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Lateral Load Carrying Capacity of Different Combination of Vertical and Batter Pile Groups in Sand

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ABSTRACT

Lateral forces are due to impact of ships during berthing, wave action, traction and breaking forces in bridges, wind forces in towers and transmission line towers. Pile foundations in such situations are usually provided by a combination of vertical and batter piles. Literatures pertaining to lateral load carrying capacity of batter pile groups of various combinations is limited, hence in the present work an attempt is made to conduct series of experiments on various combination of model batter pile groups in sand. The model tests were conducted on pile groups of 2x2, by keeping vertical length of pile 400mm, diameter of pile 20mm. The piles were driven in both, loose state of sand (relative density=35%) and medium dense sand (relative density =50%). The Batter angle is varied from-30^0 to+30^{0}with respect to vertical axis. It was found that the combination of all the piles with batter carried more lateral load than when compared to vertical piles or combination of vertical and batter piles in a group and also the lateral resistance was found to be more for all the combination of batter pile groups with load axis perpendicular to batter, than with load and batter in the same direction as in case of conventional nomenclature of positive and negative batter. Also as the density of sand is increased the lateral resistance was found to increase.

Keywords: Batter Pile, Vertical Pile, LVDT, Lateral Load, Lateral Displacement, Loose Sand, Medium Dense Sand, Batter Angle.

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1. INTRODUCTION

Modern engineering structures require a foundation system that provides adequate support by transferring loads to the soil that are imposed on it or resisting vertical and horizontal pullout forces. Foundations may be classified into two categories: shallow and deep. In general, shallow foundations are constructed fairly close to ground surface and are usually constructed upwards from the bottom surface of an excavation. Deep foundations are employed when the soil strata immediately beneath the structure are not capable of supporting the load with tolerable settlement or adequate safety against shear failure. A pile driven at an inclination to the vertical to provide resistance to lateral or horizontal forces is defined as *Batter pile*. Also, known as *Brace pile, Spur pile or inclined pile, Raker pile*. The capability to install driven piles at an angle, or batter, gives them a distinct Benefit with respect to their capability to carry lateral loads. Batter piles carry lateral loads principally in axial compression or tension while vertical deep foundations carry lateral loads in shear and bending. When subjected to lateral loading, Batter piles will consequently have a greater capacity and be subject to smaller deformations than vertical piles of the same dimensions and material. Vertical piles are used in foundations to take vertical loads and small lateral loads. When the horizontal load per pile top the value suitable for vertical piles, batter piles are used in combination with vertical piles. The degree of batter that is the angle made by the pile with the vertical may go up to 30^0. If the lateral load acts on the pile in the direction of batter, it is called as *"In Batter* or *Negative Batter pile"*. If the load acts in the direction opposite to that of the batter, it is called as an "*Out Batter or Positive Batter pile"* as shown in Figure(refer with: Fig. 1)

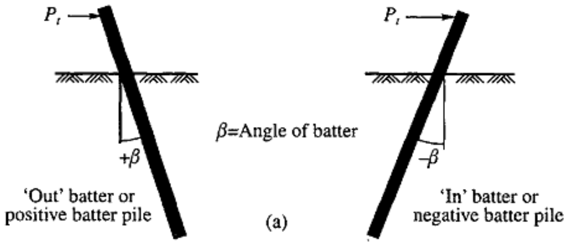
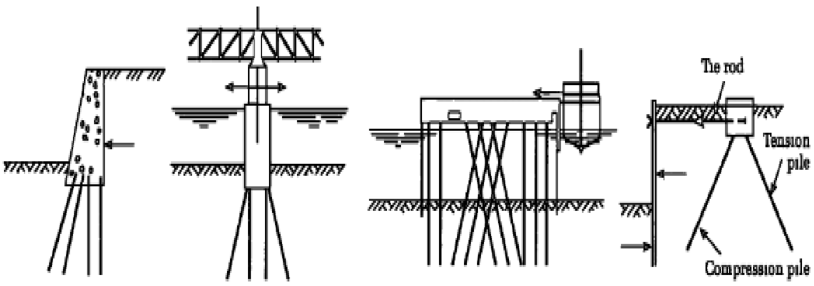


Fig.1 Battered Pile categorized into Positive and Negative Battered pile

Batter piles can supply driven pile foundations a significant benefit over drilled piers and other vertical elements for deep foundations subject to lateral loads. Batter piles are extremely advantageous when there is a large unsupported pile length or in weak soils.

