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*Research Paper*

# ANALYSIS OF PILE GROUP USING FINITE ELEMENT METHOD

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Pile foundations are slender structural elements used to transfer loads from super structure into deep hard strata below the ground level. However, single piles are rarely found in practice. It is quite complicated to analyze pile groups since pile soil interaction is complex. In this study, two dimensional analysis of pile group under vertical load is carried out using finite element software ANSYS. Pile group has 16 numbers of piles and it is located in c-ø soil, parameters like diameter (0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 m), length (3, 4, 5, 6 m) and spacing of piles (2D, 2.5D, 3D, 3.5D, 4D) and thickness of pile cap (0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4 m) are varied to study the behavior of pile group. Results of influence of diameter, length and spacing of piles and thickness of pile cap are discussed. It can be observed that, as the diameter and spacing of piles and thickness of pile cap increase, the load carrying capacity of pile group increases. The length of pile has no significant effect when compared to influence of diameter of piles on load carrying capacity of pile group.

*Keywords:* Pile group, Pile cap, Spacing, Finite element method, ANSYS

## INTRODUCTION

Pile foundation can be defined as a single or a group of a structural vertical long strut members, driven or bored to a depth to attain sufficient capacity to support external loads from the superstructure. Single piles are rarely found in practice. Generally, there will be a minimum number of two or three piles under a footing to allow for eccentricities. The load carrying capacity of pile group may not be equal to sum of the load carrying capacities of individual piles. This is because, when several piles are clustered, the soil pressures produced from either side friction or point bearing will overlap and reduce the load carrying capacity. But when the piles are driven into loose soil, the load carrying capacity of pile group will be more than sum of individual capacities of piles due to compaction of surrounding soil.

The super imposed pressure intensity will depend on both the pile load and spacing of piles. The stress intensity from overlapping stressed

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zones will obviously decrease with increased pile spacing, however, large spacings are often impractical since a pile cap is cast over the pile group for the column base and to spread the load to the several pile in the group (Bowles, 1996). Analysis on single piles under axial load is examined in details by many researchers (Nabil, 2001, Rajgopal *et al*., 2008, Jasim *et al*., 2012). The pile settlement due to axial load is always influenced by axial load intensity, length of pile and soil parameters like modulus of elasticity and cohesion intercept (Jasim *et al*., 2012). Ranadive *et al*. (2008) concludes that the settlements are insensitive to change in Poisson's ratio of soil.

Since piles are generally installed in groups, it is important to know the behavior of pile groups. The behavior of pile group is more complex, it is different from that of single pile. Designing a suitable pile group system is essential, since inappropriate design of pile group increase pile sizes that can ultimately increase the cost of foundation (Nath *et al.,* 2011). Leung *et al*. (2010) varied pile length across the pile group to optimize the performance of foundation. Neglecting the pile cap resistance may result in estimate of deflections that are double the actual values (Mokwa *et al*., 2001). When the pile cap is above ground, the pile loads can be estimated reasonably well. When the pile cap in contact with ground, the pile load is considerably indeterminate (Bowles, 1996). The settlement of pile group is the controlling factor in design because the primary purpose of pile group is to limit the deformation of structures (Yang *et al*., 2011).

Hence, while designing a pile group, optimization of various parameters of pile group should be done for given soil and loading conditions by conducting parametric studies. In this paper, pile group under vertical load which is located in c-ø soil is considered for analysis under different parameters like length, diameter and spacing of piles and thickness of pile cap.

## METHODOLOGY

Since soil-pile interaction is highly complex and the soil is semi-infinite medium, numerical methods are best suited for analysis of pile group. Finite Element Method (FEM) is one of the effective numerical methods and suitable to complex geometry, non-linear, an isotropic and non-homogeneous materials.

ANSYS software is being used in this study and it is one of the sophisticated FEM software to deal and analyze thoroughly with different types of problems in Engineering and other fields also. Validation of ANSYS software has been done with the data from the literature (Yang *et al*., 2011). The load vs. settlement graph from ANSYS software is similar to that from literature.

