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Research Article

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Behavior of Single Pile Subjected to Lateral Soil Movement in Different Rates

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Abstract The amount of lateral displacement due to lateral movement is typically ranges from a few centimeters to several meters and can cause a considerable damage to an engineering structure and lifelines. The movement velocity can be classified from high speed to slow.

A new experimental physical model has been developed, which allows applied lateral soil movements with different rates. A brief description of the apparatus was presented in this paper.

A series of laboratory model tests in loose sand are implemented to assess the behavior of single pile subjected to different rates of lateral soil movements and to determine the horizontal displacement at pile head and bending moment developed along pile shaft. These experimental model are used as a benchmark for verification the model with experimental work and numerical model using finite element commercial program PLAXIS 3D 2013. It was found that PLAXIS 3D 2013 has the ability to predict the response of the single pile under different lateral soil movement rates.

Increasing movement rate from 5 mm/min to 20 mm/min leads to increase the maximum horizontal soil movement from 7.5% to 20%, and the maximum horizontal displacement is occurred with the high rate of soil movement. Also, the bending moment is proportional with the movement rate; a high soil movement rate developed a peak bending moment along the pile shaft. Finally, slow movement rate has a high effect on maximum values of bending moment and horizontal displacement.

Keywords soil movement; passive piles, movement rates, pile deflection

Introduction

Lateral movement can occur in marginally stable or unstable ground slopes. In some cases, time dependent slop movement also can occur from soil creep. Such slopes may be stabilized by piles to providing additional shear resistance against soil movement [1].

In recent years, some researchers have conducted empirical solutions, experimental studies (small scale model or centrifuge model) and numerical studies for piles under a lateral soil movement.

The lateral soil movements induce forces can cause additional bending moment and lateral deformation in piles. Xiaobi and Lansheng (1991) suggested a method, which may be used to calculate the maximum velocity of a landslide [2]. Their calculations are based on three motion features; the height drop of rear edge, equivalent slope gradient of the rupture surface, and friction angle. Hungr et al., (2001), explained that the soil movement velocity depends on material in site and the water content [3].

De Beer and Wallays (1972) experienced a case of the pile loaded by lateral soil movements caused by an embankment. They proposed a semi-empirical method to calculate the soil pressure acting on face of pile in soft layer [4]. Dagistani (1992) investigated the behavior of rigid pile under lateral soilmovement. It was concluded that bearing capacity factors depend on the depth of penetration and consistencies of the moving and stabilizing soil [5].

Poulos et al. (1995) described a series of laboratory tests on single instrumented model piles in dry sand undergoing a lateral movement. It which be observed that bending moment increased with increasing the soil movement but the rate of increase reduced [6].

Chen et al. (1997) described a series of physical model tests on instrumented pile and pile groups embedded in sand undergoing lateral movements. For piles in a row of pile group, the maximum bending moment was found to decrease with decreasing the pile spacing, and was not significantly affected by either the number of piles or the pile head condition. The piles experienced relatively large negative bending moments in the upper part of the pile due to the restraint of the pile cap [7].

Ilamparuthi and Madhumathi (2011) presented results of experimental model tests to study the effect of lateral ground movement on behavior of piles embedded in loose and medium dense sand behind a retaining wall. They observed that the deflection of wall increases as the excavation depth increases. The response also showed that the deflection is more in loose sand compared to medium dense sand bed [8].

Parametric studies using the finite difference method were carried out to study some of the factors influencing the development of pile displacements and moments, such as the boundary conditions, shape and magnitude of soil movement profile, relative pile flexibility, and the diameter of pile. In addition, regarding to some values of soil parameters that are required for practical problems, some of comments are given below.

Viggiani (1981) gave three failure mechanisms supposing that only the soil can fail; these are shown in Figure (1). Failure modes are labeled as: A (translational), B (rotational) and C (flow). Mechanism (A) represents a short pile that only penetrates a small distance below the sliding plane. Above the sliding surface the earth pressure doesn't reaches to the ultimate value, besides unknown, as are the distributions of shear force and bending moment for this section of the pile [9].

