Experimental Study on Piles with Pile Cap at Varying Position under Different Loading Conditions

M. Sugunadevi, S. P. Jeyapriya

Abstract: High rise buildings and offshore structures are usually constructed over foundation which comprises of several number of piles connected together using pile cap. These piles and pile caps frequently are subjected to a mixture of lateral, vertical as well as twisting forces. Conventional method tends to emphasis predominantly on foundation resistance under vertical loading. The piles are essential subjected to horizontal loads along with vertical loads. Resistance to the vertical and the lateral loading is generally provided by base and side friction, pile-soil-pile cap interaction between pile and surrounding soil, position of the pile cap, number of piles and piles arrangement with respect to the loading direction. In this study, the piles are placed in the sand with pile cap i) above the soil surface at a height of 35mm ii) pile cap bottom resting on surface of soil medium iii) pile cap top placed at the surface of soil and iv) pile cap placed below soil surface to a depth of about 35mm. Experimental analysis were carried out for all the above cases under vertical, lateral and combined loading conditions. Parameters like position of the pile cap, quantity of piles and their arrangements were varied and analysed. The test results reveal that the pile cap placed below the soil surface increases lateral resistance capacity of the piles in the range of 56% to 66% compared with pile cap placed above the soil surface under both independent and combined loading conditions in cohesionless soil.

Keywords: Cohesion less Soil, Lateral Resistance Capacity, Pile Foundations, Pile cap, Pile - Soil - Pile Cap Interaction

I. INDRODUCTION

Whenever an enormous amount of super structural masses ought to be transferred through subsoil which is weak in load distribution, the pile foundations are usually used. Piles are subjected towards substantial amount of lateral loads and moments besides to that of axial loads, once they are used beneath elevated chimneys, altitudinous structure and structures located away from the shoreline. Conventional method of designing the foundation tends to focus primarily on vertical loading. Besides the axial loads, piles must also be accounted for some amount of lateral loads. In offshore structures, lateral loads may surpass 30% of vertical loads and in onshore structures it's about 10-15% of vertical loads. The problems on laterally loaded pile or pile group are due to complex soil – pile – pile cap interaction. As the pile deflection depends on reaction provided by the surrounding soil which consecutively influences pile deflection [6]. In several field conditions piles groups are often used rather than solitary pile system. These pile groups are usually connected by using pile cap through which superstructure loads are transmitted. Pile caps are typical huge concrete blocks positioned on the surface of soil immediately after the pile groups have been driven.

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The building and several individual piles are connected using pile caps which are frequently exposed to lateral and vertical loads along with overturning moments. Pile to pile cap connection and passive earth pressure offers the rotational resistance to the structure. In many cases, pile cap provides lateral resistance greater than piles themselves [11].

A study conducted on the investigation of resistance of pile caps to lateral loading evaluated that about 50% of overall lateral resistance of the pile group is provided by pile caps in which the passive resistance contribution is almost 50% of total lateral resistance [6]. The lateral resistance provided by pile cap in pile groups is frequently ignored in the design which could exceeds the deflection and bending moment of structure for around 100% or else more [12]. Certain pile caps are partly or entirely positioned into the soil. Based on the field test results conducted on single H piles and 2×3 fixed head piles with pile cap together in contact with the soil surface and 0.1m beyond the ground. It was found that deflection and bending moment of piles above the ground surface were approximately twice over compared with the piles placed on the ground surface [5].

In this study, an eclectic experimental analysis was carried out on the single model pile and 1×2 piles placed in cohesionless soil subjected to static independent vertical, lateral as well as combined loading conditions. The effects of the position of the pile cap, length of the pile, number of piles in the group and arrangement of piles with respect to the direction of loadings are studied in detail.

II. MATERIALS AND METHODOLOGY

A. Materials

1. Sand

The foundation medium selected for the study is sand and its properties were tested in the laboratory as per IS 2720 and the results are tabulated in Table I.

Table I. Physical Properties of Foundation Medium

Parameter	Values
Specific gravity	2.65
Effective grain size (D_{10}),mm	0.20
Coefficient of uniformity (C_u)	2.8
Coefficient of curvature(Cc)	0.91
BIS Classification	SP
Minimum density, kN/m^3	14.7
Maximum density, kN/m^3	17.8
Angle of internal friction (φ)	31°

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2. *Pile*

Model piles and pile caps were fabricated using perspex material. In order to bring out the exact field condition various researchers performed model analysis using perspex material. Threads were provided at the top portion of pile to connect the pile cap. Details of pile material are specified in Table II.

