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NUMERICAL STUDY ON STABILITY OF PLATE ANCHOR IN SLOPING GROUND

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ABSTRACT

This study focuses on the uplift capacity of strip plate anchor placed in homogeneous clay for both the horizontal and sloping ground. The effect of anchor embedment ratios and inclination angle of sloping ground have been studied by finite element analysis. From the analyses results, the uplift capacity of plate anchor was found to be decreased linearly in relation to the increasing of inclination angle of slope. It is clear that, the slope angle is an important factor for computing uplift capacity of strip plate anchor embedded in sloping ground and should considered in design.

1. INTRODUCTION

The layout of many engineering systems calls for the foundation system to resist pullout forces. Plate anchors are often used as an economical solution for the foundation system of transmission towers, dry docks and pipelines under water, etc. In the previous times several studies have been done on the uplift capacity of plate anchors embedded in horizontal ground surface (Das, 1978;Rowe and Davis,1982; Murray and Geddes, 1987; Merifield et al., 2001; Merifield et al., 2006; Dickin and Laman 2007, Song et al., 2008, Hanna et al., 2011, Rokonuzzaman and Sakai 2012, Kumar and Sahoo 2012; Sahoo and Kumar 2014). Surprisingly, the study on uplift capacity of plate anchors in sloping ground surface, especially clayey sloping ground is rare. A few studies have been done on sloping grounds. Lower Bound Solutions for Uplift Capacity of Strip Anchors adjacent to Sloping Ground in Clay is done by Sahoo and Khuntia (2017). Kumar (1997) analytically and experimentally (Dos and Singh, 1994, RAO and Prasad, 1992, Emirler et al., 2016) investigated the behaviour of anchor plates installed in a sloping ground. Sawwaf (2007) experimentally studied the uplift behavior of horizontal anchor plates located near sandy earth slopes with and without geo synthetic reinforcement. Bildik et al.(2013) analysed the uplift capacity of a strip anchor buried in sandy soil near a sloping ground using finite element method. Based on the interaction between anchor and underlying soil two cases are observed, called immediate break way (unbounded) and no break way conditions. In immediate break way case, it is assumed that there remains no adhesion or suction force between the anchor and the soil. But, in no break way condition, adhesion force developed between the anchor and the soil at the time of loading. Das et al., (1994) observed that the suction force is dependent on the embedded depth of anchor, permeability of soil, and rate of loading. In this study, the uplift behavior of anchor plates in clayey sloping ground has been investigated by finite element analyses. The effects of several factors, such as embedment ratio of anchor plate, inclination angle of slope, have been investigated by using ABAQUS. The results of these analyses are summarized, compared with existing published results and presented in the familiar form of pullout capacity factor N_c.

2. PROBLEM DEFINITION

A rigid strip plate anchor of width (B) and thickness (t=B/20) is placed in a clayey sloping ground. The ground surface having inclination angle, β. Height from the top surface of the anchor to the sloping ground is H as illustrated in Figure1.The embedment ratio varied over a large range(H/B=1 to 10). The uplift capacity factors N_c is computed by the equation;

$$N_c = q_u/C_u * B; \quad (1)$$

Where, C_u is the cohesion of cohesive soil. The collapse load (qu) per unit length of the plate anchor is computed for both the immediate breakaway (vented) and no break-way (attached) cases. The effect of different embedment ratios and ground surface inclination (0º to 45º) has been studied.

