International Journal of Material Science & Engineering– IJMSE
Volume 2 : Issue 1 [ISSN : 2374-149X]
Publication Date : 30 April, 2015

Numerical Investigation of Anchor Plates in Layered Soil

[Buse Emirler, Selçuk Bildik, Mustafa Laman]

***Abstract*— This paper presents the results of numerical analyses of the uplift capacity of square anchor plates in layered soil. Many factors, such as the effects of the embedment ratio of anchors (H/B), the thickness of granular fill layer (d_1/d_2) and the area ratio of fill have been investigated by finite element method (FEM). The numerical analyses performed by using PLAXIS 3D. The influence of these parameters on failure mechanism and the uplift capacity of anchor is discussed.**

***Keywords*— uplift behavior, layered soil, embedment ratio, finite element method.**

I. Introduction

Plate anchor systems are used in various civil engineering structures as a structure member, primary to resist uplift loads and overturning moments; and to ensure the structural stability. An anchor is capable of resisting tensile force with the support of surrounding soil in which anchor is embedded. During the last thirty years, several theoretical and semi-empirical methods have been developed to predict the net ultimate uplifting load of continuous, circular and rectangular foundations embedded in soil. The ultimate uplift capacity of the foundation is the sum of two components: (a) the weight of the soil and the foundation in the failure zone and (b) the shearing resistance developed along the failure surface. The soil media surround of the anchor is effected uplift capacity of anchor plates. Various studies have been performed by different researchers to estimate the uplift behavior of anchors. These studies generally have focused on uplift capacity of anchors in homogenous soil [1-4]. However, the information available on determining the vertical uplift behavior of anchors in layered soil is rather limited. Stewart [5] reported the uplift resistance of a circular anchor in layered soil. One of the objectives of this study was to investigate the effectiveness of placement of a cohesionless fill layer over a clay seabed in increasing the uplift capacity of a shallow anchor buried in clay.

Buse Emirler, Research Assistant
Cukurova University
Turkey

Selçuk Bildik, Asst. Prof. Dr.
Osmaniye Korkut Ata University
Turkey

Mustafa Laman, Prof. Dr.
Cukurova University
Turkey

Bouazza and Finlay [6] reported some model test results of the uplift capacity of a shallow plate anchor in two-layered sand. Manjunath [7] suggested a theory to define the vertical uplift capacity of a shallow horizontal strip anchor plate in two layered frictional-cohesive soil. The effect of surcharge has also been considered. The theory has been developed by using theory of characteristics coupled with log spiral failure surface having different foci for different layers. Niroumand and Kassim [8] reported the behavior of an irregular anchor plate buried in a two layered frictional-cohesive soils. It was reported that for upper layer thickness ratio of less than one and for a given ratio, D/B there was no difference between the uplifting an anchor plate from a clay-loose sand bed.

In this study, the uplift behavior of anchor plates in layered soil was investigated numerically. Many factors, such as the effects of the embedment ratio of anchors (H/B), the thickness of granular fill layer (d_1/d_2) and the area ratio of fill have been investigated by finite element method (FEM). Numerical analyses were performed by a series of three-dimensional non-linear finite element analyses by using Plaxis 3D.

II. Problem Definition

In this study, numerical analyses have been performed in 4 series using by finite element program, Plaxis 3D. In the first series, the effect of the embedment ratio of anchor plates is investigated. The anchor is embedded in homogeneous clay and anchor geometry is square. In the first series, the problem geometry and investigated parameters are shown in Figure 1a. In the second series the granular soil effect on the uplift capacity is investigated and granular fill constructed from top to down. The investigated parameters and model geometry are presented in Figure 1b. In the third series of analyses, the investigated parameters are the same with second series but the granular fill constructed from bottom to top (Figure 1c). Finally, the effect of area ratio of the fill on uplift capacity is investigated in the fourth series of analyses and model geometry of this case is shown in Figure 1d.

The uplift capacity of anchors is expressed using a non-dimensional factor for homogenous clay, called breakout factor (F_c). F_c calculated in the following form;

$$F_c = \frac{Q}{A \times c} \tag{1}$$

Where; Q is uplift capacity of anchor plate, A is the area of anchor plate and c is cohesion of clay.

