PURE HORIZONTAL, VERTICAL AND MOMENT CAPACITY OF PLATE ANCHOR IN SAND

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ABSTRACT

The pullout capacity of plate anchor subjected to general (horizontal, vertical and moment) loading is of interest to the geotechnical engineer. Literature reveals that no precious design method is available that can be used to determine the pullout capacity of plate anchor in the sand under such loading. Therefore, a two-dimensional finite element analysis (2D-FE) is used to investigate the pullout capacity of a strip horizontal plate anchor in sand subjected to vertical, horizontal and moment loading. The effects of the embedment ratio and friction angle on the pullout capacity factor is also investigated. It is seen that both the embedment ratio and friction angle significantly affects the pullout capacity of plate anchor. Both the horizontal and moment capacity increases nonlinearly, while the vertical pullout capacity increases linearly with the friction angle of sand for every embedment depth of anchor. The horizontal pullout capacity is found lower compared to vertical capacity for small friction angle ($10°$ to $30°$), while for higher friction angle ($>30°$) the horizontal capacity is higher than that of the vertical capacity of horizontal strip plate anchor embedded in the sand. Therefore, for compacted dense sand the horizontal capacity is higher than vertical capacity.

Keywords: *plate anchor, pullout capacity, general loading, sand, numerical analysis*

1. INTRODUCTION

Plate anchors are commonly used cost-effective and geotechnically efficient anchoring system widely used in transmission tower, sheet piles, retaining wall, deepwater offshore developments, and mooring system for floating structure (Hanna et al. 2014; Merifield and Smith 2010; Sutherland et al. 1983). However, Yang et al. (2010) mentioned that it cannot be preferred for permanent mooring system due to the uncertainties have arisen in predicting anchor performances. Because the available design approach is reasonable for the normal loading (in-plane) conditions. But this anchor may be subjected to the horizontal and overturning moment (out-of-plane line) loadings due to the movement of wind, wave, and many other environmental loadings. This out-of-plane loads can significantly reduce the pullout capacity of the anchor embedded in a particular location and for a particular soil. Literature reveals that very few studies are available that can be used to determine the pullout capacity of the anchor in clay subjected to in-plane and or out-of-plane loading. The study on the pullout capacity of strip anchor subjected to general loading (combined vertical, horizontal and moment) have been first stated by (O'neill et al., 2003). The results obtained from their study for both the upper bound and small strain FEM techniques showed that the horizontal and moment pullout capacity of a horizontal plate anchor in clay is about one-third and one-eighth of the vertical capacity. The similar results are found from small strain FEM

(Yang et al. 2010) and Eulerian FEM (Nouri et al., 2017). Gilbert et al. (2009) conducted both the experimental and analytical method to determine the rectangular and square plate anchors with zero thickness in terms of plastic envelopes subjected to multiaxial loading. Gilbert et al. (2009) investigated the effect of plate-soil interface friction and plate thickness on the pullout capacity of drag anchor using FEM. According to the author knowledge, there is no established technique for predicting pullout capacity of plate anchor under general loading. Therefore, it is required to develop design methods and or charts for the practitioner to understand the performance of plate anchor subjected to general loading.

In the current study, a two-dimensional finite element analysis (2D-FE) is used to investigate the pullout capacity of a strip horizontal plate anchor in sand subjected to general loading. The effects of the embedment ratio and friction angle on the pullout capacity factor is also investigated.

2. METHODOLOGY

2.1 Finite Element Analysis

The objectives of this study are to improve the understanding of the fundamental mechanism of the continuous pullout of horizontal anchor under combined loading condition (V, H, M). The two-dimensional finite element analysis (FEM) is carried out by commercial software ABAQUS is used in this study. The strip plate anchor of width B is assumed to be deeply embedded, with localized plastic flow forming around the plate anchor and not extending to the surface, resulting in capacity factors that are not affected by overburden and soil weight (Song et al. 2008; Wang et al. 2010). Conventional small strain analysis is carried out to determine the pullout capacity of the embedded anchor, where the anchor movement is limited to 0.1 times to the anchor length. The contact between the anchor and the soil is assumed to be rough. In order to ensure the rough condition, the interfaces between the anchor plate and soil domains are defined as (i) tangential behaviours and (ii) normal behaviour. In tangential behaviour is assumed to be rough and normal behaviours is defined as hard contact with separation between soil and anchor when tension develops.