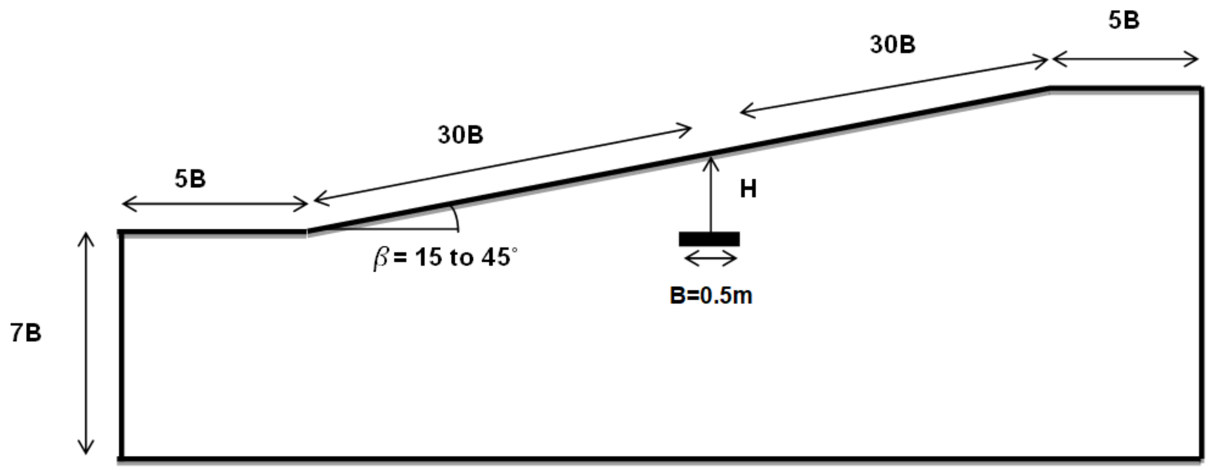


Figure1: Definition of the problem

3. FINITE ELEMENT MODEL

The analysis type was elasto-plastic finite element (FE) analysis over a wide range conducted using ABAQUS to find out the ultimate pull-out load of the strip plate anchor. The soil is assumed to be isotropic and homogenous and Mohr-Coulomb yield criterion is specified by cohesion value c, angle of internal friction ϕ. The strip rigid plate anchor is made contact with the soil and it is made displaced through the pullout direction. The interface between the soil and anchor is defined by (i) tangential behavior and (ii) normal behavior. In no break way case (Attached/fully bonded) the tangential behavior is defined by 'Rough' friction formulation and normal behavior is specified by 'Hard contact' for pressure over-closure. In immediate break-way (vented) case the tangential behavior is defined by 'penalty' friction with a friction coefficient 1.0 and the normal behavior is specified by 'Hard contact' with separation occurs immediately when tension develops. The analyses are conducted on six-nodded modified quadratic element. Figure 2 shows a typical two-dimensional finite-element mesh for a strip plate anchor embedded at H/B=4 and B=0.5m.