The granular fill soil effect is expressed using Uplift Capacity Ratio (UCR). UCR is expressed below.

$$\text{UCR} = \frac{Q_R}{Q} \qquad (2)$$

Where; Q is uplift capacity of anchor plate in homogenous clay, Q_R is uplift capacity of anchor plate reinforced with granular fill.

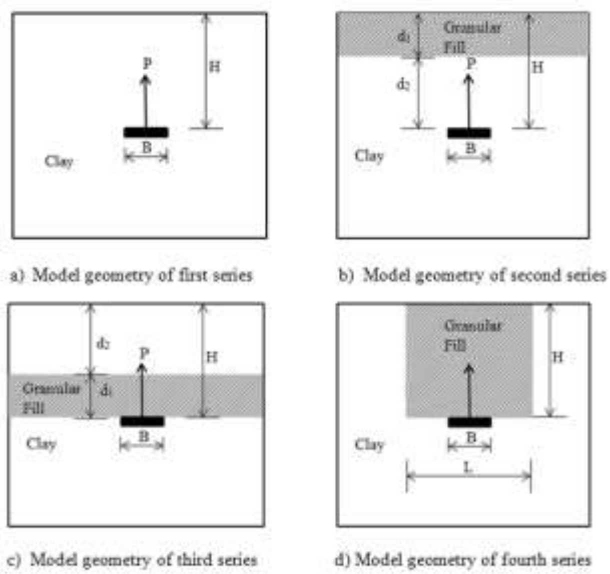

Figure 1. Model Definition

III. Finite Element Analyses

In this study a series of finite element analyses was carried out to investigate the uplift behavior of anchor plates in layered soil. The program Plaxis 3D was used in the analyses. The program is a FE package specially developed for the analysis of deformation and stability in geotechnical engineering problems [9]. An elastic-plastic Mohr Coulomb (MC) model was selected for the clay and granular-fill material behavior in this study. The MC model is a practical and user-friendly model that includes only a limited number of features that the soil behavior shows in reality. Although the increase of the stiffness with depth can be taken into account, the MC model does not include either the stress dependency or the stress-path dependency of the stiffness or the anisotropic stiffness. In general, the stress states at failure are quite well described using the MC failure criterion with effective strength parameters [10]. The clay soil and granular-fill bed material parameters used in the numerical analyses are presented in Table 1. Element number is an important parameter at finite element method. The medium mesh was adopted in this study because the element effect is minimized for this option [11].The anchor plate is square and dimensions are 1mx1m. The anchor plate is defined rigid in numerical analyses. The model geometry, finite element mesh and the boundary conditions are shown in Figure 2.

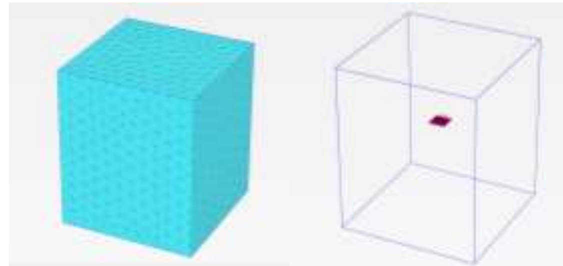

Figure 2. The Finite Element Mesh and Boundary Condition

Table 1. Mohr-Coulomb model parameters

Parameter	Clay	Granular-Fill
Unit weight, γ_n (kN/m^3)	18	21
Loading stiffness, E_U (kN/m^3)	8500	42500
Cohesion, c (kN/m^3)	75	1
Poisson's ratio, υ	0.35	0.20
Friction angle, ϕ (degrees)	0	43
Dilatancy angle, X (degrees)	0	13

IV. Results and Discussion

In this section a total of 4 series analyses results are presented and the effect of different parameters are discussed. The uplift capacity of anchors is expressed using a non-dimensional factor for homogenous clay, called breakout factor (F_c) and the granular soil effects are expressed using Uplift Capacity Ratio (UCR). The ultimate uplift capacities for the model are determined from the load-displacement curves. The displacement criteria were used in analyses and the displacements are limited at 10% of the width of the anchor width.

