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Response of square anchor plates embedded in reinforced soft clay subjected to cyclic loading

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Abstract. Plate anchors are generally used for structures like transmission towers, mooring systems etc. where the uplift and lateral forces are expected to be predominant. The capacity of anchor plate can be increased by the use of geosynthetics without altering the size of plates. Numerical simulations have been carried out on three different sizes of square anchor plates. A single layer geosynthetic has been used as reinforcement in the analysis and placed at three different positions from the plate. The effects of various parameters like embedment ratio, position of reinforcement, width of reinforcement, frequency and loading amplitude on the pull out capacity have been presented in this study. The load-displacement behaviour of anchors for various embedment ratios with and without reinforcement has been also observed. The pull out load, corresponding to a displacement equal to each of the considered maximum amplitudes of a given frequency, has been expressed in terms of a dimensionless breakout factor. The pull out load for all anchors has been found to increase by more than 100% with embedment ratio varying from 1 to 6. Finally a semi empirical formulation for breakout factor for square anchors in reinforced soil has also been proposed by carrying out regression analysis on the data obtained from numerical simulations.

Keywords: plate anchor; soft clay; geosynthetics reinforcement; cyclic loading; breakout factor

1. Introduction

The increase in exploration of ocean resources like oil and gas has led to increased construction activities in coastal areas, offshore regions and continental shelves, which, commonly consist of soft clay deposits. Since offshore structures were generally supported on the seabed through large gravity bases or bearing pile foundations, the need for tension foundations such as plate anchors as cheaper and alternative designs got importance in recent times. The plate anchors in the offshore conditions have to resist the sustained pull and a superimposed cyclic load. During cyclonic storms, these loads become very significant and may lead to failure of anchors. The interaction of the anchors with the foundation soil is very complex, which includes anchor type, soil, water and loading pattern. It is a known fact that the capacity of the anchor plates can be increased by various methods such as, grouping of the anchors, increasing the size and embedment depth of the anchor plate or by increasing the unit weight of the backfill (Dickin 1988). However such methods are generally expensive. One of the possible alternatives for such kind of problem is use of geosynthetics. Some researchers (Krishnaswamy and Parashar 1994, Banerjee and Mahadevuni 2017) have studied the pull-out behaviour of the anchors in various types of soils with reinforcement and obtained the capacity considering the effects of embedment, size and shape of the anchor, reinforcement and density of soil under different loading conditions. Bhattacharya *et al.* (2008) reported uplift response of square anchor plates in reinforced Kaolin. The experimental tests were conducted with anchor plates of sizes 7.5 cm × 7.5 cm and 5 cm × 5 cm for embedment ratios (H/B) of 2 to 4 with geotextile layers. A single layer of woven geotextile was laid horizontally above the top surface of the anchor plate at variable distances of 0.25H, 0.5H and 0.75H, where H was the depth of embedment of the anchor. The length of geotextile was kept as four times the width of plates used in the test. It was noted that the uplift capacity was dependent on embedment ratio H/B and the position of the geotextile with respect to the embedment depth. Maximum value of uplift capacity was obtained when the geotextile layer is placed at a depth of 0.25 times the embedment depth. Ravichandran *et al.* (2008) carried out an experimental study on the behavior of plate anchors of size 350 mm × 50 mm × 5 mm under static and cyclic loading in sand under reinforced and unreinforced conditions. It was found that the movement of anchor increases with the increase in density and embedment ratio. This corroborated the earlier observations that the magnitude of anchor movement is primarily governed by density and depth of embedment as

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in unreinforced case. It was also observed that the cyclic loading caused significant movement of plate anchors and the magnitude of movement was governed by the amplitude of cyclic load, density of sand bed and depth of embedment. Das *et al.* (2013) reported that with the use of geotextile sheet of suitable diameter, the breakout capacity of shallow anchors can be increased and presented a theoretical model for predicting the breakout capacity of circular plate anchors overlain by coaxial geotextile sheet. The breakout capacity of such combination was found to depend on the diameter of anchor, ratio between the diameter of coaxial sheet to that of the anchor, angle of friction between the geotextile sheet and the surrounding soil, depth of embedment and the properties of surrounding soil. Yu *et al.* (2015) conducted 1 g model tests to investigate the strain softening behavior of the bearing capacity of plate anchors in clay under cyclic loading. The resistance of the anchor under cyclic loading showed obvious hysteretic behaviour with absolute value of the maximum uplift resistance was found to be dependent on loading amplitude.

