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Numerical Analysis of Plate Anchors in Clay

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Abstract. Anchors are geotechnical foundation systems consisting of central steel shaft and number of plates welded along the shaft. These shaft and plates are generally made up of steel. The anchor shaft is used to transmit torque during installation and to transfer loads to the plates. In this paper, comparative study of the ultimate pullout and lateral load capacities of circular plate anchor, square plate anchor, helical plate anchor and star plate anchor resting in clay deposit with different configurations are studied using finite element analysis software MIDAS GTS NX. Different types of anchor configurations are considered in the analysis, 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 plate are varied. The load–displacement curve for each anchor configurations is obtained, and subsequently, the ultimate pullout and lateral load capacity for each configuration is determined. The soil is assumed to follow Mohr–Coulomb failure criteria
.

Keywords: Circular Plate Anchor, Square Plate Anchor, Helical Plate Anchor, Star Plate Anchor, Ultimate Pullout Capacity, Finite Element Analysis, MIDAS GTS NX.

1 Introduction

Soil anchors are made up of various materials such as steel plates, timber sheets, fiber reinforced polymer and precast concrete slabs. They are used to resist vertical, horizontal, and inclined loads in various geotechnical projects such as retaining walls, deep excavations, transmission towers, pipelines etc. Type of soil anchor can also be used for tieback resistance in waterfront structures and also against thermal stresses. Tension members should be fixed to the structure and then embedded into the ground to a considerable depth in order to resist uplifting forces. In general, soil anchors are foundation systems used to transmit forces from the structure to the ground, in order to resist overturning moments and pull out forces which can threaten a structure's stability. The study regarding the behaviour of soil anchors for homogeneous soil has been carried out analytically and experimentally by various researchers to predict the uplift resistance. Ghosh. P., *et al*. 2019[1] carried out numerical analysis for ultimate pullout capacity (P_u) of isolated helical anchor in homogeneous soil. They found that the uplift capacity of helical anchor increased with increase in plate spacing, diameter ratio and embedment depth of anchors. Mittal. S., *et al*. 2015[2] carried out experimental investigations on the behaviour of single, double and triple helical screw anchors under the influence of vertical compressive loads. It was observed that the compressive load varied significantly with the installation depth of the anchor. Bhattacharya. P., *et al.* 2019[3] carried out experimental study on load-displacement behaviour and vertical uplift capacity of horizontal anchor plate embedded in layered sand deposits. It was observed that the pullout capacity of circular plate anchor was invariably greater than that of strip plate. But the displacement undergone by the strip plate anchor was higher than that of the circular plate anchor, keeping the relative thickness of the medium dense and loose sand layers and total embedment depth constant.

2 Problem Definition

2.1 Anchors used for Analysis

A single isolated circular, square, star and helical plate anchor with multiple plates of diameter "D" for circular and helical anchor, length "L" for square and width "a" for star plate anchor, embedded in a soil bed with an plate embedment ratio "λ= H/D", where "H" is the embedment depth of the uppermost plate of all anchors which is considered for the analysis, as shown in Fig. 1.