A. *Effect of Embedment Ratio of Anchor on Uplift Capacity*

The effect of the embedment ratio of anchor plates on uplift capacity is investigated in homogenous clay soil. The analyses were conducted for embedment ratios (H/B) of 1 to 8. The results are presented in breakout factor (F_c) form in Figure 3. The results indicate that the uplift capacity increases significantly with increasing depth of anchor plate from the soil surface. When the anchor is moving away from H/B=1 to H/B=3, there is a serious increase in uplift capacity (an average value of 175%). The increment in uplift capacity is about 6% for the anchor is moving from H/B=3 to H/B=4. However, the rate of increment in uplift capacity decreases with increasing embedment ratio of anchor plate. There has been a fluctuation at H/B=7 and this small error can be seen as a failure of solution error of finite element method. When the increment in uplift capacity compared with the cost of the construction stages, H/B=3 can be accepted as an optimum rate for the embedment ratio of anchor plate.

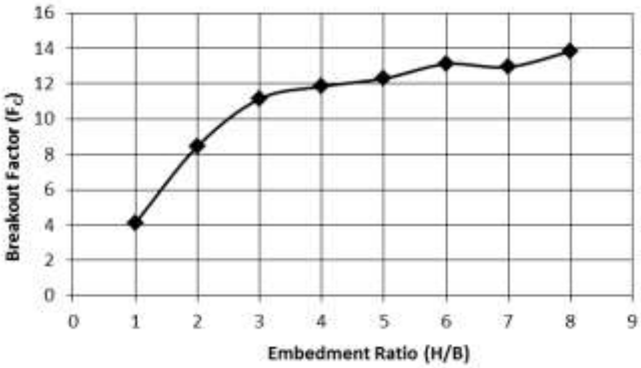

Figure 3. Variation of Embedment Ratio-Breakout Factor

B. The Granular Soil Effect on the Uplift Capacity (Top-Down Construction)

In the second series of analyses, it is considered that the homogenous clay soil is reinforced with granular fill soil and the granular fill is constructed from top to down. The analyses were performed for H/B=2 and 5 and the results were described using Uplift Capacity Ratio (UCR). The results indicate that the thickness of granular fill layer affect the uplift capacity of anchor plate. The granular fill layer thickness (d_1/d_2) is increased from 0 to 2 with 0.5 increments for H/B=2. When the layer thickness increases from 0 to 0.5, the uplift capacity increases about 6% (as seen in Figure 4). When the layer thickness increases from 0.5 to 1.0, the increment in uplift capacity is about 18%. The increment in uplift capacity is 13% for the layer thickness increases from 1.5 to 2.0. However, the rate of increment in uplift capacity decreases with increasing thickness of granular fill layer. When the granular fill is constructed top-down, d_1/d_2=1.0 is a good rate for the thickness of granular fill layer. The displacement contours are presented in Figure 5 for H/B=2. The contours show that when the granular fill soil is closer to anchor plate, the displacements reaches soil surface.

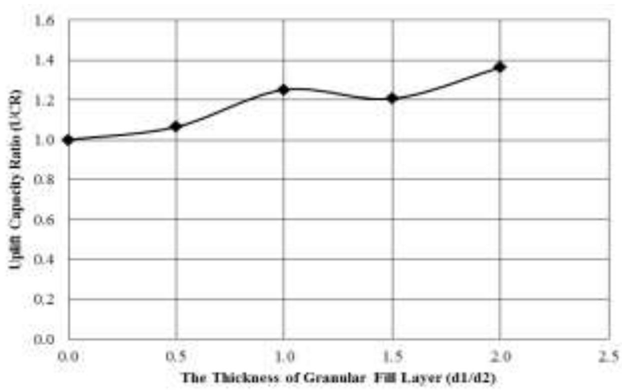

Figure 4. Variation of UCR-Thickness of Granular Fill Layer for H/B=2 (Top-Down Construction)

