BEHAVIOUR OF VERTICAL & BATTERED PILES IN GROUPS SUBJECTED TO LATERAL LOADS

SURAJ PRAKASH, RASHMI YADAV

Abstract: Pile foundation are provided to transfer the vertical & horizontal loads of superstructure like high rise buildings, bridges, offshore structures etc. to the deep strata in the soil. These vertical and horizontal loads are due to the loads coming from the superstructure and wind, water thrust, earthquake, earth pressure respectively. In a pile foundation, piles are used in groups. Vertical piles in a group of piles are more efficient to take vertical loads as compared to horizontal loads and when the horizontal load per pile exceeds the bearing capacity of the vertical piles in that case batter piles are used with vertical piles because batter piles can take more lateral loads than vertical piles. In this paper, a model study was conducted on four vertical pile group, four positive battered pile group & four negative battered pile group subjected to lateral loads. The batter angle for battered piles was $\pm 35^{\circ}$ with the vertical axis. Pile were spaced at 2.5d (d=diameter of pile) to each other. The soil used for model test was cohesionless soil. Lateral loads were applied in three stages on all the pile groups individually and it was found that under the repeated action of lateral loading, the deflection of the piles increased under the same loading. After comparing the results, it was found that the deflection of positive batter pile group is 23.07% less & deflection of negative batter pile group is 16.72% more than the deflection of vertical pile group under the same amount of lateral load. For better results in a pile foundation positive & negative batter piles can be used with vertical piles.

Keywords: Cohesionless soil, lateral loads, positive & negative battered piles, vertical piles.

Introduction: Pile foundations are often used in bridges and other structures to support the applied axial and lateral loads. It is considered a cost effective approach to utilize the stronger bearing capacity of deep layer soil where either the top layer of soil is not strong enough to bear the structure's load or the water level is higher than the ground level. Pile are classified into different types depending on the kind of material used in the construction such as timber, concrete, steel pile etc., the shape of pile such as square, circular and tapered; and the alignment of pile such as vertical and batter pile which furthermore classifies as positive and negative batter pile depending on the loading direction. Battered piles are usually used in offshore foundations and bridges to resist the lateral impact caused by wind and waves. Piles are usually slender, having high length to width ratio, and are mainly designed to resist axial loads. However, some structures such as high rise buildings, offshore structure, earth retaining walls are also subjected to horizontal or lateral pressure caused by wind force, wave force, traffic movement, water pressure and earth quake. For instance, in the bridge abutment, foundations can be subjected to lateral load induced by water waves and ship impact. Hence, the pile in a single or in a group as part of deep foundation of a structure has to resist both axial load and lateral load induced by the super-structure. Reese and Matlock, 1956 [1], Reese, Cox, and Koop, 1974 [2] and Broms, 1964 [3] proposed theoretical approaches for the analysis of laterally loaded. Tschebotarioff, 1953 [4] conducted model studies on single pile, three pile and seven pile group. He used wooden piles in submerged sand & clay. Murthy, 1965 [5] performed tests on battered piles with battered angles of 0°, ±30°, ±45°. He used aluminum alloy tubes of 30″ length and 0.75″ outer diameter and 0.035″ thickness as model piles. The tests were conducted in the laboratory with dry sand under controlled density conditions. The static tests were applied laterally and also normal to the pile axis in the case of single batter pile. From the tests he found that in a group of piles having battered piles are more resistant to lateral load than the pile groups having only vertical piles. And positive battered are more resistant than negative battered piles. Giannakou et al., 2010 [6] conducted an experimental study on seismic response of batter piles. The key goal of the study was to explore the conditions under which the presence of batter piles is beneficial, indifferent, or detrimental. Ren, Ming, and Hua, 2011 [7] made a study on proportional relation of lateral bearing capacity of batter pile by model experiments. Hirani and Verma, 2011 [8] investigated about the lateral load carrying capacity of model pile groups. The behavior of batter pile groups buried in sand and subjected to lateral loads were mainly focused. Goit and Saitoh, 2013 [9] conducted an investigative study on model tests and numerical analyses on horizontal impedance functions of inclined single piles embedded in cohesion less soil.

