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PILE HEAD RESPONSE OF GROUP PILE TO EXCAVATION INDUCED SOIL MOVEMENTS

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ABSTRACT: This paper presents the results of small scale laboratory model tests on 1x2 group pile embedded in medium dense sand subjected to progressive unsupported excavations. Tests were conducted on 1x2 group pile, to investigate the effect of slenderness ratio, orientation of pile group with respect to excavation face and distance from excavation face on performance of pile foundation. The tests were carried out on group piles with lengths 12D, 18D and 24D (D- pile diameter) by varying pile locations from excavation face in both parallel and series configuration. Pile group in parallel configuration deflected more than that in series configuration.

INTRODUCTION

Excavation process forms one of the inevitable construction sequences which have to be carried out with utter care. Movements induced by excavation greatly influence the safety of buildings, subways, underground pipelines and other municipal constructions around a pit. So the consequent environmental effects have become key problems in excavation and caused much attention. Major problem associated with the excavation process is its influence on the performance of the adjacent pile foundations. The lateral forces acting on piles from soil movement are of significant concern in the design of pile foundations, especially since they may result in additional internal forces and excessive deflection on the piles. In extreme cases, they might damage the piles and groups and compromise the serviceability and stability of the supported structures. Often piles are constructed in groups to support the structures and behaviour of pile groups differ substantially from that of a single pile. In view of the deadly hazards associated with excavation near existing buildings, it is vital for geotechnical engineers to develop a better understanding of pile behaviour due to excavation-induced lateral soil movements.

Previous experimental studies on laterally loaded piles and pile groups include theoretical methods to evaluate the lateral response of vertical piles subjected to lateral soil movements (Chen and Poulos 1997; Goh and Wong 1997; Guo and Ghee 2006; Liang and Han 2013). However, as Leung et al. (2000) have pointed out, very limited field data are available to verify these theoretical methods as it is practically impossible to instrument existing piles in the field. Several researchers had conducted centrifuge tests to investigate the adverse effects of supported deep excavation on existing pile foundation (Leung et al. 2000; Chow et al. 2006; Leung et al. 2009). Also a number of numerical methods have been proposed for analyzing the response of single piles subjected to lateral loading from supported excavation-induced lateral soil movements (Martin and Chen 2004; Karthigeyan and Rajagopal 2007). A very few researchers have studied the lateral response of group pile due to an unsupported adjacent progressive excavation (Leung et al. 2009; Guo and Ghee 2010; Chandrasekaran et al. 2010; Qin and Guo et al. 2012). In real field situations, unsupported excavations at shallow depth are also carried out. In the present paper, an attempt has been made to study the response of piles in a group due to an adjacent unsupported excavation.

The objective of this paper is to investigate experimentally the effect of lateral loading due to adjacent unsupported excavation induced soil movements on the existing 1x2 group pile embedded in medium dense sand. The test results in terms of lateral pile head deflection with excavation depth, location of pile from the soil movement source for different pile slenderness ratios and 1x2 group pile orientation with respect to excavation face, are reported in this paper.

MATERIALS USED

The materials used in this experimental study are as follows:

Test Tank

Dimension of test tank was taken as 660mm x 660mm x 660mm, which was fabricated from plain galvanized steel sheet of thickness 0.28mm. To simulate the excavation process, one side of tank was made by removable aluminium planks of 50mm high. Fig. 1 given below shows the test tank fabricated for the study.

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Fig. 1 Test tank fabricated for the model study

Soil

The soil used in this study was river sand collected from Pattambi region, Kerala. The properties of sand were determined by carrying out laboratory tests as per IS recommendations and are listed in Table 1.

Table 1 Properties of Sand

Parameter	Values
Effective size, D_{10} (mm)	0.25
D_{30} (mm)	0.40
D_{60} (mm)	0.70
Uniformity Coefficient C_u	2.80
Coefficient of Curvature, C_c	0.91
Specific Gravity, G	2.68
Minimum density, $\gamma_{d\ min}$ (kN/m^3)	15.30
Maximum density, $\gamma_{d\ max}$ (kN/m^3)	18.40
Maximum void ratio, e_{max}	0.72
Minimum void ratio, e_{min}	0.43

The sand was classified as poorly graded sand, designated as SP. The value of dry density of soil and angle of internal friction for a relative density of 50% are given in Table 2.