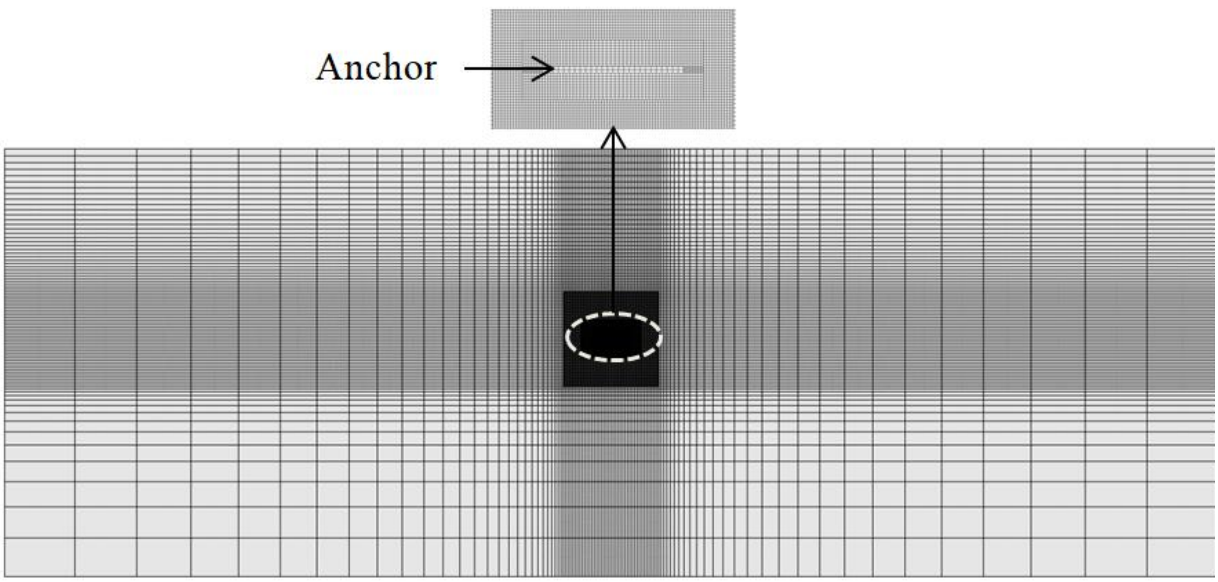


Figure. 1: Finite element model used for numerical analysis

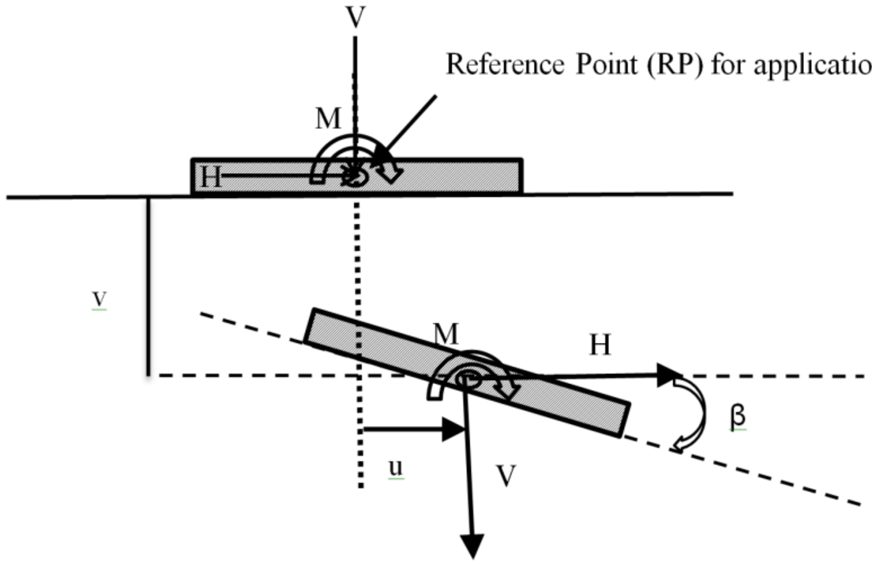


Figure. 2. Load and displacement convention adopted

An elastic-perfectly plastic associative Mohr-Coulomb material model is used for purely cohesive soil with cohesion c=3 kPa, modulus of elasticity E=30 Mpa and the Poisson's ratio 0.33. The anchor is modeled as a rigid body with Young's modulus 10^7 times that of soil and Poisson's ratio 0.15(Andersen et. al, 2003). The FE analyses are based on 8-noded quadrilateral elements of type CPE8R with reduced integration. Figure 1 presents a typical two-dimensional finite-element mesh for a strip plate of width B=0.5m and thickness t=L/7=0.071m. The soil domain is extended to 25B in horizontal and 10B in vertical directions, respectively. Zero-displacement boundary conditions are applied to prevent out-of-plane displacements of the vertical boundaries and the base of the mesh is fixed in both horizontal and vertical coordinate directions. To obtain more accurate results, elements are kept very small (L/60) near the plate, increasing gradually in size and moving away from the plate (Nouri et al., 2017). To determine the collapse load of the footing, displacement-based analyses are performed. The total displacement is applied over a number of sub-steps in the reference point (RP) of the anchor as shown in Figure 2. All the nodes defining the soil