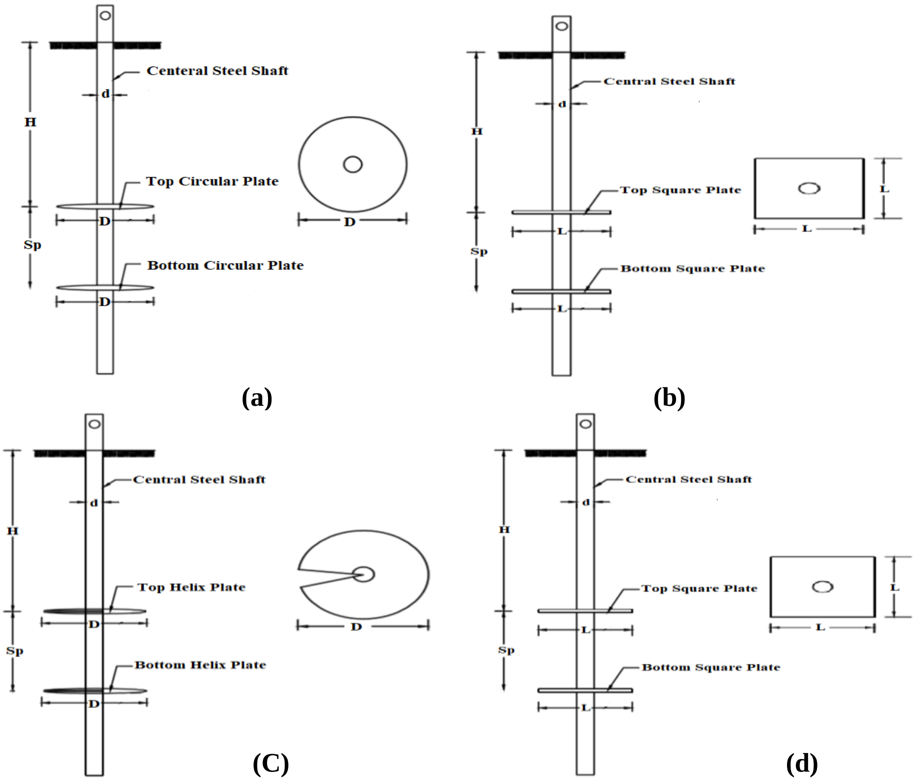


Fig. 1 Schematic Diagram of **(a)** Circular Plate Anchor **(b)** Square Plate Anchor **(c)** Helical Plate Anchor **(d)** Star Plate Anchor

All anchors are considered to be made up of steel, and the surface is considered as perfectly rough. The diameter of the plate and the central shaft is considered as 2.4 and 0.4 m, respectively for circular and helical plate. And for square and star plate anchors area of plate is taken equal to that of cross sectional area of circular plate. Pitch of the helical plate anchor is taken as 0.46 m. The thickness of the plate is assumed as 0.1 m for all types of anchors, which is considered to be negligible as compared to the diameter and length of the plate

2.2 Anchor Configurations and Properties used for Analysis

Properties assigned to anchors for analysis are taken from Wang *et al.* 2013[4] and are mentioned in Table 1. Eight different model anchor configurations are considered for the analysis of circular, square, star and helical plate Anchor as shown in Fig. 2. Details of configurations of anchors adopted for analysis is given in Table 2. Configurations C1–C3 consist of three plates, C4–C6 consist of two plates, and C7–C8 comprise of single plate with varying plate embedment depth for each type of anchor. In each set of anchors, the spacing between two plates (Sp) is kept constant except C3; for which the spacing is unequal among the plates.

Table 1. Properties Assigned to Anchor for Analysis (Wang et al. 2013)[4]

Sr. No.	Properties	Symbol	Values	Units
1	Young's modulus	E	2.1×10^8	kN/m^2
2	Density	ρ	76.5	kN/m^3
3	Poisson's ratio	υ	0.25	

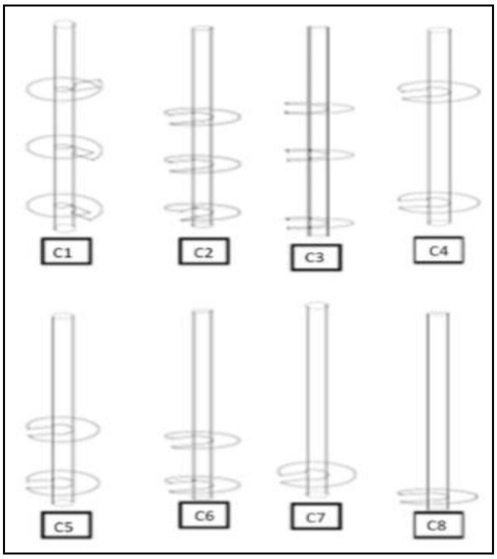


Fig. 2. Helical Anchors Configurations adopted for analysis

Table 2. Detail Configurations of Anchors adopted for analysis

Configurations for each type of Anchor.	Number of plates	Depth of uppermost plate, H (m)	Depth of lowermost plate, h (m)	Spacing between plates, S_p (m)	Plate Spacing By Diameter Ratio (S_p/D)	Plate Embedment Ratio (λ=H/D)
C8	1	9.85	9.85	-	-	4
C7	1	6.25	6.25	-	-	2.5
C6	2	5.05	7.45	2.4	1	-
C5	2	6.25	9.85	3.6	1.5	-
C4	2	2.65	9.85	7.2	3	-
C3	3	2.65	8.65	2.4,3.6	1,1.5	-
C2	3	2.65	7,45	2.4	1	-
C1	3	2.65	9.85	3.6	1.5	-

2.3 Soil considered for analysis

To determine the ultimate uplift load and ultimate lateral load capacities of the anchors, a single layer of clay soil deposit is considered. The soil properties are taken from (Wang *et al.* 2013)[4] and are mentioned in Table 3. A Mohr–Coulomb failure criterion is considered for soil. The soil bed was considered in undrained condition.

