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Performance of Helical and Square Plate Anchors in Cohesionless Soil

A.I. Dhatrak[1], L .S. Amrutkar[2], S.W.Thakare[3] and R.R. Badnakhe[4]

[1]Dean Academics, Government College of Engineering, Amravati-444604, Email: anantdhatrak@rediffmail.com,
[2,4]P.G. Student, Civil Engineering Department, Government college of Engineering, Amravati-444604, Email: lalit.geotech@rediffmail.com;
[3]Associate Professor, Department of Civil Engineering, Government college of Engineering, Amravati-444604, Email: sanjay.thakare1964@gmail.com

Abstract. Anchors have been developed for various purposes such as strengthening the slopes, retaining walls, stability of tunnels, stability of foundations etc. There are many types of anchors depending on the type of load, type of structure and local subsoil conditions. The behaviour of anchors in the field indicates that the collapse mechanism and bearing capacity of the anchor can be determined by many factors. Most studies focus on massive models shaped anchor plates with various shapes (Helical, square) with a variation of the dimensions, depth, and type of load. In the present investigations, the uplift capacity of Helical & Square Plate Anchor resting in cohesionless soil deposit with different plate configurations was determined experimentally. Different types of anchor model were cast for experimental study, where mainly the number of plates, the depth of upper- and lowermost plates, and the ratio of spacing between the plates to the diameter of the plates were varied and ultimate uplift and Lateral capacity of each anchor was determined. In experimental investigation the uplift and lateral load carrying capacity of square and helical plate anchors are found to be increased with increase in Embedment depth and spacing between the plates. In the present study the helical plate anchor system is more efficient than square plate anchor system as they are providing more uplift and lateral load carrying capacity.

Keywords: Helical and Square Plate Anchors, Experimental study, Ultimate uplift and lateral capacity of anchors.

1 Introduction

Anchors are foundation systems that are designed primarily to resist uplift load known as tensile load. Generally, all type of foundation can be designed for uplift load and many are used to resist compressive load, lateral load or other loading combinations. The anchor is a small scale version and more traditional foundation types. Soil anchors are foundation systems used to transmit forces from the structure to the ground, in order to resist overturning moments and pullout forces which can threaten a structural stability. Some factors such as shear strength and unit weight of the soil surrounding an anchor can improve the anchor strength.

Now a days, helical anchors are being extensively used in the construction of pipelines, foundation of transmission tower, and braced excavations. The choice of foundation systems has an important role in the design of many structures, to ensure that they support any vertical or horizontal loads. Structures such as tunnels, seawalls, transmission towers, buried pipelines, and retaining walls are subjected to pullout forces and overturning moments. The soil anchor can also be used for tieback resistance in waterfront structures and also against thermal stresses.

Awdhesh Kumar Choudhary *et al.* (2016)[1] carried out the experimental study on the load-carrying mechanism of vertical plate anchors. Adel Hanna *et al.* (2014)[2] carried out an experimental investigations on the pull-out capacity of inclined shallow strip plate anchors in sand. Satyendra Mittal *et al.* (2015)[4] conducted experimental investigations on single, double and triple helical screw anchors under the influence of vertical compressive load. P. Ghosh *et al*. (2019)[5] carried out numerical analysis on ultimate pullout capacity of helical plate anchor in homogeneous soil to study the behaviour of helical plate anchor with respect to spacing between helical plates (Sp/D), changing number of helical plates, diameter and embedded depth (H/D) of helical plates. The ultimate pullout capacity for different anchor configurations obtained from the finite element analysis was compared with the values reported by Wang *et al.* (2013). Their values compared reasonably well with the experimental and numerical results proposed by Wang *et al.* (2013). They concluded from their study that the uplift capacity of helical anchor increased with increase in S_p/D and H/D ratio.

2 Experimental Investigations

In the present investigations, the uplift and lateral capacities of Helical & Square Plate Anchor resting in cohesionless soil deposit with different plate configurations was determined experimentally. Different types of anchor model were cast for experimental study, where mainly the number of plates, the depth of upper- and lowermost plates, and the ratio of spacing between the plates to the diameter of the plates were varied and ultimate uplift capacity and lateral capacity of each anchor was determined.