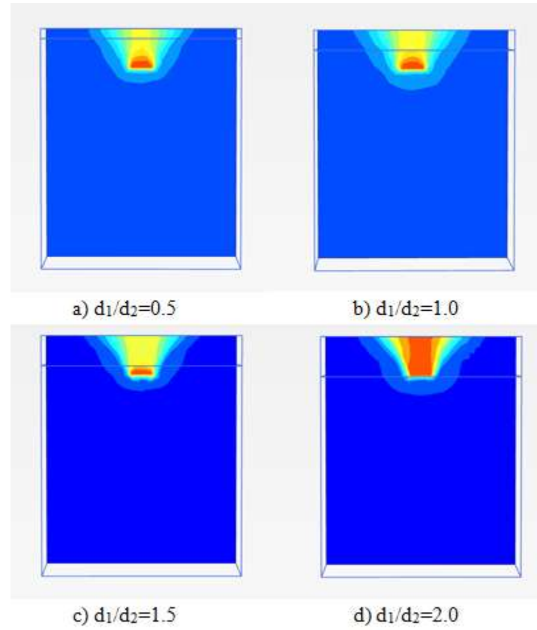

Figure 5. Failure Mechanism of Anchor Plates for H/B=2 (Displacement Contours, Top-Down Construction)

The analyses were also performed for H/B=5 and this time the granular fill layer is increased from 1 to 5. When the layer thickness increases from 1 to 3, the uplift capacity increases about 8% (as seen in Figure 6). When the layer thickness increases from 3 to 4, the increment in uplift capacity is about 43% and this value is 80% for the thickness increases from 4 to 5. The results show that when the granular fill soil is closed to plate, the rate of increment increases. The cost of the construction stage compared with increment in uplift capacity, d_1/d_2=5 is an optimum rate for thickness of granular fill layer.

In literature, H/B=5 is considered as deep foundation condition and the failure mechanism takes place in soil. If Figures 7a, b and c are analyzed; it can be seen that the failure mechanism takes place in soil and anchor behavior is similar with the deep foundation case. However, when the granular fill soil is closer to anchor plate, the displacements reaches the soil surface (Figure 7d) and the behavior of anchor plate is similar with the shallow foundation behavior.

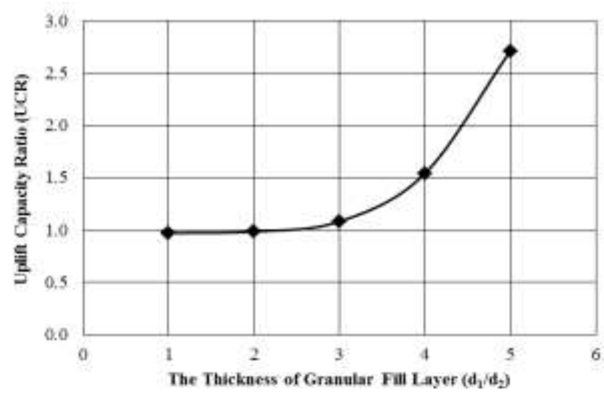

Figure 6. Variation of UCR-Thickness of Granular Fill Layer for H/B=5 (Top-Down Construction)

International Journal of Material Science & Engineering– IJMSE
Volume 2 : Issue 1 [ISSN : 2374-149X]
Publication Date : 30 April, 2015

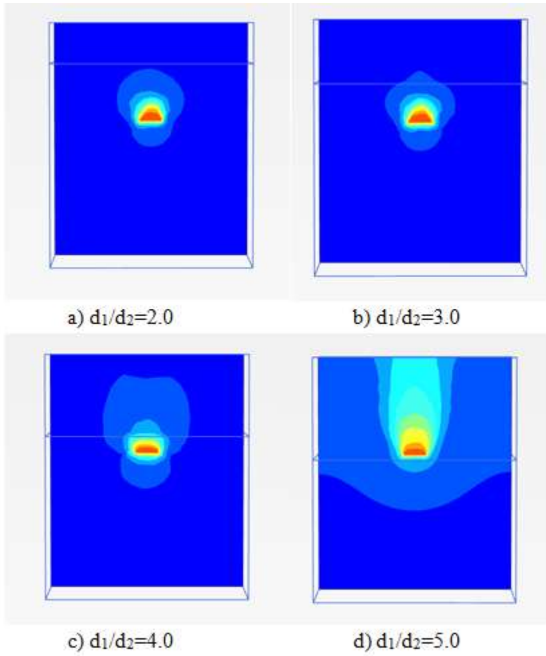

Figure 7. Failure Mechanism of Anchor Plates for H/B=5 (Displacement Contours, Top-Down Construction)

C. *The Granular Soil Effect on the Uplift Capacity (Bottom-Top Construction)*

In this series, the granular soil is constructed from bottom to top and the analyses are performed for H/B=2 and 5. The results are described using Uplift Capacity Ratio (UCR). The granular fill layer thickness (d_1/d_2) is increased from 0 to 2 with 0.5 increments for H/B=2. When the layer thickness increases from 0 to 0.5, the uplift capacity increases about 14% (as seen in Figure 8). When the fill layer thickness increases from 0.5 to 1.0, the increment in uplift capacity is about 12%.