anchor interfaces are forced to move together either parallel to the anchor (sliding), perpendicular to the anchor (normal) and in a path corresponding to the rotation of anchor plate about the centre. All results are presented here as non-dimensional forms using the factors defined as

$$N_v = \frac{F_V}{B\gamma H};\ N_s = \frac{F_H}{B\gamma H};\ N_m = \frac{M_m}{B^2\gamma H} \tag{1}$$

2.2 Sign Convention for Load and Displacement

The centroid of the anchor is used as the reference point (RP) for application of combined load components V, H and M. The V, H, and M loads, as well as the corresponding footing movements' v, u and β, are illustrated in Figure. 2, following the convention of Butterfield et al. (1997).

3. RESULTS AND DISCUSSIONS

3.1 Vertical Pullout Capacity

The variation of vertical pullout capacity factor ($N_{v,\ Vertical}$) due to the contribution of soil weight with the soil friction angle for different embedment ratio is shown in Figure 3. It is seen that the vertical pullout capacity factor of strip plate anchor embedded in sand shows nearly linear behaviour with the friction angle. Similar to the horizontal pullout capacity factor, the vertical pullout capacity factor increases gradually up to the embedment ratio of 4 and increases steeply for embedment ration greater than 4.

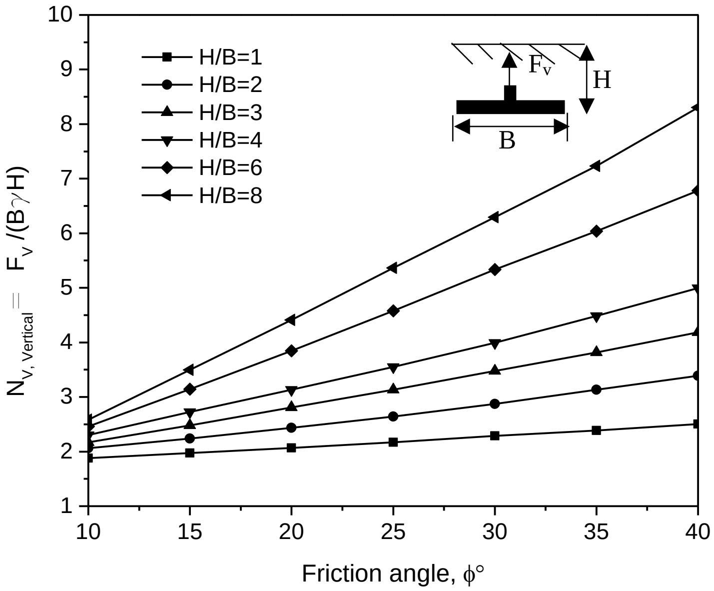


Figure 3: Vertical pullout capacity factor of horizontal strip anchor embedded in sand