The foundation of offshore structures on such unfavorable sub ground presents a challenge for both geotechnical and structural engineers. Pile foundations are generally preferred when heavy structure loads must be transferred through weak sub-soil to hard strata. All piles supporting offshore construction are subject to cyclic loading because of waves, tide and wind which could be lateral cyclic loading with different force and period. Due to the nature of these loads, the loads can be one way or both ways. In design of offshore constructions, it is consequently important to be able to predict the reaction of the soil subject to lateral cyclic loading.

Foundation piles are often required to carry inclined loads which are the resultant of the dead load ofthe structure and horizontal loads from wind, water pressure, or earth pressure on the structure. Where the lateral component of the load on the piles is small in relation to the vertical load, it can be carried safely by vertical piles.in the case of piles in wharves and jetties carrying the impact forces of berthing ships, and piledfoundations to bridge piers, trestles to overhead travelling cranes, tall chimneys, and retaining walls, pressure of winds, currents, waves, and floating ice the horizontal component is relatively large and vertical piles cannot generally be relied on to withstand the lateral forces. Raking or Batter piles have a very much higher resistance to lateral loading. The uses of batter piles are shown in Figure(refer with: Fig. 2)



(a) (b) (c) (d)

Fig.2: Uses of BatterPiles (a) Retaining Wall (b) Bridge pier (c) Wharf (d) Sheet pile Retaining Wall.

[1][Meyerhof and Yalcin (1993) studied the behavior of flexible batter piles under inclined loads in layered soil. The behavior of single free–head model of flexible vertical and flexible batter piles under central inclined loads in two-layered soil is Examined.

The bearing capacity of the piles is found to depend on the layered structure, load inclination, and pile batter.[2]Limin Zhang et al(1998) conducted Centrifuge lateral load tests on single battered piles at five pile inclinations. i.e., 1:0.25, 1:0.125, plumb, 1:–0.125, and 1:–0.25. The square aluminum model piles were 304 mm (12 in.) long and9.5 mm (0.375 in.) wide. The piles battered against the loading direction (positive batter) show greater resistance than the plumb pile, whereas those battered in the loading direction (negative batter) show lesser resistance than the plumb pile.[3]Akira et al(2004) studied seismic bearing capacity of grouped piles with battered piles. The passive earth resistance zone for the in-batter pile is slightly higher than that for the out batter pile, and the deformation of the in-batter pile is lesser than that of the out-batter pile. Consequently, the lateral bearing capacity of the battered pile was found to become greater in accordance with the degree. Vertical bearing Capacity of group piles was found to become less slightly in accordance with the increase of the degree of the battered piles.[4]Ghadge(2008)studied the axial pullout capacity of model batter piles in dry sand.It is seen that net ultimate pullout capacity increases with increase in α(batter angle),attains maximum value and then decreases.[5]Hiraniandverma(2011)carried out model test on batter pile group configuration (3×1) in uniform sand under horizontal loads. Batter pile groups (0^0, 0^0, $+10^0$) to (0^0, 0^0,$+30^0$) and(-10^0, 0^0, $+10^0$) to (-30^0, 0^0, $+30^0$) offer 40-55% more resistance as compared to vertical pile group. Batter pile groups (0^0, 0^0,-10^0) to (0^0, 0^0, -30^0) offer10-15% more resistance as compared to vertical pile group. This is similar to vertical pile groups.[6]AshrafandAhmed (2013)carried out pullout capacity of batter pile in sand. In order to delineate the significant variables affecting the ultimate uplift shaft resistance of batter pile in dry sand, a testing program consist of 62 pullout tests were conducted.The ultimate pullout capacity of a batter pile constructed in loose sand decreases with the increase in batter angle of the pile.