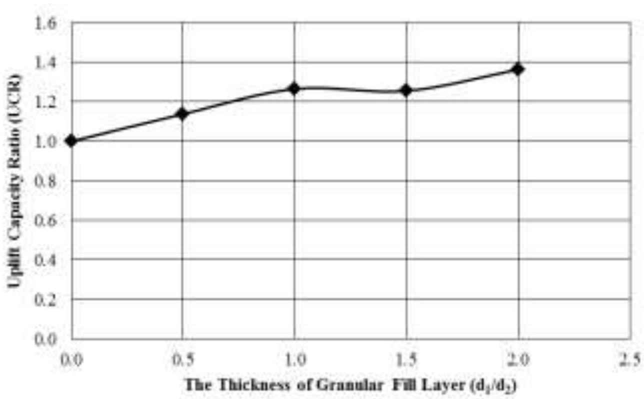

Figure 8. Variation of UCR-Thickness of Granular Fill Layer for H/B=2 (Bottom-Top Construction)

The increment in uplift capacity is 8% for the layer thickness is increased from 1.5 to 2.0. However, the rate of increment in uplift capacity decreases with increasing thickness of granular fill layer. When the granular fill is constructed from bottom to top, d_1/d_2=1.0 is a good rate for the thickness of granular fill layer. The failure mechanism of anchor plate is presented in Figures 9 for H/B=2. The contours show that the granular fill soil is closer to anchor plate, the displacements reaches soil surface.

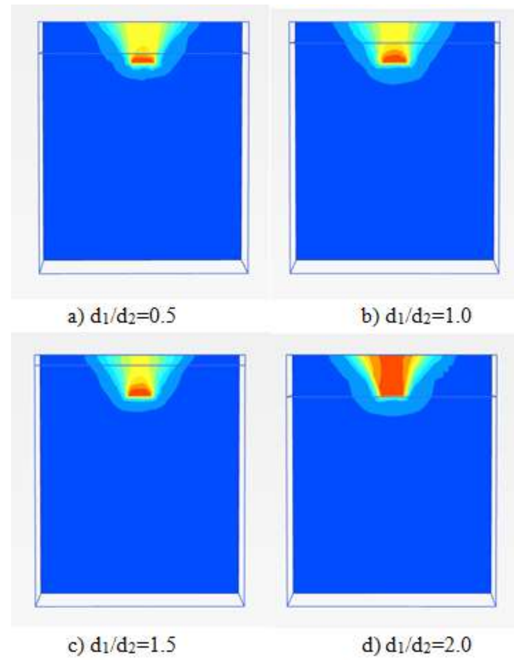

Figure 9. Failure Mechanism of Anchor Plates for H/B=2 (Displacement Contours, Bottom-Top Construction)

The analyses were also performed for H/B=5 and this time the granular fill layer is increased from 1 to 5. When the layer thickness increases from 1 to 2, the uplift capacity increases about 23% (as seen in Figure 10). When the fill layer thickness increased from 2 to 3, the increment in uplift capacity is about 4% and this value is about 3.6% for the thickness increases from 3 to 4. The results show that when the granular fill soil is closed to plate, the rate of increment increases. The cost of the construction stage compared with increment in uplift capacity, d_1/d_2=2 is an optimum rate for thickness of granular fill layer.

When the failure mechanism is analyzed; the failure mechanism takes place in soil and anchor behavior is similar with the deep foundation case. However, when the granular fill soil is closer to anchor plate, the displacements reaches the soil surface (Figure 10) and the behavior of anchor plate is similar with the shallow foundation behavior.