### Significant Zone of Soil

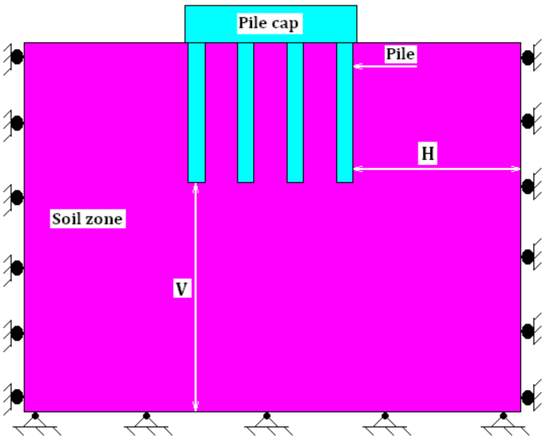
Significant zone of soil is determined by trial and error method using static formulae from IS codes. H = 10 D and V = 14 D are the values obtained, where, D is diameter of piles. Measurement of H and V is shown in Figure 1.

### Development of FEM

Because of symmetry the problem can be considered as plain strain problem. Any one of vertical plane as shown in Figure 1 can be considered for analysis.

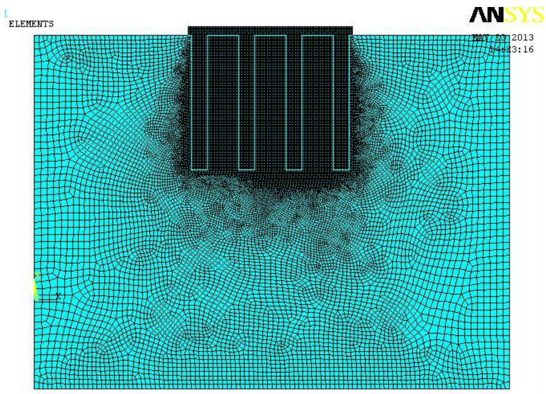
PLANE82 element is used to model pile group as well as soil. This element has 8 nodes and 2 degrees of freedom in x and y direction. At the interface of pile and soil, TARGE169 and CONTA172 elements are used for pile and soil, respectively.

**Figure 1: Measurement of Significant Zone and Boundary Conditions**




Mesh density is maintained constant throughout the work for comparison of values. Meshed area is shown in Figure 2. Hinged and roller support conditions are applied at bottom and sides of soil zone respectively as in Figure 1.

**Figure 2: Meshed Area**




## PARAMETRIC STUDIES

Parametric study on pile group having 16 number of piles located in c-ø soil is conducted by varying parameters like diameter (D), length (L) and spacing (s) of piles and thickness (t) of pile cap. Cross sectional view and plan of pile group are shown in Figures 3 and 4, respectively. Material properties are listed in Table 1.

**Figure 3: Cross Sectional View of Pile Group**

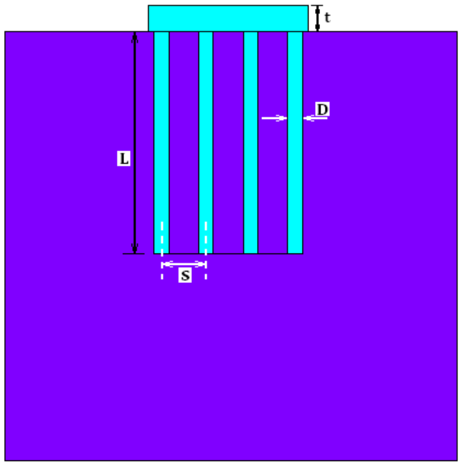



**Figure 4: Plan of Pile Group**

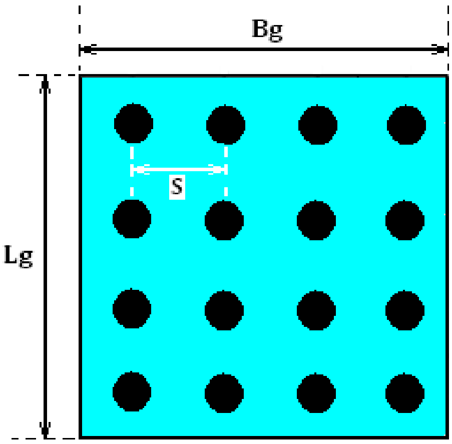



**Table 1: Material Properties**

| Properties | Piled Group | Soil |
|---|---|---|
| Modulus of Elasticity, E (kPa) | 23 * 106 | 40 * 103 |
| Poisson's ratio, μ | 0.15 | 0.3 |
| Density, ρ (kg/m3) | 2400 | 1700 |
| Cohesion, C (kPa) | - | 50 |
| Friction Angle, Ø (°) | - | 25 |
| Flow Angle, ψ (°) | - | 7.5 |

Pile cap is made to touch the ground surface. Uniform pressure is applied on the pile cap, the value of ultimate load of pile group (Qu) and corresponding settlement (δ) of pile group is noted down.