Table 2 Dry Density and Angle of internal friction of soil in medium dense state

Denseness of soil	Dry Density (kN/m^3)	Angle of internal friction, Ø (°)
Medium Dense	16.70	40°

Model Pile Group and Pile Cap

Model piles were fabricated from hollow circular stainless steel pipe of outer diameter 15mm and thickness 1mm. M20 grade reinforced cement concrete pile of 750mm diameter was considered as prototype in this study. Three pile lengths (9m, 13.5m and 18m) were chosen for the study, which corresponds to short, intermediate and long piles as per recommendations given by Terzaghi (Muttharam and Sherin Nisha 2009). Dimensions and material properties of the pile designed for the study are given in the following Table 3.

Table 3 Dimensions and Properties of Pile Group

Description	Model Values
Diameter of pile	15mm
Length of pile	180m, 270mm, 360mm
Material for pile	Stainless Steel Pipe
Poisson's Ratio	0.30

A pile cap was connected rigidly to the free head of pile. Rigid connection at the top end was made by bolting. The properties of pile cap used in this study are given in Table 4.

Table 4 Dimensions and Properties of Pile Cap

Description	Model Values
Size of pile cap	120mm x 120mm
Depth of pile cap	20mm
Material for pile cap	Mild Steel

EXPERIMENTAL PROGRAMME

Laboratory model study was performed carefully by simulating progressive unsupported excavation induced soil movements. Fig. 2 given below show the schematic diagram of the test set up.

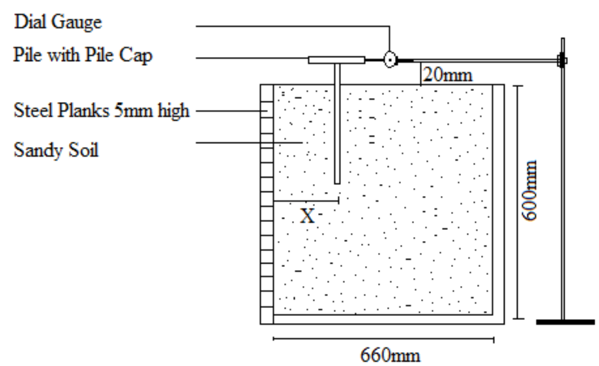

Fig. 2 Schematic Diagram Showing the Test Set up

A brief description of the stages involved in model study is as follows:

Preparation of Model Ground

Model ground was prepared by controlled volume filling technique. Computed mass of soil was filled and compacted up to the desired height so as to achieve a consistent density of model ground. The dry density of sand taken for testing is 16.70kN/m^3, which corresponds to 50% relative density. For each test, the model ground was so prepared that a uniform relative density of the soil bed is maintained.

Installation of Model Pile

After filling the soil bed up to the base of pile foundation, the pile tip was forced into the model ground manually and the verticality of the pile was checked by keeping the spirit level. Pile foundation was kept in such a way that the pile head projects by 20mm above the ground surface.

Setting up Deformation Dial Gauge

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After filling the test tank, the measurement system was installed which includes the deformation dial gauge (least count 0.01mm) for the measurement of the pile head deflection. Before commencement of excavation, the deformation dial gauge was set to zero.

Simulation of Excavation Process

The process of excavation was simulated by removing the steel planks at a time interval of 10 minutes. Readings at which the soil movement ceases was noted down. Upon completion of test, the dial gauges were removed and the pile was withdrawn. The procedure was repeated by varying distance of model pile from the excavation face as 2cm, 4cm, 6cm, 8cm and 10cm which is equivalent to 1m, 2m, 3m, 4m and 5m of the prototype.

Testing Phases

In a single model test, pile length, pile group orientation and spacing from the excavation face was kept constant and the variation of pile head response with respect to depth of excavation was observed. Keeping the parameters, pile length and pile group orientation constant, variation of pile head response with respect to excavation depth was studied by varying only the spacing from excavation face. Five model tests each were performed for 3 pile lengths under 2 different pile group orientations with respect to excavation face (parallel and series orientation). Thus a total of 30 model tests were performed to study the influence of pile location from the excavation face, pile group orientation and slenderness ratio with respect to depth of excavation.