2. EXPERIMENTAL SETUP

Pile groups of 2x2 are used in the present experimental study. The piles are driven in the sand bed with particular batter angle for batter piles and vertically for vertical piles using wooden blocks. Lateral load is applied to the pile group through a pulley arrangement with steel wire attached to the hook provided at center of pile cap, and displacements are monitored for applied load with the help of LVDT. The schematic diagram with pile group combinations and model box with pile group is shown Figures (refer with: Fig. 3,Fig. 4)

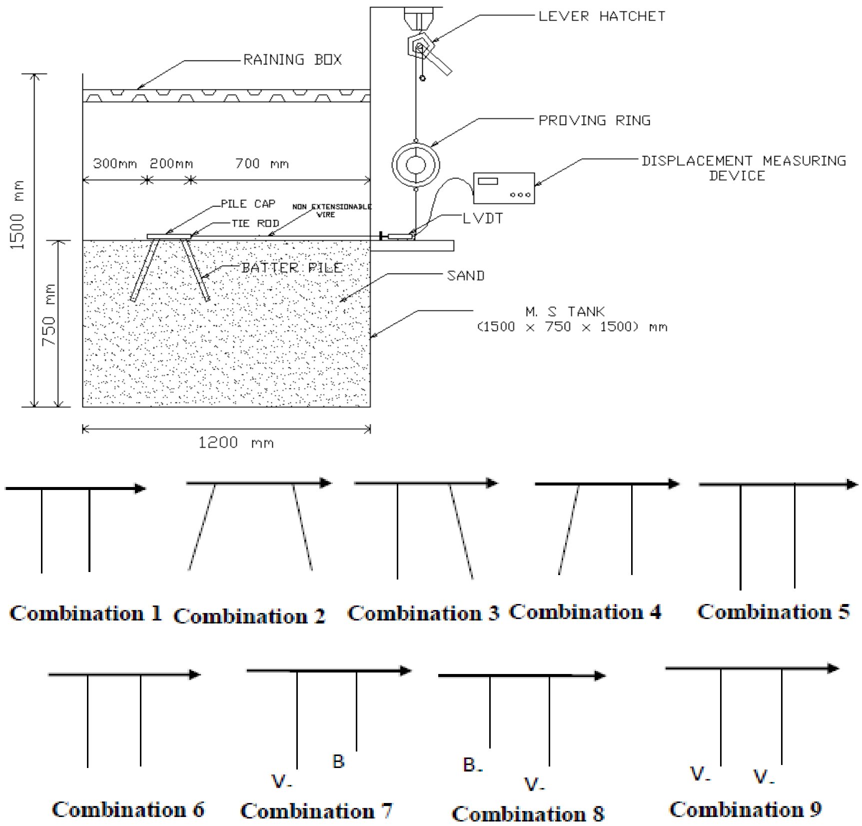


Fig.3 Schematic diagram of experimental set up and various pile groups combinations driven in sand

Fig.4 Model box with Pile Group Combinations

Experimental Programme

The following table shows the experimental program which has been put forth to study the behavior of different combinations of batter and vertical piles under lateral loading.Table (refer with: Table 1)

Results and Discussions

Figures show the load – displacement plot for different combinations of vertical and batter pile group with three different batter angles 10^0,20^0,30^0.Figures(refer with: Fig. 5 to Fig. 14)

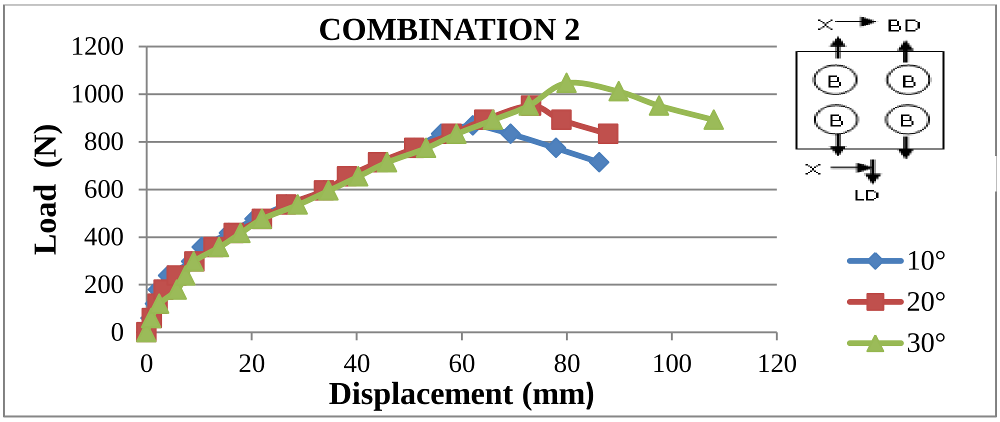


Fig.5 Lateral Load-Displacement curves for Batter pile group of combination 2 in loose sand