Model test setup & procedure

Preparation of model Cutting of piles cap: Pile caps were cut from a large sheet of mild steel of 12 mm thickness by using gas welding of desired shapes. The size of pile caps for all caps are 11.5 cm × 11.5 cm.

Grinding of piles cap: After cutting the piles cap, the process of grinding is done on bench grinding machine to remove the extra slag and to achieve the proper alignment.

Marking of drill hole: Marking is done with the help of hand punching tool for the purpose of drilling the hole at proper location.

Making of holes in piles cap: Holes were drilled vertical & inclined at an angle of ±35° with vertical axis.

Marking of tank: Marking of tank was done for the purpose of filling the tank in layers for getting uniform density of the sand in the tank.

Soil used: Sand was used in the model test for providing the foundation to the piles groups. After sieve analysis various test were conducted to find out the properties of sand. Results are given in Table 1.1.

Table 1.1: Properties of the sand

S. No.	Property	Value
1.	Effective size (D_{10})	0.135mm
2.	Uniformity coefficient (C_u)	2.00
3.	Coefficient of curvature (C_c)	1.00
4.	IS Classification	SP
5.	Passing 1.18 mm IS Sieve	100%
6.	Mean specific gravity (G)	2.64
7.	Minimum void ratio (e_{min})	0.55
8.	Maximum void ratio (e_{max})	0.83
9.	Minimum dry density	1.47gm/cc
10.	Maximum dry density	1.70gm/cc

Table 1.2: Lateral load v/s deflection of 4V pile group

Load (kgf)	Deflection (mm)		
	Loading	Unloading	Reloading
0	0	4.19	4.19
2	0.18	4.71	4.4
4	0.76	6.01	5.08
6	1.32	6.49	5.52
8	2.15	7.12	6.08
10	2.84	8.02	6.61
12	3.48	8.53	7.06
14	4.16	8.94	7.59
16	5.06	9.17	8.07
18	5.96	9.61	8.63
20	6.58	9.83	9.11
22	7.27	10.17	9.68
24	8.24	10.62	10.06
26	9.06	10.8	10.58
28	10.76	11.07	11.27
30	11.21	11.21	12.02

Model Piles & Pile Caps: Steel pipes were used for making model piles. The external diameter of these piles was 20 mm and 1.6 mm wall thickness. The total length of the pile is 80 cm with an embedded length of 70 cm.
Model Tank: The tank used in test with pulley arrangement for applying lateral load is shown in Figure 2.

The dimensions of the testing tank were kept large enough to avoid the boundary effect. The shape of tank was rectangular with length 120 cm, width 90 cm, height 90 cm. It was provided with a pulley arrangement for applying lateral loads.

