Annals of Pure and Applied Mathematics
Vol. 5, No.1, 2013, 53-63
ISSN: 2279-087X (P), 2279-0888(online)
Published on 13 November 2013
www.researchmathsci.org

Annals of
Pure and Applied
Mathematics

Pullout Capacity of Plate Anchors with Coaxial Geotextile Reinforcement

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Received 28 September 2013; accepted 5 October2013

Abstract. For resisting the pullout load horizontal plate anchors are commonly used. Pullout capacities of shallow plate anchors are limited and to resist higher applied pulling load, capacity of anchor needs to be improved. As result, the depth of embedment or size of anchor plate needs to be increased which in its term increases the construction cost due to cost of excavation, supporting arrangement of soil, dewatering system etc. In this paper a method has been presented to increase the pullout capacity of shallow anchors with coaxial circular geotextile sheet. A theoretical model to present such capacity is presented and theoretical results have been compared with conducted model anchor test result.

Keywords: Pullout load, anchors, coaxial circular geotextile sheet

1. Introduction

Foundation of many civil engineering structures are subjected to vertical or inclined pulling loads. To resist such loads horizontal plate anchors are widely used for both onshore and offshore structures. Different types of anchors are being employed in the field depending on the magnitude and type of loading, type of structure to supported, importance of the structures and subsoil conditions. An excellent description and use of different type of anchors in field are reported by Dutta and Singh[1]. Plate anchor is one of the most common types of anchors used in civil engineering constructions. Ultimate resistance of such plate anchors depend on the shape and size of anchor, depth of embedment, characteristics of the embedding soil, inclination of the pulling loads etc.

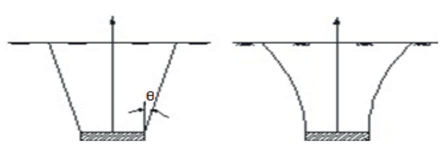
However when the depth of embedment of such anchor is shallow, then the excavation cost of the pit to house the anchor becomes less, and control of placement density of the filling the pit becomes easy and more certain. But if the pulling load to be resisted is large, then either the size of the anchor plate or the depth of embedment or both need to be increased resulting increase in the size of the excavation area and depth of excavation.

This not only leads to increase in size of the foundation area and cost of excavation, but also problem of excavation below possible existing water table and compacting fill material below water table at great depths. In such condition it will be worthwhile to search alternate cost effective method to improve the resistance capacity of a shallow anchor by adopting suitable method (Khatun and Chattopadhyay[2]). Without changing the depth of embedment and size of the anchor plate the pullout capacity of such anchors may be increased by introducing coaxial geotextile sheet over the anchor plate and then compacting the fill above the layer. The increase in the capacity to resist pulling load of such combination will be dependent on the relative size of the laid coaxial geotextile sheet compared to that of the anchor plate, depth of embedment, characteristics of the geotextile layer and properties of the fill materials. However neither theoretical nor systematic experimental studies on the effect of introduction of coaxial geotextile layer over the anchor plate on pullout capacity of such combination is reported in available literature.

In this paper, a theoretical model for evaluating ultimate vertical breakout resistance of horizontal circular plate overlain by coaxial circular geotextile sheet, embedded in sand, is proposed. In absence of the experimental results on uplift capacity of such combination in literature, an extensive model tests on pullout capacity of circular plate anchors of varying sizes and depth of embedment with or without coaxial geotextile sheets embedded in dry sand were performed. Comparisons have been made between theoretical values predicted by proposed theory and the experimental values observed from laboratory studies conducted.

2. Brief review

For pullout capacity of horizontal plate anchors, two models have been presented as show in Fig. 1.