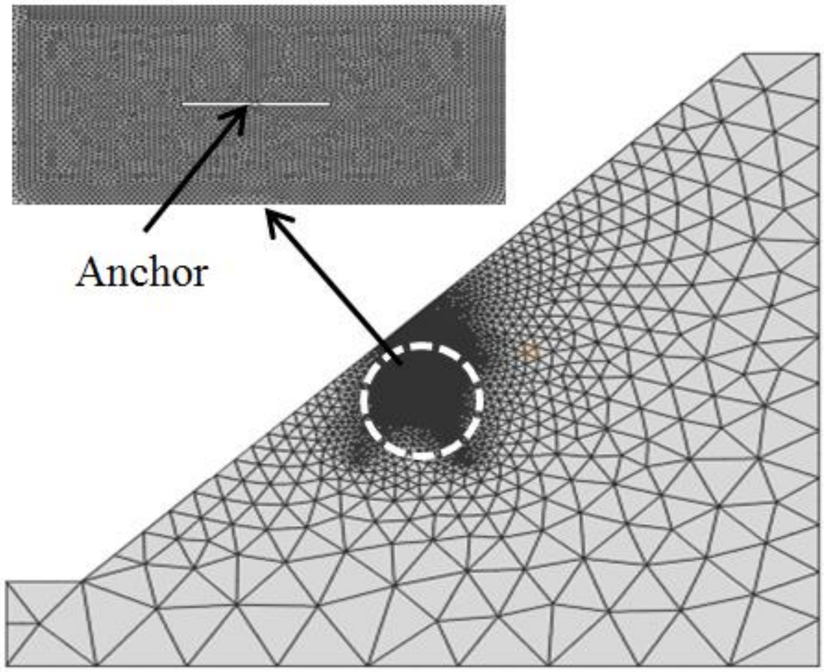
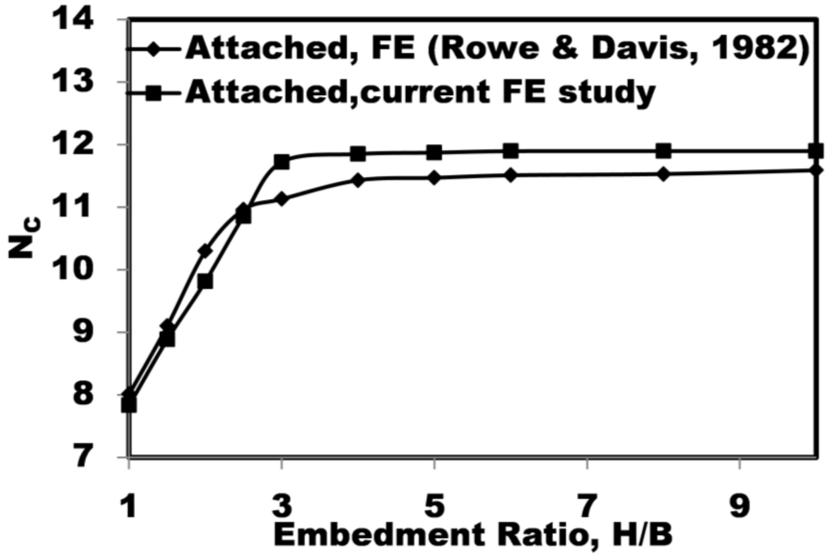


Figure 2: Typical two-dimensional finite-element mesh for H/B=4

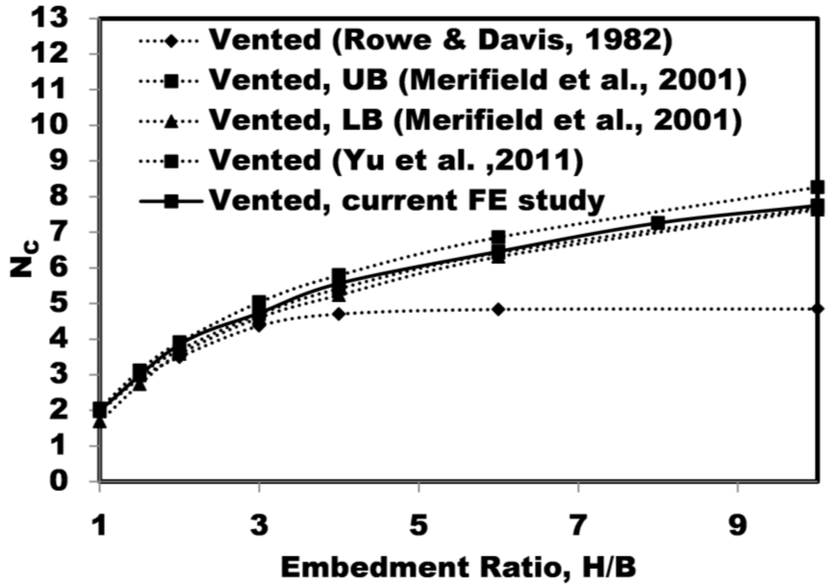
The anchor is assumed to be perfectly rigid and displacement is applied to reference point (RP) anchor node with the contact of soil. In case of horizontal ground surface (surface inclination angle zero degree) the soil domain is extended to 20*B* from the edge of anchor. Amount of extended soil domain in the crest is 5B in horizontal directions both sides. Soil domain is extended 7B in vertical direction from the bottom crest. Two vertical edges are made hinged and the base of the mesh is fixed in all three coordinate directions. The element size near the plate is kept smaller and increasing steadily with the increase of distance from the anchor. Displacement based analyses are performed to obtain collapse load. The gravity loads on soil was assigned after initial step. The total displacement has been then applied and the collapse load has been calculated from the load-displacement curve.