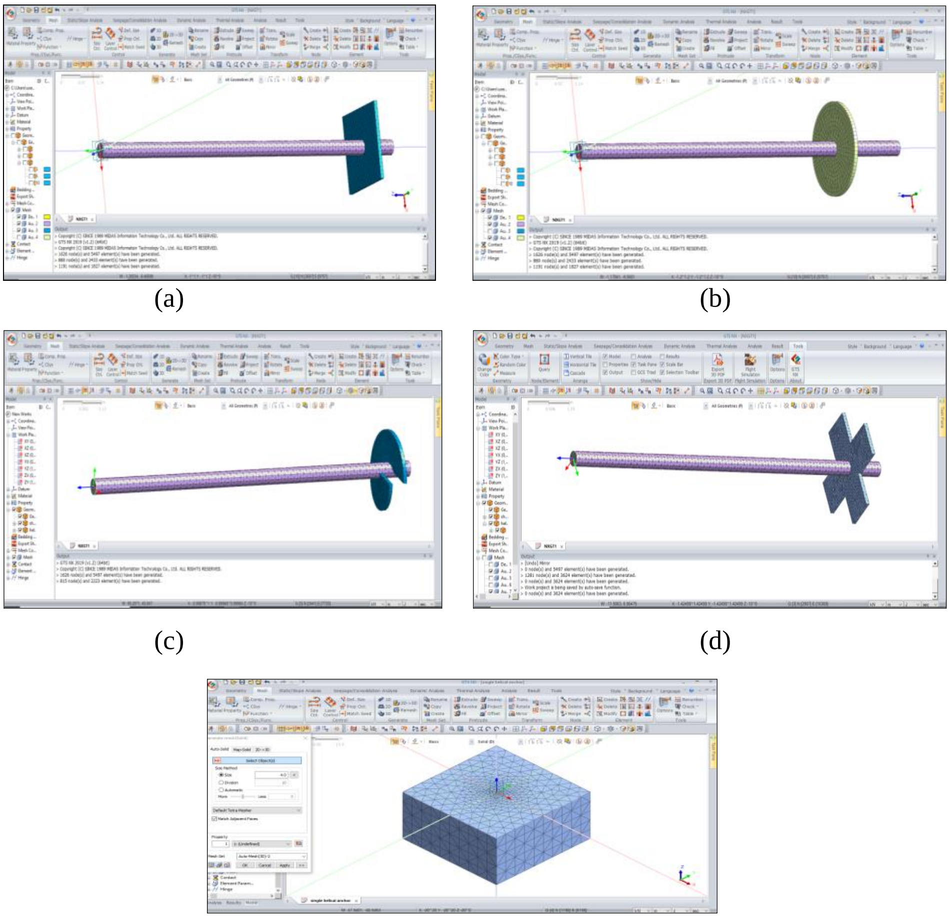
Table 3. Properties of Cohesive Soil considered for analysis (Wang *et al.* 2013)[4]

Young's modulus(E) (kN/m^2)	Undrained cohesion(cu) (kN/m^2)	Unit weight(γ) (kN/m^3)	Poisson's ratio (v)	Angle of internal friction (ϕ°)
12.75 x 10^3	12.75	16	0.4	0

3 Analysis

The objective of work was to determine the ultimate uplift and lateral load capacities of plate anchors. For analysis, each anchor was pulled with an incremental velocity in the upward direction for calculating the uplift load capacity and pushed with incremental velocity in lateral direction for calculating the lateral load capacity.

The present analysis was performed in finite element analysis software MIDAS GTS NX. The finite element meshing was done using four nodded tetrahedral elements. The anchors and the details of finite element meshing are shown in Fig. 3.



