Behavior of Dual Pile Under Lateral Load: Experimental and FEM Analysis

Aman Tiwari[1], Nitin Dindorkar[2] and Suneet Kaur[2]

[1] *Research Scholar, Department of Civil Engineering, Maulana Azad National Institute of Technology, Bhopal-462003 E-mail:* aman20tiwari@gmail.com
[2] *Professor, Department of Civil Engineering, Maulana Azad National Institute of Technology, Bhopal-462003*

Abstract. Apart from the vertical load of the superstructure, the pile may be subjected to lateral loads caused by earthquakes, wind and water currents, vehicle loads, etc. Negligence of this lateral load may be dangerous if the structure is going to experience lateral thrust in any way. In previous studies, a single pile has been examined under lateral load for different soil characteristics, where deflection and maximum bending moment were determined. In the present study, dual pile (two) is taken with spacing of 2.5D and considered as a single unit. Lateral load is applied at the top of the dual pile, which is connected with a pile cap (connection plate). Experimental data of deflection is collected with the help of strain gauges installed over the periphery of each pile. In PLAXIS 3D software, a FEM model of the same setup with soil pile condition is created and analyzed. Results from both the analyses are in good agreement, and shows that as the slope increases, lateral load capacity of assembly decreases.

Keywords: *Lateral Load; Dual Pile; FEM; PLAXIS 3D.*

1 Introduction

When load need to be transferred in the deep strata or when there is a significant amount of horizontal force acting on structure, pile foundations are the preferred foundations. Resulting lateral forces can come from different places, depending on the structure on top of the pile foundation. The most significant contributors to the formation of the lateral forces are the gusts of wind, water waves, seismic waves, impact of ships, etc. An accurate evaluation of the soil-pile interaction is required when a pile is subjected to lateral load. While designing laterally loaded piles, two crucial parameters are taken into consideration: the maximum bending moment and the pile top displacement. The reaction of lateral-loaded piles on level ground has been the subject of numerous computational and experimental studies. It has been seen that the response of the pile is highly dependent on the relative stiffness of both the pile and the soil beneath it. In the case of onshore structures, lateral loads account for only 10–15% of vertical loads, whereas in the case of offshore structures, they account for 25–30% of vertical loads [1]. Most of the time, piles are built in groups to support structures, and the way pile groups behave is very different from how single piles behave. A substantial reduction in ultimate soil resistance was measured in the group piles relative to that of a similarly cyclic loaded single pile [2]. The p-y curve approach is frequently used in the design of laterally loaded piles because to its ability to simulate nonlinear behavior of soil, its flexibility, and its simplicity.

In the past, researchers have conducted full-scale field experiments, 1-g model tests, and centrifuge model testing on laterally loaded piles and pile groups [3] [4] [5]. Different L/D ratios were thought about in order to figure out how the flexibility of the pile affects the p-y curves [6]. Due of the cost and logistical complexity of evaluating big pile groups, no experimental research is available as of now. In earlier studies presented on group action of pile under lateral loading a p-multiplier is used through which the soil resistance is decreased, to consider the reduction in lateral resistance due to group effect.

In the present study two piles inferred as dual pile are used instead of pile group and results are seen in the form of p-y curve which shows soil resistance, p and horizontal pile deflection, y and bending moment curves. The experimental data are used to construct and validate numerical models. The proposed p-y curve was then used to conduct a parametric analysis on the lateral response of piles.

2 Experimentation

2.1 Test Setup

Tests were conducted in a tank with three different slope ratios (1V:1H, 1V:2H and 1V:5H). Dimensions of the tank in which experiments were carried out is 2000mm X 1000mm X 1000mm. The size of the tank was selected so as to eliminate the effect of borders on the outcome. In experimental model, lateral loads were applied using dead weight, and pile head deflections were measured using dial gauges. We used a model dual pile system made from an aluminium pipe with an external diameter of 25 mm and a wall thickness of 1 mm, two pipes are then connected with a plate at the top to confirm it as a composite system. To minimize any possible friction arising from the interface between the side walls and the soils, the test tank was covered with a film [7]. Spacing between two piles is kept as 2.5D. The model test pile was embedded by 889mm into the soil and 111mm above the ground level which is also considered as eccentric length of the pile for all the cases of ground slopes. The model dual pile was instrumented with strain gauges of the electrical resistance type with a gauge length of 5 mm and resistance of 110 Ω. The strain gauges were positioned 50 mm apart along the whole length of the pile. Data is recorded by a system with a frequency of 50 Hz linked to the strain gauges.

