Performance Evaluation of Piles for Slope Reinforcement

Dinesh Kumar Malviya[1*], Ganesh Kumar[2] and Madan Chandra Maurya[3]

[1,2]CSIR- Central Building Research Institute, Roorkee, UK 247667, India
[3]Madan Mohan Malaviya University of Technology, Gorakhpur, UP 273001, India
[1*]dineshmalviya2010@gmail.com, [2]ganeshkumar@cbri.res.in,
[3]mcmce@mmmut.ac.in

Abstract. Landslides, defined as the mass movement of materials down the slope under the force of gravity. The landslides can be initiated by various causes such as rainfall, earthquake, change in ground water level and increase or decrease in shear strength of slope materials. Occurrence of landslides always cause problems to the safety and security of people and infrastructure facilities. To mitigate landslides various slope stabilization techniques such as provision of slope drainage, soil nailing, construction of piles and retaining walls, installation of slope anchor system and biotechnical slope stabilization etc. were employed. In this paper, studies involving pile as a reinforcing member in unstable slopes were performed experimentally using large direct shear box (LDSB) apparatus. For experimental studies, two layers of clay soil having undrained shear strength 30 kPa representing unstable soil at top and 60 kPa representing stable firm soil at bottom were prepared. Experiments were then performed with and without pile reinforcement in soil. The unstable soil slope model was reinforced with single, two and three pile group system with 2D and 3D spacing to evaluate the effect of reinforcement and improvement in shear strength of unstable soil. From, experimental results it was understood that, when piles installed as a reinforcing member in soil slope, the installation improves the shear strength of unstable soil, minimizes slope movement and increases the factor of safety of the slope thus improving the safety of slope against landslide hazards.

Keywords: Slope reinforcement, Pile, LDSB, Landslide.

1 Introduction

Piles improve the stability of slope by resisting the lateral loads due to movement of unstable soil mass. Various studies in the past were performed to provide design guidelines and assessment of lateral loads on single and multi-rowed stabilizing piles in failure soil slope (Ito and Matsui 1975, Ito et al. 1981, Ito et al. 1982, Hassiotis and Chameau 1984, Hassiotis et al. 1997, Laora et al. 2017). The lateral displacement of pile and corresponding soil element is related with the pile bending stiffness, horizontal pile-soil interaction stresses and soil modulus or stiffness, horizontal soil movement respectively (Chen and Poulos 1997). A large number of numerical studies (Kanagasabai et al. 2011, Kim and Jeong 2011, Ellis et al. 2010, Ho 2012, Kahyaoglu et al. 2012, Al-abboodi and Sabbagh 2018), centrifuge studies (Viswanadham and Mahajan 2007, Yoon 2008, Yoon and Ellis 2009, Yu-zhen et al. 2010, Askarinejad and Springman 2015, Lei and Wu 2017) showed that effect of lateral soil movement on pile behavior varies and no standard design guidelines for slope stabilizing piles were available. Location of piles at critical slope also varied and studies were carried out by the researchers. Hajiazizi et al. (2017) suggested that pile installed at middle portion of the slope shows reasonable improvement in slope reinforcement in case of saturated sandy slope. Poulos (1995) suggested that installation of stabilizing piles in row at the centre of critical failure wedge improves the factor of safety of the slope. Further, through numerical modeling Cai and Ugai (2000) also confirmed that maximum factor of safety for the slope increases when stabilizing piles were located in the middle portion. Rathod et al. (2016), Sawant and Shukla (2012) studied the effect of slope angles and embedment length of pile for a sloping ground and found that, for the increase in slope angle, the bending moment for the piles increases even for the same amount of applied lateral load. Lee et al. (1995); Hassiotis et al. (1997); Jeong et al. (2003); Li et al. (2012) suggested that installation of piles near the crest of slope resulted in improving factor of safety. Although, some case studies on successful application of stabilizing piles for slope stability improvement were reported in Australia (Poulos 1995), Greece (Anagnostopoulos and Georgiadis 2004) and Korea (Song et al. 2012), there are some structural damages to the piles when used as slope reinforcement also mentioned in the literatures (Hagerty and Peck 1971, Finno et al. 1991). In this paper an attempt has been made to study the experimental behaviour of piles for slope reinforcement through large direct shear test apparatus. Single and pile group were installed inside the large direct shear apparatus with unstable soil at top and stable soil at bottom. The improvement in shear strength of the soil with and without pile was studied and presented.

