

Analytical and Numerical Studies of Vertical Anchor Plates in Cohesionless Soils

Hamed Niroumand

*Department of Geotechnical Engineering, Faculty of Civil Engineering,
University Technology Malaysia(UTM), Skudai, Johor, Malaysia,
e-mail:niroumandh@gmail.com*

Khairul Anuar Kassim

*Deputy Dean, Faculty of Civil Engineering, University Technology Malaysia
(UTM), Skudai, Johor, Malaysia*

Ramli Nazir

*Associate Professor, Department of Geotechnical Engineering , Faculty of Civil
Engineering, University Technology Malaysia (UTM), Skudai, Johor, Malaysia*

ABSTRACT

A history of theoretical and numerical studies of vertical anchor plates for the last sixty years is critically reviewed. To estimate the ultimate pullout capacity of vertical anchor plates a number of analytical and numerical methods, have been developed. Vertical anchor plates are used in different applications including seawall, retaining wall, excavations and etc. In the article takes place a discussion based on different theories and numerical studies in vertical anchor plates done by previous researchers. Analysis, beginning from Terzaghi (1943) until the most recent analysis are reviewed. This analysis was pioneered by Hansen (1953), Ovesen (1964), Biarez et al. (1965), Meyerhof (1973), Neely (1973), Das (1975) and Rowe and Davis (1982), Hanna (1998), Murray and Geddes (1989), Basudhar and Singah (1994), Merifield, Sloan and Yu (2006) are also discussed. The conclusion shows that previous theories and numerical studies agree closely with the results of experimental works.

KEYWORDS: Vertical Anchor plates, Theoretical, Numerical, Loose Sand, Dense Sand, Retaining Wall.

INTRODUCTION

Types of Soil Anchors

The anchors are a thin foundation system designed and constructed specifically to resist any pullout force or overturning moment placed on a structure. Generally, anchors are used to transmit different forces from a structure to the soil. Their strength is obtained through the shear strength and dead weight of the surrounding soil. The different types of anchors used in geotechnical engineering and anchors are including of grout system, helical system and plate system. Figure1 is shown type of soil anchors.

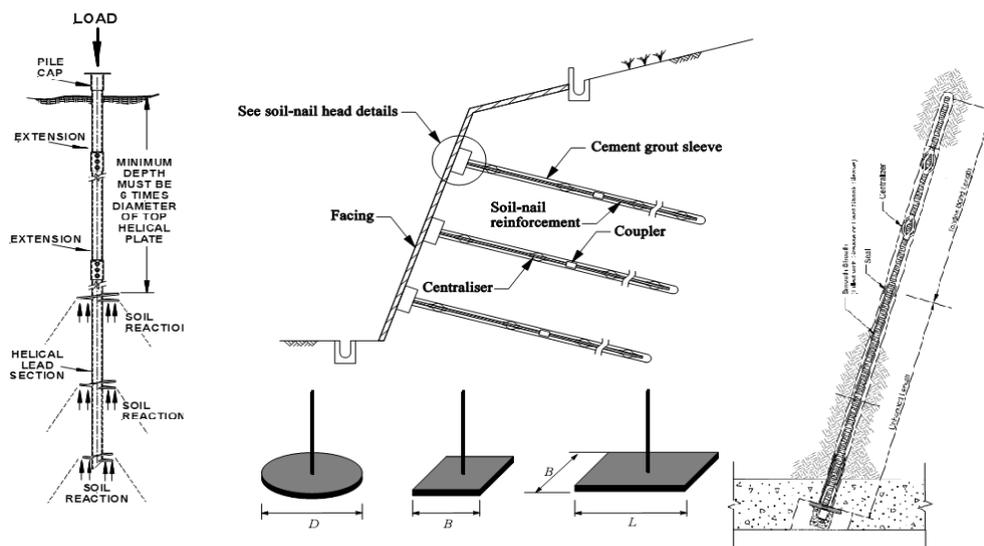


Figure 1: Types of soil anchors

BRIEF REVIEW OF DESIGN METHODS

Theoretical and numerical analyses of the ultimate capacity of vertical anchor plates may be divided broadly into those based on earth pressure for shallow, and those based on bearing capacity for deep anchor plates. In this respect, a shallow anchor plate might be defined as one for which failure zones extend to the soil surface. The application of typical Rankine Theory has been widely selected for the evaluation of the ultimate capacity T_u of shallow vertical continuous anchor plates assuming passive and active pressures P_p and P_a , to be completely developed in front of and behind the anchor plate that it shown in Figure 2.