From the analytical point of view, it is well accepted to consider anchors as footings subjected to uplift loading (Yoo 2001, Alamshahi and Hataf 2009, Basudhar *et al.* 2007, Chakraborty and Kumar 2012, Ghosh *et al.* 2017). However all of this considered static loading with equivalent linear soil profiles. Nevertheless there are a few analytical studies reported on the pull out capacity of the single or group anchors embedded in clays (Bhattacharya 2017, Bhattacharya and Roy 2016, Demir and Ok 2015, Bhattacharya and Kumar 2013) or in sands (Bhattacharya and Sahoo 2017, Khan *et al.* 2017, Emirler *et al.* 2016, Niroumand and Kassim 2014a, b, c, Kame *et al.* 2012). While there are few studies reported on pullout capacity of reinforced sands (Biswas and Mittal 2017, Keskin 2015, Niroumand and Kassim 2013), the studies on response of anchors embedded in reinforced clay are extremely scarce.

Besides there are several studies carried out to evaluate performance of horizontal or inclined strip anchors subjected seismic loading using pseudo-static approach (Rangari *et al.* 2011, 2012a, b, Choudhury and Rao 2007), pseudo-dynamic approach (Pain *et al.* 2016, Rangari *et al.* 2013a, b, 2004, 2005) or simple analytical and numerical approach (Shukla and Chndra, 1994, Sharma *et al.* 2009, Bhandari and Han 2010). More recently studies have been carried out on the influence of geotextile reinforcement on seismic performance of shallow foundations (Munoz *et al.* 2012, Xu and Fatahi 2018).

In summary it can be said that most of the studies have been restricted to the pull-out load of the anchor plates under static loading in cohesive soils, cohesionless and reinforced soils. There has been very little research on response of anchor plates under cyclic loading. It has also been observed that the effects of size of plate anchors, different loading frequencies and amplitudes on the response of plate anchors were not fully explored in the previous research.

In the above context the present study aims to understand the pull-out behaviour of anchor plates in reinforced soft clay using numerical modelling for different sizes of anchors subjected to cyclic loading. The effect of various factors such as embedment ratio, frequency and amplitude of the cyclic loading, the size and depth of the reinforcement on the variation of pull out load was studied. The capacity of the anchor plate has been expressed in terms of breakout factor which is a function of embedment ratio, position and extent of reinforcement, frequency and amplitude of loading cycle. Furthermore an attempt has been made to predict breakout factor by carrying out a multiple regression analysis with the available results considering all governing parameters which may be useful for practicing engineers in designing anchor plates in soft clay subjected to cyclic loading.

2. Numerical analysis

The numerical analyses of both reinforced and unreinforced soil-anchor models were carried out using general-purpose finite element analysis software ABAQUS v 6.14 (ABAQUS user manual, 2014). First the results of the present numerical analysis were compared with the experimental results reported by Bhattacharya (2010) on plate anchors, embedded in kaolin clay, subjected to static loading. The experimental investigation was carried out on square anchor plates in reinforced Kaolin. The experimental tests were conducted with anchor plates of sizes 7.5 cm × 7.5 cm and 5 cm × 5cm for embedment ratios (H/B) of 2- 4 with geotextile layers. Square tank of size 650mm × 650mm and height of 800mm was used for conducting tests. A single layer of woven geotextile was laid horizontally above the top surface of the anchor plate at variable distances of 0.25H, 0.5H and 0.75H, where H is the depth of embedment of the anchor. The length of geotextile was kept as four times the width of plates used in the test. Parametric study has been done in the form of relative failure displacement, breakout factors and ultimate load factor for plate sizes of 50 mm and 75 mm.

The schematic diagram of the problem is shown in Fig. 1, where the horizontal rough anchor plate of width of 'B' is placed at a depth of 'H' from the ground surface. The soil is reinforced with single layer of geotextile at 0.25, 0.5 and 0.75 times of depth of embedment measured from the plate. The width of geotextile reinforcement (Bg) considered in the analysis is 2, 4 and 6 times the width of plate.

The anchor and geotextile are modelled as linear-elastic materials. The size of soil medium is taken as 1m x 1m to minimize the influence of boundary constraints on the behavior of anchor plates. Three square horizontal anchor plates of size 50 mm, 75 mm and 100 mm have been considered in the present study. The properties of the anchor plate that has been defined as a beam section in the model, is given in Table 1.