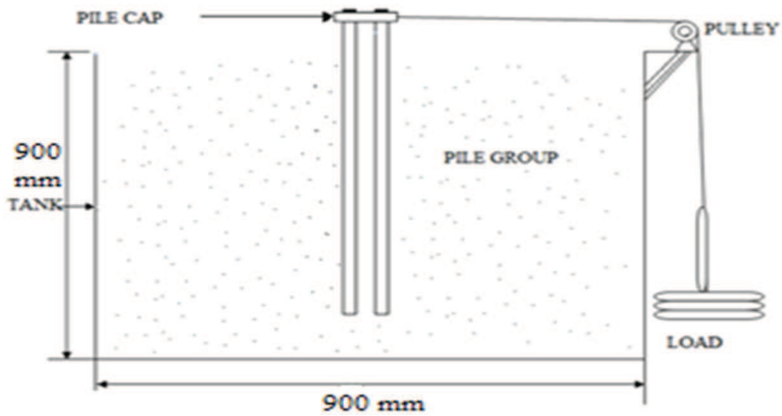

Fig.1: Model test setup for 4 vertical piles

Test Procedure: The testing tank was filled up to a height of 80 cm by rainfall technique for getting the uniform density of 1.6 gm/cc. After that piles were driven vertical or inclined according to the group in the sand at 2.5d (d=diameter of pile) spacing. The embedded length of pile was 70 cm. Pile cap was placed over piles surface and adjusted horizontally. Then free end of the wire was attached gently to hook of the piles cap and by passing it over the pulley attached other end with hanger. A dial gauge was attached to the bottom of the hanger to note down the horizontal deflection of the piles group. After doing this, load was applied in steps (2kg every time) and increment of the load was done up to the point till total horizontal deflection exceeded 10-15 mm. After this, load was brought back to zero in same steps corresponding reading of dial gauge were noted.

Table 1.3: Lateral load v/s deflection of +4B pile

Load (kgf)	Deflection (mm)		
	Loading	Unloading	Reloading
0	0	5.92	5.92
2	0.68	6.57	6.05
4	1.36	7.6	6.25
6	1.47	8.19	6.59
8	2.89	8.9	7.09
10	3.24	9.77	7.6
12	4.11	10.57	8.28
14	5.89	11.27	9.06
16	6.81	12.17	9.34
18	7.85	12.73	10.82
20	8.82	13.2	11.58
22	9.57	13.36	12.43
24	11.95	13.42	13.46
26	13.77	13.77	14.67

The reading was also done in steps and corresponding reading of dial gauge were noted. Each time the reading of dial gauge was noted only after it had attained a constant value.

Results: The tests were performed on four vertical, four positive & negative battered pile groups. Tables 1.2, 1.3 & 1.4 gives the results of four vertical pile group, four positive batter pile group & four negative batter pile group. Fig. 2,3 & 4 show load deflection curves for four vertical pile group (4V), four positive batter pile group (+4B) & four negative batter pile group (-4B) respectively. Fig. 5 show comparison between these three pile groups & it was found out that deflection of positive batter pile group is 23.07% less & negative batter pile group is 16.72% more than the deflection of vertical pile group under the same amount of lateral load.

Table 1.4: Lateral load v/s deflection of -4B pile group

Load (kgf)	Deflection (mm)		
	Loading	Unloading	Reloading
0	0	4.19	4.19
2	0.18	4.71	4.4
4	0.76	6.01	5.08
6	1.32	6.49	5.52
8	2.15	7.12	6.08
10	2.84	8.02	6.61
12	3.48	8.53	7.06
14	4.16	8.94	7.59
16	5.06	9.17	8.07
18	5.96	9.61	8.63
20	6.58	9.83	9.11
22	7.27	10.17	9.68
24	8.24	10.62	10.06
26	9.06	10.8	10.58
28	10.76	11.07	11.27
30	11.21	11.21	12.02