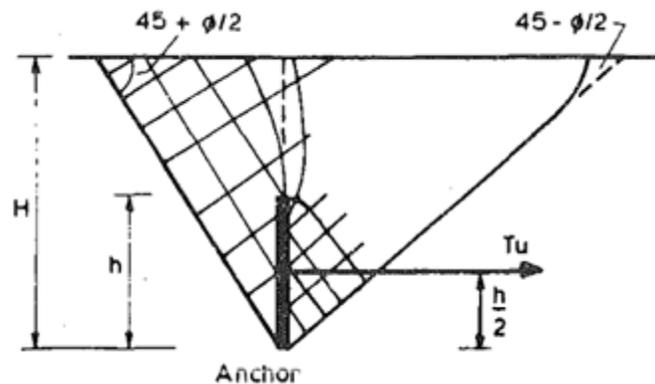


Figure 2: Shear pattern of Shallow Anchor plate in Cohesion less by Terzaghi (1943)

Thus

$$\frac{T_u}{\text{unit width}} = P_p - P_a \quad \text{Eq.1}$$

Terzaghi stated that Eq. 1 is approved for embedment ratios (H/h) less than 2, and further specified that for single anchor plates, allowance for the additional shear resistance on the side faces of the wedge the anchor plate tends to push out may be involved. The sides of the wedge were assumed to form parallel to the tie rod, as shown in Figure3. Thus, for a single anchor plate:

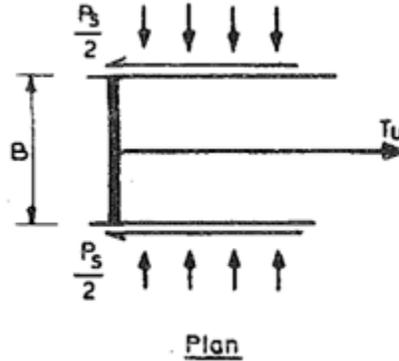


Figure 3: Side Shear Resistance P_s for Single Anchor Plate by Terzaghi (1943)

$$T_u = (P_p + P_s) - P_a \quad \text{Eq.2}$$

This approach is selected in the British Code of Practice , which gives the side shear resistance for sand as

$$P_s = K_a \frac{\gamma H^3}{3} \tan\left(45 + \frac{\phi}{2}\right) \tan\phi \quad \text{Eq.3}$$

where

K = active earth pressure coefficient,

γ = soil density,

ϕ = friction angle of soil,

H = depth to the base of the anchor plate.

If the height h of a anchor plate is smaller than relate to embedment depth H , Terzaghi suggested, the anchor plate would fail by plugging through the ground without make a shear plane extending to the ground surface. Terzaghi proposed that the force required to pull out such a anchor plate is approximately equal to the bearing capacity of a continuous footing with a width h whose base is positioned at depth $(H - h/2)$ below the earth surface. Thus

$$T_u = \frac{1}{2} \gamma h^2 \quad \text{Eq.4}$$

where

$$N_\gamma = (N_q - 1) \tan(1.4\phi),$$

$$N_q = e^{\pi \tan\phi} \tan^2\left(45 + \frac{\phi}{2}\right)$$

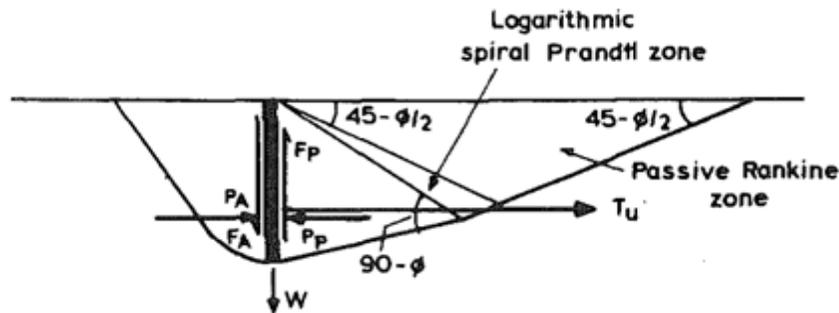


Figure 4: Failure Mechanism of Anchor Plates by Hansen (1953) and selected by Ovesen (1964)