The thickness of the plate has been so chosen that there

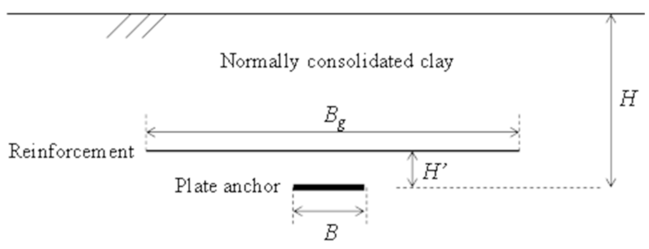


Fig. 1 Schematic diagram of the problem

Table 1 Properties of the anchor plate and geosynthetics used in the present study (Bhattacharya 2010)

Properties	Anchor plate	Geosynthetic
Density (kg/m^3)	7850	-
Mass per unit area (gm/m^2)	-	146
Poisson's ratio	0.3	0.40
Young's modulus (GPa)	210	0.42
Tensile strength (kN/m)	-	27.60
Thickness (mm)	5	0.36

Table 2 Properties of soil used in the present analysis (Bhattacharya 2010)

Properties	Value
Density (kg/m^3)	1900
Undrained Cohesion (kPa)	25
Angle of Internal Friction (º)	7
Liquid Limit (%)	48
Plastic Limit (%)	24
Water content (%)	38
Plasticity Index (%)	24

should not be any considerable deformations or bending at the failure conditions of the soil. The properties of the geotextile (Table 2) that has been also defined as a beam section in the model have been adopted from Bhattacharya (2010). The soil body was discretized using 6400 nos. of 4-noded quadrilateral plane strain elements (0.0125 m element size) with reduce integration (CPE4R). The geotextile reinforcement along with the anchor plate was modelled as beam elements. The horizontal and vertical movement of the bottom boundary of the model is restrained. Additionally the anchor, reinforcement and side boundaries of model were allowed to move in vertical direction but restrained against horizontal movement.

The soil anchor interfaces were modelled using the surface to surface small-sliding approach with the friction coefficient of 0.36 was chosen for the anchor plate (Zhao *et al.* 2015). Similarly the soil and reinforcement interfaces were modelled using master / slave approach with friction coefficient was taken as 0.2 for reinforcement. The modelling of square anchor plates in a 2D plane strain model brings limitations, because plate-soil interaction is a strongly 3D phenomena. However 3D model of the anchor plates with contact pairs would require significant computing resources. Moreover anchor plates in conjunction with large geosynthetic layers may not introduce significant discrepancies in the present analysis. Similar observation has also been made by other researchers (O'Kelly *et al.* 2013, Nouri *et al.* 2017).

The anchor plate was then subjected to two cycles of sinusoidally varying displacement with the amplitudes of 2 mm, 5 mm, 8 mm and 10 mm at the plate surface. Load displacement behaviour of the anchor plate-geosynthetic-soil system was analyzed by applying loading frequencies of 0.2 Hz, 0.5 Hz, 0.8 Hz and 1.0 Hz.

2.1 Soil properties

The basic properties of soil (Table 2) have been adopted from Bhattacharya (2010). It is well established that the selection of soil model and interface properties strongly influence the behaviour reinforced soil-structure interaction problems (Yu and Bathurst 2016). The soil was modelled using undrained hypoelastic constitutive relationship which considers the strain dependent modulus degradation as presented by Vucetic and Dobry (1991). The further details about the soil model are given elsewhere (Banerjee and Mahadevuni 2017). The modulus degradation curves showing the variation of normalized shear modulus and damping ratio with respect to the strain amplitudes for different plasticity index as proposed by Vucetic and Dobry (1991) are used as an input to the present soil model. The maximum shear modulus was considered as a function of the mean confining stress (p') and over-consolidation ratio (R) (Viggiani and Atkinson 1995) as shown in Eq. (1),

$$G_{max} = A\,(p')^{n}\,(R)^{m} \tag{1}$$

where, for IP=20-25 and normally consolidated clay, the parameters A= 1960, n= 0.653 & m= 0.3 (Viggiani and Atkinson 1995).

