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# Numerical Analysis on Behaviour of Horizontal Plate Anchor in Cohesionless Soil using Plaxis-3D

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**Abstract.** The anchors are used as a tension member which attached to the foundation of the structure, mainly to counter any uplift reaction or overturning moment or combination of both. Structures such as transmission towers, tension cable for suspension bridges, guyed lattice tower, marine structure like floating platform and tension leg platform and, buried pipelines carrying fluids are subjected to uplift force like wind force and buoyant force, which are inevitable and are much greater than the dead weight of the structure itself. This study uses Plaxis-3D to demonstrate the uplift behaviour of a horizontal square anchor plate in a cohesionless soil. The study describes the load-displacement behaviour, representing the anchor plate's pullout capacity in terms of non-dimensional breakout factor, the impact of soil density, and the embedment depth of the pullout capacity.

**Keywords:** Plate anchors; Embedment depth; Relative density; Breakout factor; Plaxis-3D.

## 1. Introduction

The anchor plate is a tension member which is connected to the structure and embedded into the soil to a sufficient depth so as to resist any uplift load or overturning moment or combination of both. Structures like tension leg platform, tank subjected to flooded, light structures such as electric transmission towers, communication signal towers, and buried pipes line etc. are likely to experience the uplift pressure or buoyant force. These forces are substantially greater than the structure's own weight, resulting into sudden collapse of structure. Hence, to avoid such types of failure, there is a need to develop an idea to resist these types of forces. For this, an anchor plate, made up of mild steel, can be the solution for such types of problems. On the basis of orientation of loading, anchor may be horizontal plate anchor to resist vertical uplift force, inclined anchor plate to resist axial pullout load and vertical anchor plate to resist horizontal pullout load. A comprehensive study based on the uplift capacity of a horizontal anchor plate and its application in several geotechnical engineering construction has been reported systematically [1]. There are so many researchers who have carried out model test on small-scale to explore the influential parameters which can significantly alter the behaviour of horizontal plate anchor. Several authors put forward the theoretical procedure to calculate the ultimate uplift capacity of anchor plate system [2-7]. Majority of the earlier studies were focused on either the small-scale laboratory test or the field studies and theoretical methods. However, research can't always be based on fieldwork and experiments or the theoretical methods because either they based on the assumption or usually arduous and time-consuming. With numerical software's capacity, more detailed parameters can be analyzed and will be beneficial while designing process. Besides, this approach offers rapid and ideal information to engineers. In light of this, the present study will concentrate on the accuracy as well as to perform a series of 3D finite element model to understand the behaviour of horizontal anchor plate.

## 2. Numerical Analysis

Numerical analysis is a magnificent mathematical tool which has the ability to solve very complex engineering problems within finite time. The finite-element is a well-known analytical method that is frequently used in various civil engineering applications, both for research and the creation of actual engineering issues.

PLAXIS-3D, which is a computer programme that performs finite element analysis to examine the stability and deformation of geotechnical engineering structures [8]. For analyzing the behaviour of horizontal anchor plate, a finite element model was created using finite element software. Large domain has been employed in order to remove the boundary impact. The FEM model having length = 1.5 m, width = 1.5 m and height = 1.0 m were developed. The anchor plate was of square geometry having a side length 0.15 m and thickness 0.02 m. The tie rod of mild steel having diameter 0.012 m was attached to the middle of the square anchor plate. The plate anchor was considered to be inflexible and rigid. The finite element mesh was created using 10-node tetrahedral elements. To represent soil behaviour, an elastic, fully plastic constitutive model was used. A plate structural element from the Plaxis library was used to approximate the rough shape of an anchor plate by restricting its mobility in the lateral direction. The tie rod was modeled using embedded beam structural element. The interface reduction of, Ri = 0.65, was taken. This model consists of 12108 number of elements and 20260 nodes, and was found to be adequate for modelling the horizontal pullout behaviour of anchor plates in sand for RD = 75% (dense sand) and RD = 30% (loose sand) respectively. Also, it was discovered that a medium mesh with a coarseness ratio of 0.125, surrounded by a finer mesh, was sufficient. The analysis was done using a displacement control method, in which the plate underwent a series of predefined displacements, and the resulting plate's resistance was measured. The load-displacement relationship is used to determine the capacity, which is then considered to be equal to the highest load at which the curve becomes a plateau. The geometry of the plaxis model with generated mesh and boundary conditions with interface elements around the plate anchor is shown in Fig. 1. In Fig. 1. 'H' represents Embedment depth whereas 'B' represents width of the plate anchor. Table 1 lists the characteristics of the anchor plate and tie rod employed in this study.

