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Uplift Capacities of Double-Plate Anchors in Sand

Vidya Tilak B., Narendra Kumar Samadhiya
Department of Civil Engineering, IIT Roorkee
Roorkee, Uttarkhand, India
tilak2015.dce@iitr.ac.in; nksamfce@iitr.ac.in

Abstract **-** In this paper, a number of laboratory tests on the uplift capacities of single-plate and double-plate anchors in medium-dense sand have been taken up for the investigation. The main purpose of the work is to present few laboratory test results for the square and circular plates in sand at a constant compactive effort. The study summarizes the pullout load at failure of anchor plates of different sizes and also describes the variation of load-displacement curves of the tests. The pullout load at failure for all the anchors increases with the increase in the size of the anchor and the depth of embedment. The pullout load at failure of double-plate anchors is found to be lesser than the single-plate anchors.

Keywords**:** plate anchors, single-plate anchors, double-plate anchors, pullout load, sand.

1. Introduction

Anchors are used to resist force in any direction. Anchors can be divided into vertical, horizontal and inclined anchors, based on their angle of inclination. There can be square, circular, rectangular, and strip, based on their shape. Also are the block anchors, helical anchors, and shank anchors, based on the way they provide resistance to the pullout loads. Anchors have been used in the foundation systems of the transmission towers, sheet pile bulkheads, and lateral load bearing structures. Anchors are also used for supporting diaphragm walls situated deep in the soil.

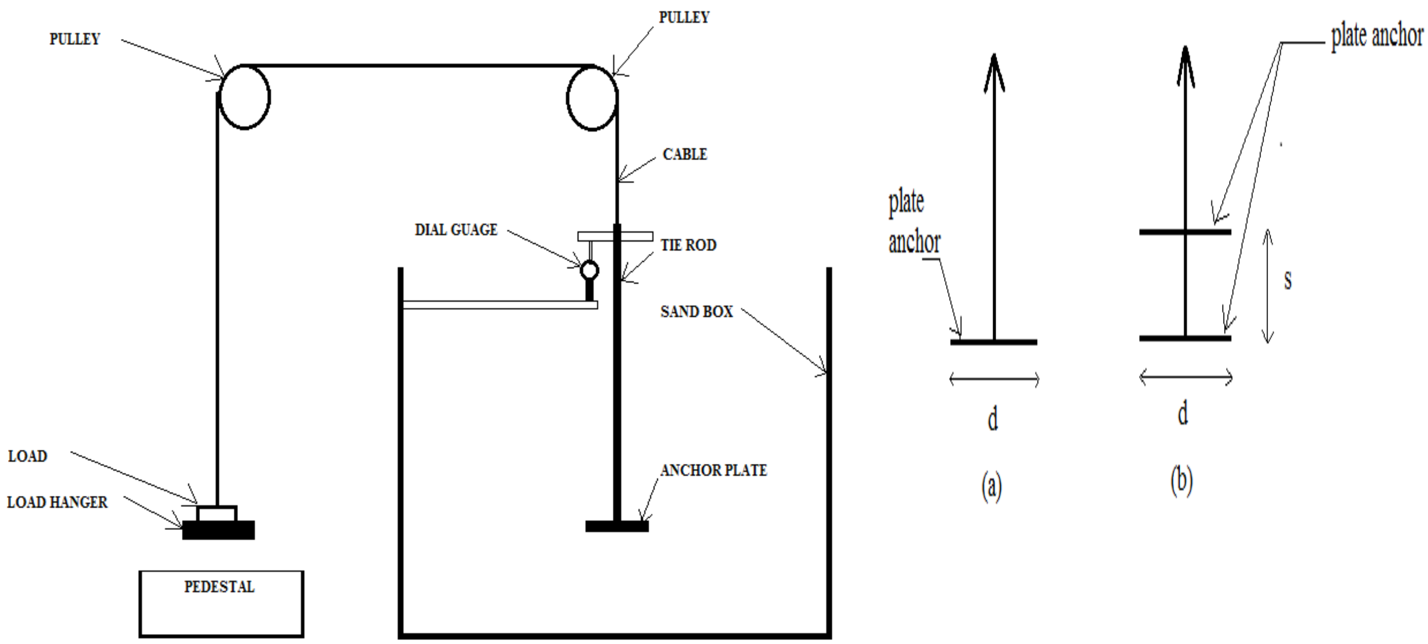
Numerous researchers have studied the effect of anchors on the pullout load. The laboratory investigations were conducted on the vertical anchors [1], inclined anchors [2], and horizontal anchors [3]. Load-displacement relationship for the vertical anchor plates was developed to assist the design of structures using anchors where the total displacement was the controlling criteria [4]. Tests on the application of oblique loads to anchors gave higher ultimate failure loads due to the unsymmetrical soil failure developed around the anchor [5]. Model tests on rectangular anchors were conducted to find the breakout resistance of shallow horizontal anchors [6]. There have also been attempts to study the shallow anchor resistance to eccentric uplift load [7]. Horizontally loaded deep vertical plate anchors in sand were studied [8], along with the group action [9]. Uplift tests on plate anchors buried in a two-layered sand summarized the relative strength of the two layers as an essential component influencing the ultimate uplift capacity of plate anchors [10].