3. Validation study

3.1 Response to static loading

As discussed earlier the results of the present numerical analysis were compared with the experimental results reported by Bhattacharya (2010). The model has been analyzed for various embedment ratio values to validate for the prediction of anchor capacity. The embedment ratio values considered are 2, 4 and 6; in which it is allowed to change the behaviour from shallow to deep anchor. For each embedment depth, the ultimate pull-out load and corresponding displacement have been calculated. Displacement contours have been observed along with ultimate pull-out capacity of the anchors as shown in Fig. 2 (for H/B = 4, unreinforced soil). It has been observed that for lower values of embedment ratios, the displacements and the failure surface extends up to the ground surface. For higher embedment ratios, the failure surface is around the anchor plate which represents the behaviour change from shallow to deep.

Fig. 3 shows the typical load versus displacement plot obtained from the numerical analysis of the anchor plate embedded in unreinforced clay layer for different embedment ratio (plate size 50 mm × 50 mm). In general, it shows that the patterns are almost identical irrespective of their embedment ratios. Figure also shows that the ultimate pull-out load increases with the increase in the embedment ratio.

The maximum load was normalised as breakout factor as, $N_c = \frac{F}{AC_u}$, where F is the maximum load, A is the cross-section area of the anchor plate and C_u is the undrained cohesion of the clay. Fig. 4 shows the variation of the breakout factors with the embedment ratio as computed from the present numerical analysis along with that

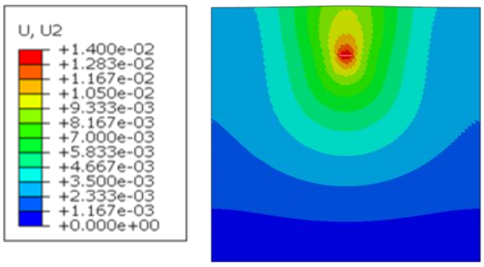


Fig. 2 Displacement contours in unreinforced soil H/B = 4, plate size 50 mm × 50 mm

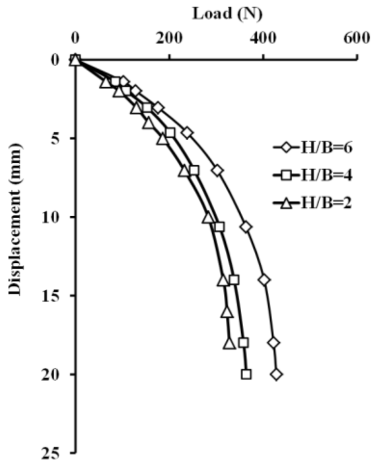


Fig. 3 Variation of pull-out load in unreinforced soil for different embedment ratio, plate size 50 mm × 50 mm

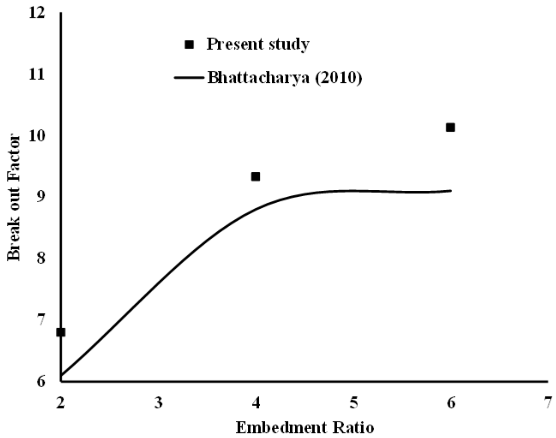
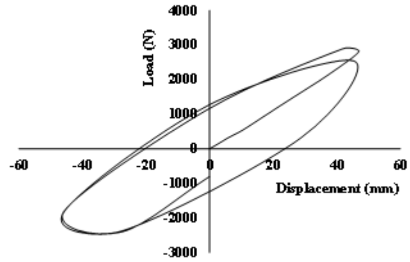


Fig. 4 Comparison of breakout factors in unreinforced soil, plate size 50 mm × 50 mm

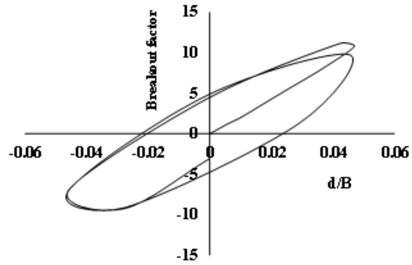
obtained from the experimental results reported by Bhattacharya (2010). Figure shows that the present numerical analysis slightly overestimates the break out factor compared to that obtained from experiments.