Lee et al. (1995) exhibited a simplified approach to the study of piles in row that used for slope stabilization. The approach is based in an uncoupled formulation in which the pile response and slope stability are considered separately [10].

Chen and Poulos (1997) evaluated a pile response subjected to lateral soil movement using a boundary element method [11], also Zhang et al. (2012) proposed a nonlinear mechanical mechanism model for piles subjected to lateral soil movement. This proposed based on the Winkler elastic model and the plastic deformation of surrounding soils. It was taken into account using a simplified elastoplastic fundamental model [12].

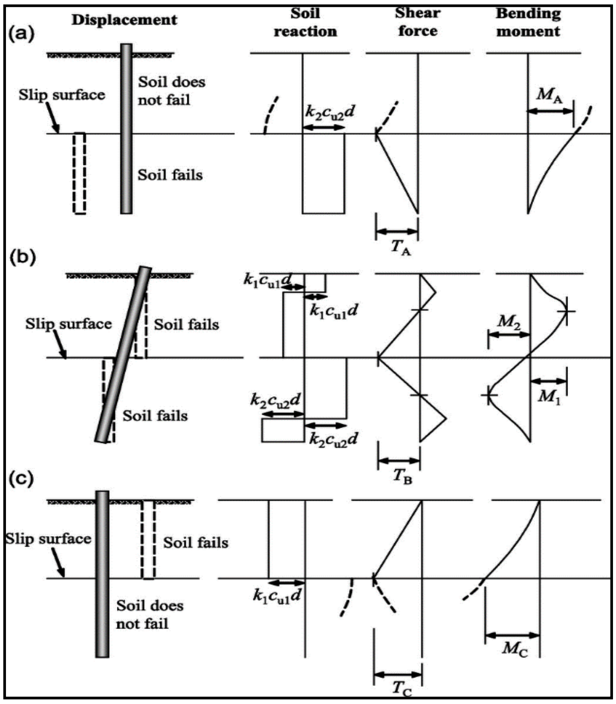


Figure 1: Pile failure modes.

Experimental work

Soil used

Dry sand brought up from site in middle of Baghdad Cityat depth of (10-15) m was used in this research to study the effect of lateral soil movement on pile, and the physical properties are shown in Table 1.

Table 1: Properties of the sand used

Property	Value
Effective size, D10 (mm)	0.14
D30 (mm)	0.18
Mean size, D50 (mm)	0.22
D60 (mm)	0.24
Coefficient of uniformity, Cu	1.70
Coefficient of curvature, Cc	0.96
Classification (USCS)*	SP
Specific gravity, Gs	2.67
Maximum void ratio, e_{max}	0.99
Minimum void ratio, e_{min}	0.74
Initial dry unit weight, γ_d (test)	13.74 ,14.13
Initial relative density, R.D%	30%, 55 %
Initial γ_{sat} (test) kN/m^3	18.14 , 18.65
Initial void ratio, e (test)	0.922 , 0.868

Pile Used

A hollow cylindrical smooth aluminum pipe of 18 mm in diameter and 570 mm in length, and 1.5 mm thickness with a bending stiffness of 0.18×10^6 kN.mm^2, is used as a model pile. The embedded length of pile is 540 mm. Thus the embedment depth to diameter ratio (L/D) in this study is equal to 30, where L embedded length of pile and D represents the outer diameter of the pipe pile.

A typical test utilized ten instruments: Eight strain gauges (Four in each side) placed along the pile to measure bending moments (Plate 1), and one linear variable differential transformer (LVDT) to measure the horizontal displacement at head of pile are used. Data from this instrument (strain gauges and LVDT) were recorded using strain indicator and LVDT indicator, respectively.

