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Pile Head Response of Vertical and Belled Pile to Excavation Induced Lateral Soil Movements

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Abstract: - **Deep excavations performed in urban populated cities forms an inevitable part of the construction sequence. During excavation, excessive soil movement may cause severe damages to the adjacent structures. Lateral forces acting on the piles from surrounding soil movement results in additional internal forces and excessive deflection of piles. In this present study, the behavior of pile foundation subjected to lateral soil movements was studied by conducting laboratory model tests. Excavation was carries out in stages at vertical intervals of 2.5m from the ground surface up to a depth of 10m. No study was carried out to compare the excavation induced lateral movement in belled and vertical pile. The study was carried out by varying excavation depth, distance of pile from excavation face. Belled piles have minimum lateral deflection compared to vertical pile during excessive soil movement. For a depth of excavation 2.5m belled and multi belled piles have shown 66 % to 82 % and 71 % to 100% less deflection when compared with short piles. When compared with short piles, intermediate piles and long piles have shown 14 % to 45% and 47 % to 63 % less deflection values for 2.5m depth of excavation.**

Keywords: Belled pile, excavation, lateral deflection, soil movement, vertical pile.

1. INTRODUCTION

Excessive soil movement due to excavation may cause severe damages to the adjacent structures and foundations. Major applications of carrying out excavations include explorations, mining, environmental restoration and construction. The process of moving earth, rocks or other material with tools, machinery or explosives are referred as excavation. It forms the primary step involved in any construction process. In order to construct various types of underground utilities like subways, basements, tunnels, underground pipe lines and other municipal constructions deep excavation has to be carried out. During excavation, sudden reduction of horizontal earth pressure lead to movement of soil towards the excavation face. Apart from that, basal heave may be induced due to the release of vertical stress. This inward soil movement and basal heave often cause ground subsidence around the excavation. Hence, deep excavation must be carried out in a proper and systematic way, so that it must provide adequate safety. Else, excessive soil movement may cause damage to the adjacent structures, structural foundations and sometimes this can even be fatal.

Numerical analyses on excavation induced lateral movement on adjacent piles have been conducted, e.g. S. Karthigeyan et.al. (2007). Number of studies on pile load deflection behavior under lateral soil movement were reported, e.g. Kasinathan Muthukkumaran et.al. (2014), Mostafa E.I. (2012), H.Y.Qin et.al. (2010). However, the researches just only investigated the behaviours of supported excavation adjacent to pile.

In this paper present a comparative study on excavation induced lateral movement on vertical and belled pile. Laboratory model studies were conducted varying the parameters such as distance of pile from soil movement source, excavation depth, length of pile.

Locally collected clean river sand was used in all the experiments as a soil medium with 35% relative density. Model piles were fabricated from hollow circular stainless steel pipe of outer diameter 15mm and thickness 1 mm. The tips of the piles were closed. Three pile lengths were chosen for the study- 12D, 18D, 24D (D =Diameter of pile), which corresponds to short, intermediate and long piles (Fig. 1). The belled pile have enlarged area 1.5D at bottom and multi belled pile have one or more enlarged area at 2D intervals (Fig. 2).

Fig. 1 Model pile of length 12D, 18D and 24D

Fig. 2 Belled and multi belled pile

A. Properties of Sand

Table. I Index properties of sands

Parameters	Value
Specific Gravity	2.60
Effective size, D10 (mm)	0.18
D30 (mm)	0.35
D60 (mm)	0.71
Uniformity coefficient, Cu	3.94
Coefficient of curvature, Cc	0.95
Maximum density (g/cc)	1.7
Minimum density (g/cc)	1.45
Sand density (35% RD) (g/cc)	1.528
Angle of internal friction (35% RD) (degree)	33

III. EXPERIMENTAL PROGRAMME

Dimension of test tank was taken as 660mm × 660mm × 600mm. The test tank was fabricated from plain galvanized steel sheet of thickness 0.30mm. Model ground was prepared by controlled volume filling technique. For controlled volume filling technique, initially the depth of test tank was divided into different sections having height of 120 cm. Knowing the volume of each section and density of soil bed required to be maintained throughout the test, the quantity of soil required to fill a particular height was obtained. The dry density of sand taken for testing was 1.528kN/m3, which corresponds to a relative density of 35 %. After filling the soil bed up to the base of pile foundation, the model pile was kept in position. The pile tip was forced into the model ground manually and verticality of the pile was checked. After filling the test tank, the measurement system was installed which includes the deformation dial gauge for measurement of the pile head deflection.