Ovesen (1964) selected a composite rupture pattern, proposed by Hansen (1953), to derive the earth pressure in front of a continuous surface anchor plate, termed the "basic" case. The assumed rupture pattern, a straight line through the base of the anchor plate in combination with a rupture zone comprising Rankine and logarithmic spiral Prandtl zones, is shown in Figure 4.

In contrast to the variety of laboratory results discussed, very few rigorous numerical and theoretical analyses have been performed to determine the uplift capacity of anchor plates in soils.

Whilst it is essential to verify numerical and theoretical solutions with experimental studies wherever possible, results obtained from experimental testing alone are generally problem specific. This is particularly the case in geomechanics where we are dealing with a highly nonlinear material which often displays pronounced scale effects. As a result, it is often difficult to extend the findings from experimental data to full scale problems with different material or geometric parameters. Since the cost of performing experimental tests on each and every field problem combination is prohibitive, it is necessary to be able to model soil uplift resistance numerically for the purposes of design. Existing theoretical and numerical analyses generally assume a condition of plane strain for the case of a continuous strip anchor plate or axisymmetry for the case of circular anchor plates.

A summary of previous works for vertical anchor plates is provided in Table 1.

Table 1: Theoretical studies on vertical anchor plates in cohesion less soil

Researcher	Analysis Method	Anchor Shape	Anchor Roughness	Friction Angle	L/D
Terzaghi(1943)	limit analyses	Strip	-	All	Less than 2
Hansen(1953)	limit analyses	Strip	-	All	All
Ovesen(1964)	limit analyses	Strip	-	All	All
Biarez et al (1965)	Limit equilibrium	Strip	-	All	All
Meyerhof (1973)	Limit equilibrium	Strip	-	All	All
Neely et al (1973)	Limit equilibrium	Strip	Rough	30,45	1-5.5
Rowe and Davis (1982)	Elastoplastic Finite Element	Strip	Smooth	0 - 45	1-8
Hanna et al (1988)	Limiting Equilibrium	Strip	-	All	All
Murray and Geddes (1989)	Limit equilibrium	Strip	Smooth / Rough	43.6	1-8
Basudhar and Singah (1994)	Limit analysis	Strip	Smooth / Rough	32,38 and 35	1-5
Merifield R. S., Sloan S. W. and Yu H. S. (2006).	finite element upper and lower bound , displacement finite element	Square, Rectangular, Circular	Smooth /Rough	20,30,40	All

Biarez, Boucraut and Negre presented calculation methods for limiting the equilibrium of vertical anchor plate under to translation or rotation. Active and passive earth pressure coefficients, derived from limit analyses in which the vertical equilibrium of the anchor plate was satisfied, were summarized on design charts.