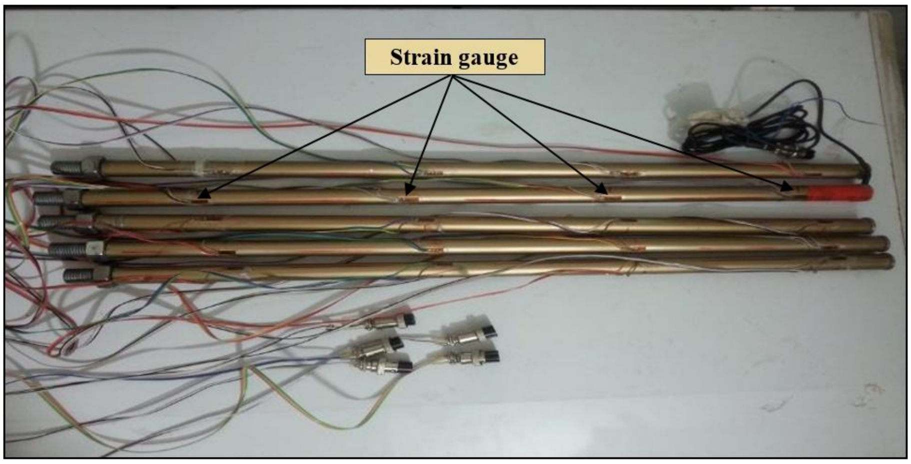


Plate 1: Aluminum model pile with strain gauges

Testing Device

The laminar shear box apparatus is used for the single pile and pile groups models subjected to lateral soil movement (rectangular profile) as shown in Plate (2). It is consisting from two parts, the lower part is fixed steel box with internal dimensions (800 mm) in length, (800 mm) in width and (500 mm) in depth. Each part of lower box container is made of steel plate of (6 mm) thickness. Sides of the container can be opened and reassembled by bolts to facilitate soil removing, the upper part of container consists of (3 to 20) rigid rectangular laminar frames made of welded (800×800×50) mm square steel pipe have a thickness of 3 mm to be firm enough to avoid a breakdown while exciting.

The Horizontal Soil Movement System

The lateral loading system encompasses of horizontal hydraulic jack system and loading steel block that exerts a lateral force which applied on upper movable laminar frames at side of moving soil in shear box as shown in Plate (2).

Testing Program

In order to evaluate the effect of moving rate of ground surface causing a sliding for single pile, many tests are conducted. In all cases, the lateral soil movement rates are selected as (5, 7.5, 10 and 12.5 mm/min) and the length to diameter ratio (L/D=30) is used.

Model Preparation and Experimental Procedures

The procedure of testing divided into three phases. Aluminum pile model installation represent the first phase. The second phase consists of the proud the homogeneous sand using raining technique. The last phase is considered the most critical part in this study which consists the assembly the control system of motorized displacement which used to generate the lateral movement with constant rate of (5, 7.5, 10, and 12.5 mm/min). Before the soil movement, all wire sensors and data loggers were checked for reading before device switch on. When the laminar box moves with selected movement rate; the test stopped when the laminar displacement reached to 6 cm.