RESULTS AND DISCUSSIONS

The observations so made on the model pile group were scaled up so as to obtain the response of the prototype and are discussed here within.

Influence of Pile Group Location from Source of Soil Movement

Pile Group with L = 9m in Parallel Orientation

Table 5 given below gives the values of lateral pile head deflection for 1x2 group pile foundation with length 9m subjected to progressive unsupported excavation induced soil movements when the piles within a group are positioned in parallel orientation.

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 (Karthigeyan et al. 2011).

Table 5 Lateral pile head deflection of 1x2 group pile with length 9m in parallel orientation

Pile Location from Excavation Face, X (m)	1	2	3	4	5
Excavation Depth, h (m)	Lateral Pile Head Deflection, mm				
2.5	4.0	3.0	2.5	2.0	1.0
5.0	5.0	4.5	3.0	2.5	1.5
7.5	15.0	14.0	12.5	8.0	3.5
10.0	88.0	49.5	35.5	28.0	15.0

From Table 5 it can be seen that up to 5m depth of excavation, the obtained deflection values are within permissible limits even when the pile group is at 1m from the excavation face. For excavation depths more than 7.5m, the lateral pile head deflection is found to be much more than the permissible limit. Therefore, as distance from the excavation face to the centre of the pile group in parallel orientation increases the lateral resistance offered by the pile group also increases and hence as distance increases, the lateral pile head deflection reduces. This percentage reduction is found to range from 25% to 75% for a depth of excavation of 2.5m and 10% to 70% for a depth of excavation of 5m, with an increase in spacing from 1m to 5m. Thus it can be concluded that it is safe to conduct unsupported excavation up to 5m depth in medium dense sand even if 1x2 group pile is at a distance of 1m from the excavation face.

Pile Group with L = 9m in Series Orientation

Lateral pile head deflections for 1x2 group pile foundation with length 9m located at 1m, 2m, 3m, 4m and 5m from the excavation face due to progressive excavation induced soil movements in series orientation is tabulated and shown in Table 6 given below.

Table 6 Lateral pile head deflection of 1x2 group pile with length 9m in parallel orientation

Pile Location from Excavation Face, X (m)	1	2	3	4	5
Excavation Depth, h (m)	Lateral Pile Head Deflection, mm				
2.5	3.0	2.0	1.5	1.0	0.0
5.0	5.0	3.5	3.0	2.0	1.0
7.5	18.0	12.5	10.5	8.0	5.0
10.0	52.5	52.0	32.0	21.0	13.0

For 1x2 group pile in series orientation also the pile group has maximum pile head deflection when the pile group is located at 1m from the excavation face. Thereafter, the deflection decreases with increase in spacing from the excavation face. The percentage decrease in lateral pile head deflection is found to range from 33% to 100% for a depth of excavation of 2.5m and 30% to 80% for a depth of

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excavation of 5m, with an increase in distance from 1m to 5m. Also the pile head deflection is within permissible limits even at a spacing of 1m from the excavation up to 5m excavation depth.

Variation of pile head response with respect to pile group orientation and excavation depth for pile with L = 9m

Fig. 3 shown below gives the variation of lateral pile head deflection 1x2 group pile in parallel and series orientation with length 9m for a depth of excavation of 2.5m.

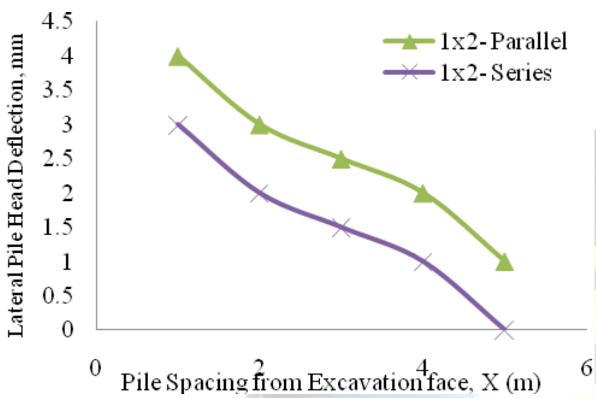

Fig. 3 Variation of lateral pile head deflection for 1x2 group pile with L = 9m excavation depth 2.5m

From Fig 3 it is apparent that 1x2 pile group in series orientation has the least deflection values compared to 1x2 group pile in parallel orientation at the same location from the excavation face. 1x2 group pile in series orientation has 10% to 50% less deflection values compared to fixed-head single pile and 25% to 100% less deflection values compared to 1x2 group pile in parallel orientation.