First the diameter of piles (0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 m) is varied by keeping all other parameters like length of piles (L), thickness of pile cap (t) and center to center spacing of piles (s) constant and values are 3 m, 400 mm and 3D, respectively. In the subsequent trials same procedure is repeated by varying length of pile ranging from 3 m to 6 m with the increment of 1 m.

## RESULTS AND DISCUSSION

Table 2 shows the values of ultimate load for different values of diameter and length of piles.

Lower value of ultimate load is observed as 11598.65 kN for the pile group having combination of 200 mm diameter and 3 m length and it is 50957.00 kN which is high value obtained for 800 mm diameter and 6 m length combination.

Figure 5 shows displacement contours of pile group and soil for length of pile equal to 6 m and diameter equal to 700 mm.

Table 3 shows the values of settlement for different values of diameter and length of piles.

Lower value of settlement observed is 69.079 mm for 400 mm diameter and 3 m length and it has high value equal to 136.872 mm obtained for 800 mm diameter and 6 m length.

### Influence of Diameter

#### *Ultimate Load*

The percentage increase in load carrying capacity of pile group from 200 mm to 800 mm diameter is found to be more than 300% for all the lengths of piles. Figure 6 shows significant increase in load carrying capacity after 600 mm diameter for

**Table 2: Values of Ultimate Load for Different Values of Diameter and Length of Piles**

| Length, L(m) | Diameter D(mm) | Ultimate Load $Q_u$(kN) |
|---|---|---|
| 3 | 200 | 11598.65 |
| | 300 | 12550.15 |
| | 400 | 14375.50 |
| | 500 | 18075.50 |
| | 600 | 21918.00 |
| | 700 | 34185.50 |
| | 800 | 48040.59 |
| 4 | 200 | 11638.00 |
| | 300 | 12741.30 |
| | 400 | 14976.90 |
| | 500 | 19438.28 |
| | 600 | 22067.64 |
| | 700 | 34798.37 |
| | 800 | 49566.35 |
| 5 | 200 | 11690.90 |
| | 300 | 12822.83 |
| | 400 | 15342.54 |
| | 500 | 19919.00 |
| | 600 | 22345.45 |
| | 700 | 35113.5 |
| | 800 | 50039.59 |
| 6 | 200 | 11928.95 |
| | 300 | 12904.65 |
| | 400 | 15624.06 |
| | 500 | 20365.25 |
| | 600 | 22623.30 |
| | 700 | 35437.85 |
| | 800 | 50957.00 |

**Table 3: Values of Settlement for Different Values of Diameter and Length of Piles**

| Length, L(m) | Diameter D(mm) | Settlement δ (mm) |
|---|---|---|
| 3 | 200 | 113.140 |
| | 300 | 80.157 |
| | 400 | 69.079 |
| | 500 | 72.686 |
| | 600 | 75.686 |
| | 700 | 93.373 |
| | 800 | 128.580 |
| 4 | 200 | 113.024 |
| | 300 | 81.880 |
| | 400 | 72.249 |
| | 500 | 75.984 |
| | 600 | 81.750 |
| | 700 | 98.548 |
| | 800 | 130.580 |
| 5 | 200 | 113.400 |
| | 300 | 82.340 |
| | 400 | 75.150 |
| | 500 | 78.050 |
| | 600 | 87.144 |
| | 700 | 100.200 |
| | 800 | 132.810 |
| 6 | 200 | 115.485 |
| | 300 | 83.630 |
| | 400 | 76.089 |
| | 500 | 80.122 |
| | 600 | 92.959 |
| | 700 | 101.658 |
| | 800 | 136.872 |