(a) (b) (c) (d) (e)

Fig. 3. Geometry of (a) Circular Plate Anchor (b) Square Plate Anchor (c) Star Plate Anchor (d)Helical Plate Anchor embedded in soil after Mesh Generation (e) Mesh Generation of Soil Domain

In the analysis, general contact properties are used to simulate the interaction among all the surfaces.

The following boundary conditions are considered for the analysis.

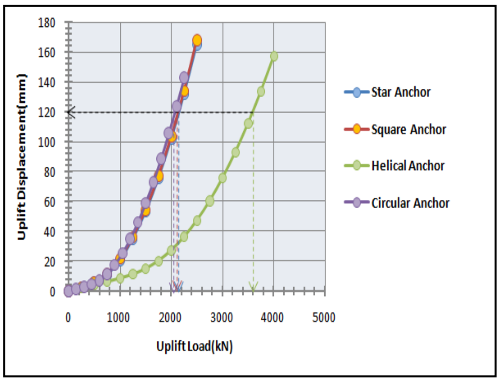
- Along X-axis displacements u_X is set to zero on the vertical boundaries parallel to YZ plane.
- Along Z-axis displacements u_Z are set to zero on the vertical boundaries parallel to XY plane.
- All displacements are set to zero on the bottom boundary, i.e., $u_X = u_Y = u_Z = 0$.

Initially, analysis was performed to determine the optimum domain size. For this purpose, configurations C1 and C8 were chosen from each sets of anchor. The main reason for selecting two configurations was that C1 anchor configuration have three plates with uniform spacing between the plates in each type of anchor, and the lower plate was embedded at a depth of 9.85 m, which was the maximum depth of plate considered in the present analysis, whereas C8 anchor configuration was having single plate with embedment depth of 9.85 m for each type of anchor. From this analysis, the depth of the clay deposit of 12.5D was found optimum and 7D in the horizontal direction from the center of the anchors.

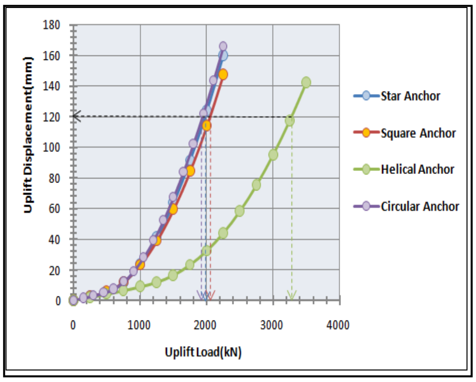
4 Results and Discussion

4.1 Ultimate uplift capacities of plate anchors

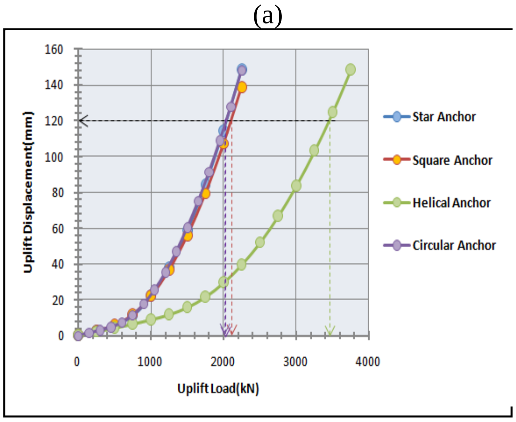
Fig. 4 shows normalized uplift load–displacement curves for all anchors placed in single-layer clay deposit for different configurations viz., C1 to C8. The ultimate uplift capacities (P_u) of the anchors were obtained by considering uplift displacement corresponding to 5% of plate diameter. Fig. 5 shows ultimate uplift load capacities for all anchors configurations.



(a)



(b)



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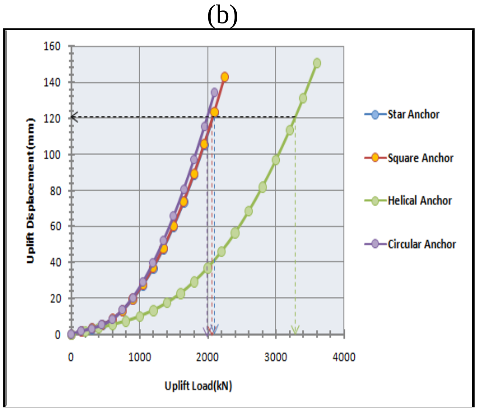