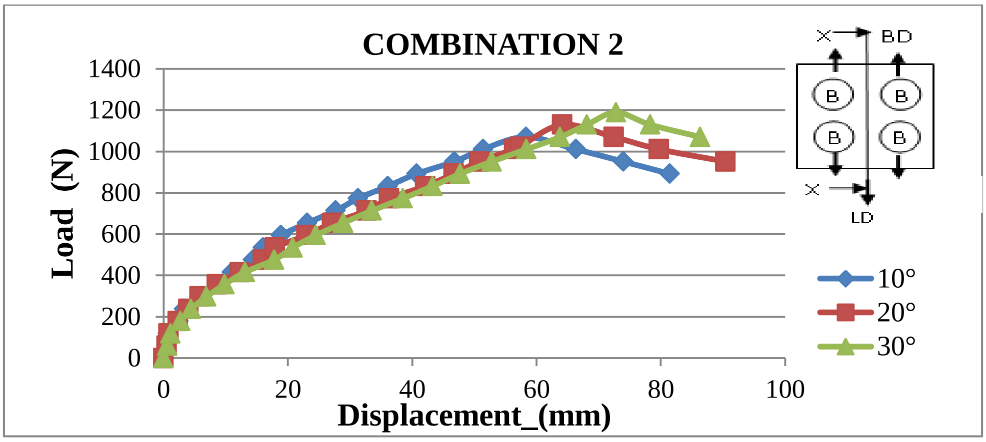


Fig.6 Lateral Load-Displacement curves for Batter pile group of combination 2 in medium dense sand

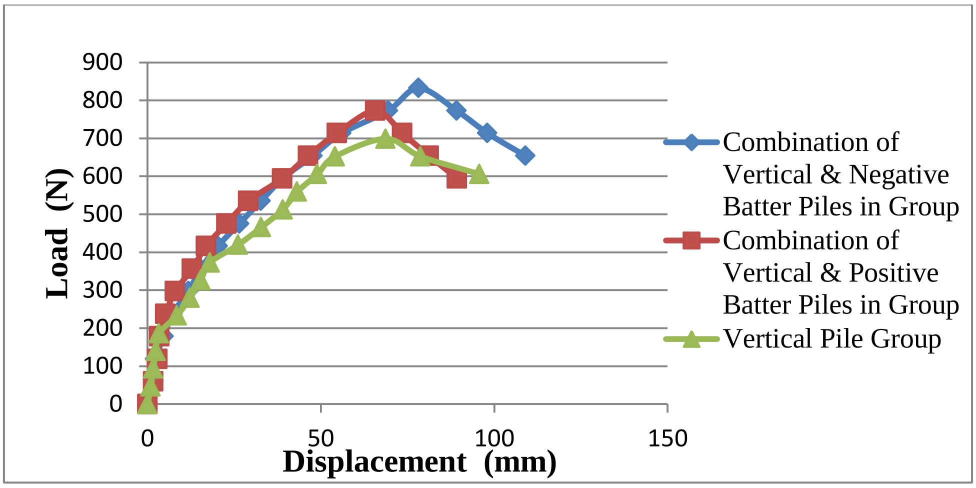


Fig.7 Comparison between various group Combinations with vertical pile group in Loose Sand