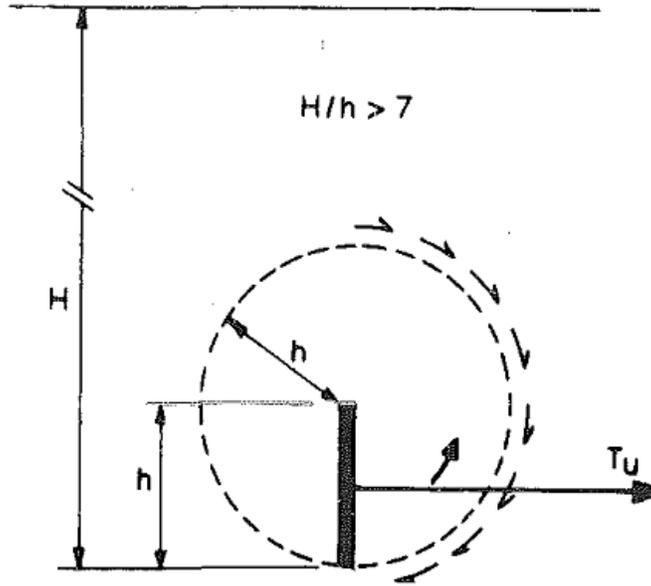


Figure 5: Failure Mechanism of Deep Anchor Plate by Biarez, Boucraut and Negre (1965)

The resistance of shallow anchors ($H/h < 4$) was shown to depend upon the anchor plate roughness and weight. At intermediate depths ($4 < H/h < 7$), computations assuming the anchor plate to be smooth gave good agreement with measured values. Their original equation may be expressed in a simplified form as

$$M_{\gamma q} = (K_p - K_a) \left(\frac{H}{h} - \frac{1}{2} \right) + \frac{K_p \sin 2\phi}{2 \tan(45 + \frac{\phi}{2})} \left(\frac{H}{h} - 1 \right)^2 \quad \text{Eq. 5}$$

Which

$$M_{\gamma q} = \frac{T_u}{\gamma B h^2}$$

B = Anchor plate width,

K_p = Passive earth pressure coefficient,

Biarez, et al., analyzed the characteristic rotational mechanism around deep anchor plates ($H/h > 7$), as shown in Figure4 ,by considering the couple necessary for the rotation of a cylinder of sand in front of the anchor plate; they derived the following relation:

$$M_{\gamma q} = 4\pi \left(\frac{H}{h} - 1 \right) \tan\phi \quad \text{Eq. 6}$$

The analysis of strip footing was extended by Meyerhof and Adams to include circular anchor plates by using a semi-empirical shape factor to edit the passive earth pressure obtained for the plane strain. The failure surface was assumed to be a vertical cylindrical surface through the anchor plate edge and extending to the sand surface. An approximate analysis for the capacity of rectangular anchor plates was obtained as for downward loads (Meyerhof 1951), by assuming the earth pressure along the circular perimeter of the two end portions of the failure pattern is governed by the same shape factor selected for circular anchor plates.

The paper by Meyerhof and Adams (1968) is widely referenced when considering the capacity of anchor plates. It is based on two main assumptions that they are involving the shape of the failure surface and the distribution of stress along the failure surface. Even so, the theory presented by Meyerhof and Adams (1968) has been found to give reasonable estimates for a wide range of anchor plate problems. It is one of only two methods available for estimating the capacity of rectangular anchor plates.

Neely et al. (1973) used both a failure surface approach and the method of characteristics to analyze a vertical strip anchor plate in sand. In the first method, a trial surface was selected which involved of a combination of straight lines and logarithmic spirals. It was assumed initially that the sand above the level of the top of the anchor plate would act as a simple surcharge. This was defined as the “Surcharge method of analysis”. However, since this approach ignores the shearing resistance of the sand above the anchor plate, the approach was edited by incorporating the strength of the sand above the anchor plate through what was termed an equivalent free surface. This method was defined as the “Equivalent free surface” method. It should be noted that although the analysis selected by Neely et al represents a more analytical and numerical attempt to predict the ultimate capacity of vertical anchors than any proceeding research, the proposed methods ignore the active stress distribution behind the anchor plate and the kinematic behavior of the material.

Neely, Stuart and Graham determined the theoretical resistance of continuous vertical anchor plates in cohesion less materials using the theory of plasticity. Failure surface solutions were based on rupture zones bounded by combinations of logarithmic spirals and straight lines.

$$\tan\left(45 + \frac{\psi}{2}\right) = \frac{\tan\left(45 + \frac{\theta_{ps}}{2}\right)}{\tan\left(45 + \frac{\theta_{cp}}{2}\right)} \quad \text{Eq.8}$$

Rowe and Davis (1982b) described a theoretical assessment of anchor plates in sand which considered the effect of anchor plate embedment, friction angle, dilatancy, and initial stress state and anchor plate roughness for vertical anchor plates. Their theoretical solution was based on an elasto-plastic finite element analysis using a soil structure interaction theory. The sand was assumed to have a Mohr-Coulomb failure criterion. The theoretical data were presented in the form of design charts which could be used in hand calculations to obtain an estimate of anchor plate capacity for a wide range of anchor plate geometries and sand.