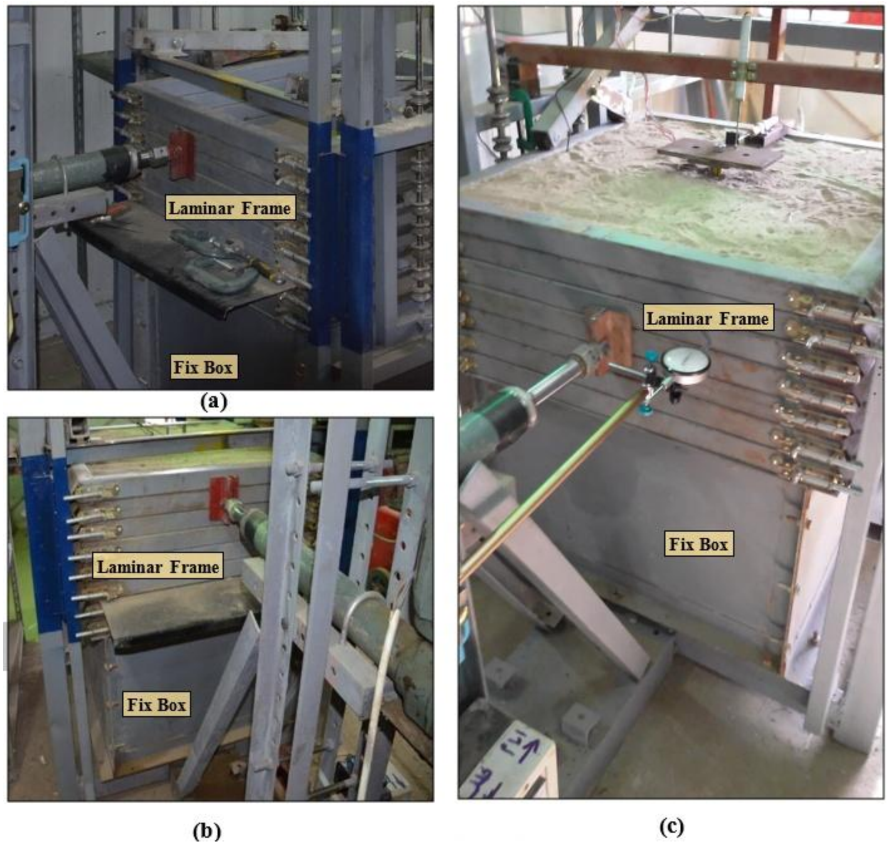


Plate 2: Laminar shear box with horizontal soil movement system

Results and Discussions

a. Experimental work

The results of the experimental work are divided to two parts (Horizontal displacement at pile cap and bending moment along pile). Due to the huge number of points recorded by data logger during testing process, only the one point per 3 points is selected to be drawn.

Total horizontal movement reads from LVDT in pile cap for a single pile are presented in this section. In order to explain the effect of soil movement rate on the response of pile, the horizontal displacement with time of soil movement and also the horizontal displacement with soil movement are drawn. Soil movement is previously fixed at 6 cm and achieved within 900 second then the test is stopped. Figure (2) and (3) show the variation of horizontal displacement of pile cap of single pile with time and with soil movement respectively.

It is readily observed that the horizontal displacement increases with time until movement of layer is stopped then a slight decreasing is occurred. The horizontal displacement of pile in all tests and movement rates are less than 20% of total amount of soil movement generated (6 cm).These observations indicate that the soil in sliding layer is flowed around the pile. Same observation is noticed by (Ghee, 2009) [13]. This behavior may be attributed to that at early stage of soil movement, the particles moved freely due to availability of voids in soil matrix, and then the friction bonds increase and the soil become more densification.

Also, it can be seen that the maximum displacement occurs at the high rate of movement due to mobilization of the lateral load applied on soil particles.

For the single pile, the maximum value of horizontal displacement at soil movement rate of (12.5 mm/min.) is 20% more than other cases of soil movement rates. While the δH_{Max} decreases when soil movement rate decreases as ratio of (7.6 %, 25%, and 42%) corresponding to soil movement rate of (10, 7.5 and 5 mm/min) respectively.