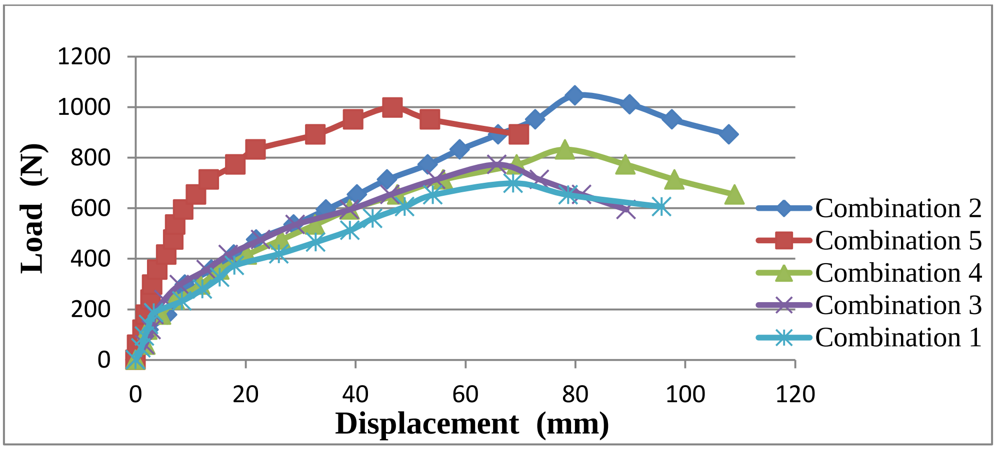


Fig.8Comparison between various Batter pile group combinations with vertical pile group in loose sand

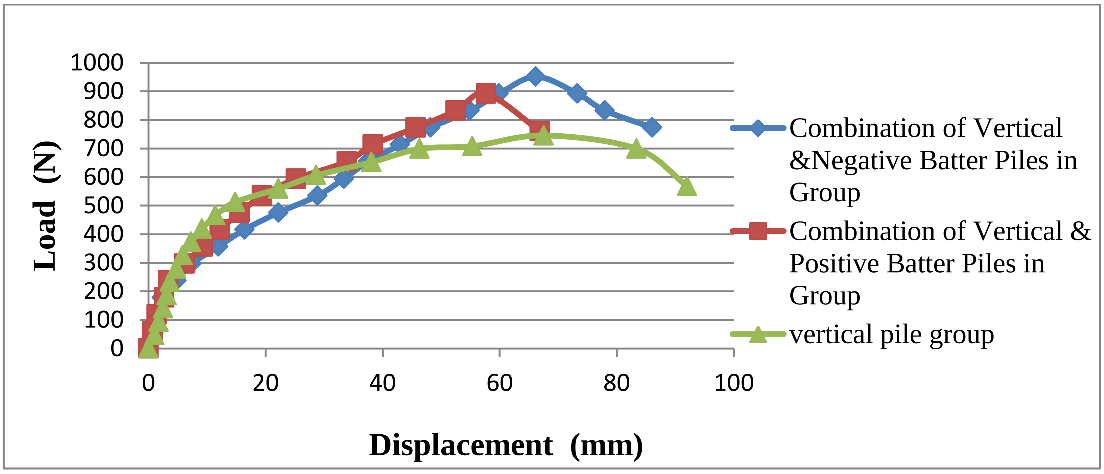


Fig.9 Comparison between various groups Combinations with vertical pile group in medium dense sand

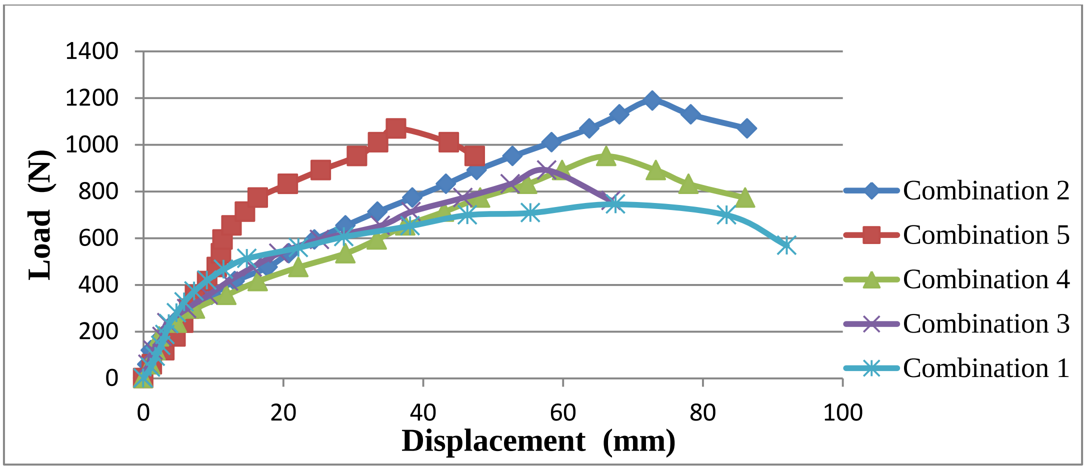


Fig.10 Comparison between various Batter pile group combinations with vertical pile group in medium dense sand

