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Experimental Investigation on Single Pile Subjected to Lateral Load And Lateral Soil Movement

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Abstract: This paper presents the results of model tests conducted on a single pile subjected to lateral load and soil movement embedded in loose sand behind a retaining wall. It is observed that the maximum pile head deflection for pile with $L/d = 10$ is more when compared with piles of L/d ratio 20 and 30. It is also inferred that the rate of increase in maximum pile head deflection increases as the distance from sheet pile wall decreases. The behavior of laterally loaded pile subjected to soil movement is also studied by applying lateral load of $5\%Q_u$, $10\%Q_u$ and $15\%Q_u$ where Q_u is the ultimate lateral capacity of single pile of $L/d = 20$. The parameters varied are distance between pile and sheet pile wall, intensity of loading and length of pile.

Key Words: single pile, lateral load, soil movement, excavation, pile deflection, retaining wall.

I. Introduction

Pile foundation is used to transfer the external load from super structure to soil of high bearing capacity. Pile foundations are generally preferred when heavy structural loads have to be transferred through weak subsoil to firm strata. Pile supported foundations of earth retaining structures and tower structures will also be subjected to the lateral loads. The building frames supported by the pile foundation exposed to wind forces subjected to lateral loads. The lateral forces in offshore structures may be due to impact of ships during berthing and wave action. Lateral loads may also be due to earthquake and landslides.

In areas where existing buildings and infrastructures are built very close to one another, any nearby excavation will cause a reduction of horizontal earth pressure on the side of excavation, leading to soil movement behind the retaining wall towards the cut (Ong 2004). Besides that, the relief of vertical pressure due to excavation may also cause basal heave. The basal heave and the soil movement often cause ground failure around the excavation. Owing to such phenomena in excavation works, excessive soil deformation in the retained soil can pose a serious threat to the nearby existing structures supported on pile foundations. Further the combination of lateral load and lateral soil movements due to an excavation can cause additional bending moment and shear stress to the piles. This leads to the serviceability problem and structural failure of piles due to the additional lateral deformation of the piles. Therefore, it is important to understand the responses of piles subjected to lateral soil movements, so that protective measures can be taken to prevent the pile foundations from damage.

Reasonably good number of research works is reported in literature for the prediction of ground movement due to excavation. Both 1g model tests (Poulos & Chen 1996, 1997; Ilamparuthi and Madhumathi, 2013; etc.) and centrifuge model tests (Leung et al., 2000, Ong et al. 2006) have been performed. Analysis were also carried out on numerically simulated models by researchers (Miao et al., 2006; Pan et al., 2002; etc.) to understand the response of piles due to excavation. However, the response of piles due to combined effect of excavation and lateral load has not been investigated adequately. Hence an attempt is made to analyze the behavior of laterally loaded single pile situated very near to an excavation in this study through 1g model tests. The performance of single pile was studied and the test results thus obtained are presented in detail in this paper.

II. Experimental Setup and Procedure

Tests were conducted on model steel tank of size $1\text{ m} \times 0.6\text{ m} \times 0.6\text{ m}$ which was stiffened at different levels to avoid volume change during preparation of sand bed. The tank was fabricated using steel plates of 6 mm thickness and one shorter side of the tank ($600\text{ mm} \times 600\text{ mm}$) was made by wooden planks of 2 cm. Figure 1 shows the schematic setup of the model tank. Hollow aluminium tubes of various diameters were selected as model piles. The length and diameter of piles are varied to perform tests at different L/d ratios (10, 20 & 30). Aluminum sheets of 0.5 mm thickness were used as sheet pile wall.

The pile of diameter (d) 19.05 mm and length (L) 254 mm, 381 mm, 570 mm is used as model piles. Air dried loose sand was poured in layers in the tank. The sand bed up to the base of the pile was prepared and model pile was placed in position. Preparation of

sand bed was continued up to the base level of retaining wall and the retaining wall was installed in position. Further preparation of sand bed was continued up to the top level of the model pile in layers of 100 mm thick for loose sand beds of unit weight $\gamma = 15.8 \text{ kN/m}^3$. Sufficient thickness of sand bed below the pile was always provided in all the experiments.

