INVESTIGATIONS ON BEHAVIOUR OF PILE GROUP UNDER COMBINED UPLIFT AND LATERAL LOADING IN SAND

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***Abstract*—**Pile foundations are normally adopted for high rise buildings and soil of low bearing capacity to exchange the loads to the soil. It constructed under off-shore structures, mooring systems for submerged ocean platforms and bridges constructed near steep slopes are subjected to high lateral loads due to earthquake,wind and wave forces. Structures like electric transmission towers and tall chimneys are subjected to both lateral and uplift loads. A study was undertaken to observe the behaviour of model aluminium piles under both uplift loads and lateral loads. The foundation medium adopted for the study is river sand. Aluminium pile of 8mm diameter and aluminium pile head of dimensions 75mm x 75mm x 12mm was used as model piles. Piles of varying L/D ratios such as 10, 20 and 30 were fabricated and tested. It was observed that the lateral capacity and the uplift capacity of piles increased with increase in L/D ratio during independent loading. Under combined loading, maintaining constant uplift load of about 20%, 40% and 60% of ultimate uplift load, the percentage increase in the lateral capacity of piles was about 28% to 156%. Under combined loading, maintaining constant lateral load of about 20%, 40% and 60% of ultimate lateral load, the percentage increase in the uplift capacity of piles was about 46% to 153%.

***Keywords*—** River sand, Aluminium pile, Lateral Load , Uplift Load and Combined Load.

I. Introduction

The important elements of pile foundation are pile cap and piles. Piles are either driven into ground or installed in pre-drilled holes. The pile foundations are necessary to ensure the safety of structure and structural stability, although its cost is expensive. Pile foundations can be either of single pile foundations or Pile group foundations and combined pile-raft foundations.

Structures constructed near coastal areas, jetty structures, mooring system for submerged ocean platforms and bridges built nearby large slopes are mostly hold up by pile foundations. These structures are subjected to lateral loads due to due earthquake shakings, wave actions and ship impacts. The increasing use of pile foundations under offshore structures and harbor structures has drawn attention to the need for more reliable methods of evaluating pile shaft resistance under combined uplift loads and lateral loads. The piles can be provided as single or group depending on the combined resistance under lateral loads and uplift loads to be carried by the foundation for the stability of the structure. The scope of present work was to study experimentally the behaviour of pile group in sandy soil under combined uplift and lateral loading for various L/D ratios of pile group.

The present study consists of investigation of load-displacement behaviour of model aluminium piles of varying L/D ratios such as 10, 20 and 30 under combined uplift loads and lateral loads.

II. EXPERIMENTAL STUDY

A. MODEL ALUMINIUM PILE GROUP

The model Aluminium pile group used in this study consists of varying L/D ratios such as 10, 20 and 30. The pile is of 2 x 2 pile group. The material used for model Aluminium pile group is aluminium of grade 6063. The aluminium pile has dimension of 8mm diameter and aluminium pile head has dimensions of 75mm x 75mm x 12mm.

Fig .1 Model pile group of L/D ratios 10, 20 and 30

B. MODEL TEST TANK

The size of the model tank was selected based on the dimension of the model footing. As per IS 1888-1982 which include plate load test, the width of tank was selected 5 times the width of footing. The depth of exploration is about 1.5 times the width of the structure from the lower third point. The test tank used for experimental investigations has dimensions of height 64cm and diameter 64cm.

C. PREPARATION OF FOUNDATION MEDIUM

The soil sample of required quantity passing through 4.75mm was taken and filled in tank following height of fall method in order to achieve the medium dense sand condition. The unit weight corresponding to the medium dense conditions conditions are 14.52g/cc, the angle of internal friction is 31° and the relative density of sand was 46.4%.

D. EXPERIMENTAL SETUP

The load frame consists of proving ring of 50kN capacity for load determination and two numbers of LVDT (Linear Variable Displacement Transducers) for observationof settlement. The following figure represents the arrangement for lateral loading, uplift loading and combined loading.

III. LABORATORY INVESTIGATION

A. SIEVE ANALYSIS

The percentage of various sizes of particles in the sand was found by mechanical sieve analysis conforming to IS 2720-part 4.The particle size distribution curve obtained was in fig 4.1.The properties of sand were tabulated in table 4.1

B. SPECIFIC GRAVITY

The specific gravity of the soil sample was found out by pycnometer method conforming to IS 2720 part 3. In this test, three trials have been done and the average value of the three values was taken as specific gravity of sand.