Table II Details of Pile Material

Description	Single pile	1×2 Piles
Pile Length	250mm	250mm
Pile Diameter	12mm	12mm
Pile cap	50mm×50mm	80mm×50mm
Spacing	-	30mm

B. Methodology

1. *Experimental Setup and Procedure*

The experimental investigations were carried out in a square tank of size 600mm×600mm×750mm which is schematically represented in Fig.1.

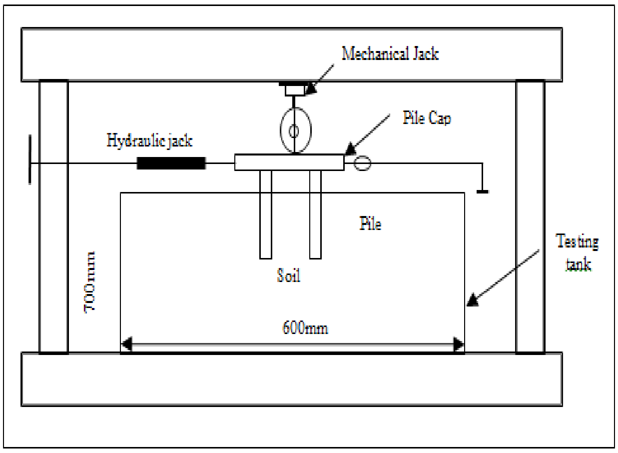

Fig. 1 Diagrammatic Representation of Experimental Setup

The sand is filled in tank by sand raining technique. The height of the hopper is fixed in such a way that required density is achieved. The model pile was placed on foundation medium and the loading tests were carried out as per IS 2911 – Part 4 – 1985.

2. *Testing Phase*

Experiments were carried out by altering the position of the pile cap and arrangement of pile with respect to the loading direction for the following four cases

Case i) Pile cap located 35mm above the soil surface
Case ii) Pile cap bottom resting on surface of soil medium
Case iii) Pile cap top placed at the surface of soil
Case iv) Pile cap placed 35mm below the soil surface

Fig. 2 represents the diagrammatic form of all the above cases.

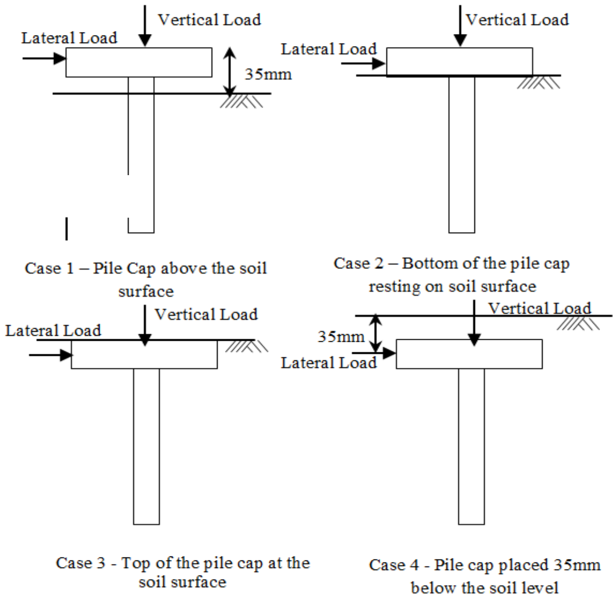

Fig. 2 Schematic Representation of Pile Cap placed at Varying Position

3. *Independent Vertical Loading*

The vertical load was applied using hydraulic jack and it was measured by 50kN proving ring. Continuous measurement of vertical displacement was carried out using LVDT with ± 25mm travel. Tests were carried out until punching shear failure occurs in the foundation medium. Results were given in the form of load vs. settlement curve.

4. *Independent Lateral Loading*

Hydraulic jack is used to put on the lateral load through a load cell which has capacity of 2kN and load indicator is used to measure the applied load. In case of 1×2 piles, horizontal load was applied in the direction parallel and perpendicular to the line joining of two piles which are known as series and parallel loading arrangements respectively. Series and parallel loading arrangements were presented in Fig.3. Tests were continued up to the permissible deflection and the results are discussed.