The finite element method has also been used by Vemeer & Sutjiadi (1985), Tagaya et al. (1983, 1988), and Sakai and Tanaka (1998). Unfortunately, only limited results were presented in these studies.

Tagaya et al (1983, 1988) conducted two-dimensional plane strain and axi-symmetric finite element analyses by the constitutive law of Lade and Duncan (1975). Scale effects for circular anchor plates in dense sand were investigated by Sakai and Tanaka (1998) by a constitutive model for a non-associated strain hardening-softening elasto-plastic material.

Koutsabeloulis and Griffiths (1989) investigated the trapdoor problem by the initial stress finite element method. Both plane strain and axisymmetric works were conducted. The researchers concluded that an associated flow rule has little effect on the collapse load for strip anchor plates but a significant effect (30%) for circular anchor plates. Large displacements were observed for circular anchor plates prior to collapse.

Upper and lower bound limit analysis techniques have been used by Murray and Geddes (1987, 1989), Basudhar and Singh (1994) and Smith (1998) to estimate the capacity of vertical strip anchor plates. Basudhar and Singh (1994) obtained estimates with a generalized lower bound procedure based on finite element method and non-linear programming similar to that of Sloan (1988). The solutions of Murray and Geddes (1987, 1989) were obtained by typically constructing kinematic ally admissible failure mechanisms (upper bound), while Smith (1998) presented a novel rigorous limiting stress field (lower bound) solution for the different problem.

Merifield et al. (2006) presented the results of a rigorous numerical work to estimate the ultimate capacity load for vertical anchor plate in cohesion less material. Rigorous bounds have been obtained using two numerical procedures that are based on finite element method of the upper and lower bound of limit analysis. For comparison purposes, numerical and theoretical results of the break-out factor have also been obtained by the more conventional displacement finite element method.