Variation of lateral pile head deflection for 1x2 group pile with length 9m in parallel and series orientation when subjected to a depth of excavation of 5m is shown in Fig. 4.

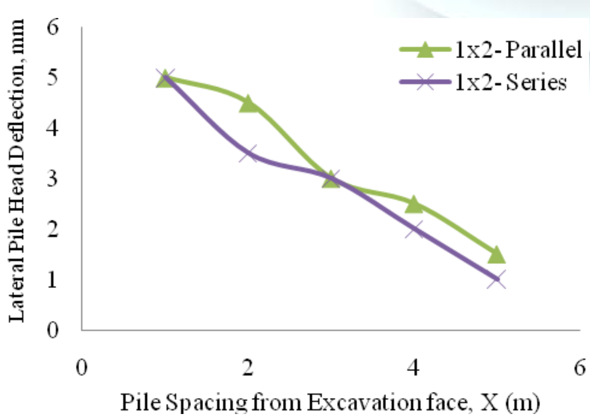

Fig. 4 Variation of lateral pile head deflection for 1x2 group pile with L = 9m for excavation depth 5m

As depth of excavation increases from 2.5m to 5m, the deflection of pile has increased considerably. For 5m depth of excavation also 1x2 group pile in series orientation has 20% to 33% less deflection values compared to 1x2 group pile in parallel orientation.

Pile Group with L = 13.5m in Parallel Orientation

Variation of pile head deflection for floating 1x2 group pile with length 13.5m located at 1m, 2m, 3m, 4m and 5m from the excavation face to the centre of pile group subjected to excavation induced soil movements is tabulated and given in Table 7 given below.

Table 7 Lateral pile head deflection of 1x2 group pile with length 13.5m in parallel orientation

Pile Location from Excavation Face, X (m)	1	2	3	4	5
Excavation Depth, h (m)	Lateral Pile Head Deflection, mm				
2.5	2.5	2.0	1.5	1.0	0
5.0	3.5	3.0	2.0	1.5	0.5
7.5	14.5	13.0	10.0	3.5	1.5
10.0	36.0	35.5	23.0	12.0	4.5

From Table 7 it can be noted that deflection values falls within permissible limit for 1x2 group pile with length 13.5m in parallel orientation up to 5m depth of excavation as in the case of group pile with length 9m. But the magnitude of deflection is less compared to that of group pile with length 9m. As the distance from the excavation face increases, a percentage decrease of 20% to 100% in lateral pile head deflection is observed for 1x2 group pile with length 18D in parallel orientation when it is subjected to 2.5m depth of excavation. Again for 5m depth of excavation the percentage decrease is found to range from 14% to 86% for 1x2 group pile in parallel orientation.

Pile Group with L = 13.5m in Series Orientation

Lateral pile head deflections for 1x2 group pile foundation with length 13.5m located at 1m, 2m, 3m, 4m and 5m from the excavation face due to progressive excavation induced soil movements in series orientation is tabulated and shown in Table 8 given below.

Table 8 Lateral pile head deflection of 1x2 group pile with length 13.5m in series orientation

Pile Location from Excavation Face, X (m)	1	2	3	4	5
Excavation	Lateral Pile Head Deflection, mm				

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Depth, h (m)					
2.5	2.0	1.5	1.0	0.5	0
5.0	3.0	2.5	1.5	1.0	0
7.5	4.5	3.0	2.5	2.0	1.0
10.0	14.0	13.5	4.5	3.5	2.0

From Table 8 it can be noted that a percentage decrease of 25% to 100% and 17% to 100% in lateral pile head deflection is observed for depths of excavations 2.5m and 5m respectively with an increase in distance from the excavation face from 1m to 5m.

Variation of pile head response with respect to pile group orientation and excavation depth for pile with L = 13.5m

Variation of lateral pile head deflection for 1x2 group pile in parallel and series orientation with length 18D for a depth of excavation of 2.5m is plotted as given in Fig. 5.