3.2 Horizontal Pullout Capacity

It is seen that the horizontal pullout capacity factor ($N_{s,\ Horizontal}$) due to the contribution of soil weight increases gradually with the increases of friction angle for embedment depth up to 4 as shown in Figure 4. While the horizontal pullout capacity factor for the deep anchor (embedded ratio>4) varied steeply with the friction angle. It is also seen that the horizontal pullout capacity factor shows nonlinear behavior with the friction angle of soil.

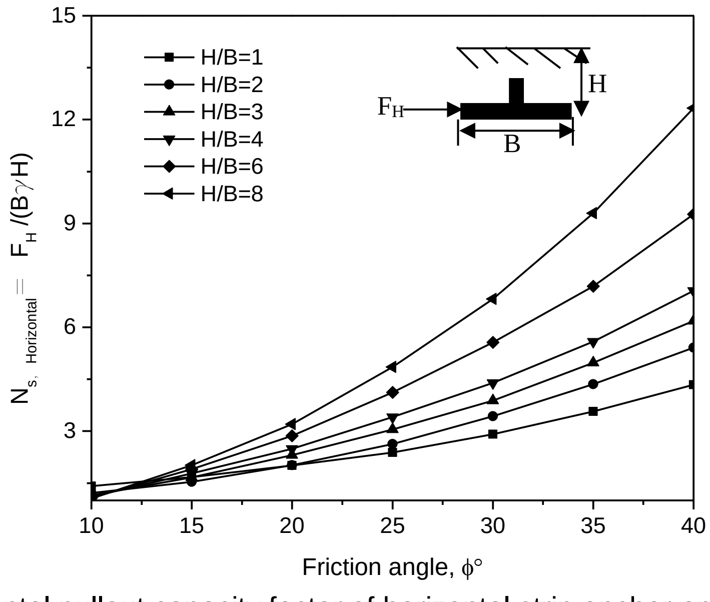


Figure 4: Horizontal pullout capacity factor of horizontal strip anchor embedded in sand

3.3 Moment Capacity

The moment capacity of plate anchor embedded in the sand for different embedment ratio and the frictional angle is shown in Figure 5. It is seen that similar to horizontal capacity factor the moment capacity factor ($N_{m,\ Horizontal}$) of strip anchor embedded in sand shows nonlinear behaviour with the friction angle. The moment capacity factor of strip plate anchor increases with both the friction angle and embedment ratio.

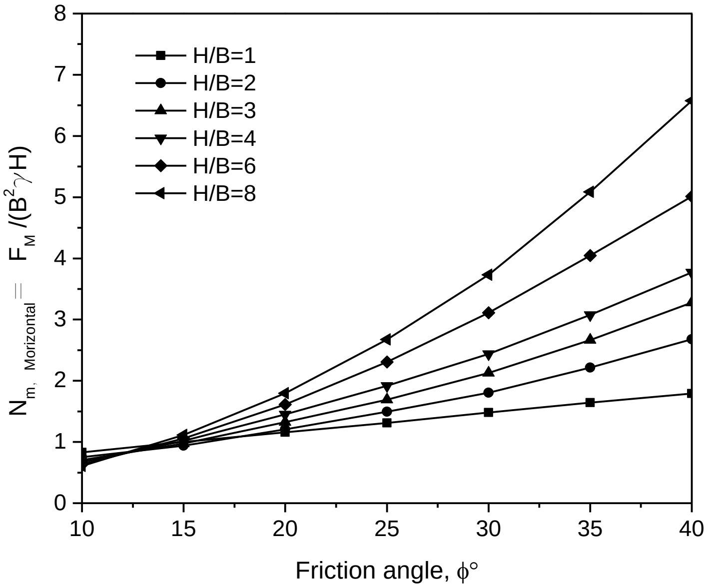


Figure 5: Moment pullout capacity factor of horizontal strip anchor embedded in sand

3.4 Comparison with the previous study

A detailed comparison study on the vertical pullout capacity factor of strip anchor in the sand is shown in Figure 6. It is found that the vertical pullout capacity factor of strip plate anchor in the current shows higher value compared to Merifield and Sloan (2006).