4. RESULTS AND DISCUSSIONS

The finite element (FE) models have been first validated against existing studies. The pull-out capacity factor of horizontal ground (C_u=20kPa,γ= 0) has been computed and compared with the results of Rowe & Davis (1982), Merifield et.al., (2001) and Yu et al., (2011). The validity of the numerical results for the horizontal anchor is established through verification against published results before conducting the detailed parametric study. The designed FE model is validated for the pullout capacity factor N_c of a strip anchor in weightless soil (γ=0). It can be seen in Figure 3a and 3b that N_c for horizontal anchor agrees well with the numerical solution obtained by Yu et al. (2011) and Merifield et al. (2001).N_c values for horizontal are closer with the upper bound solution upto a embedment ratio of 3 then deviates and maximum differences are found 6.6% for horizontal anchor. Note that, the current FE results, Yu et al. (2011), Merifield et al. (2001) and Rowe & Davis (1982) stay close together for shallow embedment ratio (H/B=2). FE result of Rowe & Davis (1982) shows lower values and almost constant at large embedment ratio (H/B>3). These differences may be due to truncation criterion, where the pullout capacity was taken at a displacement as 15-20 % of anchor width, rather than the ultimate capacity for large embedment ratio



(a)

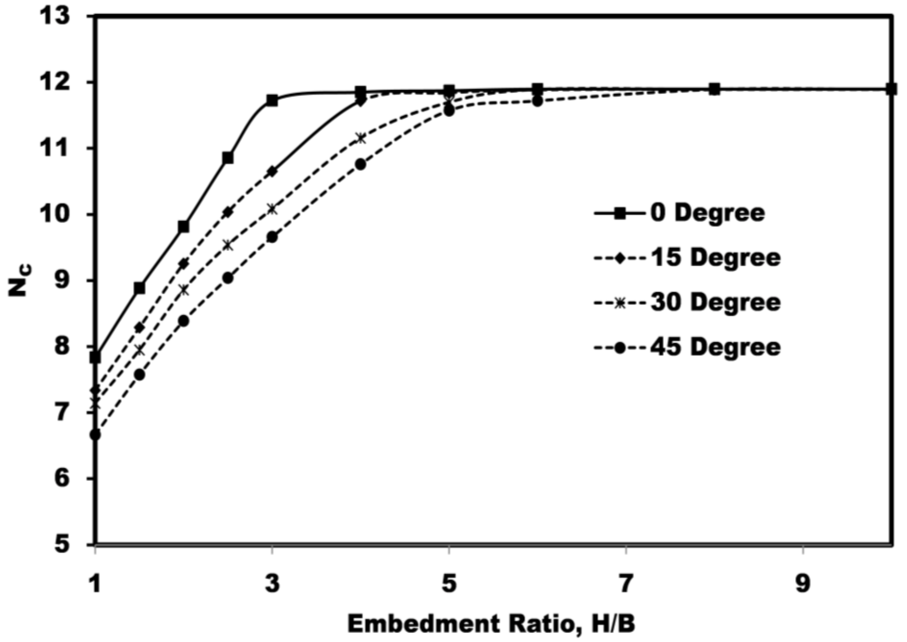


(b)