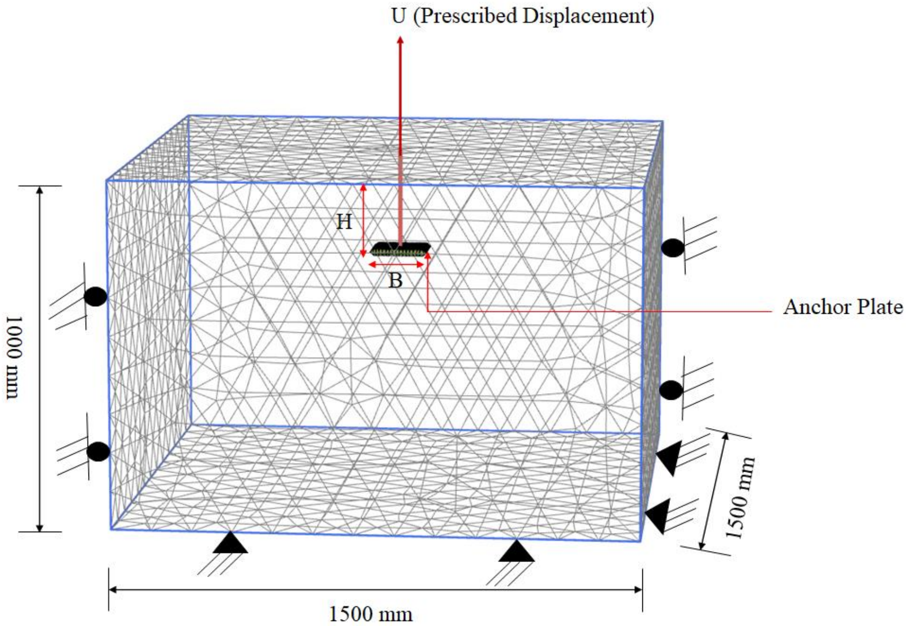


**Fig. 1.** Geometry of PLAXIS-3D model

**Table 1.** Properties of anchor plate and tie rod

| Properties | Anchor Plate | Tie Rod |
|---|---|---|
| Model | Linear Elastic | Linear Elastic |
| Structural element | Plate | Embedded Beam |
| Young's modulus (kPa) | 200 x $10^6$ | 200 x $10^6$ |
| Size (m x m) | 0.15 x 0.15 | Length=1.2 m |
| Thickness (m) | 0.02 | Dia.= 0.012 |
| Unit weight (kN/$m^3$) | 78.50 | 78.50 |

## 3. Validation of Finite Element Model

It is crucial to assess the accuracy and precision of the current model created with Plaxis 3D software before moving on to a detailed numerical analysis. To achieve this, the experimental study submitted by Choudhary and Dash (2013) [9] were replicate and the pullout load -anchor displacement behaviour of the model was compared. The results of experimental test are contrasted with the typical pullout load -anchor displacement response produced from the numerical model as shown in Fig. 2. The results obtained from the analysis and the experimental test shows a good degree of agreement.
The soil characteristics that were incorporated into the analysis are given in Table 2. The soil used in this study has characteristics that fall within the spectrum of loose and

dense sand. For loose sand, a zero dilatancy angle was assumed., while 7° for dense sand. Other researchers have also reported on similar soil characteristics [10, 11].

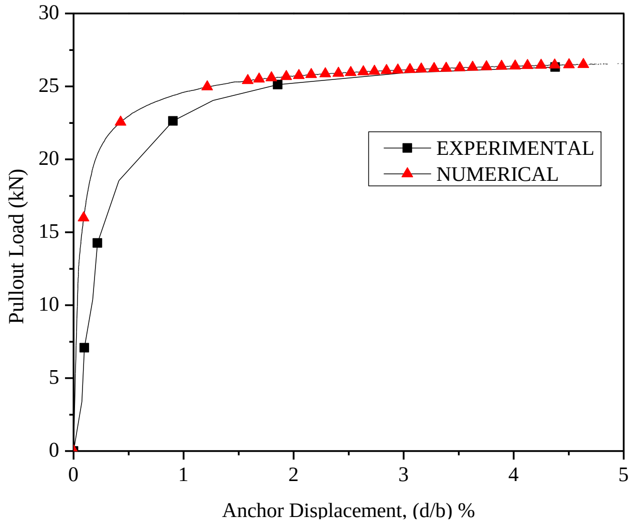



**Fig. 2.** Pullout load versus. anchor displacement response

**Table 2.** Properties of sand

| Properties | RD =75% | RD =30% |
|---|---|---|
| Model | Mohr-coulomb | Mohr-coulomb |
| Young's modulus (kPa) | 10000 | 4000 |
| Poisson's ratio, (ν) | 0.3 | 0.3 |
| Shear modulus (kPa) | 3846 | 1538 |
| Cohesion (kPa) | 0 | 0 |
| Unit weight (kN/m$^3$) | 16.20 | 15.0 |
| Friction angle (ϕ) | 37° | 30° |
| Dilation angle (ψ) | 7° | 0 |