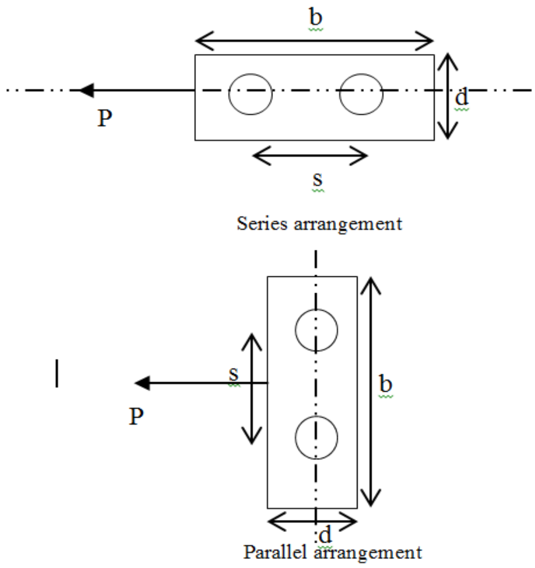

Fig.3 Series and Parallel Loading Arrangements

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5. Combined Loading

In case of combined loading, vertical load of about 0.4 times of ultimate vertical load was kept constant and then the lateral load was varied till the deflection of permissible limit was occurred. Series and parallel loading arrangements were also carried out for combined loading conditions. Two LVDTs were used to measure the lateral deflection and then results were interpreted from the load vs. settlement curve.

III. RESULTS AND DISCUSSION

A. Independent Vertical Loading

Independent vertical loading tests were carried out for all the four cases. The results are compared and presented in the Fig. 4.

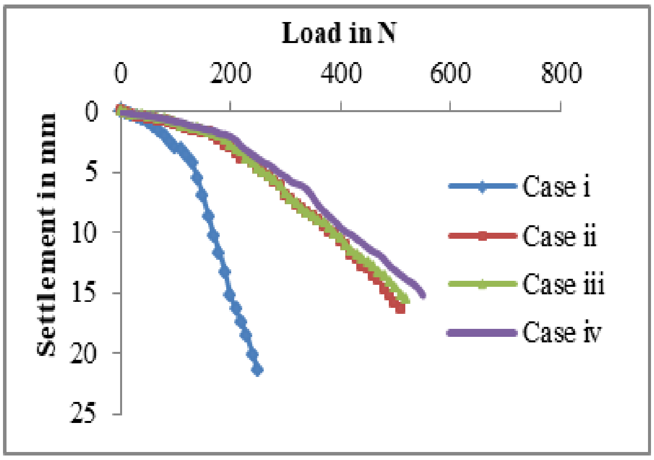

Fig. 4 Comparison of Load - Settlement Curve for Independent Vertical Loading

From the curve it is observed that during the initial stage, load settlement curve varies linearly which is mainly due to the uniform distribution of applied load to the surrounding soil by pile. Nonlinear variation was observed in the later stage due to the failure of surrounding soil by shearing action before the failure of pile occurs [14]. The pile capacity increases when the pile cap bottom rests on soil surface, top of the pile cap placed on the soil surface and pile placed below the soil surface for about 56%, 58% and 66% respectively compared with the pile placed above soil surface. Thus the load carrying capacity rises as the depth of the position of pile cap below the soil surface increased which is mainly due to increase in passive earth pressure around the pile and pile cap [13].

B. Independent Lateral Loading

Lateral load tests were carried out independently on the single pile and also on a group consisting of two piles. Similar to vertical loading, for lateral loading also the load carrying capacity and cap resistance increased when the pile cap is placed below the soil surface. Fig. 5 shows that the load carrying capacity and cap resistance increased as the depth of the position of pile cap increases below the soil surface. Capacity increases about 28%, 36% and 47% for case ii, case iii and case iv respectively when compared with case i.

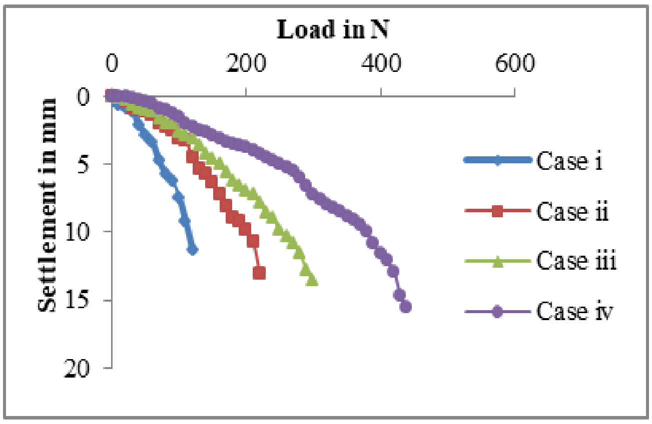

Fig. 5 Comparison of Load - Settlement Curve for Independent Lateral Loading

This increase in cap resistance and its capacity is due to increment in the passive earth pressure on the sides of pile and pile cap. It is also due to intensification in the confinement of soil with more pile – soil – pile cap interaction [2]. From the pile group placed in series and parallel orientation, the piles in series orientation repelled less than piles in parallel orientation at all the three different loading conditions when the pile cap is placed above the soil surface.