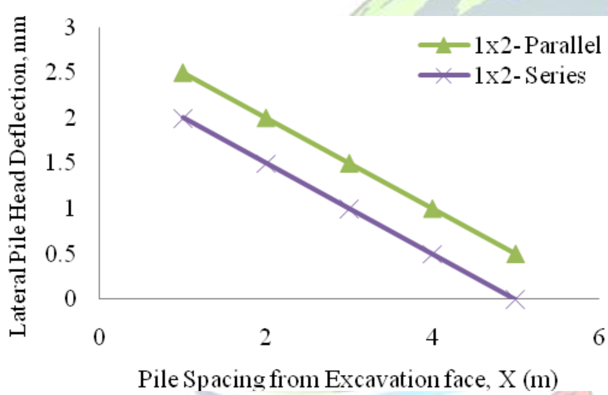

Fig. 5 Variation of lateral pile head deflection for 1x2 group pile with L = 13.5m for excavation depth 2.5m

Lateral pile head deflection for 1x2 group pile in parallel orientation with length 13.5m is found as higher than that of 1x2 group pile in series orientation for different excavation depths. However, for both cases as excavation depth increases lateral pile head deflection also increases. 1x2 group pile in series orientation has 20% to 100% less deflection values compared to 1x2 group pile in parallel orientation when it is subjected to 2.5m depth of excavation.

Fig. 6 given represents the variation of lateral pile head deflection for 1x2 group pile in parallel and series orientation with length 13.5m for a depth of excavation of 5m.

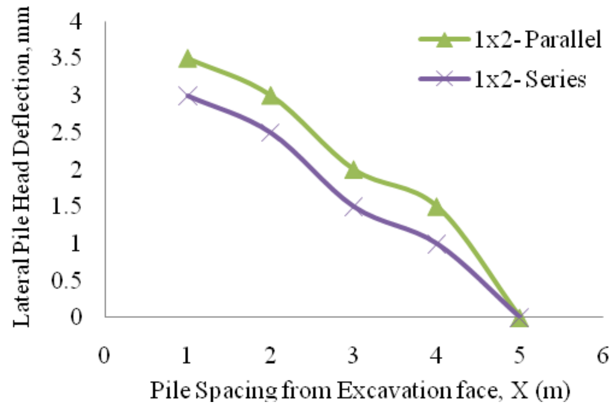

Fig. 6 Variation of lateral pile head deflection for 1x2 group pile with L = 13.5m for excavation depth 5m

1x2 pile group in series configuration has 14% to 33% less deflections compared to 1x2 pile group in parallel orientation. A similar trend as obtained for the earlier case is observed here

Pile Group with L = 18m in Parallel Orientation

Variation of pile head deflection for floating 1x2 group pile with length 18m located at 1m, 2m, 3m, 4m and 5m from the excavation face to the centre of pile group subjected to excavation induced soil movements is tabulated and given in Table 9 given below.

Table 9 Lateral pile head deflection of 1x2 group pile with length 18m in parallel orientation

Pile Location from Excavation Face, X (m)	1	2	3	4	5
Excavation Depth, h (m)	Lateral Pile Head Deflection, mm				
2.5	1.5	1.0	0.5	0.5	0.0
5.0	3.0	2.5	1.0	1.0	0.0
7.5	4.0	3.5	1.5	1.5	0.5
10.0	10.5	6.5	5.5	2.5	2.0

From Table 9, it can be seen that the lateral pile head deflection for 1x2 group pile in series orientation when subjected to excavation induced soil movements falls within permissible limit for an excavation up to a depth of 10m even if the pile group is placed at 1m from the excavation face. As distance of group pile from the excavation face increases from 1m to 5m, a percentage decrease of 33% to 100% in lateral pile head deflection was observed for an excavation depth of 2.5m. For excavation depths 5m, 7.5m and 10m a percentage decrease of 17% to 100%, 13% to 88% and 38% to 81% in lateral pile head deflection are obtained with an increase in distance from the excavation face.

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Pile Group with L = 18m in Series Orientation

Lateral pile head deflections for 1x2 group pile foundation with length 24D located at 1m, 2m, 3m, 4m and 5m from the excavation face due to progressive excavation induced soil movements in series orientation is tabulated and shown in Table 10 given below.