## 4. Result and Discussion

### 4.1 Influence of Embedment Depth

Figures 3 and 4 show variations in ultimate uplift load ($Q_u$) with embedment depth based on present analysis. It should be observed that as embedment depth advances, so does the uplift load carrying capacity. However, for both loose (RD=30%) and dense soil conditions (RD=70%), the rate of increase in the ultimate uplift load is more noticeable at considerably deeper embedding depths.

The displacement contour for loose and dense soil condition has been shown in Fig. 5. It can be noticed that the displacement contour for both the soil conditions intensify around the anchor plate with increase in the embedment depth. In case of loose sand, at

H =2B, the displacement contour reaches to top soil surface indicating a general shear failure signifying a shallow anchor whereas a balloon types of formation of displacement contour has been observed within the soil mass at H =5B indicating a deep anchor. Similar behaviour was observed under dense sand case.

The vertical stress contour at embedment depth 2B and 4B under loose and dense soil condition are given in Fig. 6. The maximum stress was found to be 4 kN/m$^2$ and 35 kN/m$^2$ at embedment depth 2B and 4B respectively in loose soil whereas 6 kN/m$^2$ and 40 kN/m$^2$ at embedment depth 2B and 4B respectively in dense soil conditions.

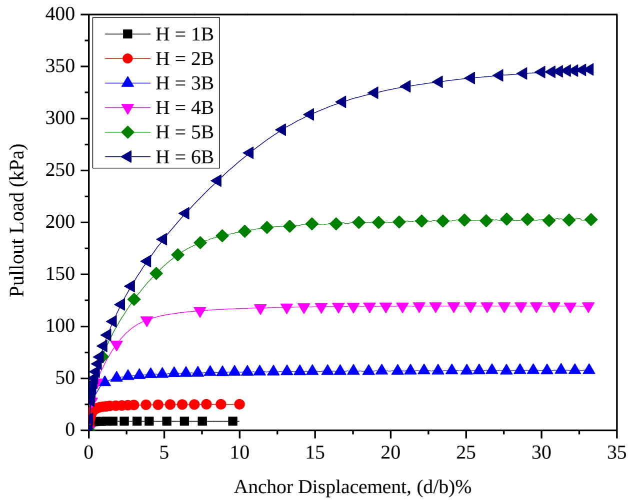



**Fig. 3.** Pullout stress versus anchor displacement curve for different embedment depth (H) at RD = 70%

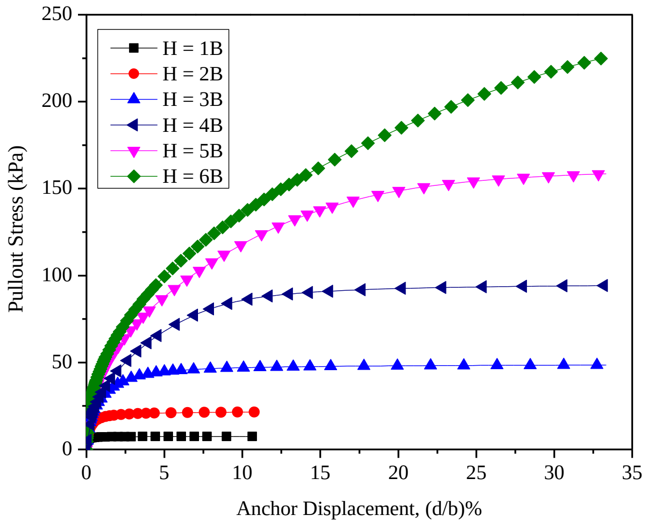



**Fig. 4.** Pullout stress versus anchor displacement curve for different embedment depth (H) at RD = 30%

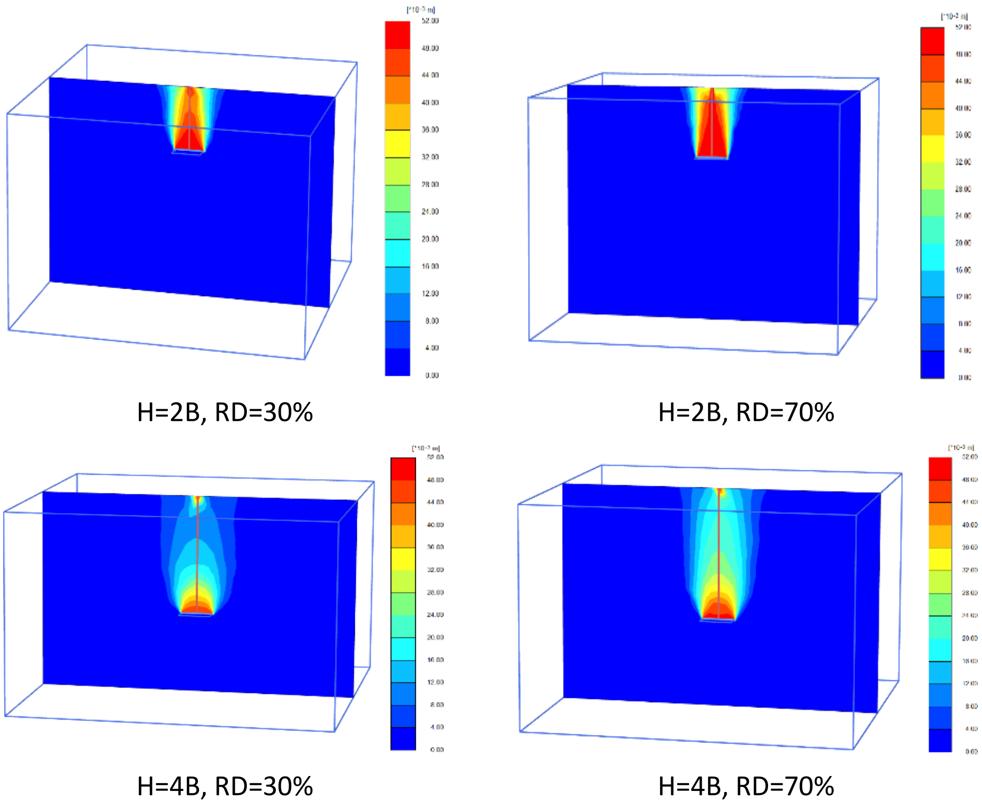
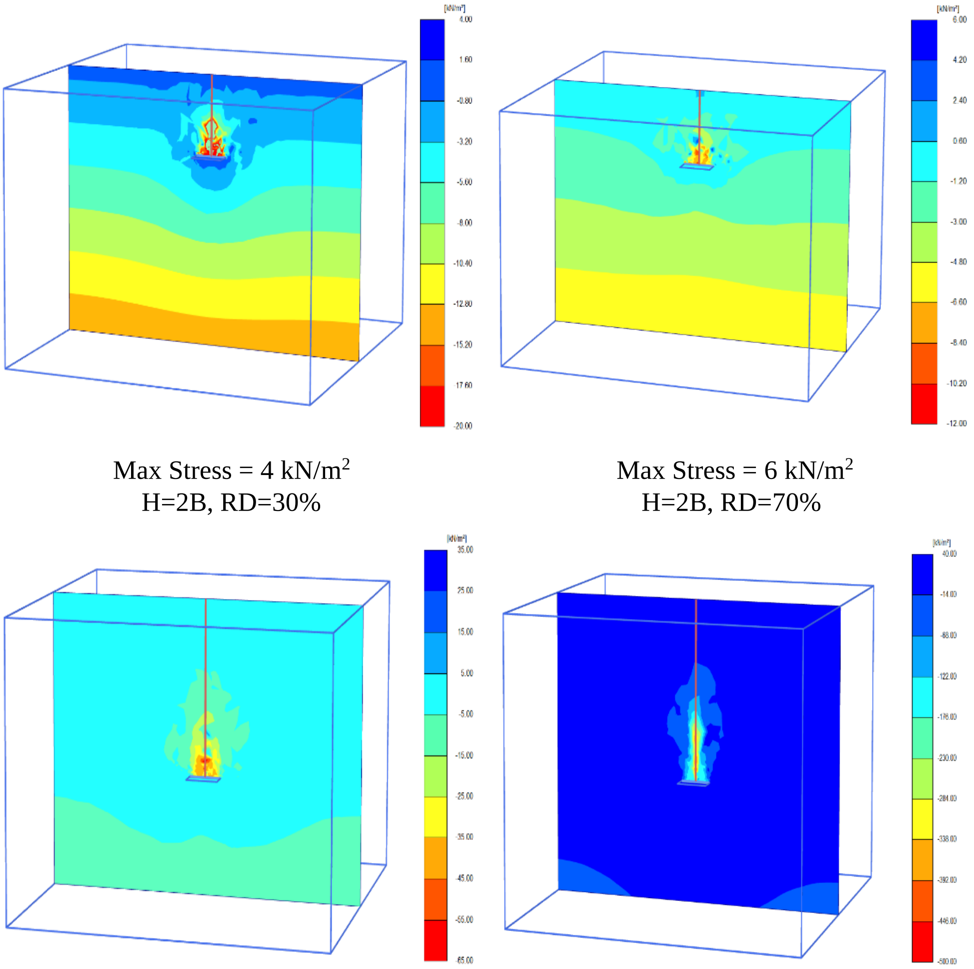