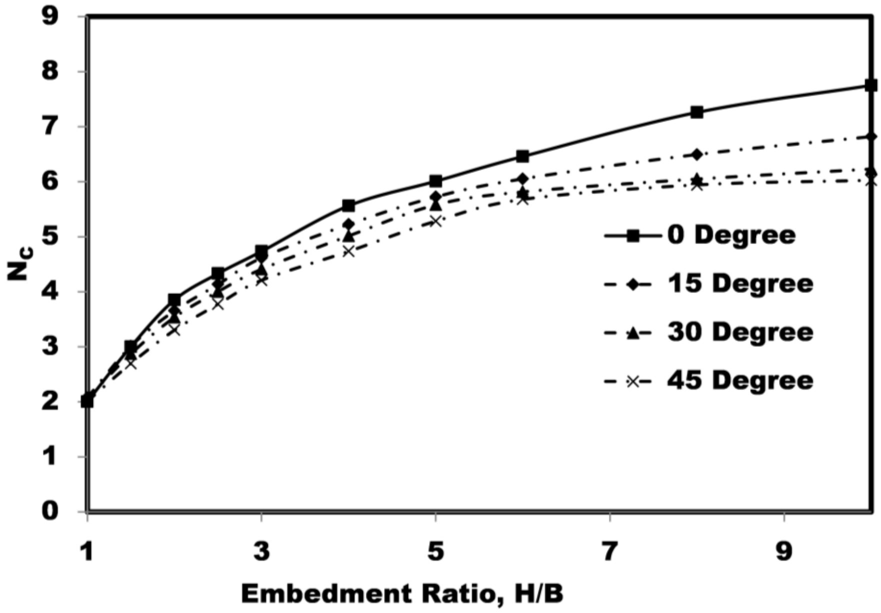
Figure 3: Comparison of the bearing capacity factors for plate anchors in weightless uniform clay: (a) Attached case; (b) Vented case

4.1 The Effect of Slope

The present study concentrated on the effect of sloping ground upon the uplift capacity of plate anchor. Subsequently, finite element (FE) models for inclination angle β=15º, 30º and 45º have been analyzed for embedment ratios (H/B) 1,1.5, 2, 2.5, 3, 4, 5, 6, 8 and 10. The analyses have been conducted for both attached and vented cases. The analyses results show that the uplift capacity of plate anchor decreases with the increase of ground surface inclination. In attached (no break-way) case, for small inclination (15º) of ground surface the value of N_c has been found to be increasing up to embedment ratio (H/B) 4.0 and then it becomes constant. The value of N_c for both ground surface inclination 30º and 45º have been found to be increasing up to embedment ratio (H/B) 6.0 and 8.0 respectively, and then it becomes constant and found same as the ultimate capacity of deep anchor (H/B≥3).



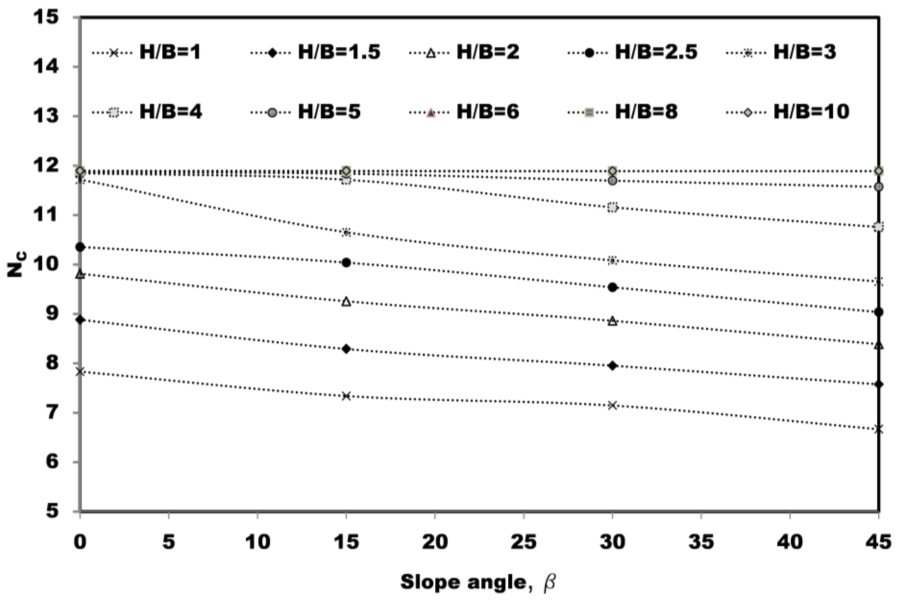
(a)