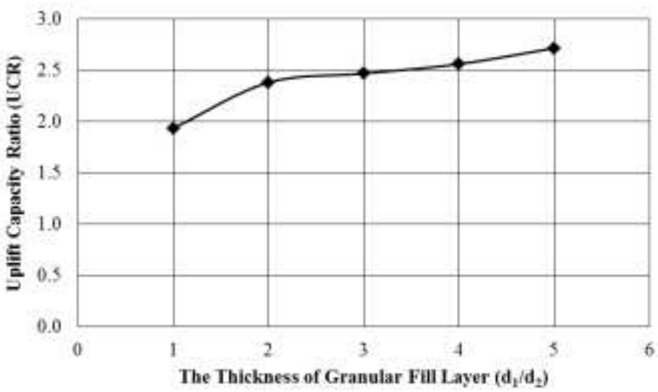

Figure 10. Variation of UCR-Thickness of Granular Fill Layer for H/B=5 (Bottom-Top Construction)

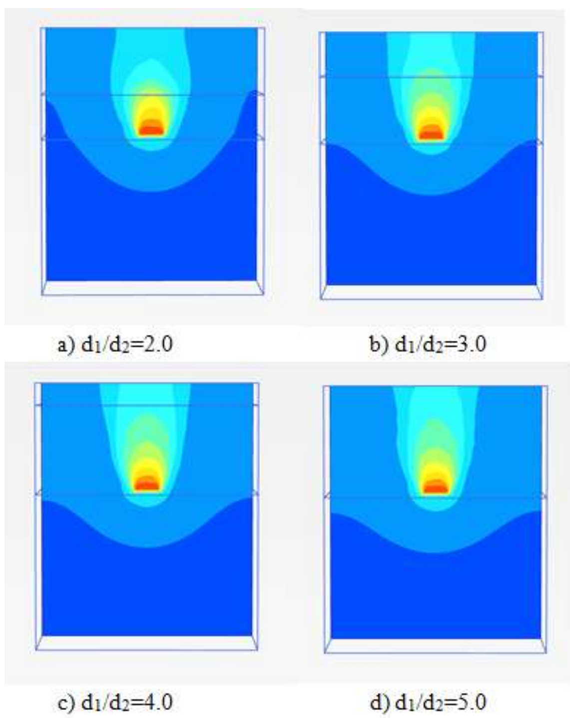

Figure 11. Failure Mechanism of Anchor Plates for H/B=5 (Displacement Contours, Bottom-Top Construction)

D. *The Fill Area Effect on Uplift Capacity*

In this series, the effect of the granular soil area on uplift capacity of anchor plate is investigated. The analyses were performed at embedment ratio of H/B =2 and 5. The results is presented in UCR form and results compared with rate of granular soil area (A_1/A_2). Where; A_1 is granular soil area per unit area and A_2 is area of anchor plate. The effect of the granular soil is presented in Figure 12 for H/B=2. When the rate of the granular soil area (A_1/A_2) is increased from 1 to 16, the uplift capacity increases about 25% and after this A_1/A_2=9 there is not any significant increase in the UCR. The results indicate that the uplift capacity increases significantly with increasing area of the granular fill soil. But, the cost of the construction stage compared with increment in uplift capacity, the value of A_1/A_2=16 is a good rate for granular soil area at H/B=2. In addition to that, the failure mechanism is affected by the granular soil area and when the area is increased, the failure mechanism shows similar behavior with homogenous soil (Figure 13).