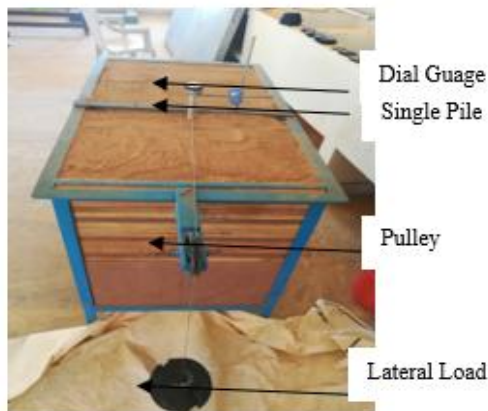


Figure 1: Model Test Setup

The deformation gauges were set in position much before the commencement of excavation. The movement of soil was induced by excavating the soil in the front face of sheet pile wall. The removal of wooden planks in stages induced soil movement. The maximum displacement of the pile at the pile head is recorded in the dial gauge and is noted.

III. Response of Single Pile Subjected to Soil Movement

Figure 2 shows the variation of single pile deflection for a pile of L/d ratio 10, embedded in loose sand. The pile is placed at a distance of $2d$, $4d$, $6d$ distance from the sheet pile wall. The result shows that the pile deflection decreases as the distance between pile and the retaining wall increases. It is evident from the figure that the rate of increase in deflection is higher after reaching the excavation depth ratio $(D/D_e) = 0.5$ where D is the depth of excavation and D_e is the maximum depth of excavation. It is also observed that the rate of increase in maximum pile head deflection increases as the distance from the retaining wall decreases.

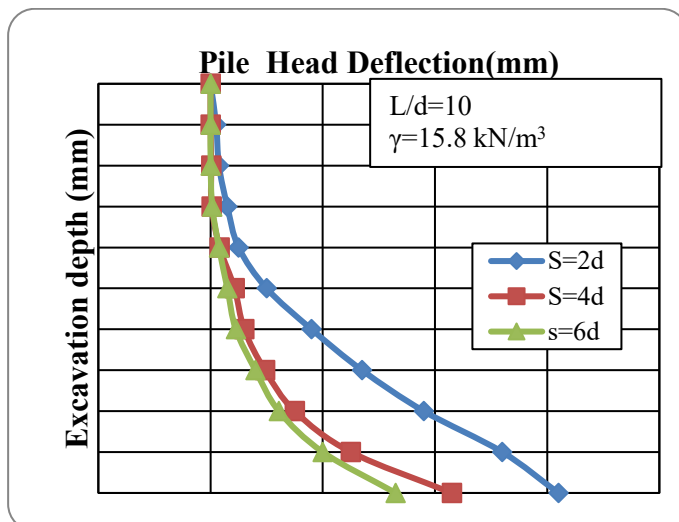


Figure 2: Variation of single pile deflection for a pile of $L/d=10$

Figure 3 shows the variation of single pile deflection for a pile of L/d ratio 20 placed at $2d$, $4d$, $6d$ distance from the sheet pile wall in loose sand. The pile head deflections are 0.8 mm , 0.5 mm and 0.24 mm for the 'S' distance of $2d$, $4d$ and $6d$ from the sheet pile wall respectively. The pile head deflection is more when the pile is placed at a distance of $2d$ when compared to the deflection of piles at $3d$ and $4d$ from the sheet pile wall