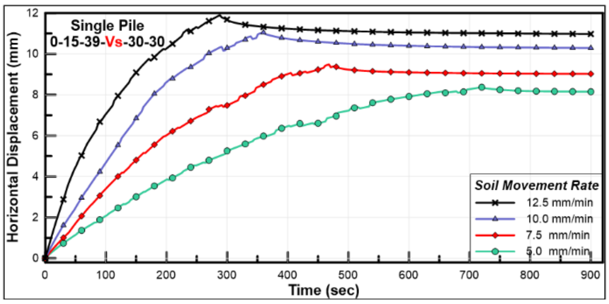


Figure 2: Variation of horizontal displacement of foundation with time

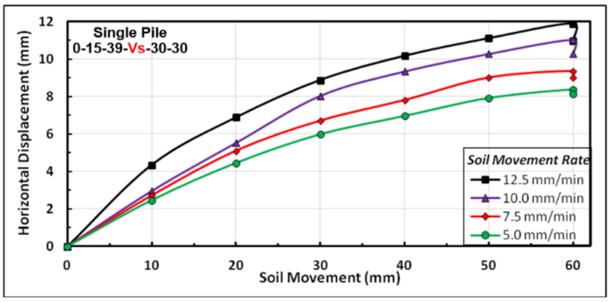


Figure 3: Variation of horizontal displacement of foundation with soil movement

In other hand, to determine the effect of movement rate on the location and magnitude of the maximum bending moment, bending strain data from strain gages attached at different depth along the pile shaft were used as mentioned above. After the lateral soil movement generated on soil matrix, the values of bending moment are measured along pile length and drawn with depth.

It should be noted that due to the interval of 170 mm between two adjacent followed strain gages, the location of the recorded maximum bending moment may not necessarily coincide with the actual location of the maximum bending moment. Bending moment curves depict successive increments distributions of bending moment developed at box (layer) displacements. Figure (4) illustrates the variation of bending moment developed along pile depth at various soil movement (Sv) [(20, 40, 60) mm (stopping moving layer) and end test] respect to the pile depth.

Generally, it can be seen that the bending moment increases with increasing the movement rate and a high bending moment is generated when the soil moved at high rate. Additional soil movement exerts more bending moment due to mobilization of active stresses in soil upon piles. Generally, from bending moment distribution, the position of maximum bending moment developed approximately at midpoint of pile depth and negative