C. HEIGHT OF FALL

Vibrating table method conforming to IS 2720 – Part 14, was used to find the relative density of sand. To obtain the required unit weight of medium dense sand condition, sand was poured from the heights of 0cm, 10cm, 20cm, 30cm, 40cm, and 50cm. The maximum and minimum unit weight obtained are 1.378 g/cc and 1.549 g/cc.

D. ANGLE OF SHEARING RESISTANCE

Angle of shearing resistance was found by direct shear test confirming to IS 2720 – Part 13. The angle of shearing resistance was determined from the plot of Normal stress versus Shear stress which is shown in fig 3.2.The angle of internal friction was found to be 31°.

PROPERTIES	VALUE
Specific gravity	2.66
Coarse sand	4.8%
Medium sand	20.1%
Fine sand	73.2%
Silt and clay	1.9%
D10	0.23mm
D30	0.43mm
D60	0.84mm
Uniformity coefficient of the sand, Cu	3.65
Coefficient of curvature, Cc	1.00
Unit weight, Ɣ	14.52 g/cc
Angle of internal friction Ø	31°
Soil classification	Poorly graded sand (SP)

TABLE .1 PROPERTIES OF SAND

IV. RESULTS AND DISCUSSION

A. LATERAL LOAD TEST

The load - displacement relation of model pile group was compared for all L/D ratios. The comparative load-displacement graph for model pile group for all L/D ratios is shown in figure 2. As the load test was carried over the model pile group, the maximum displacement was exceeding 12mm for pile group with L/D ratios 20 and 30. From the lateral load test load test procedure as per IS: 2911 part 4(1985), the ultimate load (Hu) is the final load taken at 12mm displacement of pile group. Therefore the load taken by each pile group at 12mm was taken as the ultimate lateral capacity of pile.

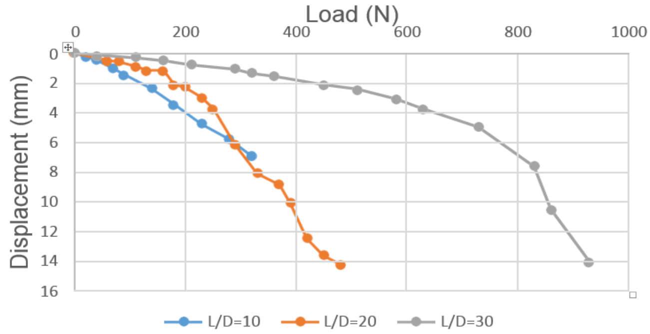

Fig. 2 Variation of lateral load with pile displacement for pile group for all L/D ratios

The ultimate resistance of the pile group increases due to the passive resistance with increase in pile length. The capacity of long flexible piles is due to mobilization of soil resistance along the effective pile length and ultimate moment capacity of pile material. The lateral capacities of the pile vary from 320N to 860N. The lateral capacity of pile group increases with increase in the L/D ratio of the pile group. As the pile length influences the pile group resistance, therefore increase in pile length increases the load carrying capacities under lateral loads.

B. UPLIFT LOAD TEST

The uplift load test was carried over the model pile group for all L/D ratios. The load-displacement of model pile group was compared together for all L/D ratios. The comparative load-displacement graph for model pile group for all L/D ratios are shown in figure 3.

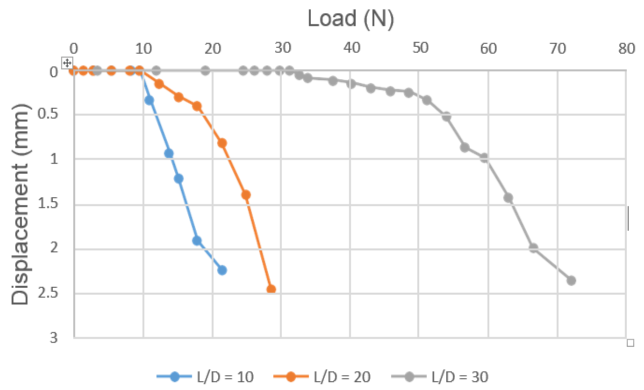

Fig.3 Variation of uplift load with pile displacement for pile group for all L/D ratios

C. COMBINED LOAD TEST

I. COMBINED LOAD TEST UNDER CONSTANT UPLIFT LOAD

In first case, combined loads test was carried over the model pile group maintaining constant uplift load of 20%, 40% and 60% of ultimate uplift load for each L/D ratio, the lateral load was varied. The comparative load-displacement graph for each L/D ratio with constant uplift load of 20%, 40% and 60% of its ultimate uplift capacity under varying lateral load was shown in figure 4 to 5.