2 Mechanism of Stabilization

Generally, piles embedded in a failure soil slope are categorized as passive piles, as in this case they are loaded by the lateral movement of surrounding soil. However in case of active piles, piles are subjected to a horizontal load at the head and transmit this load to the soil along its length.

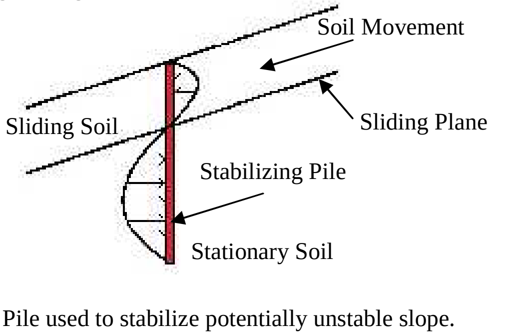

Fig. 1. Pile used to stabilize potentially unstable slope.

Sliding plane divides the soil profile into sliding soil and stable soil. Sliding soil is weaker (softer) than the stationary soil. Reinforcement of stabilizing piles improves the resistance to the soil movement above the sliding plane resulting in the stability improvement. Pile design for slope reinforcement involves three main steps: 1) evaluating the shear force needed to increase the desired value of factor of safety; 2) evaluation of maximum shear force that the pile can provide to resist sliding of the potentially unstable portion of the slope; and 3) selection of the type and number of piles and the most suitable location of these piles within the piles (Poulos 1995, Viggiani 1981).When designing the stabilizing pile, estimation of lateral forces acting over will result in improvement in shear strength of unstable soil and increase in factor of safety of the slope. Ito and Matsui (1975) developed a theoretical method for estimating lateral forces acting on the stabilizing piles, considering the plastic deformation of surrounding ground of pile when subjected to lateral loading.

3 Material Used

3.1 Soil

Soil sample collected from Uttrakhand was used for the laboratory investigation. The soil properties were determined as per IS 2720 (4), IS 2720 (5), IS 2720 (7), IS 1498, IS 2386 (3) and presented in the Table 1-

Formatted: Not Highlight

Table 1. Properties of Soil.

Liquid Limit	42%
Plastic Limit	31%
Specific Gravity	2.7
Optimum Moisture Content	21 %
Soil Classification	CI-MI

3.2 Test Pile

Scaled down aluminum piles were used for the study (Wood, 2004). The selected piles also verified for the boundary effects. For experimental testing, piles having 12 mm diameter with 1 mm wall thickness and 205 mm of length were selected. To simulate end bearing conditions, aluminum plate having 18 mm thickness with dimensions 298 mm × 298 mm (equivalent to grid plate dimensions) was fabricated with special threading arrangement for installing model piles. The surface of the plate also made rough to model grid plate interfacial behaviour.

4 Experimental Setup

4.1 Test setup for static test

All the experimental model testing were performed on large direct shear box (LDSB) apparatus at CSIR-CBRI, Roorkee. The box is 230mm deep with a cross section of 300mm X 300mm. To simulate soil slope failure conditions, two layers of clayey soil having undrained shear strength 30 kPa representing unstable soil at top and 60 kPa representing stable firm soil at bottom was chosen. To compare pile reinforcement effects, initial test was carried out on the prepared layered clay profile without any reinforcement. Then experiments were conducted with single pile, two pile group and three pile group with 3D spacing inside the clay bed to compare the effectiveness of the pile-slope system.