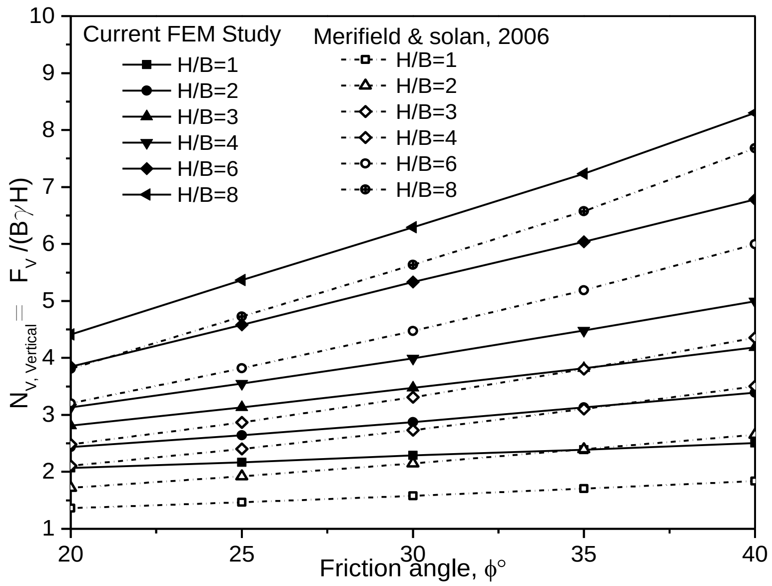


Figure 6: Comparison of vertical pullout capacity factor of horizontal strip anchor embedded in sand

3.5 Comparison of Horizontal and Vertical Pullout Capacity

A detailed comparison between the vertical and horizontal pullout capacity of strip horizontal plate anchor are also conducted. It is seen that for lower friction angle (10° to 30°), the vertical pullout capacity is higher than that of horizontal capacity as shown in Figure 7. But for friction angle above 30°, the horizontal pullout capacity is higher than the vertical capacity of horizontal strip anchor.

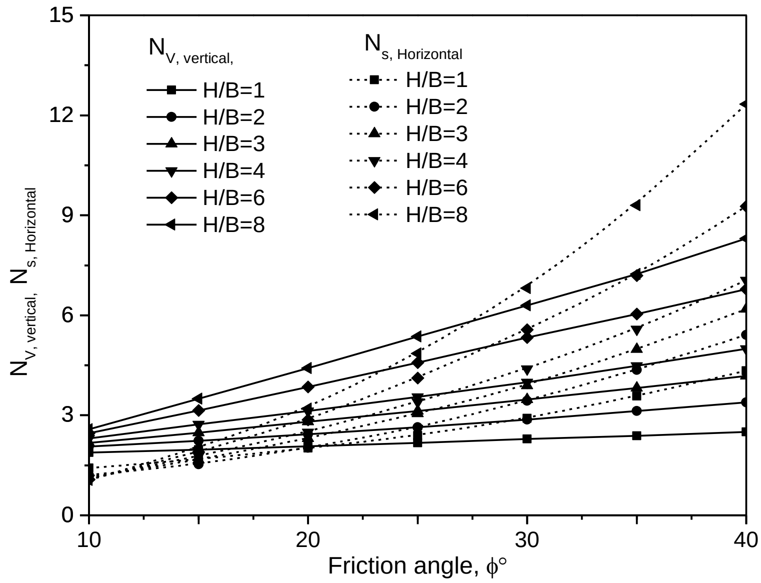
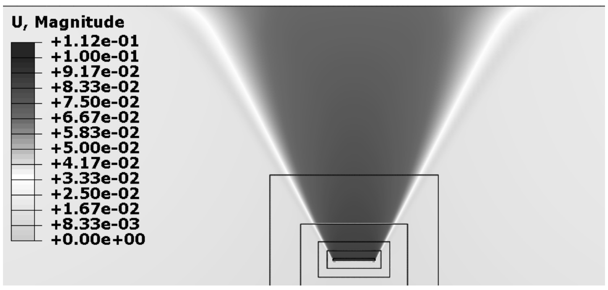