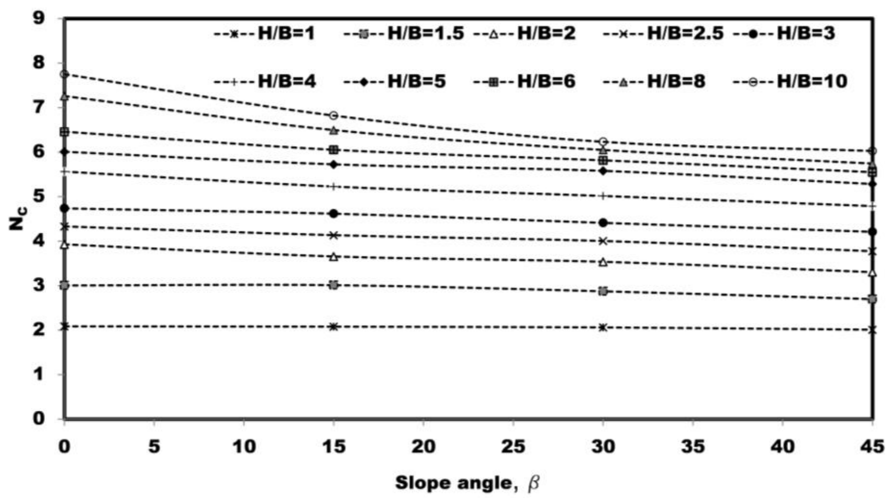
(b)

Figure 4: Effect of slope on N_c at different embedment ratios (H/B) (a) Attached case (b) Vented case

In case of immediate break-way(vented), of the pullout capacity factor (N_c) decreases at all H/B ratios. For 15º inclination of ground surface, the deviation of N_c value is small for shallow anchor but, increases with the anchor embedment ratios (H/B). The maximum value of N_c is 7.75 (H/B=10) in horizontal ground surface whereas, for 15º inclination of ground surface the N_c value shows 6.82. The maximum value of N_c decreases almost 12%. For 30º



(a)



(b)

Figure 5: Variation of N_c with slope angles, β at different embedment ratios (a) Attached case (b) Vented case

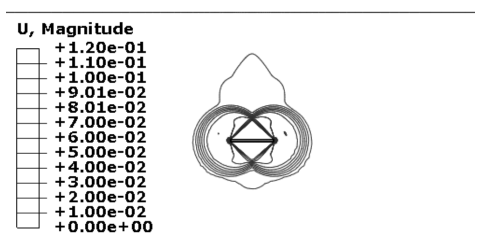
Inclination of ground surface the maximum value of N_c decreases almost 19.61%. The maximum value of N_c decreases almost 22.24% (for β=45°) from the maximum value of N_c (H/B=10) in horizontal ground surface. From this finite element (FE) study, two different behaviors of the change of the value of N_c are observed. At any slope angle, for example 15° (see Fig-4a), the N_c value increases up to certain embedment ratio (H/B=4 for 15°), then it becomes constant. On the other hand in vented case, the value of N_c in sloping ground gradually decreases also with the increase of slope angles. But, for a certain slope angle the value of N_c tends to increase with the increase of embedment ratios and it is not found to be constant. At 15º inclination the deviation from the value of N_c in horizontal ground surface starts from 0.32% (H/B=1) to 12% (H/B=10). Figure5a and Figure 5b shows the variation of uplift capacity factor (N_c) with ground surface inclination angles at different embedment ratio

(H/B) for both attached and vented cases. It is seen that, the variation of the uplift capacity factor (N_c) with ground surface inclination angles is more or less linear.