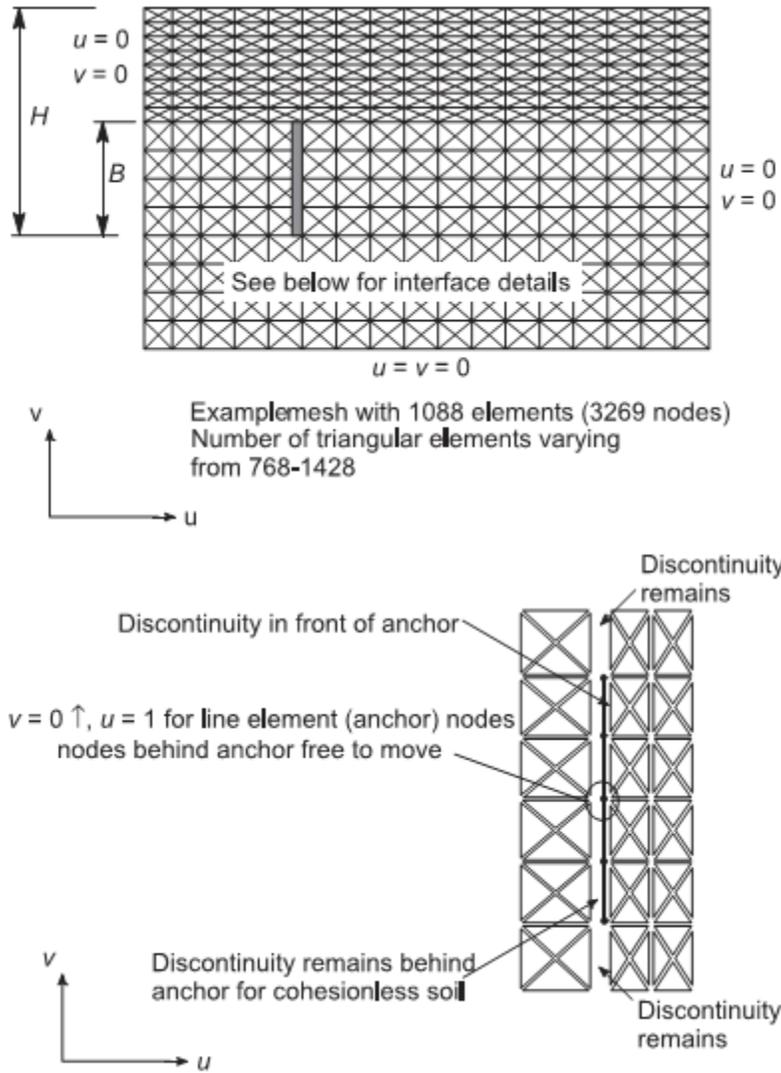


Figure 7: Upper Bound Finite Element Mesh for Vertical Anchor Plate by Merifield, Sloan, and Yu (2006).

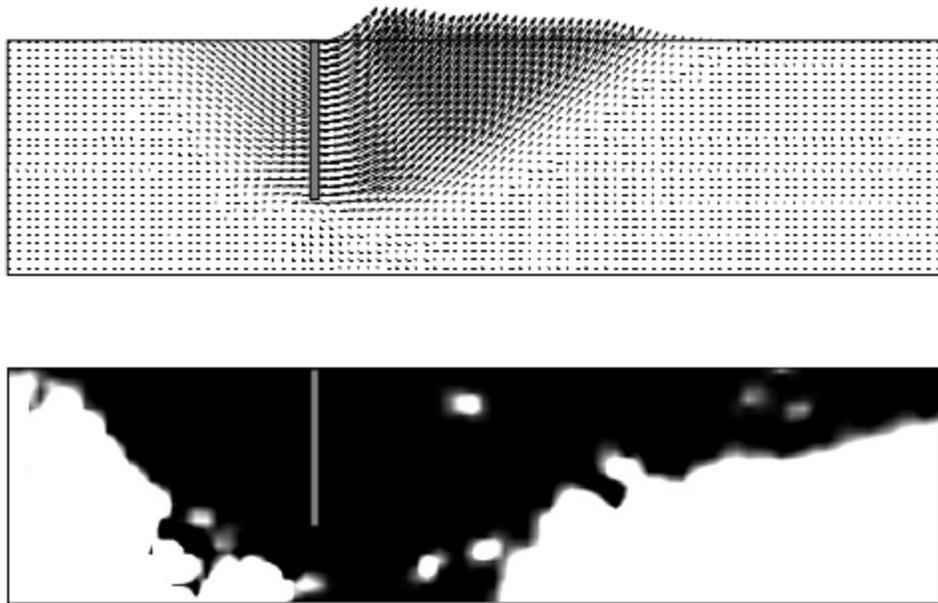


Figure 8: Failure pattern and zones of plastic yielding for rough anchor plates by Merifield, Sloan, and Yu (2006)

CONCLUSION

As a conclusion, this paper shows that last theoretical and numerical results have been done regarding to the vertical anchor plate performance in the cohesion less soil. Very few rigorous numerical and theoretical studies have been undertaken to determine anchor plate behavior. It is generally agreed that existing theories do not adequately describe the behavior of anchor plates. Most methods of analysis are based upon the initial assumption of a particular failure mode (limit equilibrium method and upper bound limit analysis and finite element method). Inevitably such a wide range of parameters will contribute to conflicting conclusions for the ultimate capacity load of the vertical anchor plates. These researches have been done, using different vertical anchor plates and soil parameters. Some of the researches did not include in their presentation the anchor plate roughness and anchor plate size. A rigorous numerical study of anchor plates by advanced numerical and theoretical methods is clearly needed. A number of researchers have proposed using various shape factors based on numerical results to quantify the effect of anchor plate shape upon the ultimate pullout capacity. Some of the researches include of full three - dimensional study of anchor plate behavior would remove the approximations typically selected when designing circular, square or rectangular anchor plates. The effects of anchor roughness have largely been ignored. The effect this may have on vertical anchor plates needs to be investigated. Theoretical analyses for deep anchor plates in dense sand give a wide disparity in values and tend to seriously over predict measured anchor plate capacity.