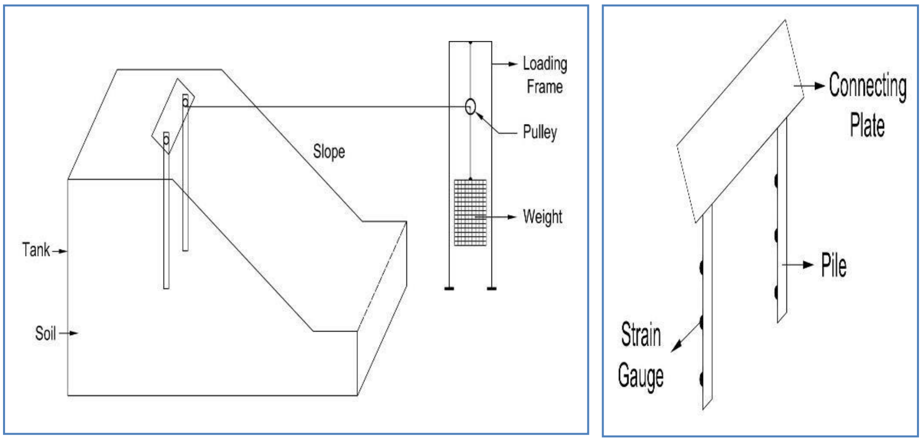

Fig. 1. Schematic diagram of experimental setup

2.2 Soil and Pile Preparation

The tests were done with clay from the area that had a water content of 28.4% and a un drained shear strength (cu) of 52.4 kPa. The clay was compressed using a plate hammer to achieve a uniform thickness of 250 mm between layers, with the dry unit weight kept at 18.3 kN/m3. The procedure described above was carried out multiple times until the desired slope height and slope angle were reached. Careful attention was paid while tamping around the pile to achieve good contact between the pile and the soil. Values of Modulus of elasticity (E) and Poisson's ratio (ν) is determined with the help of Triaxial test data done on the above soil. The above method of preparing the model is quite similar to some previous researches [7][8].

Table 1. Properties of soil used.

Property	Value
Unit weight γ_s (kN/m3)	18.3
Undrained shear strength c_u(kPa)	53.24
Modulus of elasticity **E** (MPa)	30.12
Poisson's ratio **ν**	0.35

2.3 Loading Arrangement and Measurement

Deflections at the pile head and axial strains along the pile length were recorded during lateral load tests. All static lateral loads were applied in 100 N increments until pile head displacement versus time was less than 0.01 mm/min. We did the above steps again and again until the soil in front of the pile failed plastically, which means that cracks could be seen in the soil.

2.4 Experimental Results

For each load increment, the applied lateral load and accompanying lateral displacement at ground level were measured and recorded. Fig-2 depicts the usual pile top (connecting plate) deflection against loading for slope ratios of varying steepness. The graphs show that for a given lateral load, the pile head deflects more dramatically as the slope increases. This change is because the soil in front of the pile has less passive resistance and there is less initial confining pressure. The disparity in the lateral resistance of the soils in front of the piles in each of the three scenarios can help to explain this finding. Though for the present study case, center to center distance between two piles can also vary the soil resistance for corresponding lateral load.

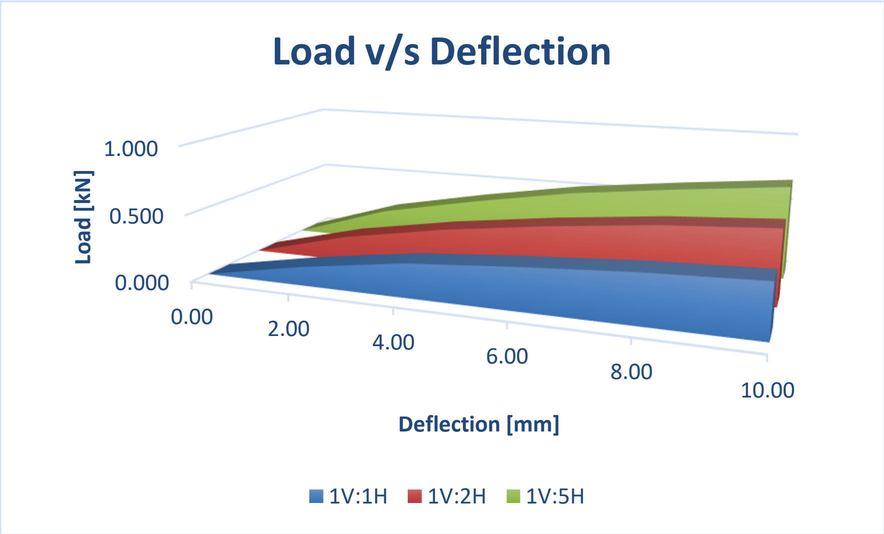

Fig. 2. Load-Deflection curves for various slope ratios recorded experimentally.