Fig.3 Excavation process in loose sand

To simulate the excavation process, one side of the tank was made by removable aluminium planks of 50mm high. These aluminium planks were connected rigidly onto mild steel flat welded to sides of the tank. Rigid connection was ensured by bolting, where 6mm diameter black bolts were inserted and tightened within holes. The process of excavation was simulated by removing the steel planks provided at one side of the tank in stages (Fig. 3). Upon removal of steel planks in stages, confining pressure within the soil mass gets released and thus exposed soil moves towards the excavation face. The same procedure was then repeated on model ground with the pile foundation installed in position. Excavation was carried out by removing the steel planks stage by stage at a time interval of 10 minutes.

IV. RESULTS AND DISCUSSIONS

Laboratory model studies were conducted varying the parameters such as distance of pile from soil movement source, length of pile and belled conditions, excavation depth. The pile head response under each parameter was studied with respect to depth of excavation. The observation so made on the model pile was scaled up so as to obtain the response of the prototype.

The allowable lateral deflections prescribed by structural design codes could be 5mm to 12mm for the foundations of

residential and industrial structures, which could even be relaxed up to 5% of the width of pile in case of the offshore structures. It can be seen that for 2.5m depth of excavation, the pile head deflection comes within the permissible deflection of 12mm (Fig. 4). For depth of excavation 5m, the lateral pile head deflection of small pile is only found to be much more than the permissible limit, at spacing of 1m from excavation face (Fig. 5). When7.5m depth of excavation, the pile head deflection of intermediate pile comes within the permissible deflection of 12mm only at spacing of 5m from the excavation face. In case of long piles at 7.5m depth of excavation permissible limit of deflection is at 3m from soil movement (Fig. 6). For 10m depth of excavation, the pile head deflection of multi belled pile is within the permissible limit at a spacing of 4m from source of soil movement (Fig. 7). In case of multi belled piles, distance of 1m from excavation face, the pile head deflection is permissible at 5m depth of excavation (Fig. 8). When compared with small piles belled piles have less deflection values (Fig. 9).

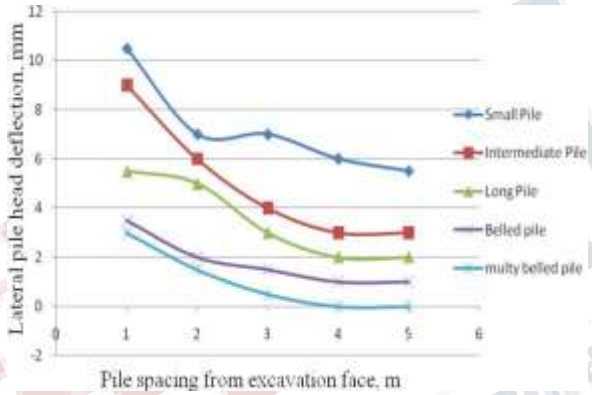

Fig.4 Variation of lateral pile head deflection of piles for excavation depth 2.5m

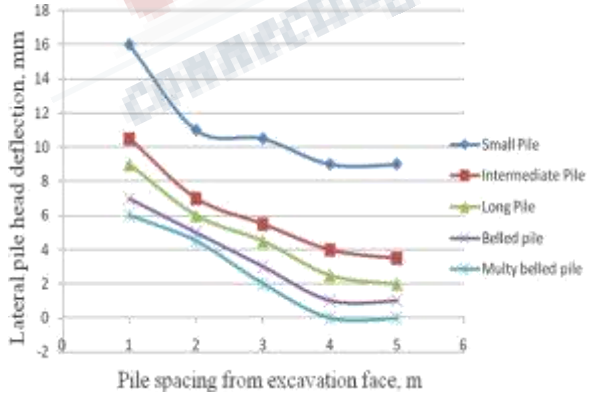

Fig.5 Variation of lateral pile head deflection of piles for excavation depth 5m

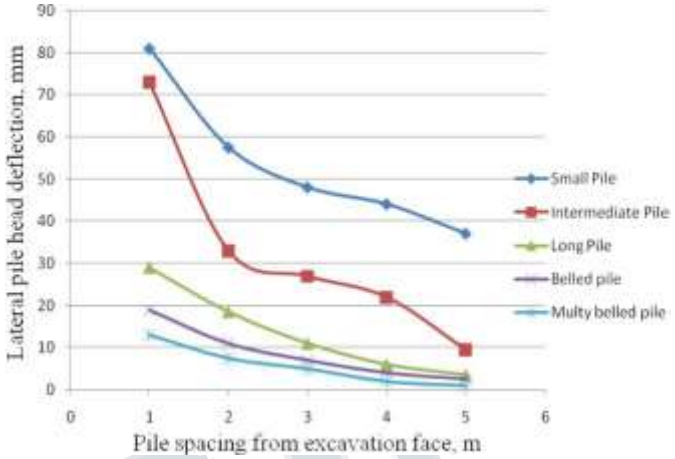

Fig.6 Variation of lateral pile head deflection of piles for excavation depth 7.5m