(a) Truncated cone (b) Curved failure surface

Figure 1: Breakout capacity models for horizontal plate anchor

In the truncated cone model, the uplift force is balanced by the weight of the anchor plate which is generally small and the weight of the soil in the truncated zone with or without the shearing resistance of the soil along failure surface. Generally value of θ for this semi empirical approach is $\varphi/2$ where φ is angle of shearing resistance of soil (Turner [3], Macdonald [4], Downs and Chieurzzi [5], Clemence and Veeseaert [6]). Curved failure surface model was initiated by Balla [7]. Meyerhof and Adams [8], Vesic [9], Bemben and Kupferman [10] developed theories on the basis of laboratory experimentations and these investigations reveal that vertical breakout resistance Q_v can be expressed as,

$$Q_v = \gamma.\ D.\ N_q.\ A \quad (1)$$

where, γ = effective unit weight of soil
D = depth to the anchor plate from soil surface
N_q= breakout factor in sand
A = area of the anchor plate

The values of the breakout factor derived from different theories show wide variation [1]. Chattopadhyay and Pise[11]presented failure model for circular plate anchor under axial uplift, with a curvilinear failure surface, which is assumed to be initiated tangentially to the periphery of the plate and moving through the surrounding soil. At the ground surface, inclination of the failure surface with horizontal approaches (45°-φ/2) [7,8]. The extent of the failure surface, from the axis of the plate, is dependent on the value of angle of shearing resistance, φ, relative depth, λ (D/B).

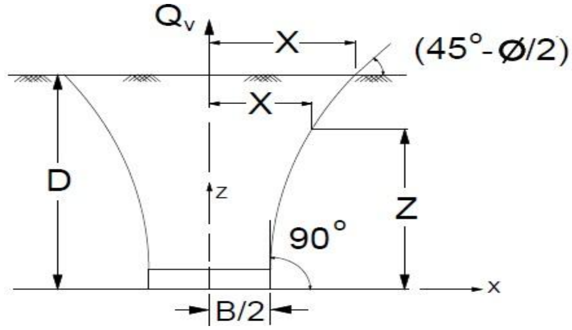


Figure 2: Angle of failure surface to horizontal surface

The failure surface (Fig. 2) is given by

$$\frac{X}{D} = \frac{1}{2} + \left(\frac{2\varphi}{50-\varphi}\right)^2 . \frac{e^{-\frac{\lambda(50-\varphi)}{2\varphi}}}{\lambda.\tan\left(45^\circ - \varphi/_2\right)} + \left(\frac{2\varphi}{50-\varphi}\right)^2 . \frac{e^{\left[-\frac{\lambda(50-\varphi)}{2\varphi}.\left(1-\frac{z}{D}\right)\right]}}{\tan\left(45^\circ - \varphi/_2\right)} . \left(\frac{z}{D} - \frac{2\varphi}{50-\varphi}\right) \quad (2)$$

Ultimate breakout capacity of the circular plate anchor was developed as

$$Q_v = \gamma.\ D.\ N_q.\ A$$

where, $N_q = \frac{4\lambda}{D}\int_o^D \left[\left(\frac{2x}{B}\right)\left(1 - \frac{z}{D}\right)\{\cot\theta + (\cos\theta + K_0 \sin\theta)\tan\theta\}dz\right]$ (3)

As direct integration being complicated, solution of Eq. 3 was derived by numerical methods and computed value of N_q are plotted against relative depth, λ for different value of φ and are presented elsewhere [11].

The experimental values ([7,6], Meyerhof [12], Das and Seeley [13], Kananyan [14], Sutherland [15]) of breakout factors are much closer to the values predicted by above theory than those from Vesic's analysis [9]. The above theory has also been extended for finding out breakout resistance of horizontal strip anchors (Barua and Chattopadhyay [16]) and horizontal plate anchor in C-φ soil (Chattopadhyay and Barua [17]). It had been recommended that adoption of a curved failure surface as proposed by

[11] could yield a more reasonable uplift capacity equation (Wang [18]). The above model has been extended in this paper to develop a theoretical model to predict breakout capacity of circular plate anchor overlain by coaxial geotextile, embedded in sand.

3. Theoretical analysis

A circular horizontal plate anchor of diameter B, is overlain by a coaxial geotextile sheet of diameter B_G and is embedded in sand over a depth, D. When the anchor plate is subjected to monotonically increasing axial pull, leading to vertical pullout, failure surface will be initiated tangentially to the periphery of the plate and moving through the surrounding soil along the curvilinear path AB, and at the ground surface, inclination of the failure surface, at B will be (45°-φ/2) with horizontal and the soil above the anchor plate will be moving up axy-symmetrically about the vertical axis of the plate [11]. But such movement can only be possible after the frictional resistance on the both sides of the circular geotextile sheet over the width AE is overcome. On this horizontal surface whose trace in the vertical section shown in Fig. 3, is AE, vertical pressure will be acting due to overburden. As soil above the horizontal anchor plate is moving up, the effective overburden pressure at A will be nil, which gradually increases to a value equal to γD at the point C, a point just below B and remain same thereafter.