REFERENCES

- [1] Biarez, I., Boucraut, L.-M., and Negre, R., "Limiting Equilibrium of Vertical Barriers Subjected to Translation and Rotation Forces," Proceedings of the 6th International Conference on Soil Mechanics and Foundation Engineering, Vol. II, Montreal, Canada, Sept., 1965, pp. 368-372.
- [2] Das, B. M., Seeley, G. R., and Das, S. C., "Ultimate Resistance of Deep Vertical Anchors in Sand," Soils and Foundations, Japanese Engineering Society, June, 1977, pp. 52-56.
- [3] Hansen, J. B., "Earth Pressure Calculations", Danish Technical Press, Copenhagen, Denmark, 1953.
- [4] Hansen, J. B., "A General Formula for Bearing Capacity," Bulletin No. 11, Danish Geotechnical Institute, Copenhagen, Denmark, 1961.
- [5] Meyerhof, G. G., and Adams, J. I., "The Ultimate Uplift Capacity of Foundations," Canadian Geotechnical Journal, Vol. 5, No. 4, Ottawa, Canada, 1968, pp. 225-244.
- [6] Neely, W. J., Stuart, J. G., and Graham, J., "Failure Loads of Vertical Anchor Plates in Sand," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 99, No. SM9, Paper 9980, Sept., 1973, pp. 669-685.
- [7] Ovesen, N. K., and Stromann, H., "Design Method for Vertical Anchor Slabs in Sand," Proceedings of Specialty Conference on Performance of Earth and Earth-Supported Structures, Vol. 1-2, 1972, pp. 1418-1500.
- [8] Rowe, R. K., and Davis, H., "The Behavior of Anchor Plates in Sand," Geotechnique, Vol. 32, No. 1, London, England, 1982, pp. 25-41.
- [9] Akinmusuru, J. O. (1978) "Horizontally loaded vertical anchor plate in sand." J. Geotech. Engrg. Div., ASCE, 104(2), 283-286.
- [10] Das, B. M. (1975) "Pullout resistance of vertical anchors." J. Geotech. Engrg. Div., ASCE, 101(1), 87-91.
- [11] Das, B. M., and Seeley, G. R. (1975) "Load-displacement relationship for vertical anchor plates." J. Geotech. Engrg. Div., ASCE, 101(7), 711-715.
- [12] Dickin, E. A., and Leung, C. F. (1985) "Evaluation of design methods for vertical anchor plates." J. Geotech. Eng., ASCE, 111(4), 500-520.
- [13] Hueckel, S. (1957) "Model tests on anchoring capacity of vertical and inclined plates." Proc., 4th Int. Conf. on Soil Mech. and Found. Engrg. Butterworths Scientific Publications, London, England, Vol. 2, 203-206.
- [14] Niroumand, H., and Kassim, Kh.A. (2010) "Compare of anchor systems in geotechnical engineering", MICCE 2010, Makassar, Indonesia, 9-10 March 2010
- [15] Niroumand, H., and Kassim, Kh.A. (2010) "Analytical and numerical studies of horizontal anchor plates in cohesion less soils", Electronic journal of geotechnical engineering (EJGE), Vol. 15, Page 281-292

[16] Neely, W. J., Stuart, J. G., and Graham, J. (1973) "Failure loads of vertical anchor plates in sand." *J. Soil Mech. and Found. Div., ASCE*, 99(9), 669–685.

[17] Terzaghi, K., and Peck, R. B. (1967) *Soil mechanics in engineering practice*. John Wiley and Sons, Inc., New York, N.Y.

[18] Merifield R. S., Sloan S. W. and Yu H. S. (2006). "The Ultimate Pullout Capacity of Anchors in Frictional Soils." *Can. Geotech. J., ASCE*, 43, 852-866.