3 Numerical Analysis

3.1 Software Modelling

It is well accepted that finite element modelling (FEM) can serve as a useful tool for simulating the behavior of the pile-soil interface. Some of the researchers [9] [10] performed 3D FEM analysis to determine piles lateral behavior in recent times. Fig-3 and Fig-4 shows a typical numerical model and 3D meshed view. Numerical model consists of soil profile with sloping ground and dual pile assembly connected to the plate at the pile surface. Many authors have proposed the Mohr-Coulomb model [11] [12] for capturing the failure and deformation properties of soils. This study therefore utilized this constitutive model to simulate the responses of a slope-built pile. Analysis of dual pile model was performed with the use of PLAXIS 3D software. Soil is made with borehole property of software and piles are made with embedded beam property of used software. Properties of soil were taken same as experimental and for pile density is 25 (kN/m3). At the interface between soil and pile standard stiffness is considered with the value of R_{inter} as 0.50. After preparing the model, horizontal load is applied on the plate and then model is subjected to mesh generation processing where mesh element distribution is taken as medium and further to final stage of calculation.

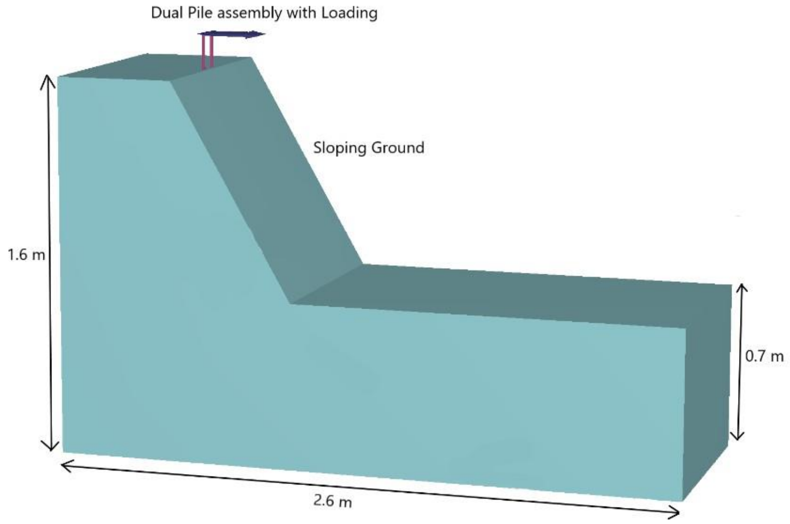

Fig. 3. FEM model of Dual pile located at the crest

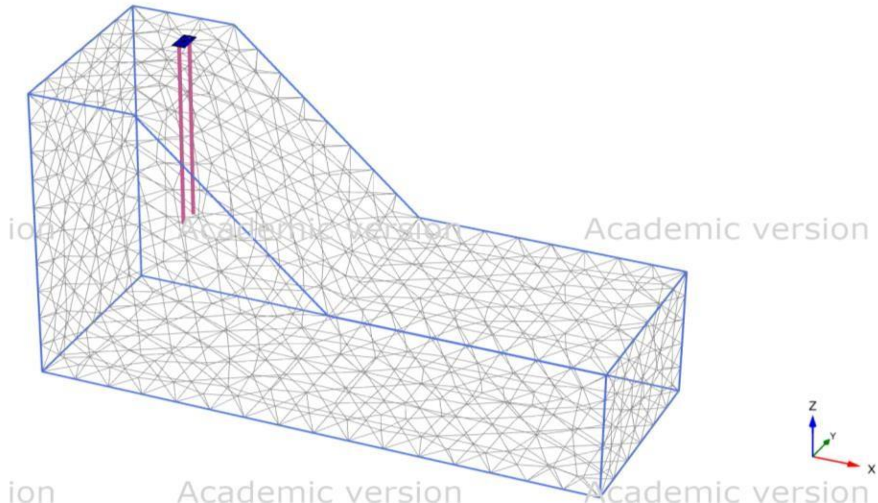

Fig. 4. Meshed model of soil pile assembly

3.2 FEM results

The influence of ground inclination on dual-pile behavior is demonstrated in Fig-5 with the help of typical findings from the finite-element analyses. Fig.-5 depicts the relationship between load applied and lateral pile head displacement ‘y’ for three different sloping conditions. It can be clearly observed that as the slope inclination increases lateral capacity of dual pile assembly get reduced. As the slope gets steep the deflection of pile head assembly occurs at lower value of load. Load capacity is reduced by 80% when slope is changed from 1V:5H to 1V:1H