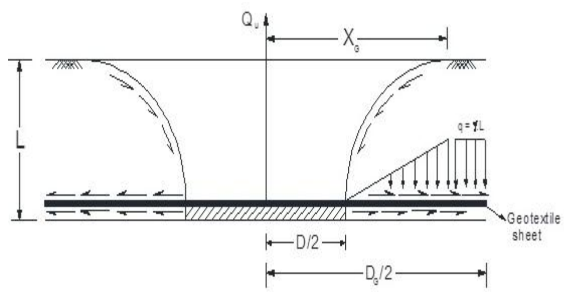


Figure 3: Pullout resistance of anchor with coaxial geotextile (when, $B_G \geq X_G$)

However, it may be possible that either X_G may be $\leq B_G/2$ or $X_G \geq B_G/2$.

In the first case, the breakout capacity of the combination will be,

$$Q_{ue} = \gamma.D.N_q.A + 2\pi\left[{X_G}^2 - \left(\frac{B}{2}\right)^2\right].\frac{\gamma.D}{2}\tan\delta + 2\pi.\left(\frac{{B_G}^2}{4} - {X_G}^2\right).\gamma.D.\tan\delta$$

$$= \gamma.D.N_q.A + \pi\gamma.D.\tan\delta\left[{X_G}^2 - \left(\frac{B}{2}\right)^2 - \frac{{B_G}^2}{2} - 2{X_G}^2\right]$$

$$= \gamma.D.N_q.A\left[1 + \frac{\tan\delta}{N_q}.\left(2\alpha^2 - 1 - \frac{4{X_G}^2}{B^2}\right)\right] \quad \text{where, } \alpha = \left(\frac{B_G}{B}\right)$$

So, $$\frac{Q_{ue}}{Q_u} = 1 + \frac{\tan\delta}{N_q}.\left(2\alpha^2 - 1 - \frac{4{X_G}^2}{B^2}\right) \tag{4}$$

Similarly for second case as shown in Fig. 4

$$Q_{ue} = \gamma.D.N_q.A + 2\pi\left[\left(\frac{B_G}{2}\right)^2 - \left(\frac{B}{2}\right)^2\right].\frac{\gamma.h}{2}\tan\delta = \gamma.D.N_q.A\left[1 + \frac{(\alpha^2 - 1)}{N_q}.\frac{h}{D}\tan\delta\right]$$

where, $\quad h = \frac{L}{\left(X_G - \frac{D}{2}\right)} \cdot \frac{1}{2}(D_G - D)$

$$\text{So,} \frac{Q_{ue}}{Q_u} = 1 + \frac{(\alpha^2 - 1)}{N_q} \cdot \frac{h}{D} \tan \delta \quad (5)$$

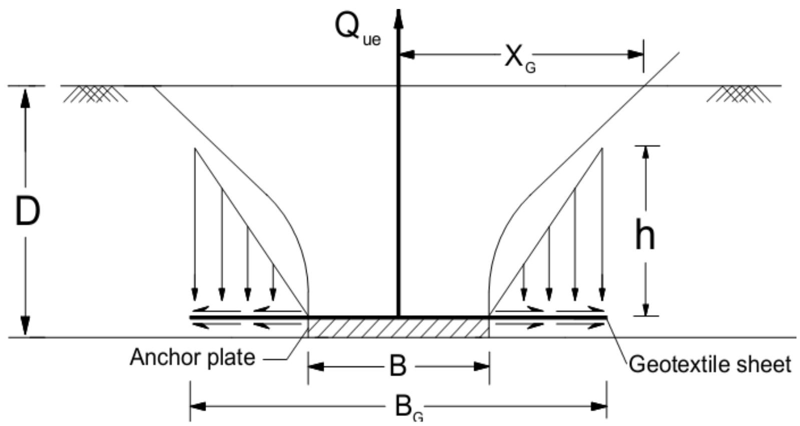


Figure 4: Pullout resistance of anchor with coaxial geotextile (when, $B_G \leq X_G$)