A number of numerical analysis have been carried out in the past. Limit equilibrium method was adopted to study the ultimate pullout resistance of single vertical anchors [11], and ultimate pullout resistance of group of vertical anchors [12]. Theoretical investigations were conducted to study the behaviour of anchor plates in sand [13]. Limit analysis approach was adopted by many researchers to predict the breakout factors of anchors. A generalized procedure for predicting the optimal lower bound break-out factors of strip anchors was given [14]. Three-dimensional lower-bound solutions were given for the stability of plate anchors in sand [15]. Numerical modelling was carried out to find the uplift resistance of strip and circular anchors in two-layered sand [16].

The past studies on group action show the arrangement of anchors in series, placed at a regular spacing next to each other [17]. Researchers have conducted studies to determine the ultimate uplift capacity of multi-plate anchors in undrained clay [18]. They has been hardly any study on the multi-plate anchors in sand. The authors have analysed the effect of double-plate anchors on the pullout load at failure published elsewhere [19]. The present work compares the effect of shape of the double-plate anchors on the pullout load at failure.

2. Methodology

The pullout tests on single plate and double-plate anchors were performed in a tank of dimensions 1.1 m × 1.1 m × 0.75 m. Fig. 1 shows the experimental setup. A uniformly graded sand was used. The dry sand was compacted to a relative density of 65 % (medium-dense) using rainfall technique. The unit weight of sand is 14.80 kN/m^3. The apparatus of the test includes a loading system consisting of a loading frame connected by a cable system, tie rod, and dial gauges with magnetic stand, strainer and frame for sand raining. The anchor plates were 50 and 100 mm squares 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 center of the pulley. The load was applied to the free end of the cable. The double-plate anchors basically consists of two 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 double-plate anchor system increases by an anchor plate and a tie rod of length equal to the diameter, as compared to the single-anchor plate system. The spacing chosen between the two plates for all the double-plate anchor system was equal to size of the anchor plate. The embedment ratio (h/d) of 2 and 4 was selected for the study, 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).



(i) (ii)

Fig. 1: (i) Test set-up (ii) Schematic diagram of (a) single plate anchor (b) double-plate anchor.

3. Results and Discussion

3.1. Load-displacement of single-plate anchors

The variation of load with displacement for the pullout tests on 50 mm and 100 mm single-plate square and circular anchors are presented in Fig. 2 (i) and Fig. 2 (ii) respectively. The pullout load of 12.51 N and 44.42 N was obtained at a displacement of 6 mm and 8.27 mm for an embedment ratio of 2 and 4 respectively for 50 mm single-plate square anchor. Any further increase in the loading led to failure, referred to as pullout load at failure. 50 mm sized circular plates failed at the very first application of load and hence, the behaviour is not shown as load-displacement curves.

An increase in the pullout load was observed for an increase of embedment ratio from 2 to 4, for both 50 mm and 100 mm single plates. The pullout load was higher for 100 mm anchor plate as compared to the 50 mm anchor plate. The increased embedment length and increased size of the anchor plate involves more soil volume responsible for the action of development of passive resistance responsible for the uplift capacity. However, there was a decrease in the pullout load of circular anchors because of decreased surface area and corresponding decrease in the soil volume responsible for the passive resistance of the soil. Similar results were obtained for the tests conducted on plate anchors subjected to horizontal pull [1].