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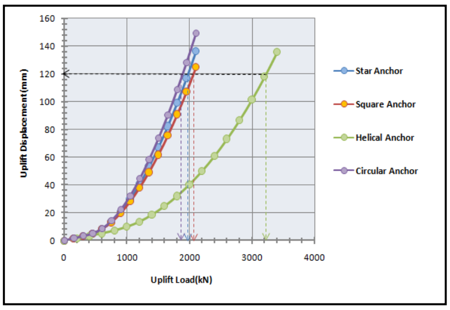

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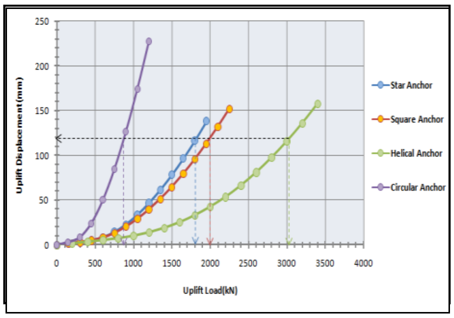

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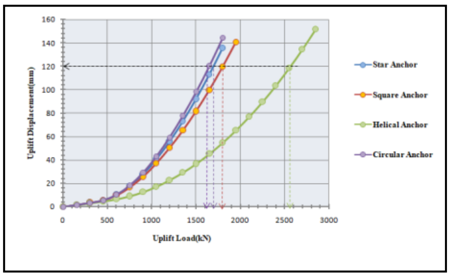

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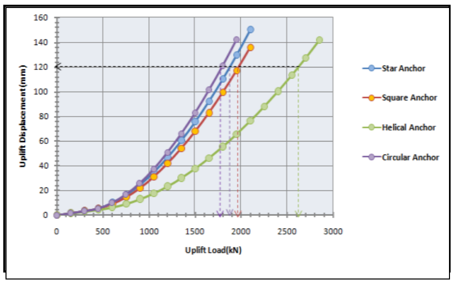


(h)

Fig. 4. Uplift Load Vs Uplift Displacement Curve – (a) C1 Configuration Plate Anchors (b) C2 Configuration Plate Anchors(c) C3 Configuration Plate Anchors (d) C4 Configuration Plate Anchors (e) C5 Configuration Plate Anchors (f) C6 Configuration Plate Anchors (g) C7 Con figuration Plate Anchors (h) C8 Configuration Plate Anchors

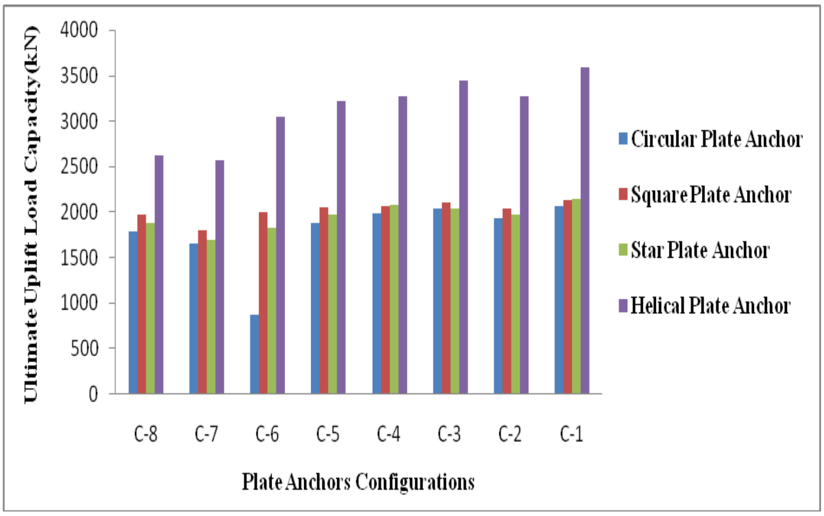


Fig. 5. Ultimate Uplift Load Capacities of all Anchors Configurations.