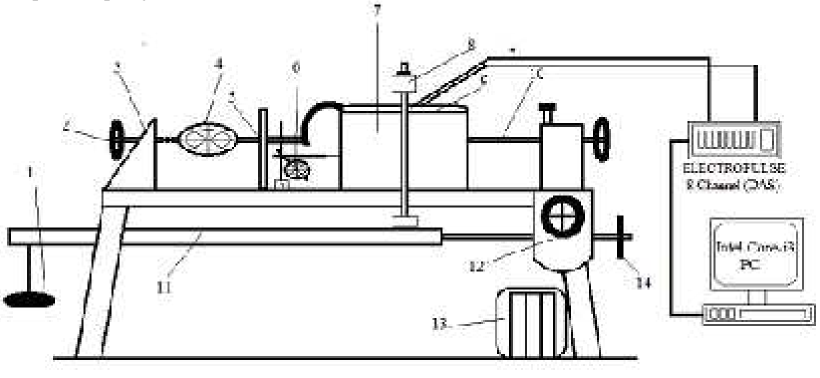

Fig. 2. Experimental Setup.

1. Loading Hanger	6. Dial Gauge	11. Lever Arm
2. Holding screw	7. Shear Box	12. Gear System
3. Abutment	8. Loading Yoke	13. Electric Motor
4. Proving Ring	9. Pullout Box	14. Counter Weight
5. Clampers	10. Lead Screw	

4.2 Instrumentation and Data Acquisition System

For the single pile experiments, the pile was instrumented with strain gauges (SG) at three locations i.e. along the outer surface of the pile at 49.5 mm, 99.5 mm and 149.5 mm (Fig. 3) respectively from pile top.

After mounting the strain gauges over the pile surface, gauge connections were made which are connected with DAS. To minimize surface damages, protective coating of Anabond was applied over strain gauges. Then, the instrumented pile was placed in the shear box before soil filling and the connections are checked and verified.

Formatted: Not Highlight

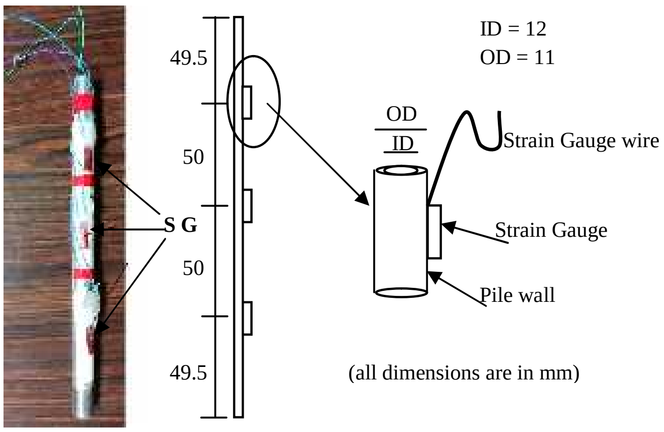

Fig. 3. Instrumented Pile.

.

5 Experimental Program

Two layers of clayey soil having undrained shear strength of 30 kPa representing unstable soil at top and 60 kPa representing stable firm soil at bottom were selected for the study. The water content required to achieve the selected undrained shear strength was further verified by conducting UCC test. For experimental testing, the soil was filled inside shear box in three layers and suitably compacted to achieve desired density and required shear strength. Special care has been taken while tamping, when pile was installed for slope reinforcement test series. Tamping rod was used for compacting soil around instrumented pile, to avoid damage to the wires connecting DAQ system. The procedure is repeated for two pile and three pile system so that required compressive strength can be achieved. All the piles were installed with the bottom base plate placed inside the shear box simulating end bearing conditions. Unreinforced and soil with single, two and three pile system is shown in Fig. 4 (a-d).
Totally four test were performed; one test without pile reinforcement and three tests were performed using pile as reinforcement i.e.1) with singe pile, 2) two pile in a row with 3D spacing and 3) three pile group with 3D spacing (group effect). Normal stress of 2.17 kPa (simulating surcharge condition) was applied using weight of 196 N (20 kg). This was selected in such a way such that it will not exceed the ultimate pile capacity. Rate of deformation of 0.125 mm/min as per IS 2720 (13) guidelines suggesting that, the test should be conducted with minimum rate of deformation to minimize generation of pore water pressure in saturated conditions.