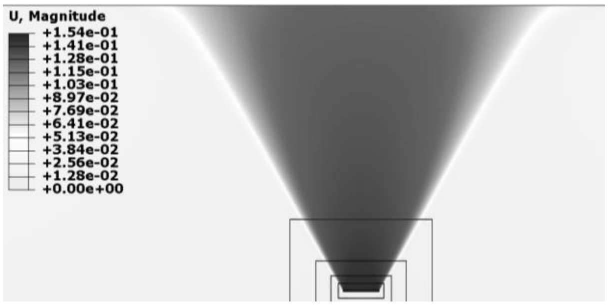
Figure 7: Comparison of vertical and horizontal pullout capacity factor of horizontal strip anchor embedded in sand

4. SOIL FAILURE MECHANISM

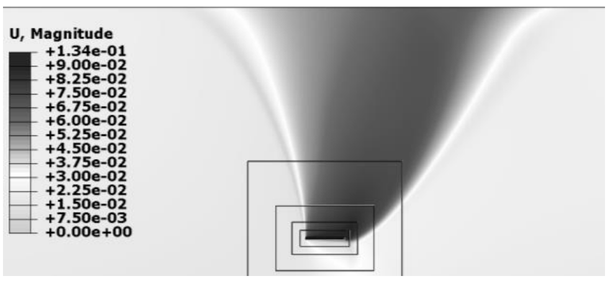
Figure 8 shows the contours of resultant soil displacement at the failure of anchors modeled at an embedment ratios of H/B=6 and H/B=8 for pure vertical, horizontal and moment. Under plane strain conditions, the contour shows the failure mechanism of the anchor in sandy soil (ϕ=30°). In all cases, displacement contours extend to the soil surface (see Figure 8a and Figure 8d) and symmetrical about vertical axis due to vertical loadings. 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 embedment ratios. But, for shear and moment loading symmetry does not exist about vertical axis. Failure surface becomes larger due to the increase of embedment ratios.