In some cases piles available in the parallel layout repelled not as much of than the piles in the series arrangement when the pile cap rests on the soil surface. The above performance is shown in Figs.6 to 9. The main reason behind this is due to the enlarged zone of passive resistance proposed by the earth mass ahead of the piles.

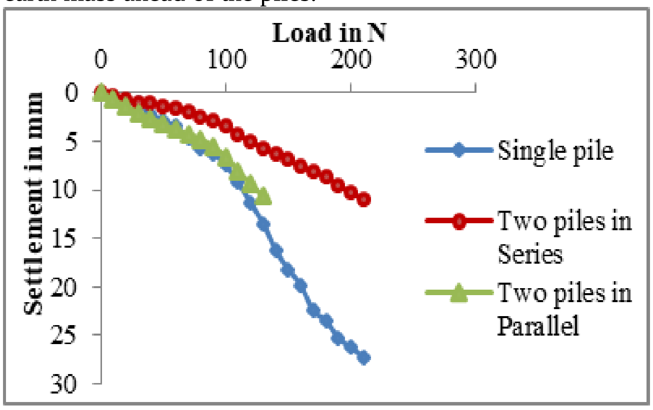

Fig. 6 Comparison of Load - Settlement Curve for case i

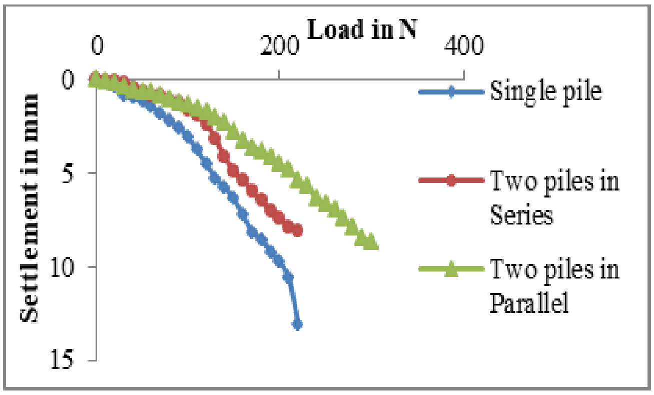

Fig. 7 Comparison of Load - Settlement Curve for case ii

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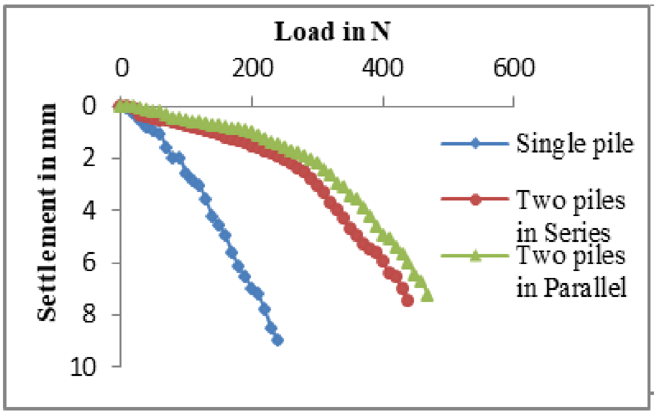

Fig. 8 Comparison of Load - Settlement Curve for case iii

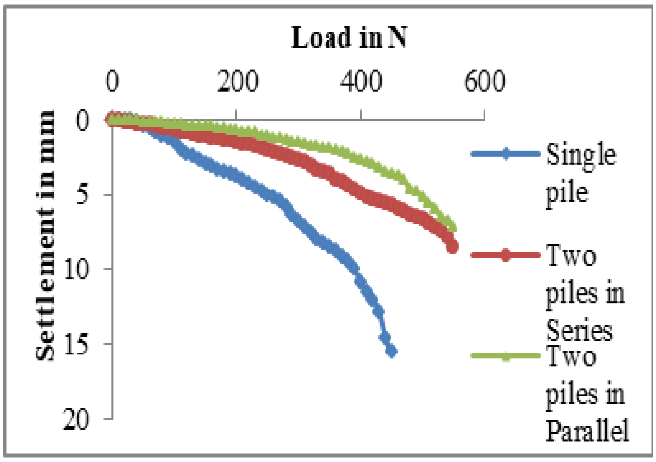

Fig. 9 Comparison of Load - Settlement Curve for case iv

C. Combined Loading

In case of combined loading, an increase in load capacity was found when the pile cap is placed below the soil surface. The percentage increase in load carrying capacity was respectively 30%, 43% and 55% when pile cap bottom rests on surface of soil medium, pile cap top placed on the surface of soil and the pile cap placed below soil surface to a depth of 35mm. Comparison graph of load vs settlement for all the four cases are presented in Fig.10.