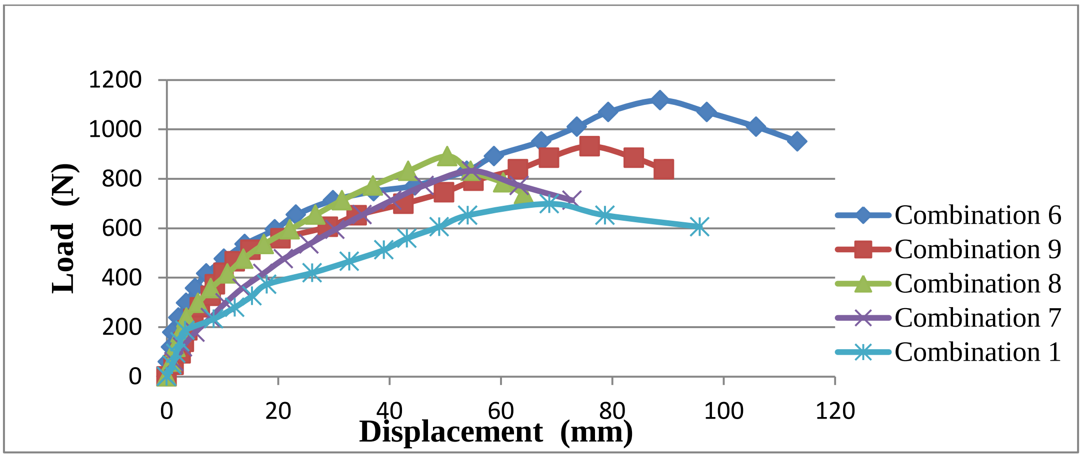


Fig.11 Comparison between various group combinations driven perpendicular to loaddirectionwith vertical pile group in loose sand

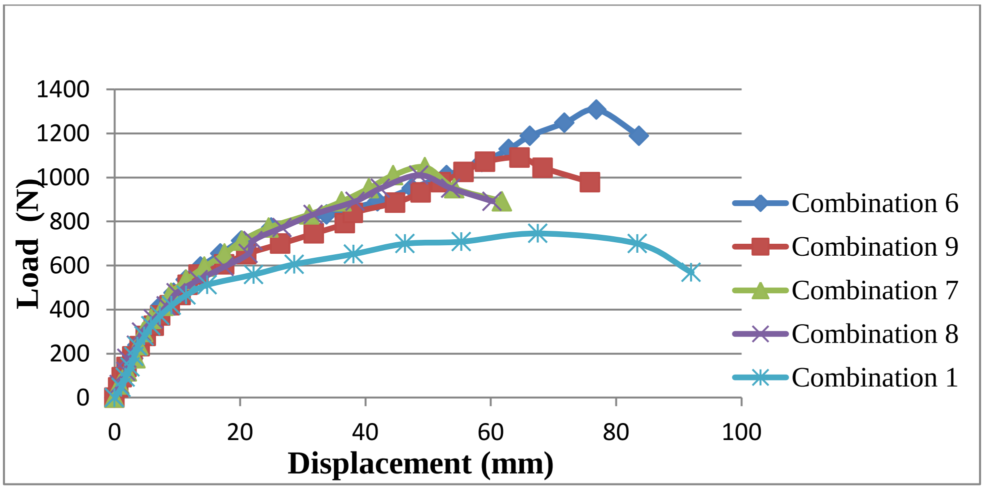


Fig.12 Comparison between various group combinations driven perpendicular to load direction with vertical pile group in medium dense sand