These Eq. 4 and 5 give the theoretical value of increment in breakout capacity for circular plate anchor due to overlain circular coaxial geotextile sheet of diameter greater than diameter of circular plate anchor. The above two equations indicate that breakout capacity of circular plate anchor overlain with coaxial circular geotextile, depends on the ratio of the diameter of the geotextile sheet placed over the anchor and also frictional coefficient between the geotextile and the embedding sand and $N_q$value of the circular plate anchor.

For the validation of the theoretical model presented above laboratory or field test result on breakout capacity of circular plate anchors overlain with coaxial circular geotextile sheet and embedded in sand over varying depth are required. However, no such data are found in available literature. Hence an experimental program was under taken to determine experimentally breakout capacity of model circular horizontal plate anchors with or without coaxial circular geotextile sheets embedded in dry sand. Such model test results were used for validation of the above presented theory.

4. Breakout tests on model anchors

Model breakout test were conducted on horizontal circular plate anchors of varying diameters B (10cm, 15cm and 20cm) embedded in dry sand of density, γ (1.62 gm/cc.) and angle of shearing resistance, φ (37.5°) for varying depth, D resulting embedment ratiosranging from (0.5 to 4). All these tests were conducted in model tank in which the model anchor plates were placed in horizontal position at chosen depth over which sand was poured by rainfall technique over calibrated height to embed the anchor over required depth of embedment. For this purpose a cylindrical tank of 56 cm diameter and 58.5 cm height was used to house the model circular plate anchors with or without coaxial geotextile sheet placed at chosen depth of embedment.

These embedded circular plates were attached to steel wire for pulling it axially in vertical direction. For this purpose the wire was taken over a pulley fixed on above and attached at the top on a horizontal frame fixed to the tank as shown in Fig. 5. The wire was then taken horizontally over another pulley fixed over the same horizontal frame and taken down and attached to a loading pan for applying loads to apply the necessary pull. The vertical movement of the anchoring system was measured with the help of dial gauge, attached on a fixed horizontal stand as shown in Fig. 5.

Each of the plate anchors were subjected to increasing pulling loads till failure, accompanied with measurement of vertical movement. Applied load vs. vertical movement of the pull was plotted and pullout load was obtained from such load-displacement diagram. A typical vertical displacement vs. pulling load for anchor plate of diameter 20cm. embedded over a depth of (D) 10cm (i.e.λ= D/B = 0.5) is shown in Fig. 6.

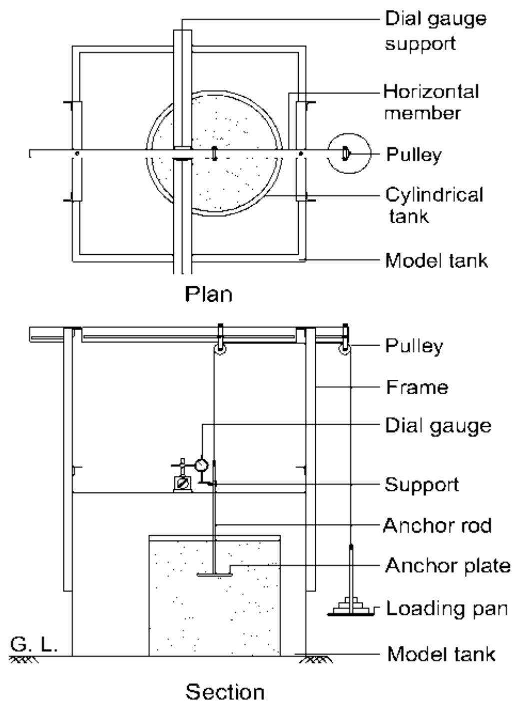


Figure 5: Plan and section of the model tank with accessories

The similar tests were further repeated for same diameter, B and embedded depth, D, but with different coaxial circular geotextile sheets of diameter D_G. The geotextile sheet used in test program, was jute geotextile having thickness 1.14 mm., mass per unit area 0.063 gm./cm.², having tensile strength 191.53 N/cm. Frictional angle (δ) between the chosen geotextile and the sand used in test was found from direct shear test and was found to be 36°. Typical vertical movement vs. pulling load diagrams for the anchor plate overlain with the coaxial jute geotextile sheet of varying diameters B_G are shown in the Fig. 6.