**Fig. 5.** Displacement contour for loose (RD=30%) and dense sand (RD=70%) condition at H=2B and H=4B



Max Stress = 4 kN/m$^2$
H=2B, RD=30%

Max Stress = 6 kN/m$^2$
H=2B, RD=70%

Max Stress = 35 kN/m$^2$
H=4B, RD=30%

Max Stress = 40 kN/m$^2$
H=4B, RD=70%

**Fig. 6.** Vertical stress contour for loose (RD=30%) and dense sand (RD=70%) condition at H=2B and H=4B

## 4.2 Influence of Relative Density

This section focus on the influence of varied relative density and the outcome are expressed in terms of non-dimensional breakout factor ($N_q$). The breakout factor is obtained as mentioned under below.

$$N_q = Q_u / \gamma AH$$

Where, $Q_u$ = Pullout capacity, γ = Unit weight of the sand, A = area of the anchor plate and H = Embedment depth.

The relative density of loose sand is 30% (γ = 15.0 kN/m$^3$) and dense sand is 70% (γ = 16.20 kN/m$^3$). The soil weight and foundation in the failure zone, unitedly added to the shearing resistance that has formed along the failure surface to determine the foundation's maximum uplift capacity [12]. The weight of the soil is directly proportional to the relative density and embedment ratio. This indicates that the soil weighs more as the relative density rises. Additionally, the embedment ratio increases with the rupture surface's length. [13-14]. Hence, pullout capacity in term of non-dimensional factor, of an anchor plate in sand is significantly influenced by their relative density and the embedment ratio. The breakout factor- embedment ratio response has been plotted as shown in Fig. 7. The numerical results demonstrate that the relative density and breakout factor are the crucial factors that significantly affect the pull out capacity of anchor plates.

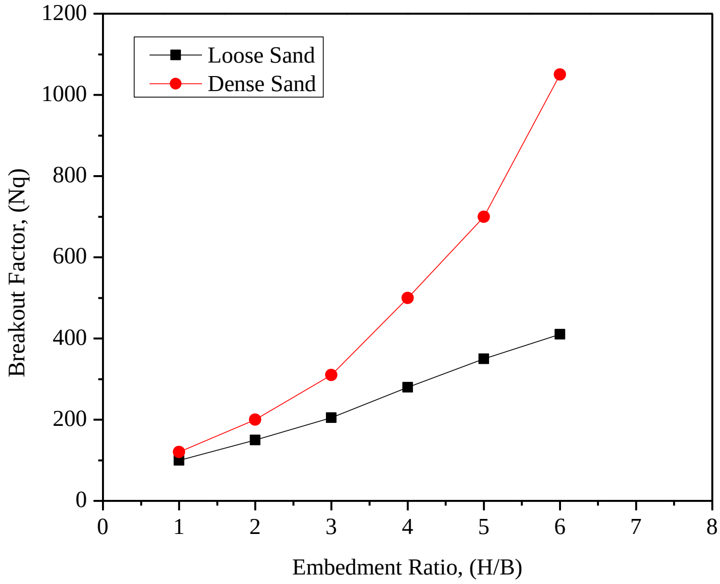



**Fig. 7.** Breakout factor versus embedment ratio

## 5. Conclusion

The main conclusion that can be drawn from the numerical analysis done on the finite horizontal plate anchor model with varied embedment depth at two different densities, namely loose sand and dense sand, is as follows:

- The uplift resistance of horizontal anchor plate in both soil conditions i.e., loose and dense sand, have significantly impact on their embedment depth and the unit weight of the soil.
- Relative density is one of the important parameters other than the embedment ratio, that affects the pullout resistance of anchor plate.
- According to the numerical findings, the breakout factor in both dense and loose sands increases parabolically with embedment ratio. However, the curve's shape is convex in dense sand whereas concave in loose sand.
- The results obtained from finite element software are found to be coherent with experimental observation.

## 6. Acknowledgement

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