ULTIMATE PULLOUT CAPACITY OF ISOLATED HELICAL ANCHOR USING FINITE ELEMENT ANALYSIS

Ghosh P[1].
Samal S[2].
[1]Associate Professor, [2]PG Student, Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur – 208 016.
Email ID: priyog@iitk.ac.in

ABSTRACT: In this paper, the ultimate pullout capacity of single isolated helical anchor resting in homogeneous soil deposit with different helix configurations is determined using finite element analysis. The anchor is pulled to its ultimate failure controlling the displacement. Eight different types of anchor configuration are considered in the analysis, where mainly the number of helical plates, the depth of upper- and lowermost helical plates and the ratio of spacing between the helical plates to the diameter of the plate are varied. The variation of load-displacement curve for each anchor configuration is obtained and subsequently, the ultimate uplift capacity of each anchor is determined by using double-tangent method. The soil is assumed to follow Mohr-Coulomb failure criteria. The present theoretical observations are generally found in good agreement with those theoretical and experimental results available in the literature.

KEYWORDS: Finite element analysis, helical anchor, homogeneous soil, plasticity, pullout capacity,

1 INTRODUCTION

The anchor is a foundation system generally designed and constructed to transmit any uplift force and over turning moments coming from a structure to the underlying soil. Anchors are important for many engineering applications such as transmission towers, suspension bridges, tall chimneys, high rise structures which experience lateral load like wind load, buried pipe lines under water, offshore structures as well as tunnel construction. As compared to the installation of conventional plate anchor, helical anchor is quite easy to install and is quite cost effective, which may be used both in tensile and compressive loading condition. Basically, helical anchors are geotechnical foundations consisting of central steel shaft and number of helical plates welded along the shaft. These helical plates are generally made up of steel and are formed with a definite pitch. The anchor shaft is used to transmit torque during installation and to transfer loads to the helical plates. A number of investigations have been performed by several researchers to predict the uplift resistance of the plate anchor with the help of different numerical as well as experimental investigations. However, the work on the helical anchor is still scarce. From the literature it has been seen that few research works (Ghaly et al. 1991, Rao and Prasad 1993, Ghaly and Clemence 1998, Hanna et al. 2007, Lutenegger 2011, Mittal and Mukherjee 2013, Nazir et al. 2013, Wang et al. 2013, Demir and Ok 2015) have been carried out to determine the ultimate uplift capacity of helical anchor theoretically as well as experimentally. From the reported investigations, it can be clearly understood that the ultimate uplift capacity of helical anchor depends upon the number of helical plates, the depth of upper- and lowermost helical plates, the ratio of spacing between the helical plates to the diameter of the plate and embedment depth.

In the present investigation, a numerical study on the pullout capacity of single isolated helical anchor embedded in homogeneous soil layer has been carried out using finite element method developed in the framework of three dimensional failure domain in ABAQUS 6.13.

2 DEFINITION OF THE PROBLEM

A single isolated helical anchor with multiple helical plates of diameter, D is embedded in a homogeneous soil layer with an embedment ratio, $\lambda = H/D$, where H is the embedment depth of the upper-most helical plate (Fig. 1). The helical anchor is made up of steel and the surface is assumed to be perfectly rough. The soil is assumed to obey Mohr-Coulomb failure criteria. The objective is to determine the magnitude of uplift capacity of the helical anchor, where the anchor is pulled with an incremental velocity in the upward direction for calculating the uplift loading capacity. Full failure domain is considered for the analysis as the helical anchor is not truly axi-symmetric member.

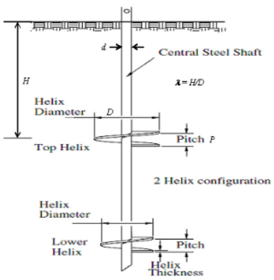


Fig. 1 Schematic diagram of helical anchor

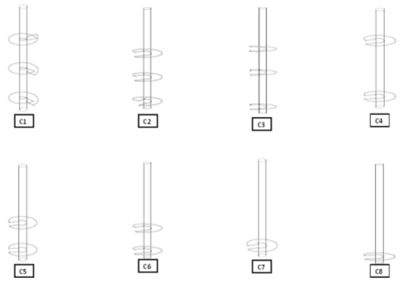


Fig. 2 Configuration of helical anchors

3 MATERIAL AND GEOMETRY

3.1 Material

To determine the uplift capacity of the helical anchor, a single layer homogeneous soil deposit is considered. The properties of the soil deposit have been taken from Wang et al. (2013) and are mentioned in Table 1, whereas the properties of steel anchor used in the analysis are given in Table 2.