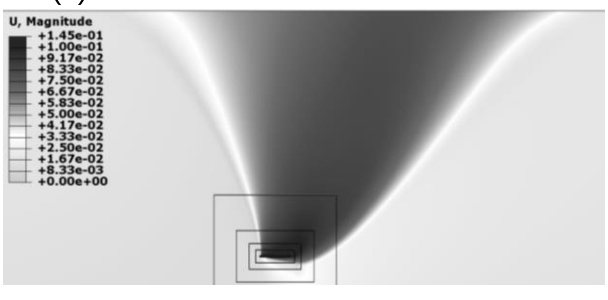
(a) Pure Vertical at H/B=6



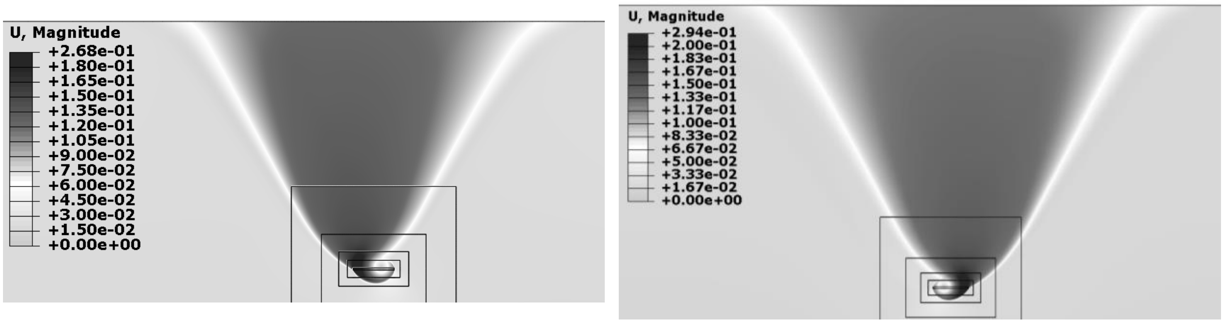
(b) Pure Vertical at H/B=8



(c) Pure Horizontal at H/B=6



(d) Pure Horizontal at H/B=6



(e) Pure positive moment at H/B=6 (f) Pure negative moment at H/B=8

Figure 8: soil failure mechanism

5. CONCLUSIONS

A detailed FEM analysis on the vertical, horizontal and pure moment pullout capacity of strip horizontal plate anchor in the sand is studied. The following conclusions can be drawn from the results presented in this paper.

(a) The embedment depth and friction angle have a significant impact on the horizontal, vertical and moment pullout capacity of horizontal plate anchor in sand. Both the horizontal and moment capacity increases nonlinearly, while the vertical pullout capacity increases linearly with the friction angle of sand for every embedment depth of anchor.

(b) The horizontal pullout capacity is found lower compared to vertical capacity for small friction angle (10° to 30°), while for higher friction angle (>30°) the horizontal capacity is higher than that of the vertical capacity of horizontal strip plate anchor embedded in the sand. Therefore, for compacted dense sand the horizontal capacity is higher than vertical capacity.

(c) The current FEM study on the vertical pullout capacity of horizontal anchor showed higher value compared to the results obtained from Merifield and Sloan (2006).

REFERENCES

Butterfield R, Houlsby GT, G. G. (1997). “Standardized sign conventions and notation for generally loaded foundations.” *Geotechnique*, 47(5), 1051–4.

Gilbert, R. B., Lupulescu, C., Lee, C. H., Miller, J., Kroncke, M., Yang, M., Aubeny, C. P., and A, J. D. M. T. (2009). “Analytical and Experimental Modeling for Out-of-Plane Loading of Plate Anchors.” *OTC 20115*, 1–15.

Hanna, A., Foriero, A., and Ayadat, T. (2014). “Pullout Capacity of Inclined Shallow Single Anchor Plate in Sand.” *Indian Geotechnical Journal*, 45(1), 110–120.

Merifield, R. S., and Sloan, S. W. (2006). “The ultimate pullout capacity of anchors in frictional soils.” *Canadian Geotechnical Journal*, 43(8), 852–868.

Merifield, R. S., and Smith, C. C. (2010). “Computers and Geotechnics The ultimate uplift capacity of multi-plate strip anchors in undrained clay.” *Computers and Geotechnics*, Elsevier Ltd, 37(4), 504–514.

Nouri, H., Biscontin, G., Aubeny, C. P., and Asce, M. (2017). “Numerical prediction of undrained response of plate anchors under combined translation and torsion.” *Computers and Geotechnics*, 81, 39–48.

O’neill, M. P., Bransby, M. F., and Randolph, M. F. (2003). “Drag anchor fluke – soil interaction in clays.” *Canadian Geotechnical Journal*, 40(1), 78–94.

Song, Z., Hu, Y., and Randolph, M. F. (2008). “Numerical Simulation of Vertical Pullout of Plate Anchors in Clay.” *Journal of Geotechnical and Geoenvironmental Engineering*, 134(6), 866–875.

Sutherland, H. B., Finlay, T. W., and Fadl, M. O. (1983). “Uplift capacity of embedded anchors in sand.” *Int Conf Behav Offshore Struct*, 451–463.

Wang, D., Hu, Y., and Randolph, M. F. (2010). “Three-Dimensional Large Deformation Finite-Element Analysis of Plate Anchors in Uniform Clay.” *Journal of Geotechnical and Geoenvironmental Engineering*, 136(2), 355–365.

Yang, M., Ph, D., Murff, J. D., Ph, D., Asce, D. M., Aubeny, C. P., Ph, D., and Asce, M. (2010). “Undrained Capacity of Plate Anchors under General Loading.” *Journal of Geotechnical and Geoenvironmental Engineering*, 136(10), 1383–1393.