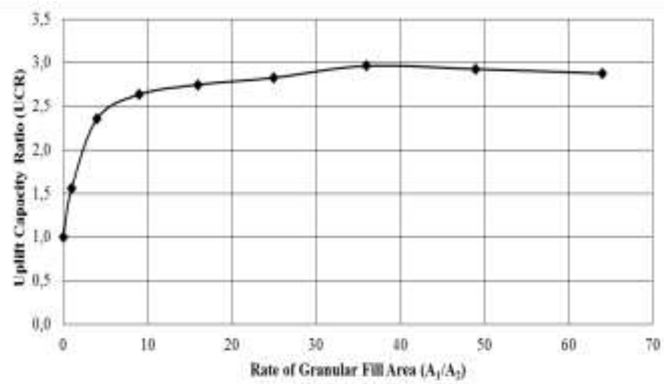

Figure 12. Variation of UCR-Rate of Granular Fill Area for H/B=2

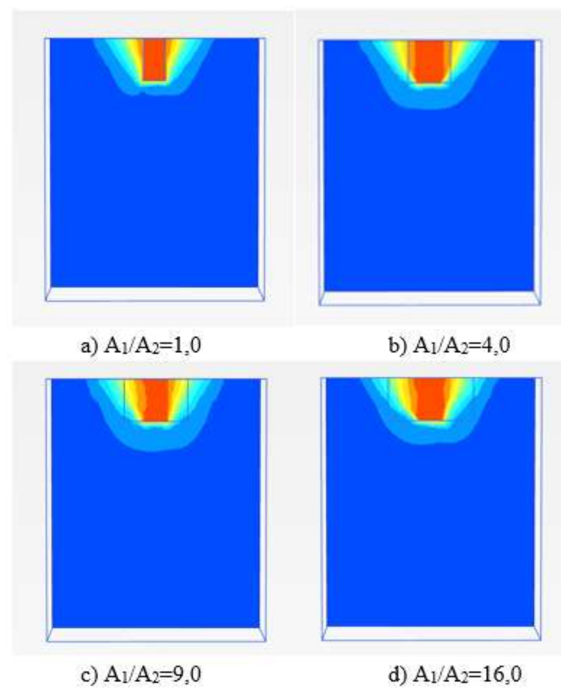

Figure 13. Failure Mechanism for Different Granular Fill Area at H/B=2

The effect of the granular soil is presented in Figure 14 for H/B=5. For this embedment ratio, when the rate of the granular soil area (A_1/A_2) is increased from 1 to 16, the uplift capacity increases about 70% and after this A_1/A_2=16 there is not any significant increase in the UCR. If the cost of the construction stage compared with increment in uplift capacity, the value of A_1/A_2=16 is a good rate for granular soil area at H/B=5. In addition to that the failure mechanism is affected by the granular fill soil area and when the area is increased, the failure mechanism shows similar behavior with homogenous soil (Figure 15).

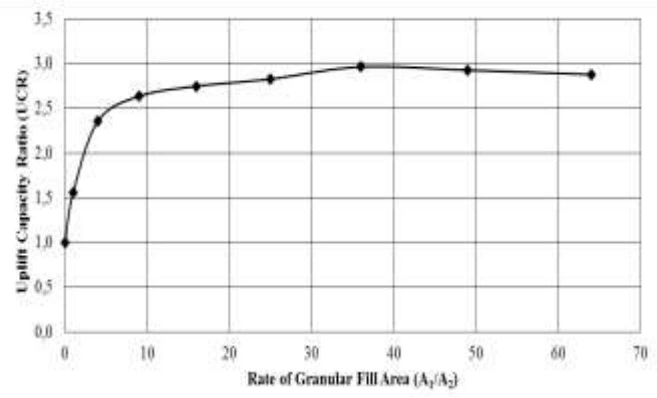

Figure 14. Variation of UCR-Rate of Granular Fill Area for H/B=5

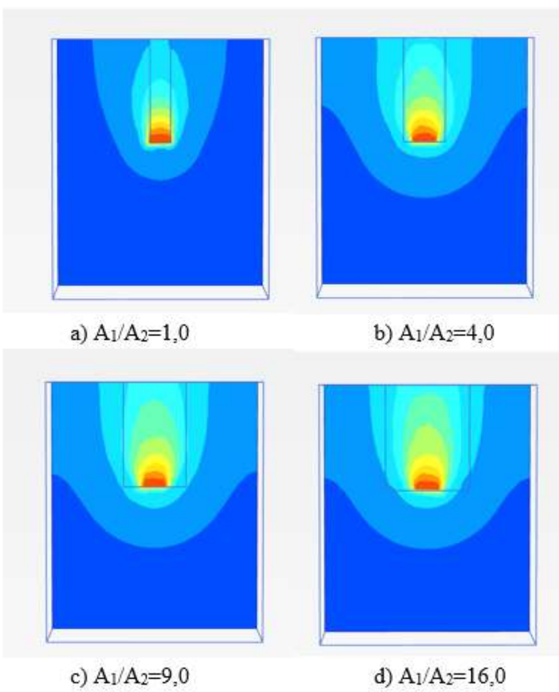

Figure 15. Failure Mechanism for Different Granular Fill Area at H/B=5

V. Conclusion

In this study, the uplift behavior of anchor plates in layered soil was investigated numerically. Many factors, such as the embedment ratio of anchors (H/B), the thickness of granular fill layer (d_1/d_2) and the area ratio of granular fill soil have been investigated by finite element method (FEM). Based on the results, the following main conclusions can be drawn:

