Uplift Capacities of Triple-Plate Horizontal Circular Anchors in Sand

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Abstract. Anchors have found varied applicability in the field of civil engineering; be it in foundations, in supporting diaphragm walls, to support waterfront structures, in bridge abutments, in supporting transmission towers. A variety of anchors have been experimented in small scale model tests in the laboratory and tested in the field. Plate anchors, screw anchors, drag anchors, cement grouted anchors, shank anchors are a few to name. Researchers have studied, in both experimental studies, and analytical and numerical ones. The use of multi-plate anchors attached to the same tie rod has however been not yet considered. The authors present their idea of the use of multi-plate anchors here. The study describes the load-displacement behavior of both single-plate and triple-plate horizontal anchors of circular shape. The triple-plate anchors consist of three single plate anchors attached to the same tie rod at a spacing (s) equal to the size of the anchor (d). The efficacy of additions of plates is checked by the detailed laboratory study, in the sand.

Keywords: plate anchors, single-plate anchors, multi-plate anchors, pullout load, sand.

1 Introduction

Plate anchors have a multitude of applications in both civil engineering structures, and offshore structures. An anchorage system is used to resist tensile forces, wind forces, and wave action. The plate anchors are of different shapes, like square, circular, rectangular, and irregular anchors; different angle of inclinations, like horizontal, inclined, and vertical; and used with different angle of load application. Foundation systems of transmission towers, offshore floating structures, construction of oil and gas extraction wells, submerged pipelines, tunnels, and rock engineering structures are some of the applications of plate anchors.

The perpetual application of plate anchors has pioneered extensive research in the area. The early 60s laid the groundwork for intensive laboratory studies in this domain. Kozlov (1967) studied the application of horizontal loads to horizontal anchors. Das and Seeley (1975) have worked with horizontal anchors in the laboratory. They used aluminum plates of 3.2 mm thickness; the plates were of rectangular size. The chosen tank was 0.6 m × 0.6 m × 0.6 m in size; the angle of friction of silica sand was

31°. The uplift load was applied to the model by a 6.5 mm diameter tie rod, attached to the centre of the plate. Meyerhof's theory was used to predict the breakout factor of shallow anchors. Das and Seeley (1976) have performed laboratory tests on eccentric loads. Saran et al. (1986) developed constitutive laws for soil anchors. They performed model tests for strip, circular, and square anchors. Dickin (1988) used a centrifuge to test the uplift resistance of horizontal plate anchors in sand. He also assessed the design method of previous researchers, like the Finite element of Rowe and Davis, Vermeer and Sutjaiadi's predictions, Meyerhof and Adams' formulas, and Mayer's vertical slip surface model.

Subbarao and Kumar (1994) used the method of characteristics coupled with a log-spiral failure surface to develop a theory for the vertical uplift capacity of shallow horizontal strip anchors in a general c-φ soil. Geddes and Murray (1996) studied the collective behavior pattern of horizontal plate anchors placed in a row, with multiple configurations. Ilamparuthi et al. (2001) conducted an experimental investigation on half-cut circular anchor plates in sand. They observed that the uplift capacity of circular anchors depends on their diameter, embedment ratio, and sand density. Merifield and Sloan (2006) based their design practice on empiricism. They have performed numerical analysis to determine ultimate pullout loads of anchors in frictional anchors. Sakai and Tanaka (2006) performed an experimental and numerical study of uplift behavior of shallow circular anchors in two-layered sand. The density of the layers was dense, medium and loose. A set of the different combinational height of the layers was chosen. Dickin and Laman (2006) performed centrifuge and numerical studies using PLAXIS, to study the response of strip anchors in cohesionless soil. Kumar and Kouzer (2007) conducted numerical analysis to study the effect of group action of horizontal anchors in sand. Liu et al. (2012) presented an experimental study of a series of scaled model tests to study the anchor behavior in air-dried sand. Rokonuzzaman and Sakai (2012) performed model tests on rectangular anchor plates in a circular tank.

The literature study reveals a series of studies on horizontal anchors and group anchors. Kumar and Naskar (2012) performed numerical studies on co-axial anchors in a general c-φ soil. However, the study on co-axial anchors, i.e. multi-plate anchors is never resorted to, in the case of sand. The authors in the present study put forward their experimental investigation on multi-plate horizontal anchors in sand.