It can be seen from Fig. 4 that for the same embedment depth of the lowermost plate, the anchor having three plates provides higher uplift load capacity as compared to that with double and single plates. It is also observed that with the same number of plates, the uplift load capacity increases with increase in plate spacing and diameter ratio (S_p/D). From Fig. 5, it is seen that the uplift load capacity increases with increase in plate embedment depth ratio ($\lambda = H/D$), in case of anchors with single plate. Also, the magnitude of P_u increases with increase in S_p/D ratio and the depth of lowermost plate. Helical Plate Anchor shows greater capacity as compared to circular, square and star plate anchors. Fig. 6 shows percentage increase in uplift load capacities of all anchors with respect to circular plate anchors. Helical plate anchors with configuration C6 (i.e. Sp/D = 1.5) gives the maximum percentage increase in ultimate uplift load capacity as compared to that of circular plate anchors of similar configuration.

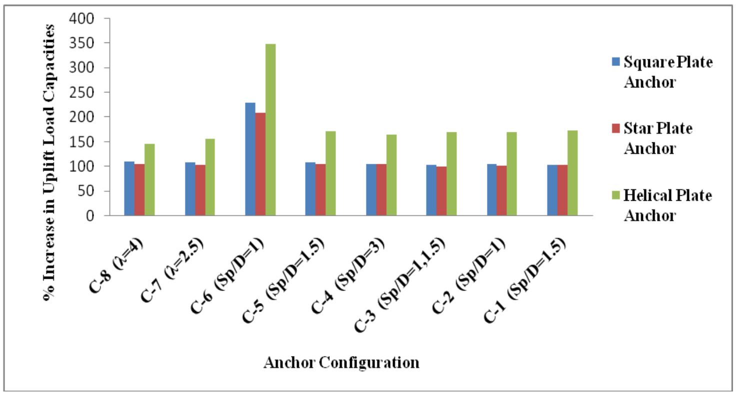
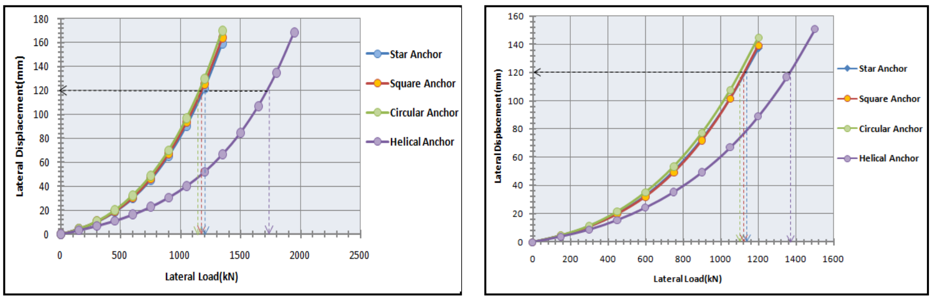


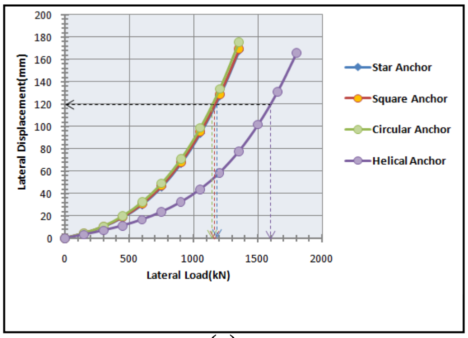
Fig. 6. Percentage Increase in Uplift Load Capacities of all anchors with respect to Circular Plate Anchor

4.2 Ultimate Lateral capacities of plate anchors

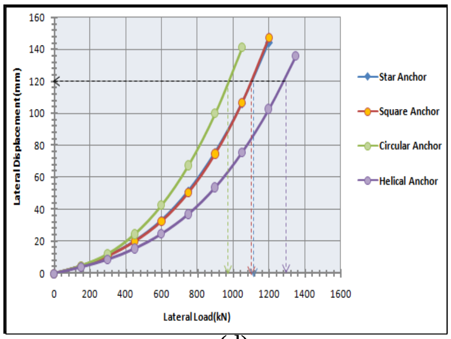
Fig. 7 shows normalized lateral load–displacement curves for all anchors placed in single-layer clay deposit for different configurations viz., C1 to C8. The ultimate lateral load capacities (P_l) of the anchors were obtained by considering lateral displacement corresponding to 5% of plate diameter. Fig. 8 shows ultimate lateral load capacities for all anchors configurations.