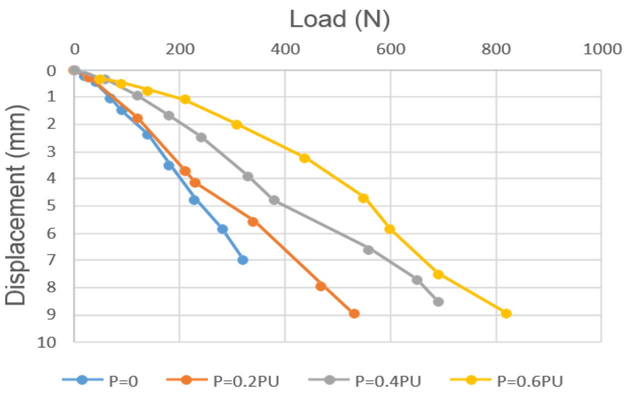

Fig.4 Variation of ultimate lateral load with pile displacement under constant uplift load for pile group for L/D ratios 10.

The ultimate lateral capacity increases with increase in constant uplift load. At the initial stage of load-displacement curve there is no effect due to the presence of constant uplift load. But at the second stage of the load-displacement curve shows variation due to the effect of increment of constant uplift load. The increase in the lateral capacity is so high in each case. In case of P=0.6PU the ultimate lateral capacity has increased to 156.25%. The Independent ultimate uplift load of pile group(Pu) is 21.57N.

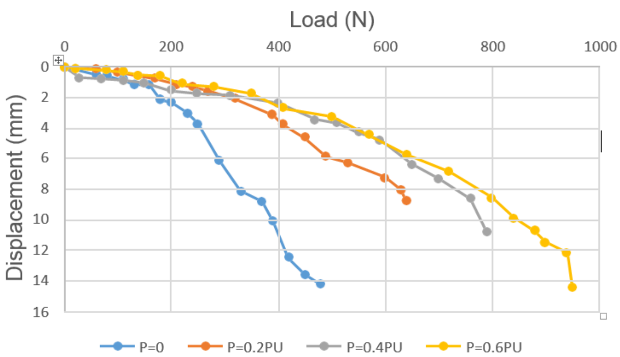

Fig.5 Variation of ultimate lateral load with pile displacement under constant uplift load for pile group for L/D ratio 20.

The displacement behaviour under combined loading should be studied for design purposes before taking the advantage of increase in lateral capacity of pile. It is observed from the fig that the lateral resistance increases for the same deflection with an increase of magnitude of constant uplift load. The Independent ultimate uplift load of pile(Pu) is 28.61N.

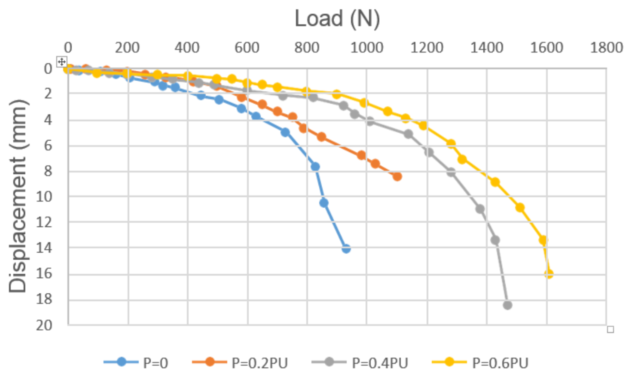

Fig.6 Variation of ultimate lateral load with pile displacement under constant uplift load for pile group for L/D ratio 30.

The increase in the ultimate lateral capacity is due to the restrained effect produced by the constant uplift load in combined loading. The Independent ultimate uplift load of the pile(Pu) is 72.07N. In case of long pile, the ultimate lateral capacity of pile increases by about 28% to 81%. In case of short pile, the ultimate lateral capacity of the pile increases by 66% to 156%. The ultimate lateral capacity increases for short piles and stabilizes for long piles.

ii. COMBINED LOAD TEST UNDER CONSTANT LATERAL LOAD

In second case combined load test was carried over the model pile group maintaining constant lateral load of 20%, 40% and 60% of ultimate lateral load for each L/D ratio, the uplift load was varied. The comparative load-displacement graph for each L/D ratio with constant lateral load of 20%, 40% and 60% of its ultimate lateral capacity under varying uplift load was shown in figure 4 to 5.