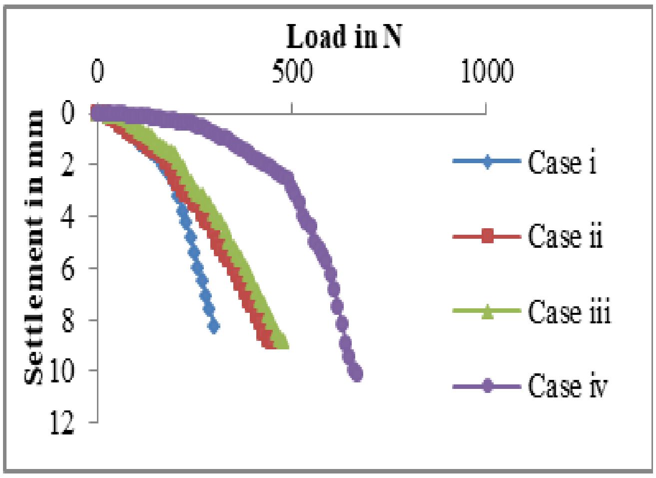

Fig. 10 Comparison of Load – Settlement Curve for Combined Loading Cases

Increase in lateral load capacity is mainly due to increase in axial capacity of pile [3] along with increased passive earth pressure on the sides of pile and pile cap [9]. It is mainly due to confinement of soil particles.

Load versus settlement graph of independent lateral loading and combined loading for both series and parallel arrangement are compared and shown in Fig. 11.

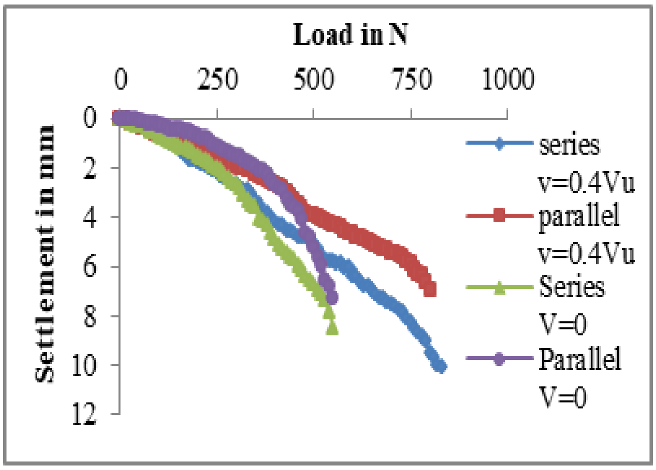

Fig. 11 Comparison of Load - Settlement of Independent Lateral Loading and Combined Loading for both Series and Parallel Arrangement

In some cases, pile group arranged in series pattern offers further resistance than piles arranged in the parallel pattern because yield moment and stiffness of piles are also the governing factors, instead of soil failure adjacent to the piles. The yield moment can be demarcated as the function of moment of inertia of the pile and cap section [10]. The value in x axis which consists of the moment of inertia is greater than the value in y axis; thereby series arrangement offers more resistance than parallel arrangement.

IV. CONCLUSION

The following conclusions were made based on the experimental observations and analysis

1. In case of vertical loading, on 1×2 pile group configuration the load carrying capacity increases about 66% when pile cap is placed below the soil surface. Similarly for lateral and combined loading, the load carrying capacity increased by 47% and 55% respectively when the pile cap is placed below the soil surface.
2. In the case single pile and pile group of 1×2, there is an increases in load capacity when piles are tested under combined loading this increase can be directly attributed to the development in confining stress along with intensification of lateral and shear stress in the frictional face. This confining stress increases the shear strength of the soil at different depths.
3. Position of pile cap is also a governing parameter in the load carrying capacity of piles. This capacity increased when the pile cap is placed below the soil surface. This increase is mainly due to maximization in the passive earth pressure.
4. The passive earth pressure and length of pile plays a dynamic role in the lateral resistance of pile. As the passive earth pressure increases with increment in pile length, the pile cap resistance is also found to be increased.

5. Load carrying capacity and the cap resistance can be increased by accumulating the number of piles and also by altering the piles arrangement with regard to the loading direction.

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