Table 10 Lateral pile head deflection of 1x2 group pile with length 18m in series orientation

Pile Location from Excavation Face, X (m)	1	2	3	4	5
Excavation Depth, h (m)	Lateral Pile Head Deflection, mm				
2.5	1.0	0.5	0.5	0.0	0.0
5.0	2.5	1.5	1.0	0.5	0.0
7.5	3.0	2.5	2.0	1.5	1.0
10.0	8.0	4.5	4.0	2.0	1.5

As distance of pile group from the excavation face increases, the lateral pile head deflection decreases considerably. This percentage decrease is found to range from 50% to 100%, 40% to 100%, 17% to 67% and 44% to 81% for 2.5m 5m 7.5m and 10m depth of excavation respectively.

Variation of pile head response with respect to pile group orientation and excavation depth for pile with L = 18m

Variation of lateral pile head deflection for 1x2 group pile in parallel and series orientation with length 18m for a depth of excavation of 2.5m is plotted as given in Fig. 7.

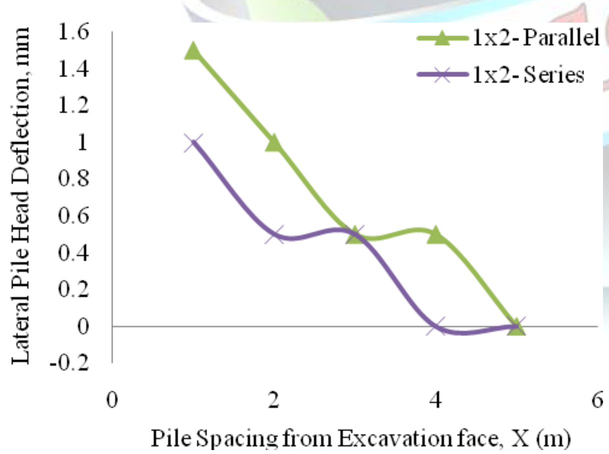

Fig. 7 Variation of lateral pile head deflection for 1x2 group pile with L = 18m for excavation depth 2.5m

For 1x2 pile group with length 24D, the lateral deflection in parallel orientation has 0% to 33% less deflection compared to fixed-head single floating pile at the same location.

Fig. 8 given below represents the variation of lateral pile head deflection for 1x2 group pile in parallel and series orientation with L = 18m for a depth of excavation of 5m.

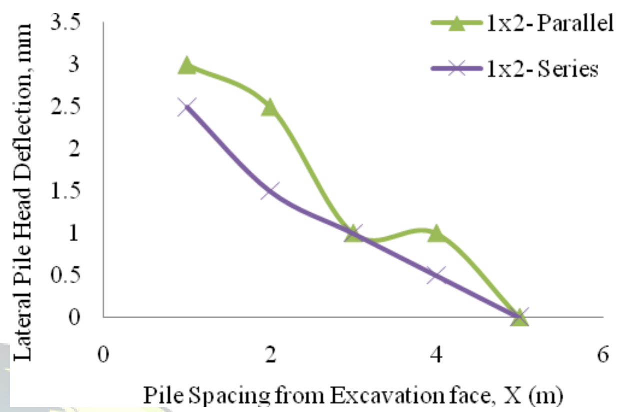

Fig. 8 Variation of lateral pile head deflection for 1x2 group pile in with L = 18m for excavation depth 5m

For an excavation of depth 5m, 1x2 pile group in series configuration has the least lateral pile head deflection compare to group pile in parallel orientation and fixed-head single pile at the same location. The percentage reduction of lateral pile head deflection is obtained as 25% to 100% when compared with 1x2 group pile in series configuration and 0% to 50% when compared with fixed-head single floating pile foundation.

CONCLUSIONS

1. As distance from the excavation face to the centre of the pile group in parallel orientation increases the lateral resistance offered by the pile group also increases and hence as distance increases, the lateral pile head deflection reduces.
2. 1x2 group pile in series orientation has 10% to 50% less deflection values compared to fixed-head single pile and 25% to 100% less deflection values compared to 1x2 group pile in parallel orientation.
3. As slenderness ratio increases, the resistance of pile to lateral soil movement also increases.

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