Table 1 Properties of Soil Deposit (Wang et al., 2013)

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

Table 2 Properties of Steel Anchor

Young's modulus (E) (kN/m^2)	Density (ρ) (kg/m^3)	Poisson's ratio (υ)
2.1×10^8	7800	0.25

3.2 Anchor configuration

Eight different anchor configurations have been considered for the analysis (Fig. 2) whose geometric specifications (Table 3) are taken from Wang et al. (2013). It can be seen from Fig. 2 that C1-C3 consist of three helical plates, C4-C6 consist of two helical plates and C7-C8 comprise of single helical plate. For any particular anchor, the spacing between two plates (S_p) is kept constant except C3, where the spacing is unequal among the plates. The diameter of the helical plate and the central shaft is considered as 2.4 m and 0.4 m respectively, whereas the pitch of the helix (*P)* is taken as 0.46 m. The thickness of the helical plate is assumed as 0.1 m, which is considered to be negligible as compared to the diameter of the helical plate.

Table 3 Geometric Details of Different Anchor Configuration (Wang et al., 2013)

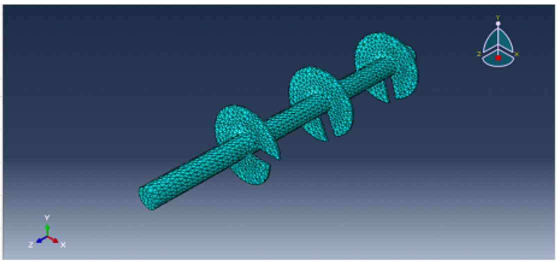
Configuration	Number of helical plates	Depth of uppermost plate, *H* (m)	Depth of lowermost plate (m)	Spacing between plates, S_p (m)	S_p/D
C1	3	2.65	9.85	3.6	1.5
C2	3	2.65	7.45	2.4	1.0
C3	3	2.65	8.65	2.4, 3.6	1, 1.5
C4	2	2.65	9.85	7.2	3
C5	2	6.25	9.85	3.6	1.5
C6	2	5.05	7.45	2.4	1
C7	1	6.25	6.25	-	-
C8	1	9.85	9.85	-	-

4 ANALYSIS

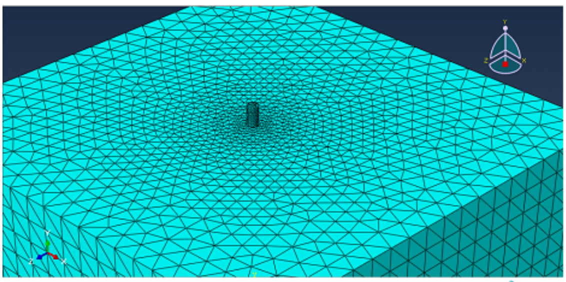
The present finite element analysis has been performed using commercially available software ABAQUS 6.13. The numerical analysis has been carried out in 3D model. The whole soil domain is assumed to be at undrained condition. The soil deposit is assumed to follow Mohr-Coulomb failure criteria available in ABAQUS. Due to complicated geometry, the helical anchor is first designed in AutoCAD and then imported to ABAQUS. The finite element meshing has been done using four nodded tetrahedral elements. The AutoCAD drawing of helical anchor and the details of finite element meshing are shown in Fig. 3. In the analysis, general contact properties are used to simulate the interaction among all the surfaces. All the interacting surfaces are considered as penalty for tangential behavior and hard for normal behavior. The penalty behavior denotes that there is a finite coefficient of friction value between the surfaces and no slip occurs. In this analysis the penalty value is taken as 0.1 as the soil is cohesive one (Table 1). The following boundary conditions are considered in the present analysis (Fig. 4).

- Displacements along X-axis, u_X are set to zero on the vertical boundaries parallel to YZ plane
- Displacements along Z-axis, 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. $u_X = u_Y = u_Z = 0$

Sensitivity analysis has been performed in order to determine the optimum domain size. For finding out the optimum domain size, anchor C1 and C8 are chosen. The main reason behind choosing these two configurations is that, C1 anchor configuration is having three helical plates with uniform spacing between the plates and the lower plate is embedded at a depth of 9.85 m, which is the maximum depth considered in the present analysis, whereas C8 configuration is having single helical plate with embedment depth of 9.85 m. In this study the depth of the soil deposit is fixed at 12.5*D*. It is found that beyond 7*D* in the horizontal direction no significant change in the ultimate uplift capacity gets observed and hence, the optimum domain size in the horizontal direction is selected as 7*D* from the centre of the anchor.