(a) (b)



(c)



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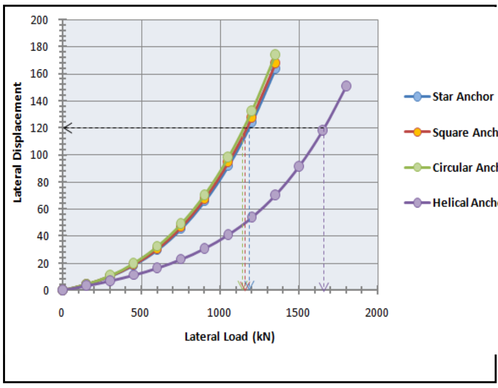
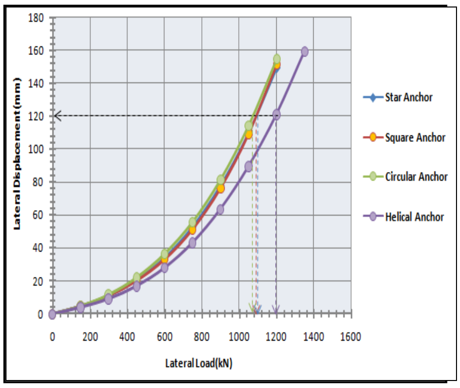
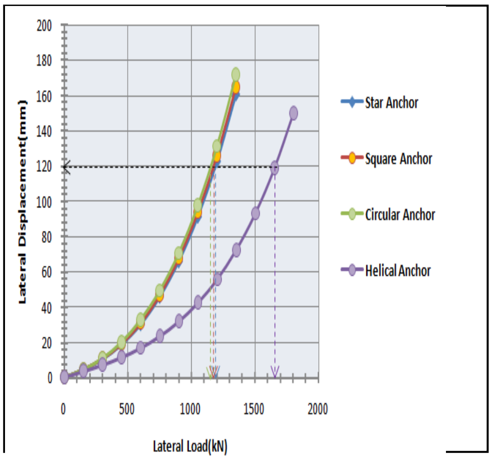


(e)





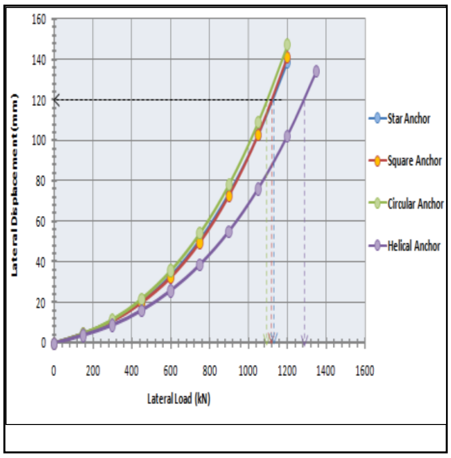


Fig. 7. Lateral Load Vs Lateral Displacement Curve – (a) C1 Configuration Plate Anchors (b) C2 Configuration Plate Anchors (c) C3 Configuration Plate Anchors (d) C4 Configuration Plate Anchors (e) C5 Configuration Plate Anchors (f) C6 Configuration Plate Anchors (g) C7 Con figuration Plate Anchors (h) C8 Configuration Plate Anchors