2 Methodology

A tank of dimension 1.1 m × 1.1 m × 0.75 m was utilized to perform the pullout tests on a single plate and triple-plate anchors. Fig. 1 shows the experimental setup. The sand was of uniform gradation. The dry sand was compacted to a relative density of 65 % (medium-dense) using rainfall technique. The sand used had an angle of internal friction of 30° and unit weight of 14.8 kN/m^3. The setup of the test includes a test tank, a loading system consisting of a loading frame and cable system, tie rod, and dial gauges with a magnetic base, strainer, load plates, load hanger, pedestal, and frame for sand raining.

The anchor plates were 50 and 75 mm in size, circular in shape, and of thickness 5 mm. The anchors were connected to a tie rod and pulled using a cable of 5 mm in diameter attached to the centre of the pulley. At the free end of the cable, the authors made a provision for the application of load. Pullout load on the anchor plate was gradually applied. A set of two dial gauges were used to record the displacements after each application of the load. Displacement was recorded until the ultimate pullout failure occurred, and the anchor system failed.

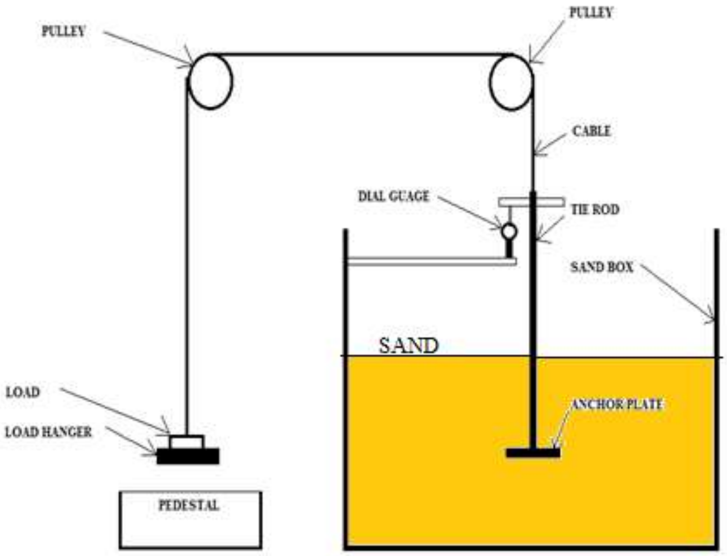

Fig. 1. Experimental set-up.

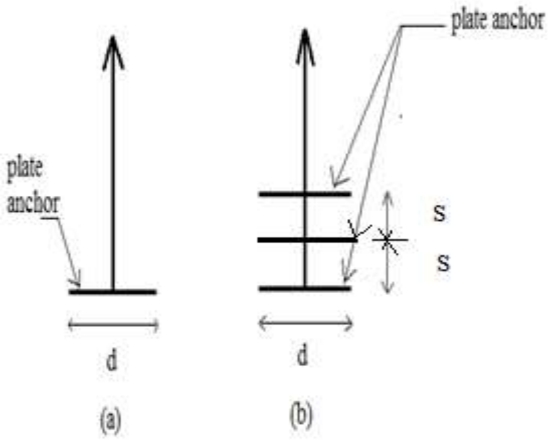

Fig. 2. (a) Single-plate anchor (b) Triple-plate anchor.

The triple-plate anchors consist of three single plate anchors attached to the same tie rod at a spacing equal to the size of the anchor (Fig. 2). The weight of the triple-plate anchor system increases by two additional anchor plates and two connectors of length equal to the diameter of the plate, as compared to the single-anchor plate system. The spacing chosen between the plates for all the triple-plate anchor system was equal to the size of the anchor plate. For the present study, embedment ratios (h/d) of 2, 4, 6 and 8 were selected; where the embedment length (h) is the height of the anchor plate from the top surface of the filled-up tank and diameter of the anchor plate (d).

3 Results and Discussions

3.1 Load-displacement of single-plate anchors

The variation of load with displacement for the pullout tests on 50 mm single-plate circular anchors with embedment ratios (h/d) of 4, 6, and 8 is shown in Fig. 3.