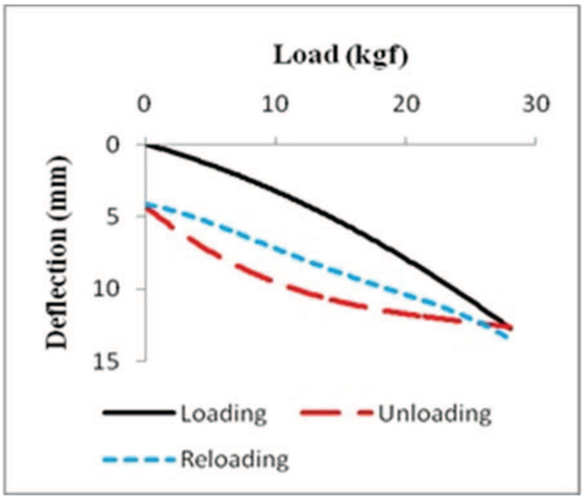

Fig. 2: Load deflection curve for 4V pile group

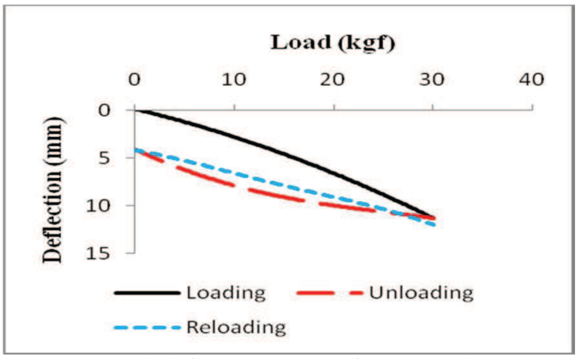

Fig. 3: Load deflection curve for +4B pile group

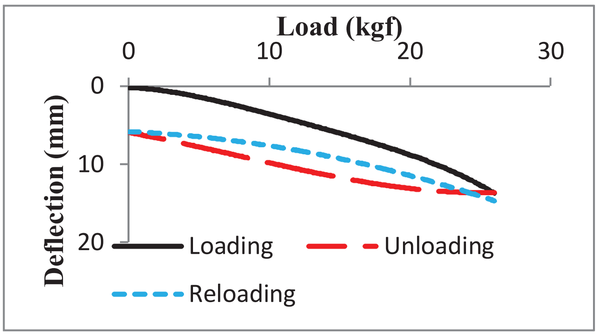

Fig. 4: Load deflection curve for -4B pile group

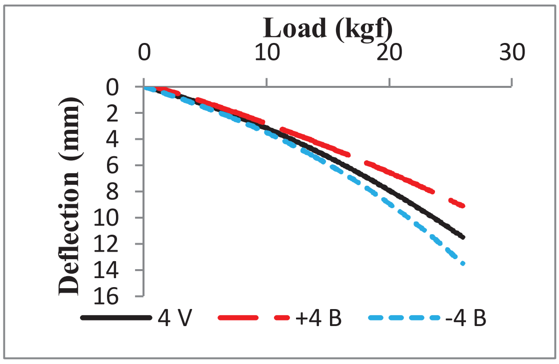

Fig. 5: Comparison curve of 4V, +4B, -4B piles

References :

1. L. C. Reese and H. Matlock, "Non Dimensional Solutions for Laterally loaded piles with soil modulus assumed proportional to depth," in Eighth Texas conference on Soil Mechanics & Foundation Engg., 1956.
2. L. C. Reese, W. R. Cox, and F. D. Koop, "Analysis of Laterally loaded Piles in Sand," in 6th Offshore Tech. Conf. Houston, 1974.
3. B. B. Broms, "Lateral Resistant of Piles in Cohesionless Soil," J. Soil Mech. Found., vol. 90, pp. 123–156, 1964.
4. G. P. Tschebotarioff, "The Resistance of Lateral Loading of Single Piles and of Pile Group," ASTM, vol. 38, 1953.

5. V. N. S. Murthy, “Behaviour of Batter Piles Subjected to Lateral Loads,” Indian Institute of Technology,Kharagpur, 1965.
6. Giannakou, N. Gerolymos, G. Gazetas, M. Asce, T. Tazoh, and I. Anastasopoulos, “Seismic Behavior of Batter Piles : Elastic Response,” J. Geotech. Geoenvironmental Eng., vol. 139, no. September, pp. 1187–1199, 2010.
7. L. F. Ren, Y. J. Ming, and J. Y. Hua, “Study on Proportional Relation of Lateral Bearing Capacity of Batter Pile by Model Experiments,” J. Soil Mech. Found. Div.,1CETCE, pp. 6888–6891, 2011.
8. K. R. Hirani and A. K. Verma, “Lateral Load Carrying Capacity of Model Pile Groups .,” in National Conference on Recent Trends in Engineering & Technology, 2011, no. May.
9. C. S. Goit and M. Saitoh, “Model Tests And Numerical Analyses on Horizontal Impedance Functions of Inclined Single Piles Embedded in Cohesionless Soil,” Earthq. Eng. Eng. Vib., vol. 12, no. 1, pp. 143–154, 2013.

* * *

Post Graduate Student, Post Graduate Student
Department of Civil Engineering
NIT, Kurukshetra (Haryana)
surajsaini64@gmail.com, yadav.rashmi573@gmail.com