2.1 Soil

The sand bed was prepared for experimental work using Kanhan sand (cohesionless, dry and clean) supplied from Bhandara region (Maharashtra). The test sand was angular and of uniform yellow colour, with small proportion of black flint stones. The particle size of sand decided for the test was passing through 2 mm IS sieve. Various laboratory tests were performed to determine the physical and index properties of sand.

Table 1. Properties of sand used for experimental investigations

Sr. No	Property of Sand	Values
1	Specific Gravity (G_s)	2.67
2	IS Classification	SP (Medium Sand)

3	γ_{max} (kN/m^3)	16.73
4	γ_{min} (kN/m^3)	15.45
5	Angle of internal friction (ϕ)	36^o
6	Cohesion (kN/m^2)	0

2.2 Model anchors

Model square and helical plate anchors were made from mild steel. For the comparison purpose, the area of both plate anchors were kept equal, which was 1963 mm^2. Accordingly, the size of square plate model anchor was 44.3 mm x 44.3 mm and that of helical plate model anchor was 50 mm dia. Length of both types of model anchor were kept equal to 250 mm. In both types of model anchors, the number of plates was varied as one, two and three. The model anchors and parameters which were varied for experimental study are listed in Fig 1 and Table 2 respectively.

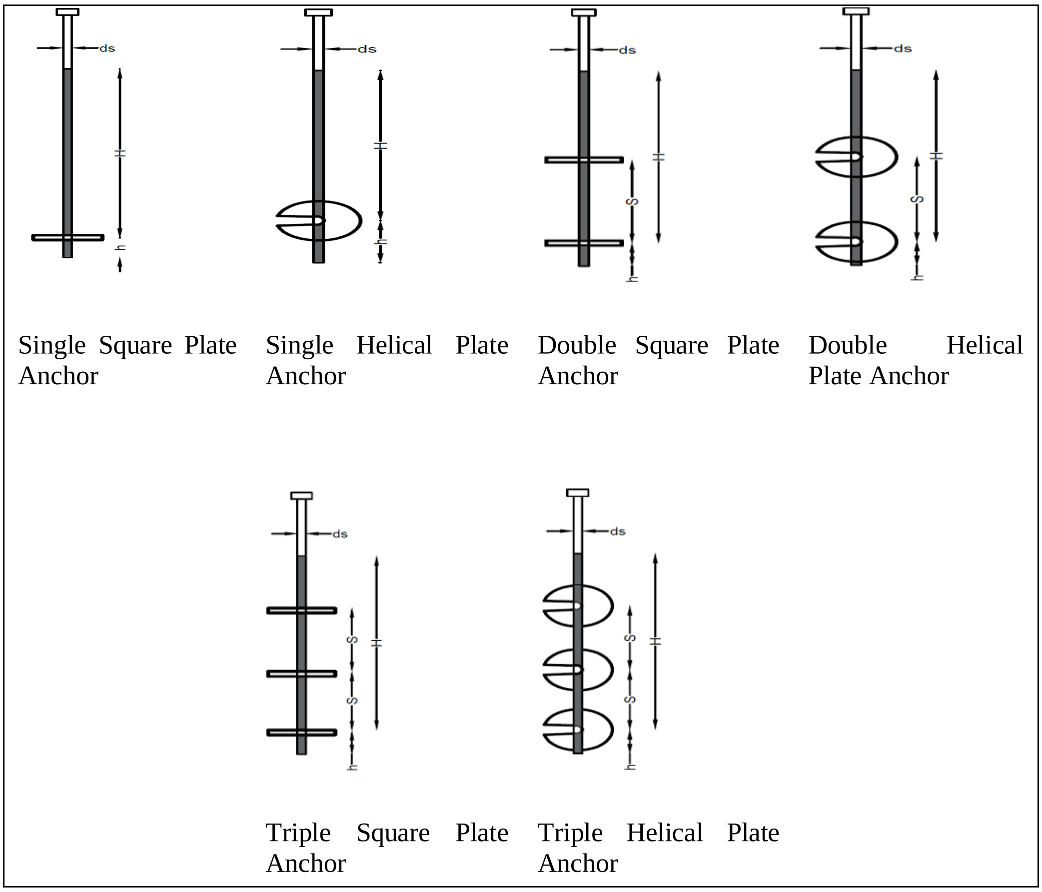


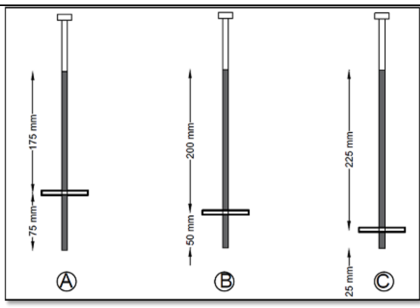
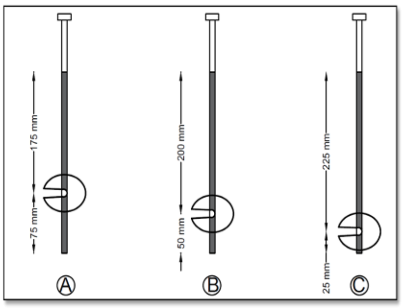
Fig. 1. Model Anchors

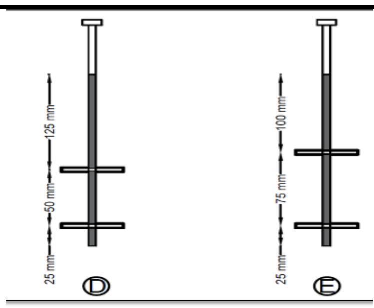
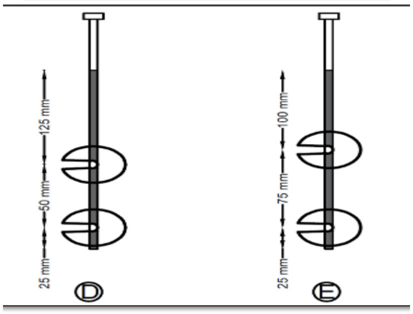
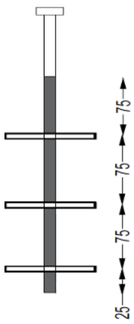
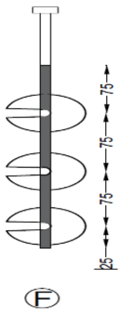
Table 2. Details of parameters varied during Experimental study