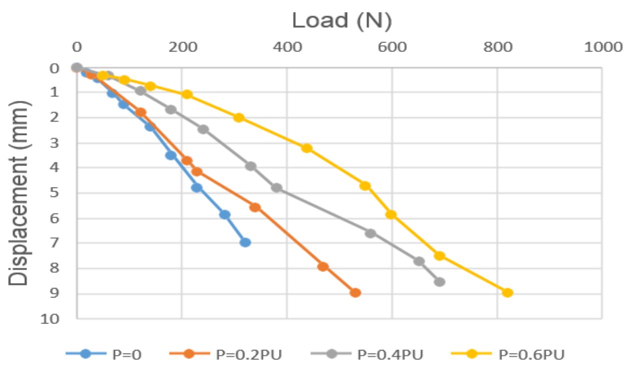

Fig.7 Variation of ultimate lateral load with pile displacement under constant uplift load for pile group for L/D ratio 10.

The ultimate lateral capacity increases with increase in constant uplift load. At the initial stage of Load-displacement curve there is no effect due to the presence of constant uplift load. But at the second stage of the load-displacement curve shows variation due to the effect of increment of constant uplift load. The increase in the lateral capacity is so high in each case. In case of P=0.6PU the ultimate lateral capacity has increased to 156.25%.The Independent ultimate uplift load of pile group(Pu) is 21.57N.

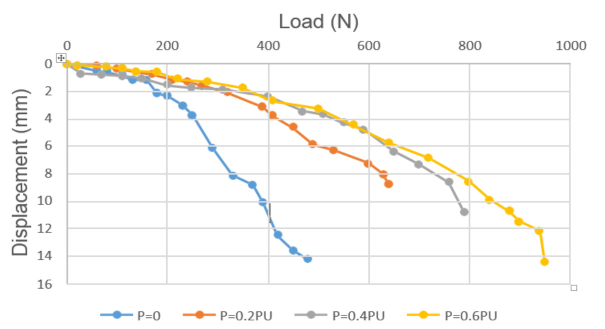

Fig.8 Variation of ultimate lateral load with pile displacement under constant uplift load for pile group for L/D ratio 20.

The displacement behaviour under combined loading should be studied for design purposes before taking the advantage of increase in lateral capacity of pile. It is observed from the figure that the lateral resistance increases for the same deflection with an increase of magnitude of constant uplift load. The Independent ultimate uplift load of pile(Pu) is 28.61N.

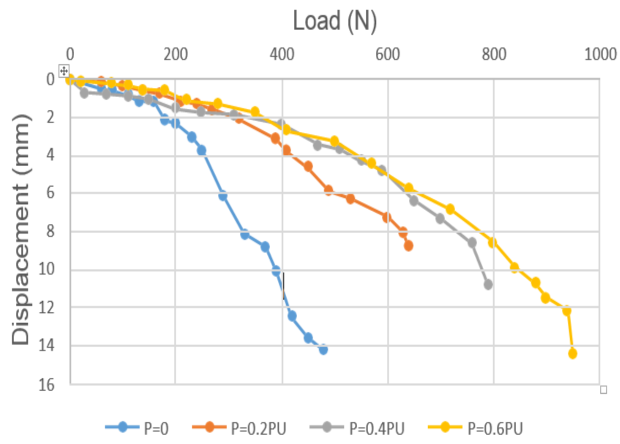

Fig.9 Variation of ultimate lateral load with pile displacement under constant uplift load for pile group for L/D ratio 30.

The increase in the ultimate lateral capacity is due to the restrained effect produced by the constant uplift load in combined loading. The Independent ultimate uplift load of the pile(Pu) is 72.07N. In case of long pile, the ultimate lateral capacity of pile increases by about 28% to 81%. In case of short pile, the ultimate lateral capacity of the pile increases by 66% to 156%. The ultimate lateral capacity increases for short piles and stabilizes for long piles.