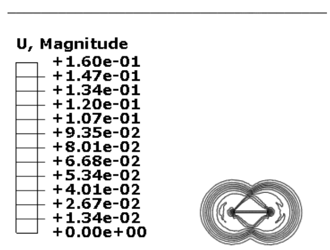
4.2 Soil Failure Mechanism

Fig. 6 shows the line contours of resultant soil displacement at failure for each of the anchors modeled at different embedment ratios on horizontal (Fig-6a through Fig-6c) and sloping ground (Fig-6d through Fig-6j). Under plane strain conditions, the contour shows the failure mechanism of anchor in clay soil (ϕ=0°) for both attached (Fig: 6a and Fig: 6b) and vented case (Fig-6c). These illustrate the variation in nature of the soil displacement depending on interface conditions. When the anchor is attached to the soil then the local failure mechanism occurs and contours do not extend to the surface. These type of failure mechanism is also observed when embedment ratio (H/B)>8 at slope 45°. This trend is also observed as shown in fig-6(j) so, it can be concluded that, the effect of slope on vertical uplift capacities is negligible after at H/B>8. At a lower inclination angle, for example β=15°, β=30° uplift capacity is found constant at lower embedment ratios (H/B=4~5) than the higher sloping angle.

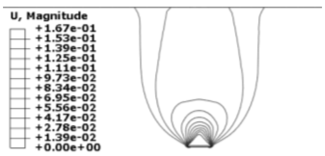
In vented case, failure mechanism extending to the soil surface (see Fig.6c). A vertical shear plane can be seen extending upward from the edge of the anchor, and soil is drawn in behind the anchor. This type of soil failure mechanism is also observed in all vented case of sloping ground and attested case of sloping ground at embedment ratios <8. Hence, it is clear that the uplift capacity of anchor decreases at all embedment ratios in vented cases.