Models for each type of Anchor	Number of helical/Square plates	Embedment Ratio (λ=*H/D*)	Spacing between the plates (Sp/D)
A	1	3.5	-
B	1	4	-
C	1	4.5	-
D	2	-	1
E	2	-	1.5
F	3	-	1.5

The different anchor configurations were considered for the study whose specifications and photographic presentation are shown in Table 3.

Table 3. Details of Model Plate Anchor used in experimental investigation

Sr. No.	Description	Shape/cross section	Photographic View
1	Single Square Plate Anchor		
2	Single Helical Plate Anchor		

3	Double Square Plate Anchor		
4	Double Helical Plate Anchor		
5	Triple Square Plate Anchor		
6	Triple Helical Plate Anchor		

2.3 Test Set up

The tests were performed in a tank made of 3 mm thick M.S. sheets having internal dimensions 1000 x 1000 x 1000 mm (L x W x H). The loading frame used for applying pull out loads and lateral loads on the anchors consisted of a rectangular horizontal base frame made up of rectangular pipe section of size 25 mm x 50 mm. Six vertical threaded rods (25mm dia.) made of mild steel were fixed to this base frame. Two horizontal rectangular pipes (25 mm x 50 mm) were fixed to these threaded rods using nut bolt system, one at the middle over the tank, and another at the end, in front of the tank. Theses pipes were having an arrangement for supporting pulleys. Pullies of mild steel having diameter 6 cm were supported by horizontal bars, to carry the non-extensible wire of mild steel for application of pull out load. The wire was having knots at the end for fixing to the anchors and hook arrangement at the other end for fixing load hanger for applying loads to the anchors. The photographic view of test set up as shown in Fig. 2.