TABLE.2 Ultimate Lateral Load Measured with and Without Constant Uplift Load

L/D	Ultimate lateral capacity of pile group Hu (N)			
	P = 0	*P = 0.2 Pu*	*P = 0.4 Pu*	P = 0.6 Pu
10	320	530	690	820
20	390	640	790	910
30	860	1100	1410	1560

Table.3 Increase in the percentage of lateral capacity under constant uplift load

L/D	Increase in the percentage of lateral capacity of pile group		
	P = 0.2 Pu	*P = 0.4 Pu*	*P = 0.6 Pu*
10	65.65	115.62	156.25
20	64.10	102.56	133.33
30	27.90	62.79	81.39

Table.4 Ultimate uplift load measured with and without constant lateral load

L/D	Ultimate lateral capacity of pile group Pu (N)			
	H = 0	***H = 0.2 Hu***	***H = 0.4 Hu***	H = 0.6 Hu
10	21.57	34.81	43.45	54.67
20	28.61	41.66	53.64	67.82
30	72.07	106.06	133.84	140.73

Table.5 Increase in the percentage of uplift capacity under constant lateral

L/D	Increase in the percentage of lateral capacity of pile group		
	H = 0.2 Hu	***H = 0.4 Hu***	***H = 0.6 Hu***
10	61.33	101.43	153.45
20	45.61	91.08	137.04
30	47.16	85.70	95.23

V. CONCLUSIONS

A. INDEPENDENT LATERAL LOADING AND UPLIFT LOADING

I. The lateral capacity and uplift capacity of piles increases with increase in L/D ratio. L/D ratio has a great influence on the load carrying capacity of the piles.

II. The uplift capacity of the piles was less compared to the lateral capacity of piles.

B. COMBINED LOADING

I. In combined loading, under constant uplift load, it was inferred that at low magnitudes of lateral load, the uplift load doesn’t affect the load- displacement response. However, with increase of lateral load, the lateral displacement doesn’t increase at the same rate, when constant uplift load was present. The same trend was observed in combined loading under constant lateral load.

II. In combined loading under constant uplift load, the percentage increase in the lateral capacity of piles is less for 20% constant ultimate uplift load compared with 40% and 60% constant ultimate uplift load.

III. The percentage increase in the uplift capacity of piles under constant lateral load of about 60% ultimate lateral load is higher than the percentage increase in the lateral capacity of piles under constant lateral uplift load of about 60% of ultimate uplift load.

IV. The ultimate lateral capacity of piles increases with increase in constant uplift load of about 20%, 40% and 60% of ultimate uplift load for all pile group.

V. The ultimate uplift capacity of piles increases with increase in constant lateral load of about 20%, 40% and 60% of ultimate lateral load for all pile group.

VI. Under combined loading, maintaining constant uplift load of about 40% and 60% of ultimate uplift load the percentage increase in the lateral capacity of piles was about 15 to 41%.

VII. Under combined loading, maintaining constant lateral load of about 40% and 60% of ultimate lateral load the percentage increase in the uplift capacity of piles was about 28% to 57%.

VI. REFERENCES

[1] Bhavik Parekh, S.W.Thakare: “Performance of Pile groups under Combined Uplift and Lateral loadings”, International Journal of Innovative Research in Science, Engineering and Technology, Vol.5 Issue 6.

[2] K.Madhusudan Reddy and R.Ayothiraman, 2015, “Experimental Studies on Behaviour on Single Pile under Combined Uplift and Lateral loading”, American society of Civil Engineers.

[3] U.K.Nath, P.J.Hazarika, “Lateral resistance of Pile cap – an experimental investigation”, International Journal of Geotechnical Engineering.

[4] Nihar Ranjan Patra, Prabhakar Jagannath Pise, 2001, “Ultimate Lateral Resistance of Pile Groups in Sand”,, American Society of Civil Engineers, Vol.127, No.6

[5] Khaled E.Gaver, 2013, “Uplift Capacity of Single Piles and Pile groups embedded in Cohesion less soil”, Alexandria Engineering Journal.

[6] Verma, A.K, Toshi, Ronak K. 2010, “Uplift Load Carrying Capacity of Piles in Sand”, IGS Mumbai chapter and IIT Mumbai.

[7] B.K.Pash, P.J.Pise, 2003, “Effect of Compressive load on Uplift Capacity of Modal Piles” American Society of Civil Engineers.

[8] L.G.Kong, R.P.chen. S.H.Wang, Y.M.chem, 2015, "Response of 3X3 Pile Groups in Silt subjected to Eccentric Lateral Loading", American Society of Civil Engineers.

[9] IS 2911 – part 1: 1985 Design and construction of Pile Foundation – code of practice.

[10] IS 2911 – part 4: 1985 Design and construction of Pile Foundation – load test on Piles.