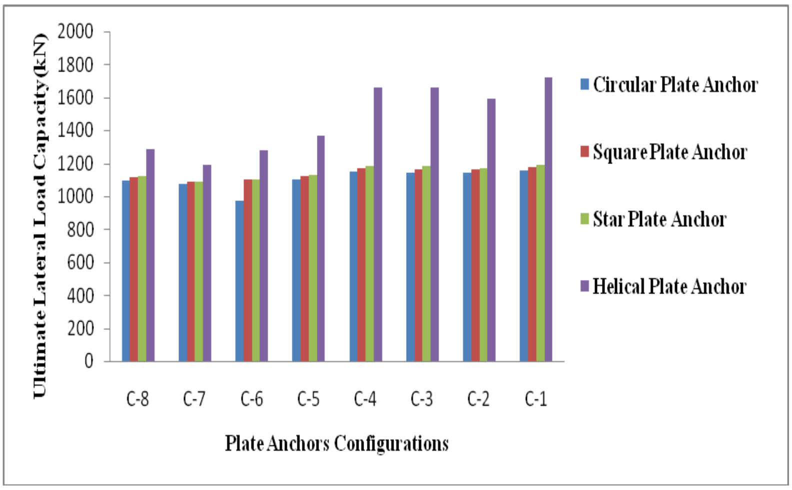


Fig. 8. Ultimate Lateral Load Capacities of all Anchors Configurations

From Fig. 8, it is seen that lateral load capacity of anchors slightly increases with increase in plate embedment depth ratio (λ = H/D), in case of anchors with single plate. Also, the magnitude of P_l increases with increase in S_p/D ratio and the depth of lowermost plate. Helical Plate Anchor shows greater lateral load capacity as compared to circular, square and star plate anchors. Fig. 9 shows percentage increase in lateral load capacities of all anchors with respect to circular plate anchors. Helical plate anchors with configuration C1 (i.e. Sp/D = 1.5) gives the maximum percentage increase in ultimate lateral load capacity as compared to that of circular plate anchors of similar configuration.

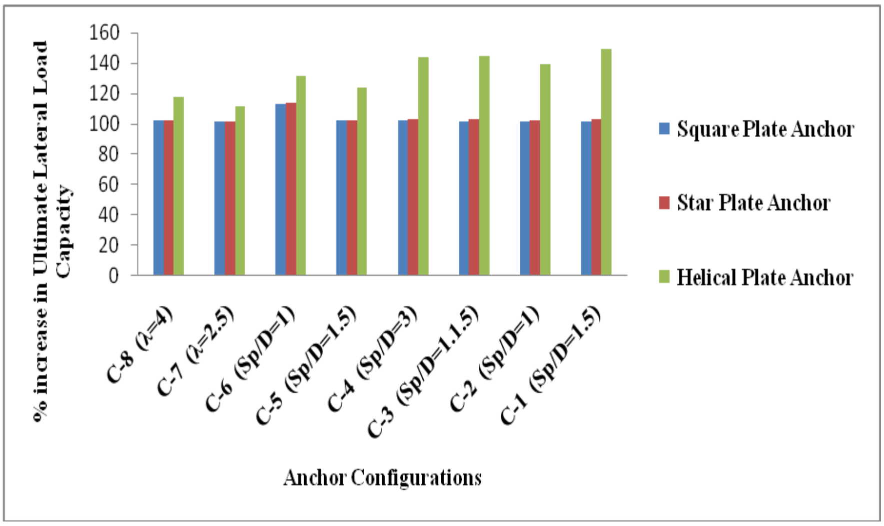


Fig. 9. Percentage Increased in Ultimate Lateral Load Capacities of all anchors with respect to Circular Plate Anchor

5 Conclusions

Following broad conclusion are drawn from the numeral analysis of plate anchors of various shapes and configurations:

1. The ultimate uplift load capacity as well as lateral load capacity of all single plate anchors increases with increase in plate embedment depth ratio ($\lambda=H/D$).
2. The ultimate uplift load capacity as well as lateral load capacity of all double plate and triple plate anchors increases with increase in plate spacing by diameter ratio (*Sp/D).*
3. The ultimate uplift load capacity and lateral load capacity of all plate anchors increases with increase in no of plates.
4. The ultimate uplift load capacity and lateral load capacity of double plate anchors and triple plate anchors is slightly higher as compared to single plate anchors.
5. The ultimate uplift load capacity and lateral load capacity of single plate square anchor, single plate star anchor, and single plate helical anchor is higher as compared to that of single plate circular anchor.
6. The ultimate uplift load capacity and lateral load capacity of double plate square anchor, double plate star anchor and double plate helical anchor is higher as compared to that of double plate circular anchor at (*Sp/D*) plate spacing by diameter ratio equal to 1.
7. The ultimate uplift load capacity and lateral load carrying capacity of triple plate square anchor, triple plate star anchor and triple plate helical anchor is higher as compared to that of triple plate circular anchor in cohesive soil at (*Sp/D)* plate spacing by diameter ratio 1.5.

The ultimate uplift load capacity and lateral load capacity of helical plate anchor is higher as compared to those of circular plate anchor, square plate anchor and star plate anchor of same cross-sectional area. Also it is observed that C1 configuration of helical plate anchor with plate embedment depth ratio equals to 4 and plate spacing by diameter ratio equals to 1.5 is most efficient among all other configurations for resisting uplift and lateral load.

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