The breakout capacities determined in this way for plate anchors without or with jute geotextile of different diameters embedded in sand are given in Table 1-3.

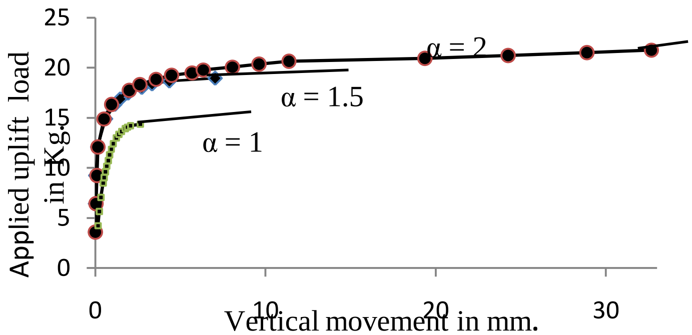


Figure 6: Vertical movement vs. pulling load curves for 20cm diameter anchor at λ = 0.5 without (α = 1) and with coaxial geotextile of various α ratio

From the result of breakout capacity of different circular anchors with or without overlain geotextile sheet as given in Table 1-3, it is observed that for any depth of embedment breakout capacity is increasing in a very large proportion when geotextile sheets of larger diameter is lain over the circular anchor. As example, for 10 cm. diameter circular anchor with embedment ratio, λ breakout capacity is only 5.726 kg. and the value increase when coaxial geotextile sheet of diameter 20 cm. is overlain to a value 10.176 kg., nearly double. When the diameter of coaxial geotextile sheet increases to 40 cm. the breakout capacity increases to 20.43 kg. nearly four times to the original capacity of the

Embedment depth (D)	$\alpha \left(\frac{B_G}{B}\right)$	X_G in cm.	Breakout pulling load (practical)	Breakout pulling load (theoretical)
10 cm.	1	14.5	5.726	5.723
	2	14.5	10.176	11.216
	3	14.5	12.164	20.373
	4	14.5	20.43	33.191
20 cm.	1	23	18.22	20.347
	2	23	24.324	31.335
	3	23	37.721	49.647
	4	23	43.558	75.285
30 cm.	1	30.5	39.176	49.596
	2	30.5	50.257	66.078
	3	30.5	68.623	93.546

Table 1: Experimental and theoretical breakout loads (in kg.) of 10 cm. diameter anchor at various embedment depths (D) without and with coaxial geotextile of various α ratios

circular anchor itself. For all the diameter of test anchor tested shows very large increment in breakout capacity for any depth of embedment with increase in the diameter of the coaxial geotextile sheet. The theoretical values of breakout capacity as given in Table 1-3, are calculated by using the given formulas of Eq. 4 and 5. The required formula is chosen, depending on the value of diameter of breakout surface at ground level, which is calculated by using the given formulas of Eq. 2.

Embedment depth (D)	$\alpha\left(\frac{B_G}{B}\right)$	X_G in cm.	Breakout pulling load (practical)	Breakout pulling load (theoretical)
7.5 cm.	1	15	6.026	5.365
	1.5	15	9.843	9.228
	2	15	15.072	14.636
15 cm.	1	21.7	15.078	19.314
	1.5	21.7	19.513	27.040
	2	21.7	21.584	37.855
22.5 cm.	1	28.4	29.796	45.066
	1.5	28.4	37.634	56.654
	2	28.4	47.82	72.878

Table 2: Experimental and theoretical breakout loads (in kg.) of 15 cm. diameter anchor at various embedment depths (D) without and with coaxial geotextile of various α ratio

Embedment depth (D)	$\alpha\left(\frac{B_G}{B}\right)$	X_G in cm.	Breakout pulling load (practical)	Breakout pulling load (theoretical)
7.5 cm.	1	20	12.795	12.717
	1.5	20	17.805	21.873
	2	20	20.638	34.692
15 cm.	1	29	31.26	25.434
	1.5	29	44.711	43.746