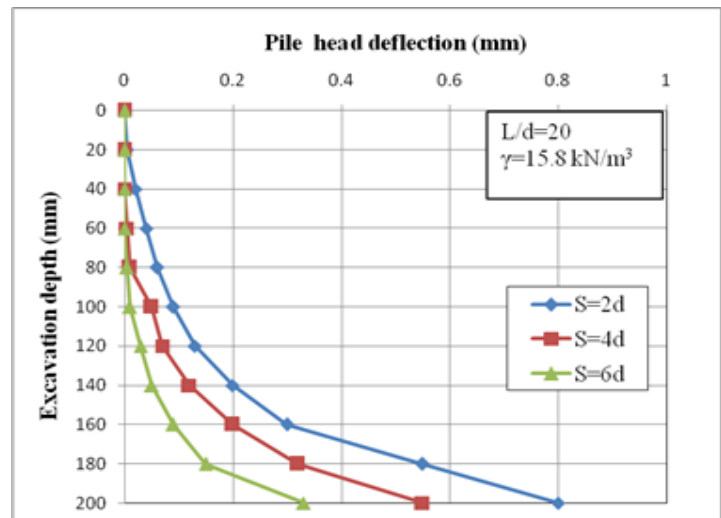


Figure 3: Variation of single pile deflection for a pile of $L/d=20$

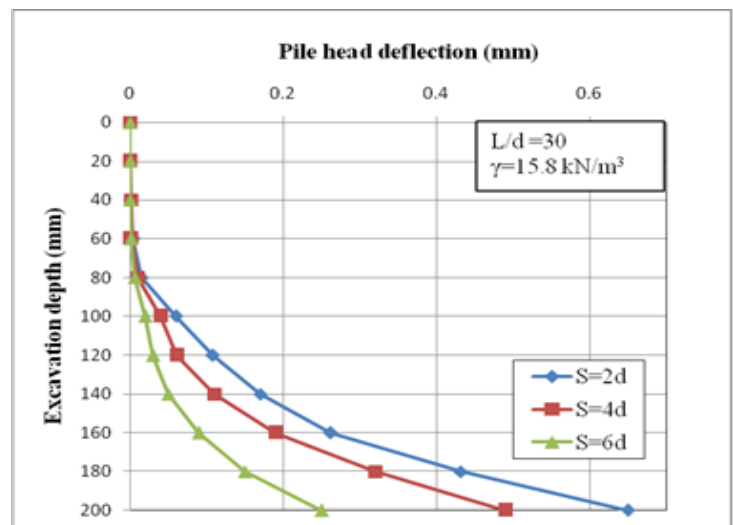


Figure 4: Variation of single pile deflection for a pile of $L/d=30$

The variation of single pile head deflection of a pile of $L/d = 30$ at $2d$, $4d$, $6d$ distance from the wall is given in Figure 4. The result shows that when comparing with $L/d = 10$ and 20 , the $L/d = 30$ shows less pile deflection irrespective of the distance from retaining wall. This shows that when the L/d ratio increases the pile deflection gets decrease due to the infinite passive resistance of the lower part of the long flexible pile. The pile deflection response is also illustrated in a non dimensional form $\delta_{\max}/L$ and S/d in Figure 5, where $\delta_{\max}$ is the maximum pile head deflection. It is observed that the deflection of pile decreases with increase in distance from sheet pile wall and it is evident that the decrease in deflection is appreciable for shorter pile.

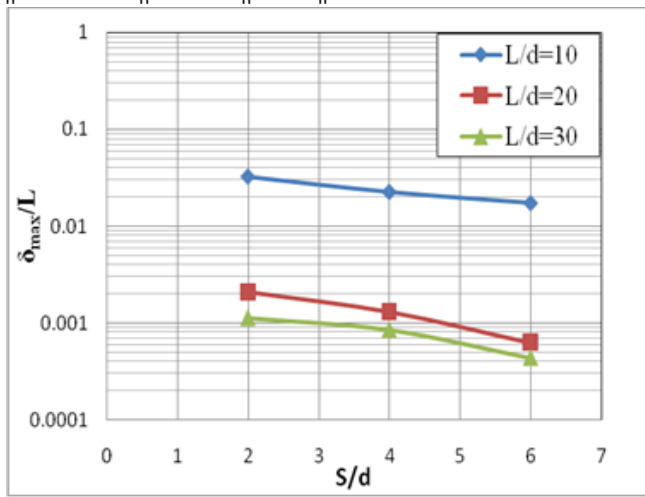


Figure 5: Relation between δ_{max}/L and S/d

IV. Response of Single Pile Subjected to Soil Movement and Lateral Load

To understand the behavior of laterally loaded pile subjected to soil movement, tests were conducted by applying lateral load of 5%Qu, 10%Qu and 15%Qu where Qu is the ultimate lateral load of single pile of $L/d = 20$. As per Broms (1964), the ultimate lateral capacity is taken as the load corresponding to a deflection equal to 20% of the diameter of pile. Hence the ultimate capacity of pile is estimated using the deflection criteria suggested by Broms.