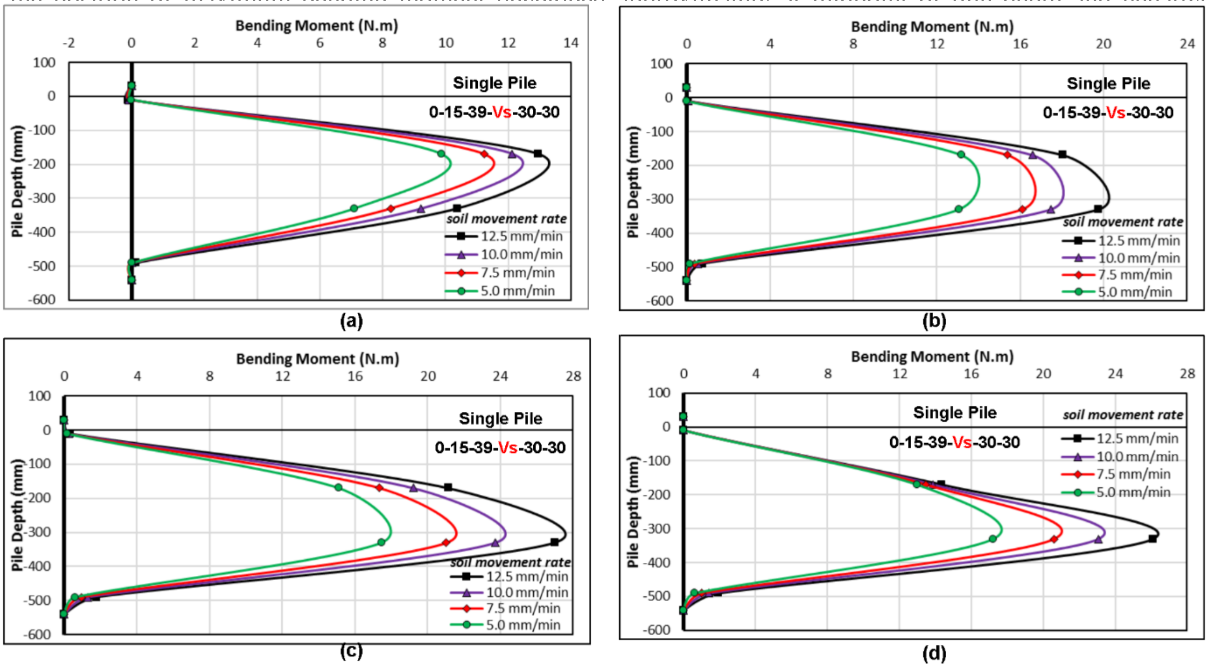


Figure 4: Variation of bending moment along pile for different lateral soil movement rate at (a.) Sv. 20 mm (b.) Sv. 40 mm. (c.) Sv. 60 mm. (d.) after stop movement at time 900 sec

b. Numerical work

Logically, any experimental work cannot take the effect of all the parameters related to the study due to the difficulty of the testing models preparation and to the limited available time, therefore, a theoretical work is used to extending the work to cover the short aging in the experimental work. For this purpose, PLAXIS 3D 2013 is used to study the response of single pile under lateral soil movement.

In order to verify the numerical model, a comparison between theoretical and experimental results is carried out. The soil is assumed to follow the Mohr- coulomb failure criterion while the piles and their cap are assumed to follow linear elastic model in all analyses. It is worth noting that the same properties of soil and pile model that used in experimental work are selected to translate the experiment model to the numerical model in PLAXIS 3D.

The predicted pile deflection in horizontal direction and bending moment profiles for single pile are plotted in Figures (5) and (6) respectively. It can be observed that the predicted deflection distribution (horizontal displacement) shows a good agreement with the measured one, in terms of the head deflection. Also, in all movement rates, the predicted bending moment profile along pile are very close to the bending moment measured in experimental work for all speeds.

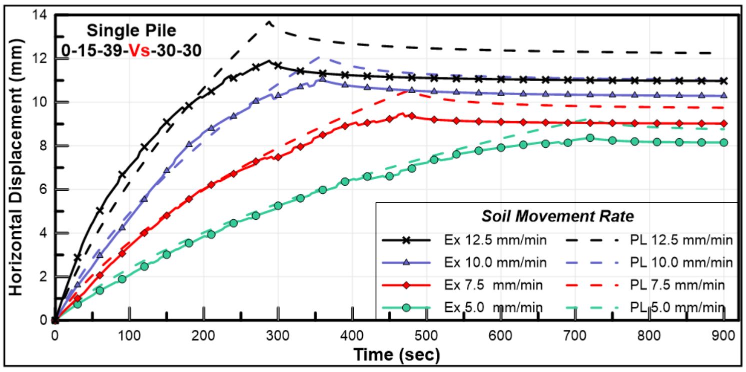


Figure 5: Horizontal soil movement in experimental and PLAXIS model

Four movement rates (12.5, 10, 7.5 and 5 mm/min) are employed to generate the lateral soil movement in the experimental model test, so to investigate the response of other lateral movement rates, movement rates with 1, 25, 50 and 100 mm/min are studied also by PLAXIS program. The movement rate of 100 mm/min can be classified as a sub-rapid velocity and the movement rate of 1 mm/min classified as sub-moderate [3].

The effect of soil movement rates on pile's response are presented in relations between the movement rate and the maximum horizontal displacement in the pile cap and the rebound ratio and maximum bending moment along the pile shaft are depicted in Figures (7-a, b and c), respectively.

It can be seen from these figures that the increasing in soil movement rate leads to nonlinear increasing in the maximum bending moment, rebound ratio and maximum horizontal displacement at pile cap.