Table 3: Experimental and theoretical breakout loads (in kg.) of 20 cm. diameter anchor at various embedment depths (D) without and with coaxial geotextile of various α ratios

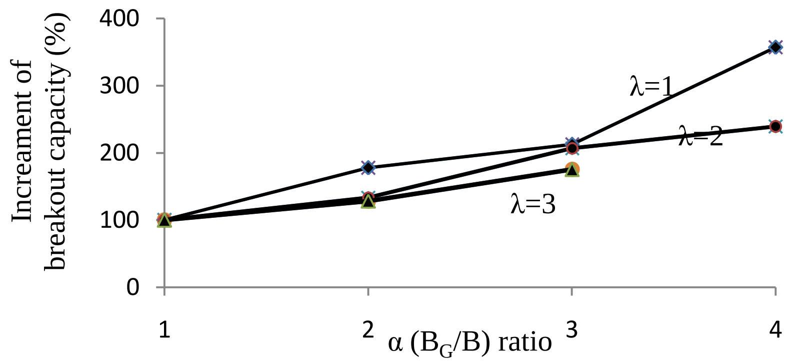


Figure 7: Curves forα (B_G/B) ratiovs. percentage increment of breakout capacity (experimental) of 10 cm. diameter anchor at various embedment depth and diameter ratio (λ=D/B)

5. Comparison of theoretical and experimental breakout capacity

Experimental breakout capacity of circular anchors of different diameter without or with coaxial circular geotextile layer overlain over the anchor plate at various depth of embedment, were found from the experiments conducted. Using the engineering characteristics of the sand and interface friction between the geotextile and sand, theoretical values of breakout capacity of the same anchors were evaluated from Eq. 4 and 5, respectively depending on the value of X_G in each case.

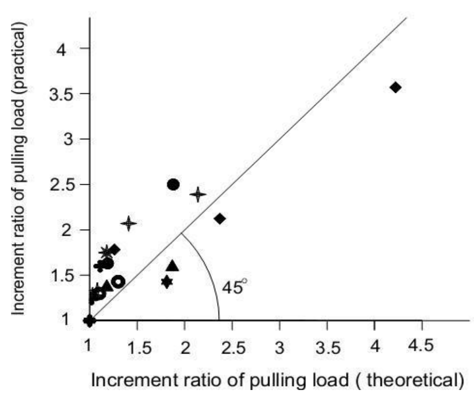


Figure 8: Comparison between practical and theoretical values of increment of pullout loads of 10cm, 15cm. and 20cm. diameter plate anchors with coaxial geo-textile sheets of various α ratio

The values of X_G were determined and corresponding breakout capacity values are calculated and shown in Tables 1-3. From the examination of the values of theoretical and experimental values excellent qualitative agreement between those values is seen. However, for comparing their relative values, increment ratio of experimental and theoretical values are plotted in Fig. 8.From the above figure it is observed that the points plotted are not exactly on 45˚ inclined line through origin. This indicates that theoretical predicted values are sometimes greater than experimental values, though at low values of embedment ratio, both the values agree quite well. Field test results if available, would probably give more rational comparison with theoretical prediction.

6. Conclusion

From the theoretical and experimental study presented in this paper following conclusions can be made.

1. The breakout capacity of shallow anchors can be increased capacity of many folds by adopting geotextile sheet of suitable diameter depending on the requirement of increase. In the experiments reported jute geotextile sheet has been used which may decay with time if used in the field. In such case for permanent improvement synthetic geotextile sheet of suitable surface roughness may be used.
2. A theoretical model for predicting the breakout capacity of circular plate anchors overlain by coaxial geotextile sheet has been presented. The breakout capacity of such combination depends on the diameter of anchor, ratio between the diameter of coaxial sheet to that of the anchor, depth of embedment, angle of friction between the geotextile sheet and the surrounding soil and the properties of surrounding soil.
3. Compared to the experimental results of model plate anchors of various sizes and embedment depth with overlain geotextile sheets of various size, the predicted theoretical values show excellent qualitative agreement and a good quantitative agreement as well.

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