**Figure 5: Displacement Contours**

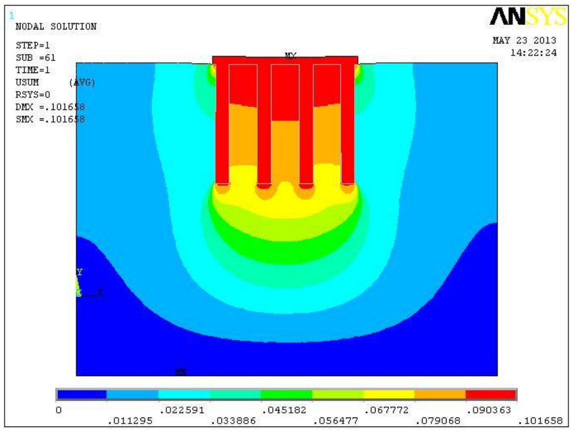
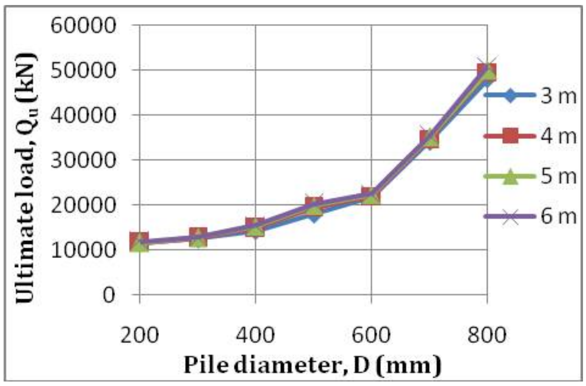



**Figure 6: Influence of Diameter on Load Carrying Capacity**

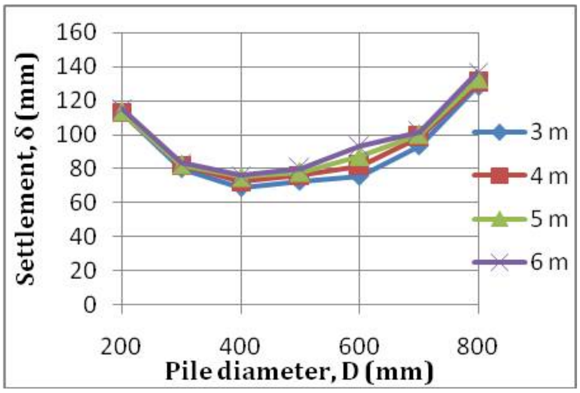



all the length of piles. The increase in load carrying capacity for different diameters is due to increased surface area of piles. Even though the graph shows increased ultimate load with increased diameter, relatively the percentage increase in load carrying capacity is high for the pile group having pile diameter equal to 700 mm and this is observed for all the lengths of piles.

## SETTLEMENT

Figure 7 shows influence of diameter on settlement. It is found that the value of settlement is more for 200 mm and 800 mm diameter for all the lengths and it is less in the diameter range

**Figure 7: Influence of Diameter on Settlement**




400 mm to 600 mm. The possible reason for the increase in settlement of pile group having diameter from 300 mm to 200 mm is due to more load is transferred to relatively less area of soil.

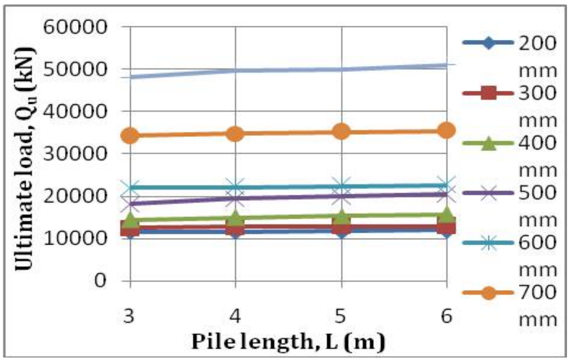
The increased settlement of 700 and 800 mm diameter pile group is because increased load carrying capacity.

## Influence of Length

### *Ultimate Load*

The percentage increase in load carrying capacity of pile group from 3 m to 6 m length is found to be 12.67% for diameter equal to 500 mm and it is highest percentage increase of all. Figure 8 shows the variation of ultimate load with length. It clearly indicates that the increase in load carrying capacity is not remarkable when the length is increased.

**Figure 8: Influence of Length on Load Carrying Capacity**




## Influence of Pile Cap Thickness

For this study, pile group of 16 numbers having length and diameter equal to 6 m and 700 mm, respectively is selected and the center to center spacing is equal to 3D. Pile group having thickness of pile cap ranging from 200 mm to 1400 mm are considered for observing behavior of pile group under vertical load in c-ø soil.