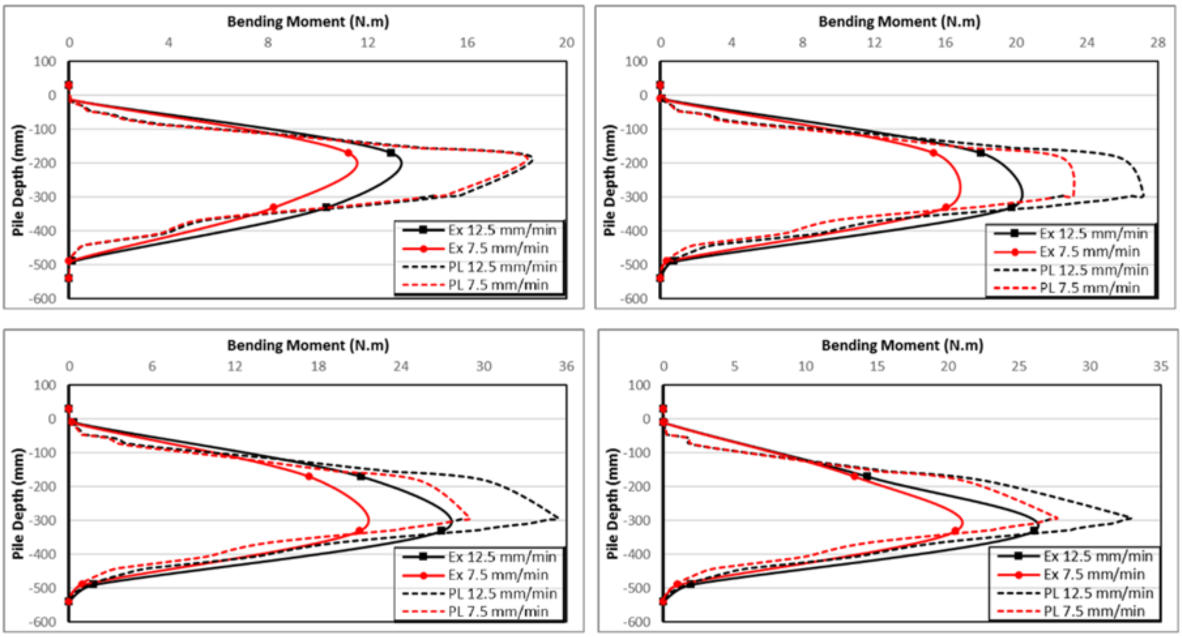
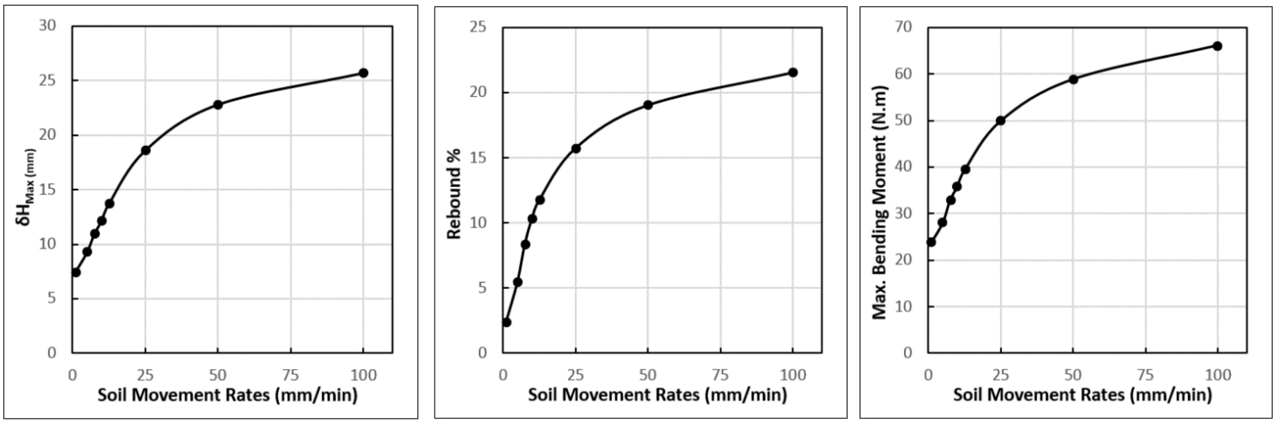


Figure 6: Variation of bending moment with depth in experimental and PLAXIS model



(a) maximum horizontal displacement (b) the rebound ratio (c) maximum bending moment

Figure 7: Single pile response in different soil movement rates

Conclusion

Based on the analysis of experimental and numerical tests carried out on model of single pile subjected to the lateral soil movement, the main conclusions may be as following:

- The maximum horizontal soil movement increases from 7.5% to 20% when soil movement rate increases from 5 mm/min to 20 mm/min.