- The uplift capacity increases significantly with increasing the depth of anchor plate from the soil surface. When the anchor is moving away from H/B=1 to H/B=3, there is a serious increase in uplift capacity (an average value of 175%). When the increment in uplift capacity compared with the cost of the construction stages, H/B=3 can be accepted as optimum rate for the embedment ratio of anchor plate.
- The granular fill layer thickness (d_1/d_2) is important parameter on uplift capacity of anchor. When the granular fill is constructed at a rate of d_1/d_2=1.0, the uplift capacity increases about 25% at H/B=2. The increment is about 170% if the granular fill is constructed at a rate of d_1/d_2=5.0 at H/B=5.
- The effect of the thickness of granular fill soil is investigated from bottom to top construction method. For this case, the rate of d_1/d_2=1.0 is optimum value for H/B=2 and the uplift capacity increases about 26%. At H/B=5, d_1/d_2=2.0 is an optimum value on thickness of granular fill soil and uplift capacity increases about 23%.
- The area of granular fill soil affect uplift capacity of anchor significantly. The rate of A_1/A_2=9 is a good value for area of granular fill soil for H/B=2. The rate of A_1/A_2=16 is a good value for area of granular fill soil for H/B=5. The uplift capacity increases about 25% and about 70% at H/B=2 and H/B=5, respectively.

References

[1] Meyerhof G. G. and Adams J. I., "The ultimate uplift capacity of foundations", Canadian Geotechnical Journal., 5(4), 225-244, 1968.

[2] Murray, E. J. and Geddes, J. D., "Uplift of anchor plates in sand", J. Geotech. Eng., ASCE, 113(3), 202-215, 1987.

[3] Dickin, E.A. and Laman, M., "Uplift response of strip anchors in cohesionless soil", Advances in Engineering Software, Volume 38, Issues 8-9, pp. 618-625, August-September, 2007.

[4] Bildik, S. and Laman, M., "Experimental Investigations of Uplift Behaviour of Plate Anchors in Cohesionless Soil", The Ninth International Congress on Advances in Civil Engineering (ACE 2010), Trabzon, TURKEY, 27-30 September 2010.

[5] Stewart, W., "Uplift Capacity of Circular Plate Anchors in Layered Soil", Can. Geotech. J., 22; 589-592, 1985.

[6] Bouzza, A. and Finlay, T.W., "Uplift Capacity of Plate Anchors Buried in a Two-Layered Soil", Geotechnique, 40 (2), 293-297, 1990.

[7] Manjunath, K., "Uplift Capacity of Horizontal Strip and Circular Anchors in Homogenous and Layered Soils", Ph.D. Thesis, Dep. of Civil Eng., Indian Institute of Science, Bangalore, 1998.

[8] Niroumand, H., Kassim, Kh.A. and Nazir R., "Numerical and Experimental Analysis of Pullout Test on Square Horizontal Anchor Plates in Sand", Geotropika, 2010, 1-3 Dec., Sabah, Malaysia, 2010.

[9] Brinkgreve RBJ and Vermeer PA, "Finite element code for soil and rock analyses", A. A. Balkema, Rotterdam, 1998.

[10] Örnek, M., Demir, A., Laman, M. and Yıldız, A. "Numerical Analysis of Circular Footings on Natural Clay Stabilized with a Granular Fill", ACTA Geotechnica Slovenica, Vol. 9 (1), 61-75, 2012.

[11] Bildik, S. and Laman, M., "Experimental and Numerical Investigations on Uplift Behaviour of Plate Anchors in Cohesionless Soil", International Balkans Conference on Challenges of Civil Engineering, BCCCE, Paper No 11, 19-21 May, EPOKA University, Tirana, ALBANIA, 2011.

About Author (s):

Image

[Type a quote from the document or the summary of an interesting point. You can position the text box anywhere in the document. Use the Drawing Tools tab to change the formatting of the pull quote text box.]