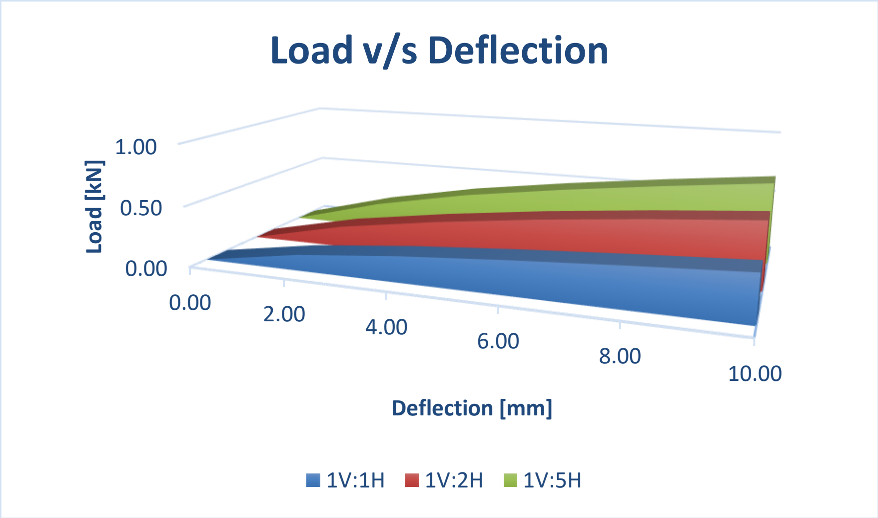

Fig. 5. Load-Deflection curves for various slope ratios through FEA.

3.3 Comparison of both the results

A comparison of the pile head deflections that were acquired from the FEAs and those that were derived from the model test data can be seen in Fig. 6. In the validation of the numerical simulation, a constant Young's modulus in horizontal and vertical directions was used. Many researchers have used this simplified approach to compare experimental and numerical calculation results for piles embedded in slopes [13] [14].

Curves shown in the Fig.6. corresponds each other for every set of slope condition and hence FEA results are in well agreement with experimental results. Thus, the study application of finite element analysis (FEA) provides a useful technique for predicting the response of laterally loaded piles. Though the deflection curve of experimental and FE results varies a bit between 4mm to 8mm, but the ultimate load corresponding to specified deflection coincides in all the cases.

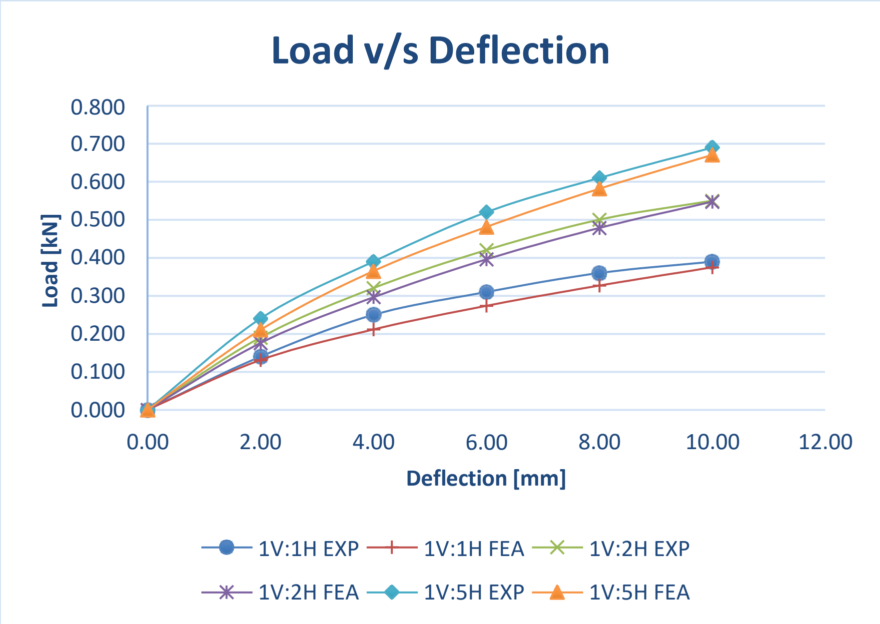

Fig. 6. Load-Deflection curves for various slope ratios through FEA and Experiments