(a)



(b)

Fig. 3 Overview of a) AutoCAD drawing and finite element meshing of C1 anchor, b) finite element meshing of soil domain

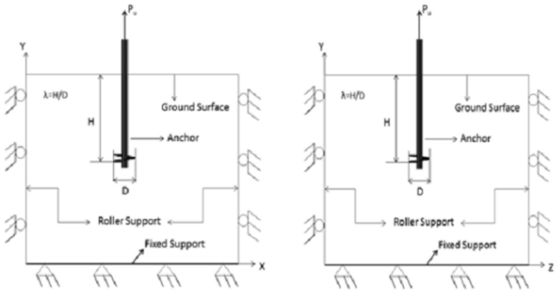


Fig. 4 Boundary conditions along XY and YZ plane

5 RESULTS AND DISCUSSION

In Figs. 5-6, the normalized load-displacement curves for isolated helical anchor placed in single layer homogeneous soil deposit are shown for different configurations from C1 to C8, where *P* is the uplift capacity and δ is the vertical displacement of the anchor. The ultimate uplift capacity (P_u) of the anchor has been obtained by considering double-tangent method. It can be seen from Fig. 5a that for the same embedment depth of the lowermost helical plate, the anchor having three helical plates provides higher uplift capacity as compared to that with double and single helical plates. It can be observed from Figs. 5b and 6a that with the same number of helical plates, the uplift capacity increases with increase in S_p/D ratio. It can be also noticed from Fig. 6b that for the anchor with single helical plate the uplift capacity increases with increase in embedment depth ($\lambda = H/D$). The variation of ultimate uplift capacity for different anchor configurations is shown in Fig. 7. It can be seen that the magnitude of P_u increases with increase in S_p/D and the depth of lowermost helical plate.

6 COMPARISON

In Table 4, the magnitude of P_u for different anchor configurations obtained from the present finite element analysis is compared with the values reported by Wang et al. (2013). It can be seen that the present values compare reasonably well with the experimental and numerical results proposed by Wang et al. (2013).

7 CONCLUSIONS

In the present study, the ultimate uplift capacity of single isolated helical anchor is determined using finite element analysis. Eight different configurations of helical anchor are considered in the analysis. The uplift capacity of helical anchor is found to increase with increase in S_p/D ratio and λ. The magnitude of P_u is found to increase with increase in S_p/D and the depth of lowermost helical plate. The present results compare well with the results available in the literature.

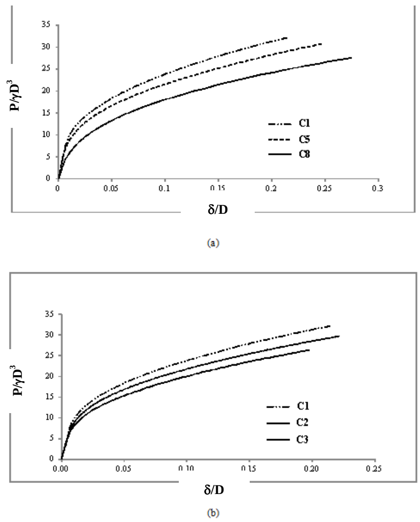


Fig. 5 Normalized load-displacement curve for isolated helical anchor with a) same depth of lower-most helical plate, b) three helical plates

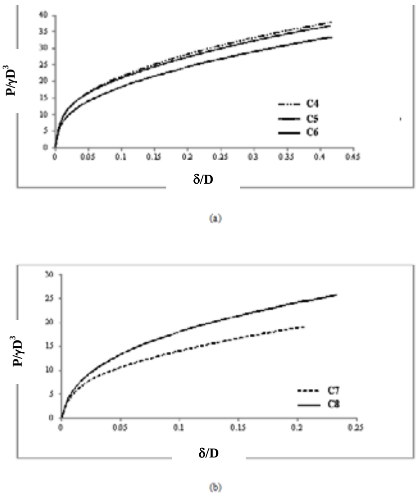


Fig. 6 Normalized load-displacement curve for isolated helical anchor with a) two helical plates, b) single helical plate

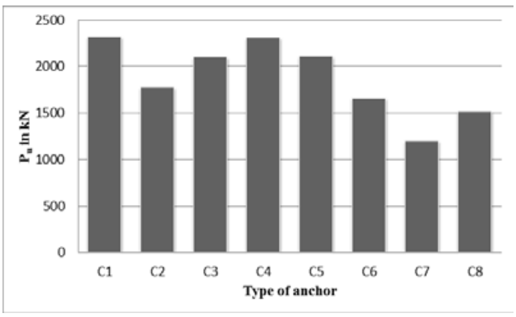


Fig. 7 Variation of P_u for different anchor configurations

Table 4 Comparison of P_u for Different Anchor Configurations

Configuration	P_u (kN)		
	Present analysis	Wang et al. (2013)	
		Experimental analysis	Numerical analysis
C1	2320	1987	2381
C2	1775	1780	1755
C3	2100	2003	2068
C4	2310	1971	2343
C5	2110	1930	2166
C6	1660	1513	1666
C7	1200	1351	1171
C8	1520	1715	1504

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