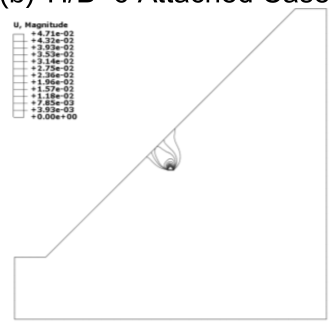
(a) H/B=3 Attached Case, β=0°



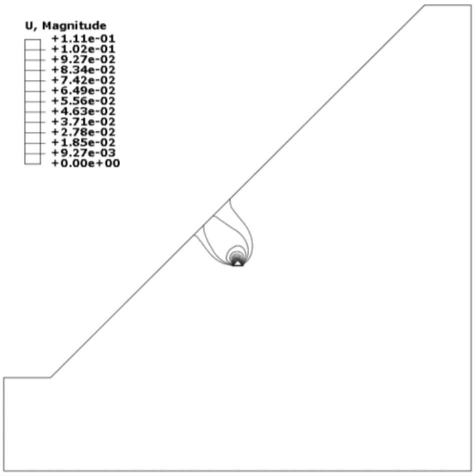
(b) H/B=6 Attached Case, β=0°



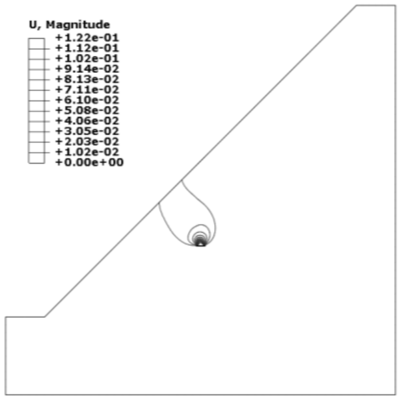
(c) H/B=6 vented Case, β=0°



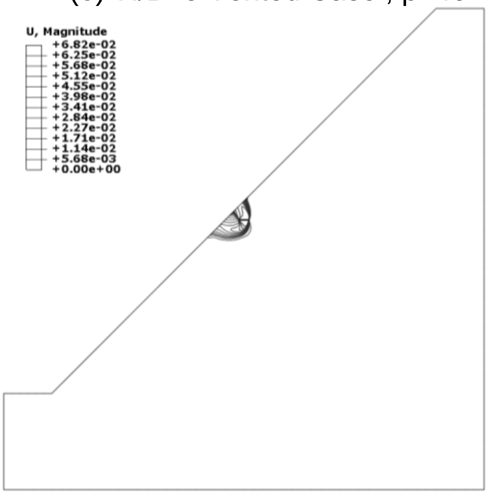
(d) H/B=6 Vented Case , β=45°



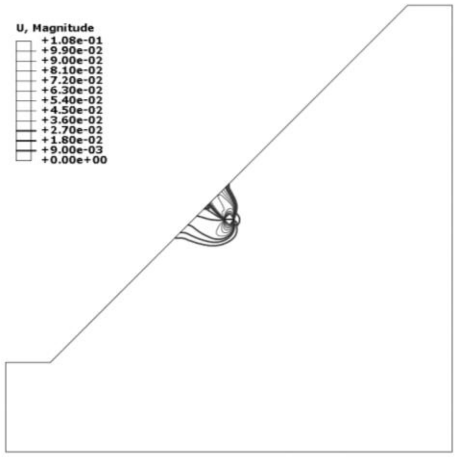
(e) H/B=8 Vented Case , β=45°



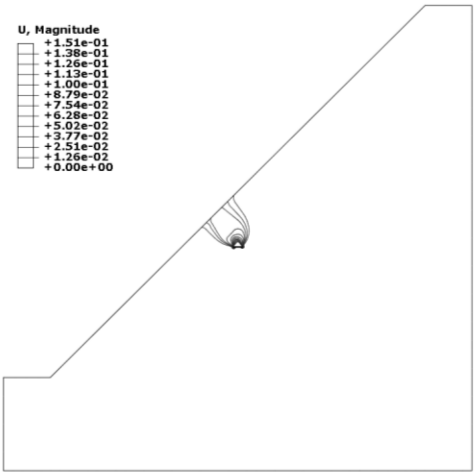
(f) H/B=10 Vented Case , β=45°



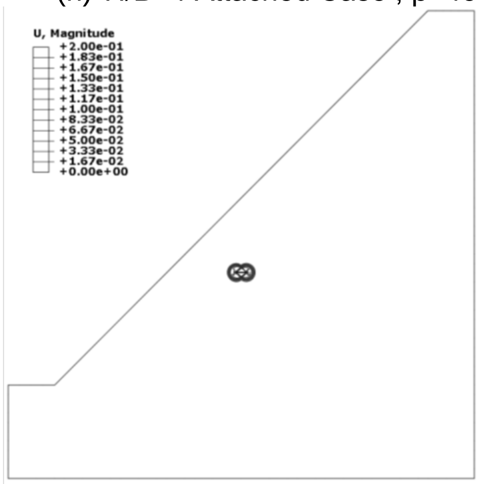
(g) H/B=2 Attached Case , β=45°



(h) H/B=4 Attached Case , β=45°



(i) H/B=6 Attached Case , β=45°



(j) H/B=8 Attached Case , β=45°

Figure 6: Soil failure mechanism for both attested and vented case

5. CONCLUSIONS

In this study finite element analysis has been performed using ABAQUS to investigate the uplift capacity of strip plate anchor embedded in clayey horizontal and sloping ground. Result reveals that the uplift capacity of plate anchor increases in relation to the increasing of embedment ratio for vented case for both horizontal and sloping ground. In addition, the uplift capacity decreases almost linearly with the rotation angle for vented case at all embedment ratios. In attested case, uplift capacities found constant and equal to 11.89 at H/B≥8,H/B≥6 and H/B≥4, for slope angle 45°,30° and 15°. Hence it can be conclude that the effect of slope is negligible at H/B≥8,H/B≥6 and H/B≥4, for slope angle 45°,30° and 15°.

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