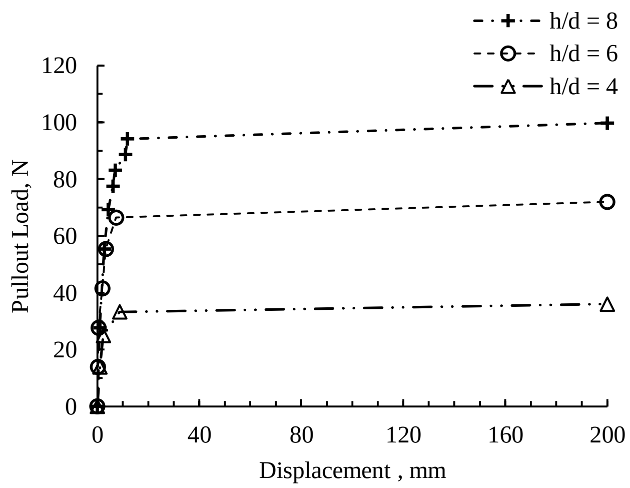

Fig. 3. Load displacement curves of 50 mm single-plate circular anchor.

The pullout test result for 50 mm single-plate anchor is not shown in Fig. 3, as the anchor was pulled out at the loading increment itself and registered a pullout load of 13 N for a displacement of 200 mm in case of embedment ratio of 2. The pullout load is mobilized by the development of the passive resistance of sand between the horizontal anchor plate and the top surface of the test tank filled with sand. Das and Shukla (2013) recommend the consideration of frictional resistance for anchors with limited width. An increase in the pullout load was observed for an increase of embedment ratio from 2 to 8. The increased embedment depth (d) encompasses a higher volume of soil mass responsible in providing higher passive resistance.

The load-displacement behavior of 75 mm circular single-plate anchors with embedment ratios of 2, 4, 6 and 8 is shown in Fig. 4. The increased size of the anchors provides higher area encompassing higher soil volume to generate better resistance and hence higher pullout capacity.

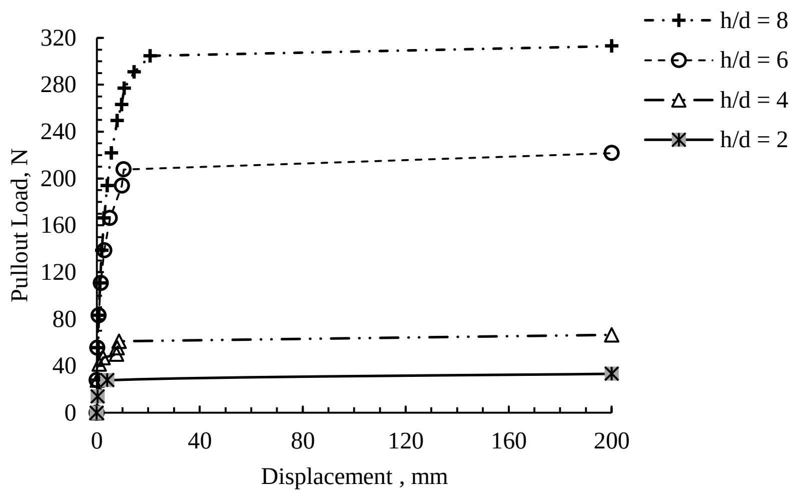

Fig. 4. Load displacement curves of 75 mm single-plate circular anchor.

3.2 Load-displacement of triple-plate anchors

The variation of load with displacement for the pullout tests on 50 mm triple-plate circular anchors with embedment ratios (h/d) of 4, 6, and 8 is shown in Fig. 5. The pullout load of 31 N was obtained at a displacement of 200 mm embedment ratio of 4 for the 50 mm triple-plate circular anchor (Fig. 5). The pullout load is mobilized by the development of the passive resistance of sand between the horizontal anchor plates and the top surface of the test tank filled with sand. An increase in the pullout load was observed for an increase of embedment ratio from 4 to 8. The increased embedment depth (d) encompasses a higher volume of soil mass responsible in providing higher passive resistance.

The variation of load with displacement for the pullout tests on 75 mm triple-plate circular anchors with embedment ratios (h/d) of 4, 6, and 8 is shown in Fig. 6. The increased size of the anchors provides higher area encompassing higher soil volume to generate better resistance and hence higher pullout capacity.