Table 4 shows values of ultimate load and settlement for different pile cap thickness.

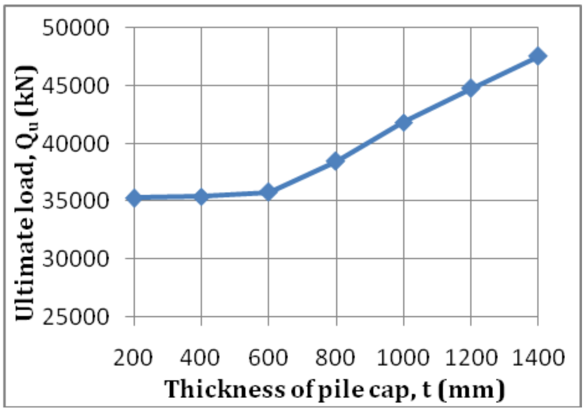
**Table 4: Values of Ultimate Load and Settlement for Different Pile Cap Thickness, (L = 6 m and D = 700 mm)**

| Thickness of Pile Cap, t(mm) | Ultimate Load $Q_u$(kN) | Settlement δ(mm) |
|---|---|---|
| 200 | 35304.63 | 103.246 |
| 400 | 35437.85 | 101.658 |
| 600 | 35784.24 | 101.818 |
| 800 | 38502.04 | 109.578 |
| 1000 | 41832.66 | 120.518 |
| 1200 | 44763.49 | 134.752 |
| 1400 | 47560.73 | 150.257 |

### *Ultimate Load*

It is found from Figure 9 that, with the increase in thickness of pile cap from 200 mm to 600 mm there is no significant increase in load carrying capacity. When the thickness is increased from 600 mm to 1400 mm, there is almost linear increase in the ultimate load. This is because at the center, pile cap deflects more and it fails by excessive deflection when the thickness of pile cap is less. With the increase in thickness of pile cap, this effect can be reduced. Relatively the

**Figure 9: Influence of Pile Cap Thickness on Ultimate Load Carrying Capacity**




rate of increase in the ultimate load is more when the thickness of pile cap changes from 800 mm to 1000 mm when compare with the other values and it is equal to 8.65%.

### *Influence of Spacing of Piles*

Pile group having diameter, length and pile cap thickness equal to 6 m, 700 mm and 400 mm, respectively is considered to assess the effect of spacing of piles on the behavior of pile group and the spacing of piles is having values 2D, 2.5D, 3D, 3.5D and 4D.

Table 5 shows the values of ultimate load and settlement of pile group for different pile spacings.

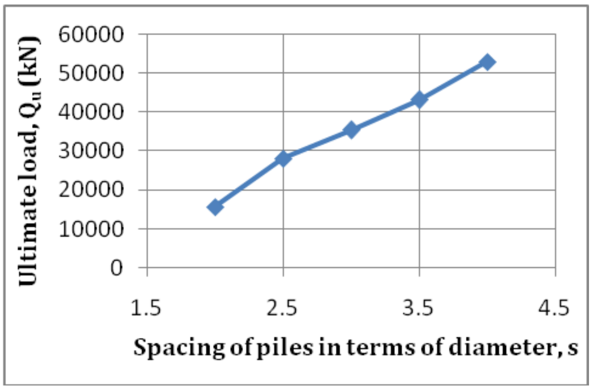
**Table 5: Values of Ultimate Load and Settlement for Different Pile Spacings, (L = 6 m and D = 700 mm)**

| Spacing s | Ultimate Load $Q_u$(kN) | Settlement $\delta$(mm) |
|---|---|---|
| 2D | 15646.62 | 76.970 |
| 2.5D | 28133.75 | 106.390 |
| 3D | 35437.29 | 101.660 |
| 3.5D | 43191.29 | 104.680 |
| 4D | 53011.58 | 107.230 |

### *Ultimate Load*

It is observed from Figure 10 that when the center to center spacing of piles is 2D, the load carrying capacity is less for the pile group. It is also found that as the spacing increases, the load carrying capacity also increases. This is because, the increase in spacing reduces the interaction between the piles. But larger spacings are not acceptable because it results in bigger size of pile cap which will be uneconomical.