Formatted: Not Highlight

Formatted: Not Highlight

Formatted: Not Highlight

Formatted: Not Highlight

Formatted: Not Highlight

Formatted: Not Highlight


a) unreinforced soil


b) single pile reinforcement


c) two piles reinforcement


d) three pile reinforcement

Fig. 4. Experimental Set up

The entire test was performed with same normal stress with same rate of deformation. Dial gauge readings and corresponding proving ring reading were taken to compute shear strength. Strain gauge readings were also observed for the single instrumented pile using the DAS described above.

Formatted: Not Highlight

6 Results and Discussion

Resisting forces in vertically embedded stabilizing piles comes mainly from the response of piles in terms of their shear and bending resistances (Hazarika et al. 2011). In this study, pile response to loading condition were determined by the stress-strain relationship under shear deformation using LDSB apparatus.

Shear deformation of failure soil slope with (single and group piles) and without pile reinforcement are shown in Fig. 5. Comparatively slope reinforced with pile performs better than unreinforced soil and strength of soil increases with the increase in number of piles. This is clearly evident from Fig. 5. Installation of end bearing pile creates resistance against slope movement, creates passive pressure on its surface and minimizes slope deformation. This increases as number of pile increases. Based on experimental studies in Fig. 5, 3 pile groups provided the highest resistance of 20 kPa, because the piles are installed with triangular pattern which form passive wedge slope and increases the resistance inside the soil against deformation.

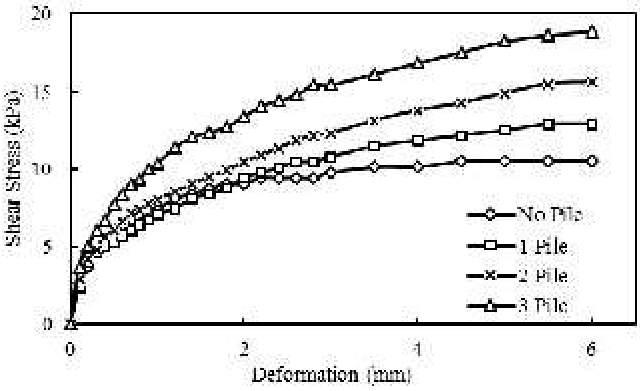

Fig. 5. Large Direct Shear Box apparatus results

Poulos (1995) summarized pile behaviour in three modes based on the location of sliding planes with respect to pile length: 1) flow mode (sliding plane at uppermost pile length); 2) intermediate mode (sliding plane at middle pile length); 3) short pile mode (sliding plane at bottom pile length) and suggested that the greatest resistance is provided by the stabilizing piles during intermediated mode of soil failure. He observed that for the intermediate mode, larger moments were developed at below and above the slide zone and highest in top zone.

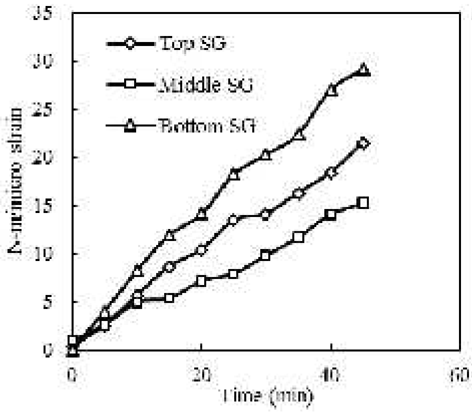

Fig. 6. Instrumented Pile results

Formatted: Not Highlight

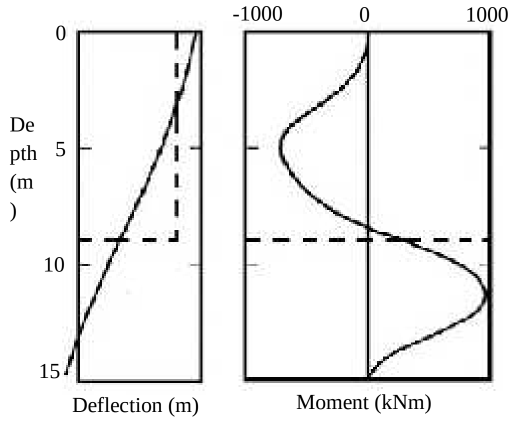

Fig. 7. Intermediate mode (Poulos 1995)

The observed experimental test results also follows intermediate mode of failure. The results obtained from the instrumented piles shows that, developed larger moments at top and bottom portion of the sliding zone, which is in agreement with the Poulos (1995) results.