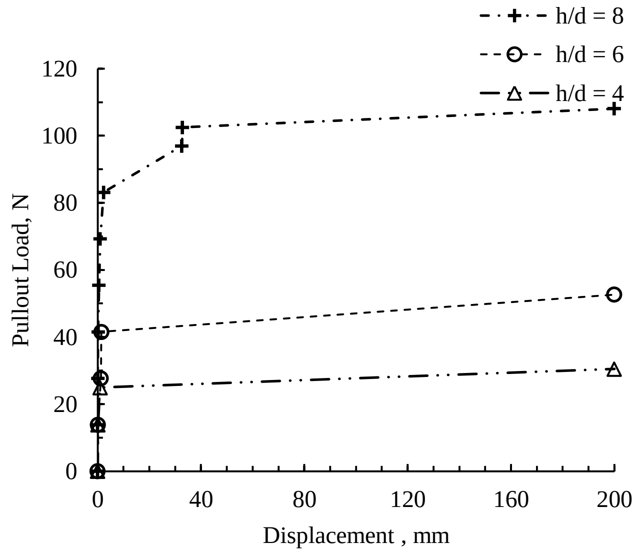

Fig. 5. Load displacement curves of 50 mm triple-plate circular anchor.

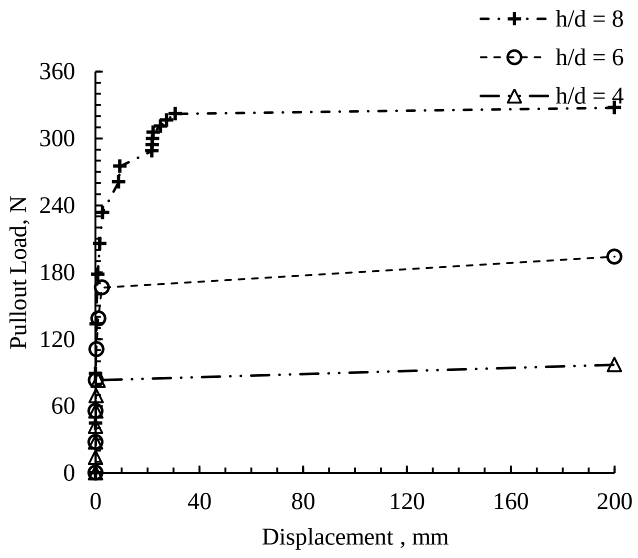

Fig. 6. Load displacement curves of 75 mm triple-plate circular anchor.

3.3 Comparisons of single-plate and triple-plate anchors

Table 1 shows the comparative study of the 50 mm and 75 mm single-plate anchors and triple-plate anchors, respectively.

Table 1. Summary of pullout load of single-plate and multi-plate anchors.

Embedment Ratio (h/d)	Pullout load, N			
	50 mm		75 mm	
	Single-plate	Triple-plate	Single-plate	Triple-plate
2	13.13	-	33.24	-
4	36.02	30.47	66.50	96.96
6	72.03	52.63	221.56	193.86
8	99.72	108.05	312.96	327.59

The results of the triple-plate anchors, for the varying embedment ratio of 4 and 6, don’t show an increasing trend. The influence of the additional plates has led to a decrease in the pullout load. The influence of an additional plate becomes instrumental in reducing the embedment depth of the top-most plate, at the same embedment ratio for the ratios 2 to 6.

For the 50 mm triple-plate anchor at an embedment ratio of 4, the embedment ratio of the top-most plate was 2. The pullout load at failure recorded was 30 N. However, the pullout load of 50 mm single-plate anchor, at an embedment ratio of 4 was 36 N. The reason for this decrease is perhaps due to the placement of the three plates before the sand filling. This kind of placement of top plates does not necessarily provide uniform distribution of sand below the top plates. The result of the unavoidable manual error in the chosen method may be attributed to this decrease, especially in embedment ratios 4 and 6.

The sequence of construction for the horizontal anchors is excavation, placement of anchors, and backfilling. An interesting comparative observation of 50 mm triple-anchor at embedment ratio of 4, with 50 mm single-plate anchor at embedment ratio of 2 brings to the next stage of the study. The pullout load of 50 mm triple-plate anchor at embedment ratio 4 had the top-most anchor plate at embedment ratio of 2, was 30.47 N; which is greater than the 50 mm single-plate anchor at embedment ratio 2 with pullout load of 13.13 N. This brings us to the positive replacement of single-plate anchors with triple-plate anchors. This idea is not economical with the horizontal anchors but probably will be effective in inclined and vertical anchors.