- At the high rate of soil movement, the maximum horizontal displacement is occurred due to mobilization of the lateral load applied on soil particles.
- The bending moment proportional with the movement rate and a peak bending moment is generated when a high soil movement rate and the position of maximum bending moment developed approximately at midpoint of pile depth.
- Slow movement rate has a high effect on maximum values of bending moment and horizontal displacement at pile caps compared with high movement rate

References

[1]. Fukuoka, M. (1977),*"The effects of horizontal loads on piles due to landslides",* Proc. 10th Spec. Session, 9th Int. Conf. on SMFE, Tokyo, pp. 27-42

[2]. Xiaobi D., and Lansheng W., (1991).,*"Some Kinematic Features of Landslide"* Landslides, Edited by Bell, A. A. Balkema, Rotterdam, ISBN 90 5410 032X.998

[3]. Hungr O, Evans SG, Bovis M, and Hutchinson JN (2001), "*Review of the classification of landslides of the flow type",* Environmental and Engineering Geoscience, VII, 221–238.

[4]. De Beer, E.E. & Wallays, M. (1972),*"Forces induced in piles by unsymmetrical surcharges on the soil around the piles*", Proc. 5thEuropean conference on Soil Mechanics and Foundation Engineering, Marid, Vol. 1, pp. 325-332.

[5]. Dagistani I., (1992),*"Model study of lateral earth pressure distribution developed on a rigid passive pile",* M.Sc. Thesis in Civil Engineering, Middle East Technical University, Ankara, Turkey.

[6]. Poulos H.G., Chen L.T. and Hull T.S. (1995),*"Model tests on single piles subjected to lateral soil movement",* Soils and Foundations, Vol. 35, No.4, pp. 85-92.

[7]. Chen L.T., Poulos H.G. and Hull T.S. (1997), *"Model tests on pile groups subjected to lateral soil movement",* Soils and Foundations, Vol.37, No.1, pp.1-12

[8]. Ilamparuthi K. and Madhumathi R.K. (2011), "*Effect of ground movement on the performance of pile foundation",* Proceedings of Indian Geotechnical Conference, Kochi, Vol. 1, pp.187-190.

[9]. Viggiani C., (1981),*"Ultimate Lateral Loads on Piles Used to Stabilize Landslides",* Proceedings, 10th I.C.S.M.F.E., Vol. 3, pp. 555-560, Stockholm. After Ghee, 2009.

[10]. Lee C. Y., Hull T. S., and Poulos H. G., (1995),*"Simplified pile-slope stability analysis",* Computers and Geotechnics, Vol. 17, No. 1, pp. 1-16.

[11]. Chen L. T., and Poulos H. G. (1997),*"Piles subjected to lateral soil movements."* Journal of Geotechnical and Geoenvironmental Engineering, Vol. 123, No. 9, pp. 802-811.

[12]. Zhang A., Mo H., and Zhu Z., (2012),*"Theoretical Elastio-Plastic Solution for Piles Subject to Lateral Soil Movement",* International Conference on Structural Computation and Geotechnical Mechanics, Procedia Earth and Planetary Science Vol. 5, pp. 58–63.

[13]. Ghee E. H., (2009),*"The behaviour of axially loaded pile subjected to lateral soil movements",* a thesis presented in fulfilment of the requirement for the degree of doctor of philosophy of Griffith University.