7 Conclusion

An experimental approach was adopted for analyzing piles for stabilization of failure soil slope. Here, pile response to loading condition were determined by the stress-strain relationship under applied shear deformation. The performance of piles used for the stabilization of failure soil slope was examined though the Large Direct Shear Box apparatus and pile-soil interaction were observed by performing an experiment with the single instrumented pile. It was found that increasing number of pile improved the strength of soil. However detailed study regarding performance assessment of pile in slope is required for improving slope stability.

References

1. Al-abboodi, I., Sabbagh, T. T.: Numerical modelling of passively loaded pile groups. Geotechnical and Geological Engineering 1-15 (2018).
2. Anagnostopoulos, C., Georgiadis, K.: Stabilization of a highway with piles in a landslide area. 9th International Symposium on Landslides, Rio de Janerio, Brazil, 1697-1700 (2004).
3. Askarinejad, A., Springman, S. M.: Centrifuge modelling of the effects of vegetation on the response of a silty sand slope subjected to rainfall. Computer Methods and Recent Advances in Geomechanics, 1339-1344 (2015).
4. Cai, F., Ugai, K.: Numerical analysis of the stability of a slope reinforced with piles. Soils and Foundation 40 (1), 73-84 (2000).

5. Chen, L. T., Poulos, H. G.: Piles subjected to lateral soil movements. Journal of Geotechnical and Geoenvironmental Engineering 123 (9), 802-811 (1997).
6. Ellis, E. A., Durrani, I. K., Reddish, D. J.: Numerical modelling of discrete pile rows for slope stability and generic guidance for design. Geotechnique 60 (3), 185-195 (2010).
7. Finno, R. J., Lawrence, S. A., Allawh, N. F., Harahap, I. S.: Analysis of performance of pile groups adjacent to deep excavation. Journal of Geotechnical Engineering 117(6), ASCE, 934-955 (1991).
8. Hagerty, D. J., Peck, R. B.: Heave and lateral movements due to pile driving. Journal of Soil Mechanics and Foundation Division 11, ASCE, 1513-1532 (1971).
9. Hajiazizi, M., Bavali, M., Fakhimi, A.: Numerical and experimental study of the optimal location of concrete piles in a saturated sandy slope. International Journal of Civil Engineering 1-9 (2017).
10. Hassiotis, S., Chameau, J. L. Stabilization of slopes using Piles. Joint Highway Research Project JHRP 84-8, Purdue University (1984).
11. Hassiotis, S., Chameau, J. L. Gunaratne, M.: Design methods for stabilization of slopes with piles. Journal of Geotechnical and Geoenvironmental Engineering 123 (4), 314-323 (1997).
12. Hazarika, H., Mujah, D., Watanabe, N., Ahmad, F., Yasufuku, N., Omine, K.: Fundamental study on Earth Reinforcing effect using small diameter model steel pile. 13th International Summer Symposium, Japan, 207-210 (2011).
13. Ho, I.: Numerical study of slope stabilization piles in undrained clayey slopes with a weak thin layer. International Journal of Geomechanics 15 (5), 1-12 (2012).Jeong, S., Kim, B., Won, J., Lee, J.: Uncoupled analysis of stabilizing piles in weathered slopes. Computers and Geotechnics 30, 671-682 (2003).
14. IS: 2386 Part 3.: Indian Standards Code of Practice for Methods of tests for aggregates for concrete. Specific gravity, Density, Voids, Absorption and Bulking. BIS, New Delhi (1963).
15. IS 1498.: Indian Standards Code of Practice for Classification and identification of soils for general engineering purposes. BIS, New Delhi (1970).
16. IS 2720 Part 4.: Indian Standards Code of Practice for Methods of test for soils. Grain size analysis. BIS New Delhi. (1985).
17. IS 2720 Part 5.: Indian Standards Code of Practice for Methods of test for soils. Determination of liquid and plastic limit. BIS, New Delhi (1985).
18. IS 2720 Part 7.: Indian Standards Code of Practice for Methods of test for soils. Determination of water content-dry density relation using light compaction. BIS, New Delhi. (1985).
19. IS 2720 Part 13.: Indian Standards Code of Practice for Methods of test for soils. Direct shear test. BIS, New Delhi. (1985).
20. Ito, T. and Matsui, T.: Methods to estimate lateral force acting on stabilizing piles. Soils and Foundation 15 (4), 43-59 (1975).
21. Ito, T., Matsui, T., Hing, W. P.: Design methods for stabilizing piles against landslide-one row of piles. Soils and Foundation 21, 21-37 (1981).
22. Ito, T., Matsui, T., Hing, W. P.: Extended design methods for multi-row stabilizing piles against landslide. Soils and Foundation 22, 1-13 (1982).
23. Kahyaoglu, M. R., Imancli, G., Onal, O., Kayalar, A. S.: Numerical analyses of piles subjected to lateral soil movement. KSCE Journal of Civil Engineering 16 (4), 562-570 (2012).