4 Conclusions

This research investigates the behavior of a dual pile assembly under lateral loads when it is set into the crest of steep clay slopes, which are prevalent in mountainous regions. To determine the behavior and capacity model assembly experimental as well as Numerical analysis is performed. This experimental and numerical analysis led to the following conclusions:

- There is a strong correlation between the slope angle and the deflections in the pile heads.
- Pile deflection is almost 1.8 times when slope inclination changes from 1V:5H to 1V:1H
- With increase in the slope angle lateral capacity of dual pile decreases.
- Dual pile assembly provides more strength and rigidity as compared to single pile which is examined by many researchers in previous studies.

References

[1] Rao, S. Narasimha, V. G. S. T. Ramakrishna, and M. Babu Rao. "Influence of rigidity on laterally loaded pile groups in marine clay." Journal of Geotechnical and Geoenvironmental Engineering 124, no. 6 (1998): 542-549.

[2] Brown, Dan A., Lymon C. Reese, and Michael W. O'Neill. "Cyclic lateral loading of a large-scale pile group." Journal of Geotechnical Engineering 113, no. 11, 1326-1343 (1987).

[3] Rollins, Kyle M., Kris T. Peterson, and Thomas J. Weaver. "Lateral load behavior of full-scale pile group in clay." Journal of geotechnical and geoenvironmental engineering 124, no. 6, 468-478 (1998).

[4] Ilyas, Tommy, C. F. Leung, Y. Khuan Chow, and S. S. Budi. "Centrifuge model study of laterally loaded pile groups in clay." Journal of Geotechnical and Geoenvironmental Engineering 130, no. 3, 274-283 (2004).

[5] Boominathan, A., and R. Ayothiraman. "An experimental study on static and dynamic bending behaviour of piles in soft clay." Geotechnical and Geological Engineering 25, no. 2, 177-189 (2007).

[6] Georgiadis, Konstantinos, and Michail Georgiadis. "Undrained lateral pile response in sloping ground." Journal of geotechnical and geoenvironmental engineering 136, no. 11, 1489-1500 (2010).

[7] Yang, M. H., Deng, B., & Zhao, M. H. (2019). Experimental and theoretical studies of laterally loaded single piles in slopes. Journal of Zhejiang University-SCIENCE A, 20(11), 838-851.

[8] Chae, K. S., K. Ugai, and A. Wakai. "Lateral resistance of short single piles and pile groups located near slopes." International Journal of Geomechanics 4, no. 2, 93-103 (2004). https://doi.org/10.1061/(asce)1532-3641(2004)4:2(93)

[9] Gupta, Bipin K., and Dipanjan Basu. "Analysis of laterally loaded rigid monopiles and poles in multilayered linearly varying soil." Computers and Geotechnics 72, 114-125 (2016). https://doi.org/10.1016/j.compgeo.2015.11.008

[10] Wang, Anhui, Dingwen Zhang, and Yaguang Deng. "Lateral response of single piles in cement-improved soil: numerical and theoretical investigation." Computers and Geotechnics 102, 164-178 (2018).

[11] Miao, L. F., A. T. C. Goh, K. S. Wong, and C. I. Teh. "Three-dimensional finite element analyses of passive pile behaviour." International Journal for Numerical and Analytical Methods in Geomechanics 30, no. 7, 599-613 (2006). https://doi.org/10.1002/nag.493

[12] Zhao, Zihao, Dayong Li, Fei Zhang, and Yue Qiu. "Ultimate lateral bearing capacity of tetrapod jacket foundation in clay." Computers and Geotechnics 84, 164-173 (2017). https://doi.org/10.1016/j.compgeo.2016.12.005

[13] El Sawwaf, M. "Experimental and numerical study of strip footing supported on stabilized sand slope." Geotechnical and Geological Engineering 28, no. 4, 311-323 (2010). https://doi.org/10.1007/s10706-009-9293-9

[14] Lirer, S. "Landslide stabilizing piles: experimental evidences and numerical interpretation." Engineering Geology 149, 70-77 (2012). https://doi.org/10.1016/j.enggeo.2012.08.002