Experimental Setup used for uplift Loading

Experimental Setup used for Lateral Loading

Fig. 2. Experimental Set Up

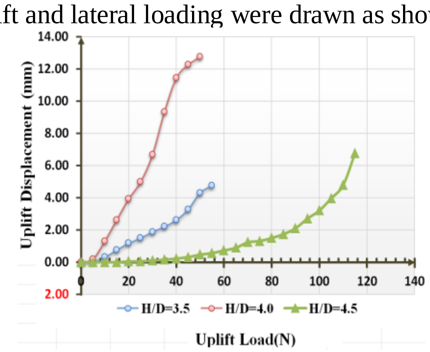
2.4 Test Procedure

The anchors were placed at the centre of the tank vertically in the sand bed and the relative density of soil was maintained at 55% (medium dense) by sand rainfall technique. The relative density achieved was confirmed by collecting samples in small containers placed at different locations in the tank and finding the density of sand at the time of filling. The static uplift load test and lateral load test were conducted on a model anchors to evaluate the uplift and lateral capacity of anchors. In load test, load was applied by adding iron weights in the pan attached to the string. Each load increment was maintained constant until the anchor displacement was stabilized. The anchor displacement was measured with the help of dial gauges. Loading was continued further, in increments, until failure occurred. Photographic representation of preparation of sand bed is shown in Fig. 3.

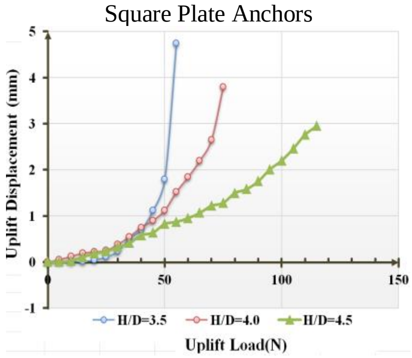
Fig. 3. Preparation of sand bed using rainfall techniques

3 Results and Discussion

The experimental investigation was conducted on Single plate, double plate and triple plate Square and Helical anchors under uplift and lateral loading conditions for different H/D ratio viz., 3.5, 4.0 and 4.5 and different S_p/D ratio viz., 1.0 and 1.5. In present study, failure load was considered as the load at which the displacement equal to 5% of the plate diameter occurred. Based on experimental results, the load verses displacement curves for uplift and lateral loading were drawn as shown in Fig. 4 to 7.

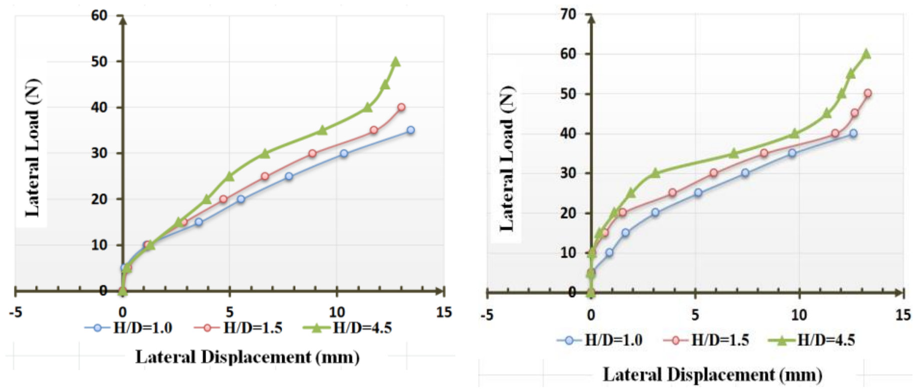


Square Plate Anchors



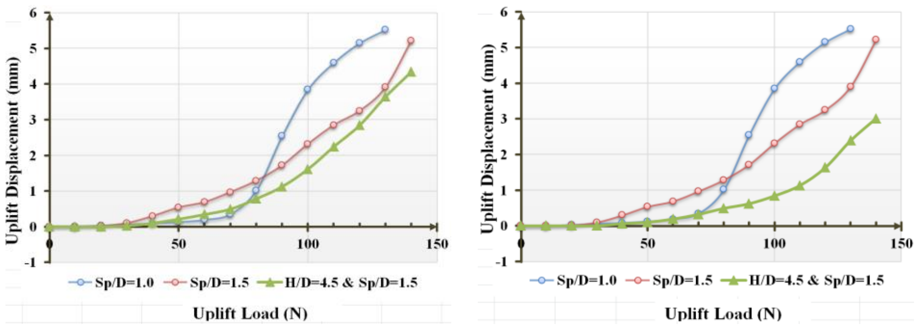
Helical plate Anchors

Fig. 4. Uplift Load- vertical displacement curves for single plate anchors for different embeded depth ratio