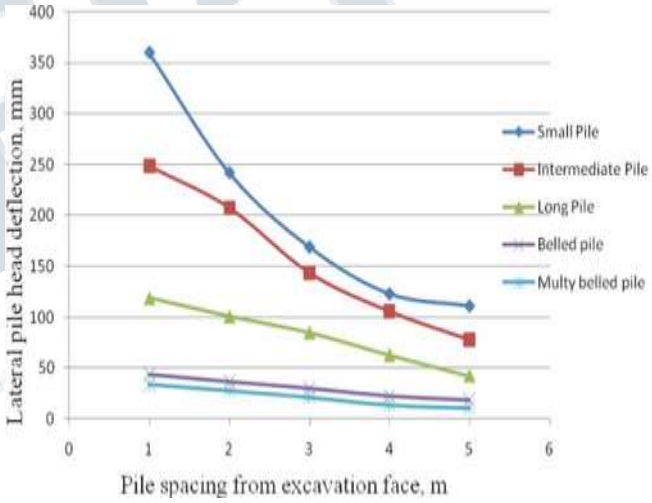

Fig.7 Variation of lateral pile head deflection of piles for excavation depth 10m

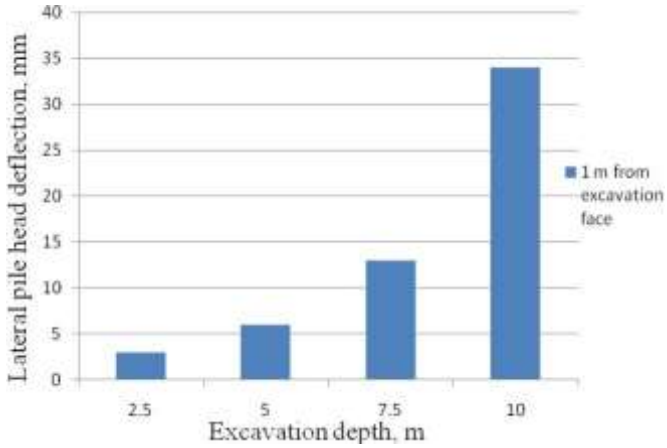

Fig.8 Lateral pile head deflection of multi belled pile 1m from excavation face

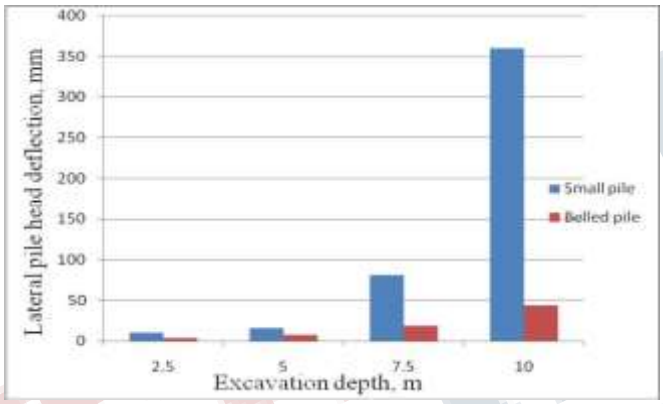

Fig. 9 Comparison of lateral pile head deflections of small and belled pile, 1m from excavation face

CONCLUSION

Severe damages to pile foundations due to adjacent excavation or constructional activities have been reported. It focuses the importance of studying the pile head response of passive pile foundations. It was found that the pile response to adjacent excavation induced soil movement in loose sand depends upon the location of the pile foundation from the source of soil movement. Lateral pile head deflection decreased exponentially with increasing distance from the centre of pile foundation to the excavation face. As the depth of excavation increases from 2.5m to 10m, the lateral passive load acting along the length of pile increases and thus the lateral pile head deflection also increases.

For a depth of excavation 2.5m belled and multi belled piles have shown 66 % to 82 % and 71 % to 100% less deflection when compared with short piles.

When compared with short piles, intermediate piles and long piles have shown 14 % to 45% and 47 % to 63 % less deflection values for 2.5m depth of excavation.

For 5m depth of excavation in loose sand intermediate pile has shown 43 % to 100 % less deflection values compared to that of short piles.

For a depth of excavation of 7.5m and 10m multi belled piles have 84 % to 97 % and 90% less deflection values compared to that of short piles.

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