Referring to Table 1, the pullout load of 50 mm single-plate anchor at embedment ratio of 8, was 99.72 N. The pullout load of 50 mm triple-plate anchor at embedment ratio of 8 was 108.05 N. The influence of additional plates affected an increase in the pullout load. The increase is credited to the effect of the top-most plate being at an embedment ratio of 6. The effect of top-plate of triple-plate anchor (of h/d=8) being in embedment ratio of 6 is better than the single-plate anchor being placed at embedment ratio if 6. The pullout load of 50 mm triple-plate anchor at h/d = 8 is 108.05 N is better than pullout load of 50 mm single-plate anchor at h/d = 6.

The authors are of the view that the triple-plate anchors beyond the embedment ratio of 8 would also prove to be better than the single-plate anchors at similar depth ratios. The non-uniformity in sand filling between the plates takes less importance for the case of deep anchors than shallow anchors.

3.4 Remarks

Table 1 shows an increase in the pullout load of 75 mm triple-plate anchor as compared to the 75 mm single-plate anchor. It can be credited to uncontrolled errors in the sand filling process, the choice of application of a set of load plates during the succession of the experiment, or a disturbance in the surrounding area leading to the densification of sand layers before the application load. The case in consideration causes an 8 % error in the tests mentioned. The authors refer this as an avertible error, common to the laboratory investigations owing to multiple facts stated above.

4 Conclusions

The laboratory study chooses the traditional single-plate anchors, tests them for the same and compares it with the novel idea of triple-plate anchors. The pullout load of triple plate anchors increased with the increase in the size of the anchors and embedment ratios. The use of triple-plate anchors, at shallow depths, proved ineffective. The use of triple-plate anchors, at larger embedment ratios, proved useful. The authors suggest direct replacement of existing methods with the triple-plate anchors.

References

1. Das, B. M., Seeley, G. R.: Breakout resistance of shallow horizontal anchors. Journal of Geotechnical Engineering 101(9), 999-1003 (1975).
2. Das, B. M., Seeley, G. R.: Shallow anchor resistance to eccentric uplift load. Journal of Geotechnical Engineering 102(4), 389-393 (1976).
3. Das, B. M., Shukla, S. K.: Earth Anchors. Second Edition, J. Ross Publishing, Inc., USA. (2013).
4. Dickin, E. A.: Uplift behavior of horizontal anchor plates in sand Journal of Geotechnical Engineering 114(11), 1300-1317 (1988).
5. Geddes, J. D., Murray, E. J.: Plate anchors groups pulled vertically in sand. Journal of Geotechnical Engineering 122(7), 509-516 (1996).
6. Ilamparuthi, K., Dickin, E. A., Muthukrisnaiah, K.: Experimental investigation of the uplift behaviour of circular plate anchors embedded in sand. Canadian Geotechnical Journal 39, 648-664 (2002).
7. Kozlov, S. M.: Investigation of the behaviour of anchorages acted on by horizontal loads. Leningrad. Translated from Osnovaniya, Fundamenty i Mekhanika Gruntov 6, 19-21 (1967).

8. Kumar, J., Kouzer, K. M.: Vertical uplift capacity of horizontal anchors using upper bound limit analysis and finite elements. Canadian Geotechnical Journal 45, 698-704 (2008).
9. Kumar, J., Naskar, T.: Vertical uplift capacity of a group of two coaxial anchors in a general c–φ soil. Canadian Geotechnical Journal 49, 367-373 (2012).
10. Liu, J., Liu, M, Zhu, Z.: Sand deformation around an uplift plate anchor. Journal of Geotechnical and Geoenvironmental Engineering 138(6), 728-737 (2012).
11. Merifield, R. S., Sloan, S. W.: The ultimate pullout capacity of anchors in frictional soils. Canadian Geotechnical Journal 43, 852-868 (2006).
12. Rokonuzzaman, Md., Sakai, T.: Model tests and 3D finite element simulations of uplift resistance of shallow rectangular anchor foundations. International Journal of Geomechanics 12(2), 105-112 (2012).
13. Sakai, T., Tanaka, T.: Experimental and numerical study of uplift behaviour of shallow circular anchor in two-layered sand. Journal of Geotechnical and Geoenvironmental Engineering 133(4), 469-477 (2007).
14. Saran, S., Ranjan, G., Nene, A. S.: Soil anchors and constitutive laws. Journal of Geotechnical Engineering 112(12), 1084-1100 (1986).
15. Subbarao, K. S., Kumar, J.: Vertical uplift capacity of horizontal anchors. Journal of Geotechnical Engineering 120(7), 1134-1147 (1994).