Formatted: Not Highlight

Formatted: Not Highlight

24. Kanagasabai, G., Smethrust, J. A., Powrie, W.: Three-dimensional numerical modelling of discrete piles used to stabilize landslides. Canadian Geotechnical Journal 48, 1393-1444 (2011).
25. Kim, Y., Jeong, S.: Analysis of soil resistance on laterally loaded piles based on 3D soil pile interaction. Computers and Geotechnics 38, 248-257 (2011).
26. Laora, R. D., Maiorano, R. M. S., Avesra, S.: Ultimate lateral load of slope-stabilizing piles. Geotechnique Letters 7, 237-244 (2017).
27. Lee, C. Y., Hull, T. S., Poulos, H. G.: Simplified pile-slope stability analysis. Computers and Geotechnics 17, 1-16 (1995).
28. Lei, G., Wu, W.: Centrifuge modelling of slope stabilized by piles. 19th International Conference on Soil Mechanics and Geotechnical Engineering, Seoul, 3505-3508 (2017).
29. Li, X., Pei, X., Gutierrez, M.: Optimal location of piles in slope stabilization by limit analysis. Acta Geotechnica 7, 253-259, (2012).
30. Poulos, H. G.: Design of reinforcing piles to increase slope stability. Canadian Geotechnical Journal 32, 808-818 (1995).
31. Rathod, D., Muthukkumaran, K., Sitharam, T. G.: Development of non-dimensional p-y curves for laterally loaded piles in sloping ground. Indian Geotechnical Journal 47(1), 47-56 (2016).
32. Sawant, V. A., Shukla, S. K.: Three-dimensional finite element analysis of laterally loaded piles in sloping ground. Indian Geotechnical Journal 42 (4), 278-286(2012).
33. Song, Y. S., Hong, W. P., Woo, K. S.: Behaviour and analysis of stabilizing piles installed in a cut slope during heavy rainfall. Engineering Geology 129, 56-67 (2012).
34. Viggiani, C.: Ultimate lateral load on piles used to stabilize landslide. 10th International Conference on Soil Mechanics and Foundation Engineering, Stockholm, 3, 555-560 (1981).
35. Viswanadham, B. V. S.,Mahajan, R. R.: Centrifuge model tests on geotextile-reinforced slopes. Geosynthetics International 14 (6), 365-379 (2007).
36. Wood, D. M.: Geotechnical Modelling. 1st Edition, Spon Press, Taylor & Francis, New York (2004).
37. Yoon, B. S.: Centrifuge modelling of discrete pile rows to stabilize slopes. Ph. D. Thesis, University of Nottingham (2008).
38. Yoon, B. S., Ellis, E. A.: Centrifuge modelling of slope stabilization using a discrete pile row. Geomechanics and Geoengineering 4 (2), 103-108 (2009).
39. Yu-zhen, Y., Li-jun, D., Xun, S., He, L.: Centrifuge modeling of dynamic behavior of pile-reinforced slopes during earthquakes. Journal of Central South University of Technology 17 (5), 1070-1078 (2010).