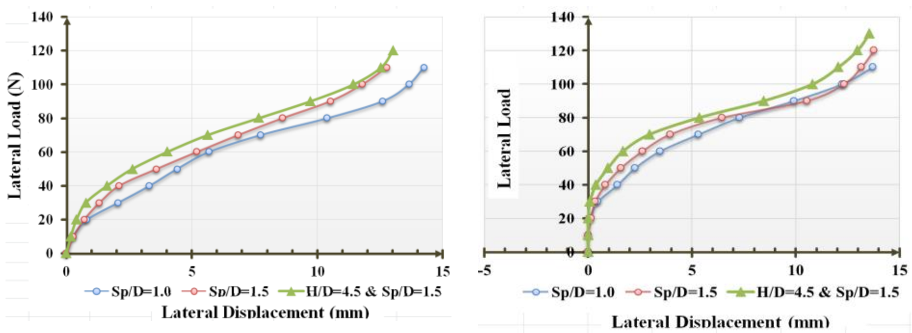
Square Plate Anchors Helical Plate Anchor

Fig. 5. Lateral Load-displacement curves for single plate anchor for different embedded depth ratio



Square Plate Anchors Helical Plate Anchor

Fig. 6. Uplift Load-displacement curves for double and triple plate anchors for different spacing ratio



Square Plate Anchors Helical Plate Anchor

Fig.7. Lateral Load-displacement curves for double and triple plate anchors for different spac ing ratio

From these figures, ultimate uplift and lateral capacities (P_u & P_L) for each set of configuration of the square and helical anchors were obtained and tabulated in Table 4 and 5 respectively.

Table 4. Ultimate uplift capacity for different anchor configurations

Sr. No	Types of Anchors	Configuration	Ultimate Uplift capacity (N)
1	Square plate Anchors	A	34
2		B	53
3		C	92
4		D	98
5		E	103
6		F	112
7	Helical Plate Anchors	A	50
8		B	69
9		C	107
10		D	114
11		E	120
12		F	131

Table 5. Ultimate Lateral capacity for different anchor configurations

Sr. No	Types of Anchors	Configuration	Ultimate Lateral capacity (N)
1	Square plate Anchors	A	13
2		B	14
3		C	16
4		D	19
5		E	22
6		F	26
7	Helical Plate Anchors	A	20.5
8		B	24
9		C	30
10		D	29
11		E	31
12		F	35

During experiments, it was observed that in case of helical plate anchors, even when the displacement was large, the shear failure area was typically near the expanded section of anchors and did not reach to the surface, indicating that local shear failure occurred. In case of square plate anchors, however, shear failure area developed up to the surface, indicating that general shear failure occurred.

From the results, it was observed that the square and helical anchors having three plates provided higher uplift capacity as compared to single and double plate anchors. Also, the uplift and lateral capacity increased with increase in embedment depth (H/D), and the spacing between the plates (Sp/D).

4 Conclusions

From the results of present study following broad conclusions are drawn:

1. The uplift and lateral capacity of square and helical plate anchors are found to be increased with increase in Embedment Ratio (H/D).
2. By changing the spacing between the plates with (Sp/D) ratio to 1.0 and 1.5, there is further increment in the uplift and lateral capacity in case of double and triple plate anchors.
3. Helical anchors are more efficient than square anchors as they are providing more uplift and lateral load carrying capacity.
4. The ultimate uplift capacity of single plate helical anchor is up to 23% greater than that of single square plate anchor.
5. The ultimate lateral capacity of single plate helical anchor is up to 40% greater than that of single square plate anchor.
6. The ultimate uplift capacity of double & triple plate helical anchor is up to 15% greater than that of double & triple square plate anchor.
7. The ultimate lateral capacity of double & triple plate helical anchors is up to 30% greater than that of double & triple square plate anchor.

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