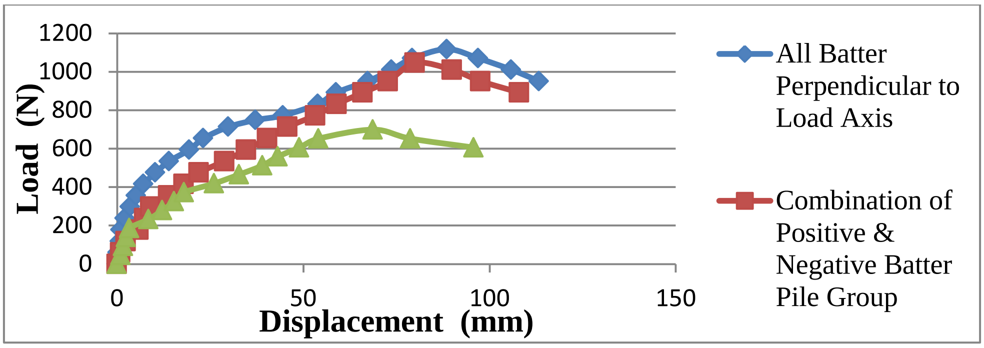


Fig.13 Comparison between various Batter Pile group combinations with vertical pile group in loose sand

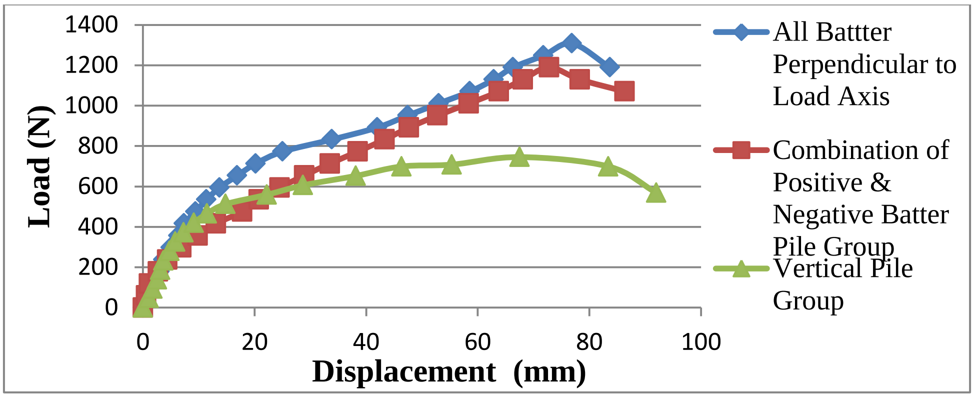


Fig.14 Comparison between various Batter Pile group combinations with vertical pile group in medium dense sand

CONCLUSIONS

The following conclusions were drawn from the present work

1. The lateral load- lateral displacement curves are practically non-linear.
2. The lateral resistance of pile was affected by pile batter and soil density.
3. The ultimate lateral load carrying capacity of batter pile groups, driven in medium dense sand, increases with an increase in batter angle and attains the maximum value (load)- once the maximum value is attained it then decreases.
4. The lateral resistance was found to be more in case of medium dense sand than loose sand for all the combinations investigated.
5. The lateral load carrying capacity of batter pile group also depends on pile group configuration/ combination.
6. The model experiment indicates that the lateral capacity of the negative 10^0 batter pile, 20^0 batter pile and 30^0 batter pile is 1.14 times, 1.19 times and 1.27 times respectively that of the vertical pile. The lateral capacity of the positive 10^0 batter pile, 20^0 batter pile and 30^0 batter pile is 1.03 times, 1.11 times and 1.19 times respectively that of the vertical pile.
7. The model experiment indicates that the lateral capacity of the negative 10^0 batter pile, 20^0 batter pile and 30^0 batter pile is1.03 times, 1.10 times and 1.19 times respectively that of the vertical pile. The lateral capacity of the positive 10^0 batter pile, 20^0 batter pile and 30^0 batter pile is 0.95 times, 1.02 times and 1.10 times respectively that of the vertical pile.
8. From the series of lateral load tests conducted on different combinations of batter and vertical pile group driven in sand, perpendicular/ normal to load direction offer more resistance than combination parallel to load direction.
9. It was observed that the lateral resistance was found to be more for all the piles with batters in a group combination with load axis perpendicular to batter, than with load and batter as in case of conventional nomenclature of positive and negative batter.
10. The optimum batter angle was not achieved, as in the present case the inclined length of batter pile and vertical pile is not the same, hence this leads to continuous increase of passive resistance with increase in batter angle.

11. Negative batter piles can expand the lateral load carrying capacity in combination with vertical pile group than positive batters.

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