Figure 6 shows the comparison of single pile response subjected to combined lateral load and lateral soil movement. The pile of $L/d = 20$ is embedded in loose sand at a distance of $2d$ from the retaining wall. The result shows that for the maximum depth of excavation, the pile head deflection increases as the lateral load increases. It is also observed that as the lateral load increases, the rate of increase in deflection also increases.

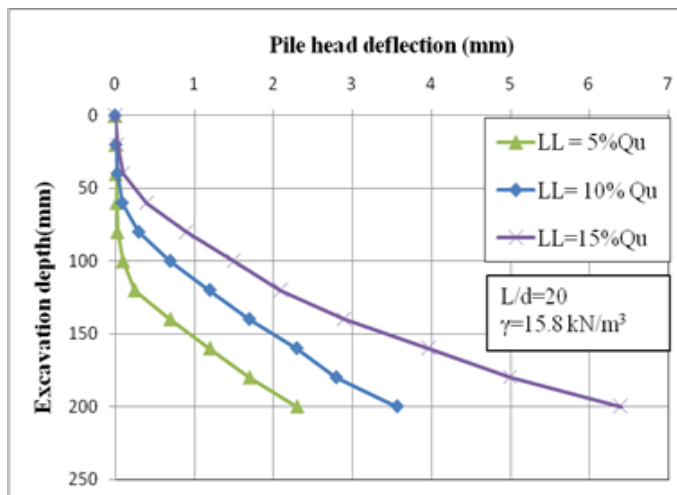


Figure 6: Effect of Lateral Load on single pile of L/d ratio 20 with $S=2d$

Figure 7 presents the deflection profile for pile group of L/d ratio 20 subjected to three different intensities of load for $S = 2d$. The deflection curve shows that the pile head deflection is higher for $LL = 15\% Qu$ than other cases of loading irrespective of excavation depth. It is clear that for $S = 2d$, the increase in deflection for single

pile subjected to $LL = 5\%Qu$, $10\%Qu$ and $15\%Qu$ is 2.86 times, 4.46 times and 8 times than the single pile with $LL = 0\%Qu$.

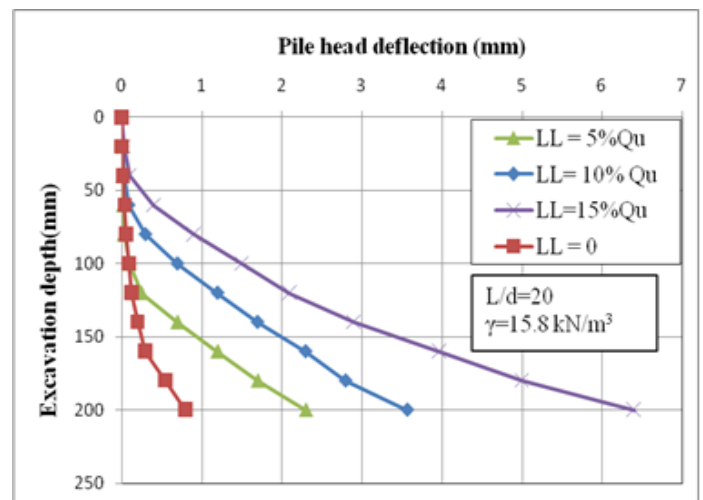


Figure 7: Comparison of effect of Lateral Load on single pile of L/d ratio 20 with $S=2d$

V. Conclusion

The following are the important conclusions derived from the tests conducted on single pile.

- The maximum pile head deflection for pile with $L/d = 10$ is more compared with piles of L/d ratio 20 and 30 and hence it can be inferred that the pile head deflection decreases as the L/d ratio increases.
- The pile deflection decreases with increase in distance between the pile and the retaining wall.
- The increase in deflection for single pile subjected to $LL = 5\%Qu$, $10\%Qu$ and $15\%Qu$ is 2.86 times, 4.46 times and 8 times than the single pile with $LL = 0\%Qu$.

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