**Figure 10: Influence of Spacing of Piles on Ultimate Load Carrying Capacity**




## CONCLUSION

- It is observed that for given soil, the percentage increase in load carrying capacity of pile group from 200 mm to 800 mm diameter is found to be more than 300% for all the lengths of piles. This shows diameter of pile has significant influence on load carrying capacity of pile group.
- From these studies, it is concluded that there is no significant influence of length on load carrying capacity when compared to diameter of pile.
- Relatively the rate of increase in the ultimate load is more when the thickness of pile cap changes from 800 mm to 1000 mm when compared with the other values and it is equal

to 8.65% for length and diameter of piles equal to 6 m and 700 mm respectively.

- The increase in spacing reduces the interaction between the piles and increases the load carrying capacity. But larger spacings are not acceptable because it results in bigger size of pile cap which will be uneconomical. Pile group having length, diameter and thickness of pile cap equal to 6 m, 700 mm and 400 mm, respectively, is found give better performance for spacing equal to 3D.

## REFERENCES


1. Punmia B C, Ashok Kumar Jain and Arun Kumar Jain (2005), *Soil mechanics and foundations*, Lakshmi Publications.
2. Bhavik S Parsiya and Dave S P (2012), "Analytical study of laterally loaded pile group", *International Journal of Advanced Engineering Research and Studies,* IJAERS/ Vol. I/ Issue III /April-June, 2012/284-286.
3. Venkataramaiah C (2009), *Geotechnical Engineering*, New Age International Publishers.
4. IS 2911-1979, Code of practice for design and construction of pile foundation.
5. IS 8009-1980, Code of practice for calculation of settlement of foundations.
6. Jasim M Abbas, Ali Laftah Abbas and Abbas M Abd (2012), "The Axial Performance of Deep Foundation", *European Journal of Scientific Research,* ISSN 1450-216X, Vol. 74, No. 4, pp. 574-582.
7. Joseph E Bowles (1996), *Foundation analysis and design*, The McGraw-Hill companies, inc.
8. Rajagopal K and Karthigeyan S (2008), "Influence of combined vertical and lateral loading on the lateral response of piles", *International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG)*, 1-6 October.
9. Ranadive M S and Parikh S K (2008)," Linear Settlement of Axially Loaded Pile -Soil Systems", *International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG),* 1-6 October.
10. Nabil F Ismael (2001), "Axial load tests on pile and pile group in cemented sands", *Journal of geotechnical and geoenvironmental engineering*, pp 767-773.
11. Shengaga R Kaniraj (2010), Design aids in soil mechanics and foundation engineering, Tata McGraw Hill.
12. Chandrasekaran S S, Boominathan A and Dodagoudar G A (2010), "Group interactions on laterally loaded piles in clay", *Journal of geotechnical and geoenvironmental engineering*, pp. 573-582.
13. Nath U K, Hazarika P J, Giri V and Tesfaye A M (2011), "Study of Lateral Resistance of Pile Cap using Finite Element Analysis", *International Journal of emerging trends in engineering and development*, Issue 1, Vol. 1, (August-2011) ISSN 2249-6149.
14. Murthy V N S (2011), *Advanced design of foundations*, CBS Publications.
15. Yang Ming-hui, Zhang Xiao-wei and Zhao Ming-hua (2011), "A simplified approach for settlement calculation of pile groups

considering pile to pile interaction in layered soils", *J. Cent. South Univ.Technol.*, Vol. 18, pp. 2131-2136.

16. Leung Y F, Klar A and Soga K (2010), "Theoretical Study on Pile Length Optimization of Pile Groups and Piled Rafts", *Journal of geotechnical and geoenvironmental engineering*, pp. 319-330.

17. Xu Y and Zhang L M (2007), "Settlement Ratio of Pile Groups in Sandy Soils from Field Load Tests", *Journal of geotechnical and geoenvironmental engineering*, pp. 1048-1054.

18. Zamri H Chik, Jasim M Abbas, Mohd Raihan Taha and Qassun S Mohammed Shafiqu (2009), "Lateral Behavior of Single Pile in Cohesionless Soil Subjected to Both Vertical and Horizontal Loads", *European Journal of Scientific Research*, ISSN 1450-216X, Vol. 29, No. 2, pp. 194-205.

19. Zhao Ming-hua, LIU Dun-ping, Zhang Ling, and Jiang G Chong (2008), "3D finite element analysis on pile-soil interaction of passive pile group", *J. Cent. South Univ. Technol.,* Vol. 15, pp. 75-80.

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