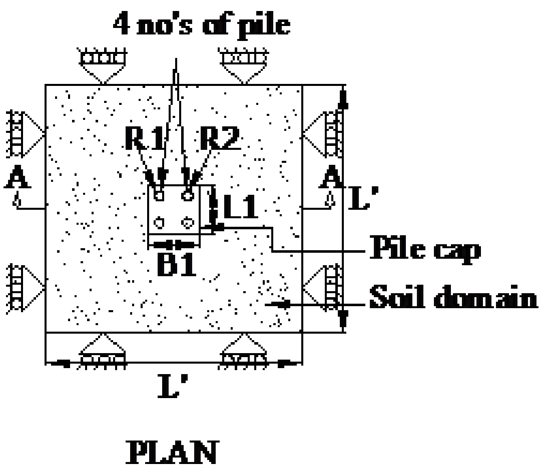


Figure 6: (1x3) pile group



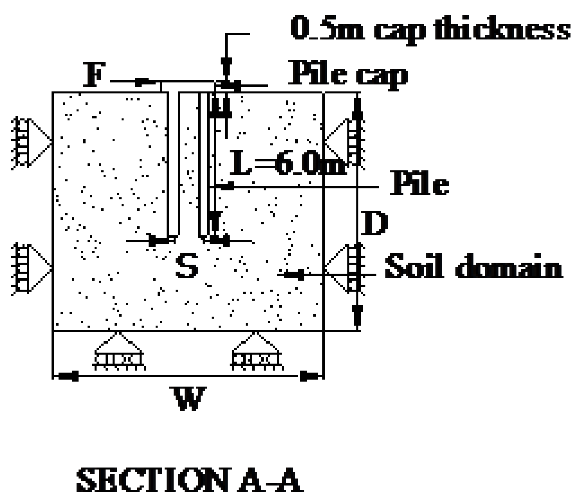


Figure 7: (2x2) pile group

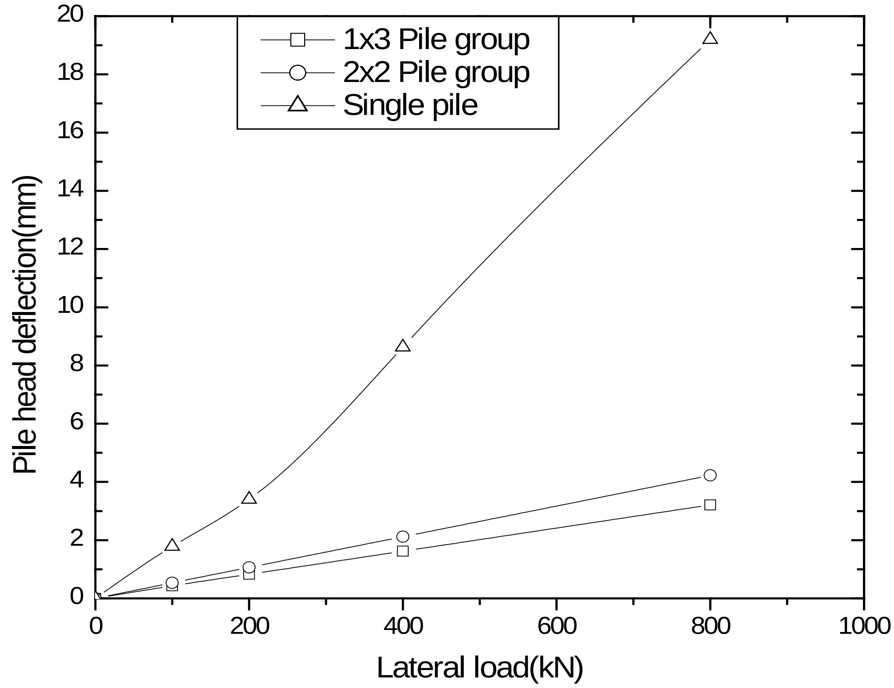


Figure 8: Lateral load *vs* deflection

Horizontal loads are applied at the top as shown in the figure and the results were plotted in Fig. 8. It was found that in a pile group the passive resistance depends on the orientation of the piles in the group. In this case, both 1x3 and 2x2 pile group has the same numbers of pile i.e. 4, but the resistance of the 1x3 pile group became more than the 2x2 pile group. This is due to the increase in the volume of soil between the piles in 1x3 than in 2x2 pile group which increases the passive resistance of the group.

CONCLUSIONS

Based on the results of the present study, the following conclusions can be made related to the influence of horizontal load on lateral response of a pile group.

(a) The increase in L/D ratio of pile did not give any increase in lateral load capacity of pile group if the diameter is kept constant and length changes.

(b) The lateral load carrying capacity of a pile group increases with the increase in diameter of the piles.

(c) The lateral load carrying capacity of a pile group increases with the increase in spacing between the piles.

(d) The passive resistance offered by a pile group depends on the orientation of the piles in the group. When the volume of soil between the piles increases, the resistance of the pile group against the lateral load also increases.

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