2.2. Load-displacement of double-plate anchors

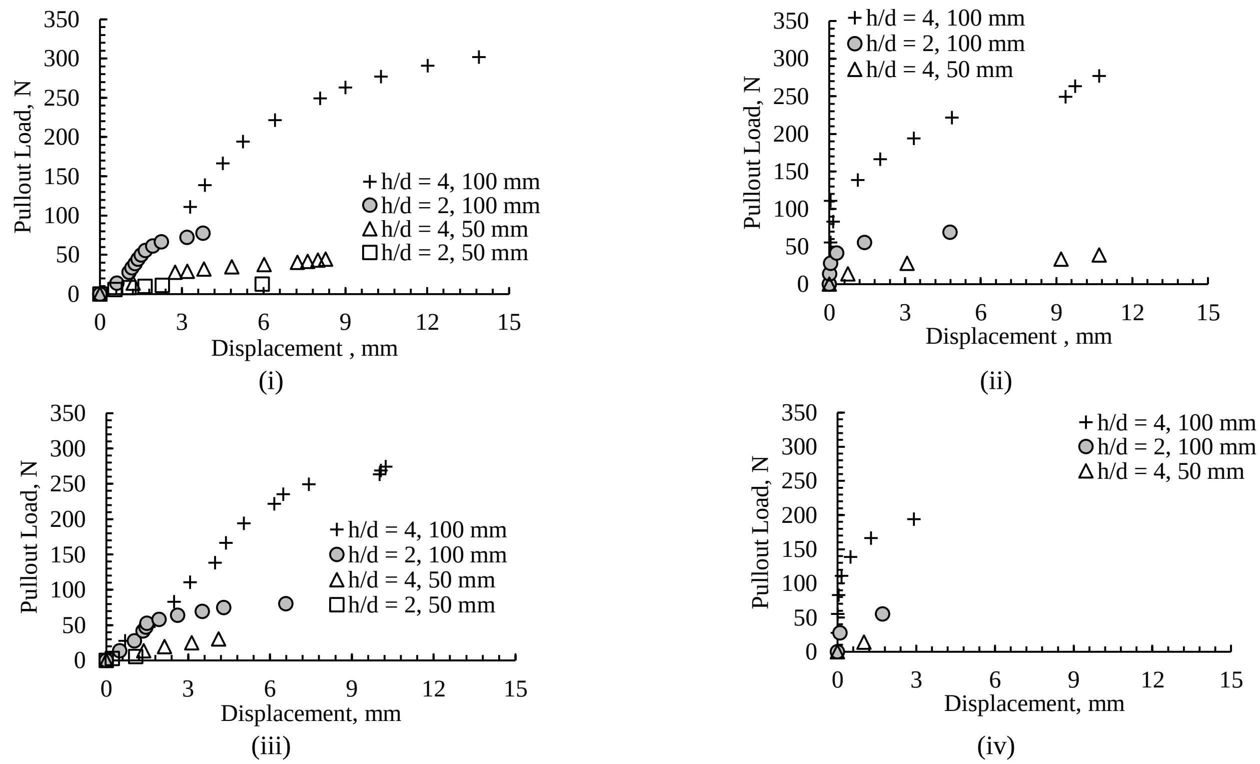


Fig. 3: Load displacement curves (i) for single-plate square anchor (ii) for single-plate circular anchor (iii) for double-plate square anchor (iv) for double-plate circular anchor

The variation of load with displacement for the pullout tests on 50 mm double-plate square and circular anchors are presented in Fig. 3 (iii) and Fig. 3 (iv). The pullout load of 5.572 N and 30.48 N was obtained at a displacement of 1.080 mm and 4.115 mm for an embedment ratio of 2 and 4 respectively for 50 mm double-plate square anchor.

An increase in the pullout load was observed for an increase of embedment ratio from 2 to 4, for the 50 mm and 100 mm double-plate respectively. The increased embedment length and increased size of the anchor plate involves more soil volume for the action of development of passive resistance responsible for the uplift capacity. Similar results were obtained for 50 mm and 100 mm double-plate circular anchors. However, there was a decrease in the pullout load because of decreased surface area and corresponding decrease in the soil volume responsible for the passive resistance of the soil.

2.3. Pullout load at failure

Table 1 summarizes the pullout loads at failure for the tests performed in the present study. The pullout load at failure of double-plate circular anchors are lesser than the corresponding square anchors. This is due to the reduction of the embedment depth of the double-plate anchors due to inclusion of an additional plate. Lesser soil volume is mobilized and the failure surface reaches the surface at lesser load.

Table 1 Summary of pullout load at failure

Size of anchors, mm	PULLOUT LOAD AT FAILURE, N							
	SQUARE ANCHORS				CIRCULAR ANCHORS			
	Single-plate		Double-plate		Single-plate		Double-plate	
	h/d = 2	h/d = 4	h/d = 2	h/d = 4	h/d = 2	h/d = 4	h/d = 2	h/d = 4
50	13.91	47.20	8.36	36.02	13.131	44.33	5.54	27.70
100	94.22	312.95	85.89	279.73	77.56	310.19	69.24	221.55

3. Conclusion

Based on the limited laboratory investigations, the study brings forth few conclusions. The uplift capacity of single plate anchors is greater than the double-plate anchors for 50 mm and 100 mm square and circular anchor plates. The uplift capacity of single plate anchors is greater than the double-plate anchors for an embedment ratio of 2 and 4. The decrease in the uplift capacity of the double plate anchor is more for smaller sized anchor plates (50 mm) as compared to the bigger ones (100 mm). Circular plate anchors provide lesser resistance to pullout loads compared to square plate anchors.

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