3.2 Response to cyclic loading

The performance of the numerical model was further compared with the results from the experimental study reported by Yu *et al.* (2015) where the plate anchors, embedded in kaolin clay, were subjected to cyclic loading. The soil has been modelled as hypoelastic material as



(a) Load vs displacement



(b) Breakout factor vs normalized of displacement

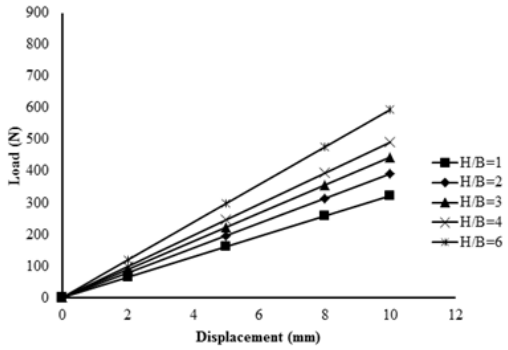
Fig. 5 Computed response of plate anchors on which experiments carried out by Yu *et al.* (2015)

Table 3 Comparison of the breakout factor obtained in the present analysis with reported by Yu *et al.* (2015)

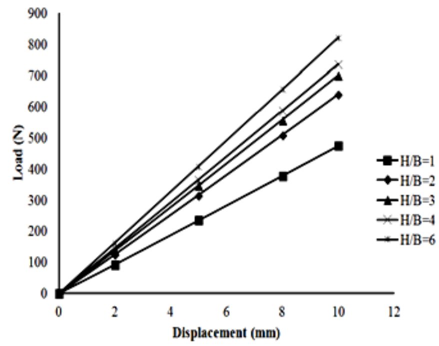
	Embedment Depth (mm)	Breakout Factor $\frac{F}{AC_u}$	
		1st Cycle	2nd cycle
Present Study	510	11.10	9.76
Experimental Study (Yu *et al.*, 2015)	500	10.36	9.42
		10.32	9.67
Numerical Analysis		10.36	9.42
		10.32	9.67

described in the previous section (Plasticity index of 24%) and plate anchor as linear elastic material. The square anchor plate of size 102 mm × 102 mm has been considered for modeling which has equivalent area of that of plate size 50 mm × 210 mm which was used in the experimental study. Bhattacharya (2010) have studied the effect of shape of plate anchor on the load displacement behaviour. It has been found that the same areas of anchors viz 50mm × 100 mm, 75 mm × 75 mm and 50 mm × 200 mm, 100 mm × 100 mm sizes with same embedment depth exhibits approximately same pullout load despite their different shapes. The embedment ratio has been taken as 5, which would ensure the equal embedment depth of 500 mm with that of the experimental study. The two cycles of sinusoidal loading has been applied with 0.1 Hz frequency and 48 mm amplitude. Fig. 5(a) shows the typical variation of pull-out load with the input displacement. Figure shows that the ultimate pull-out load reduces with the progressive number of cycles. The load-displacement plot is normalised in Fig. 5(b) showing the variation of breakout factor with ratio of displacement to width of plate anchor (d/B) as computed from the numerical analysis.

Table 3 summarizes the maximum breakout factors obtained for various embedment ratios for first and second



(a) Unreinforced soil



(b) Reinforced soil

Fig. 6 Variation of ultimate pull-out load with different amplitudes for a loading frequency of 0.2 Hz for various embedment ratios (H/B) (plate size 100 mm × 100 mm)

cycle as computed from the numerical analysis along with those reported by Yu *et al.* (2015). Table shows the breakout factors computed from the present analysis compare reasonably well that obtained from the experimental and numerical study carried out by Yu *et al.* (2015).

4. Factors affecting pull-out load of the anchor plates subjected to cyclic loading

In the present analysis, the pull-out load has been computed by applying displacements at the plate anchors applied sinusoidally with different frequencies and amplitudes for two cycles. Since the most of research has shown that the reinforcement placed at 0.25 times the embedment depth of anchor and four times the width of anchor gives the higher pull out load, the same has been considered for the reinforcement case with single layer of geosynthetics reinforcement. Simulations have been carried out on the anchor plates for different conditions by applying sinusoidal wave with frequencies of 0.2 Hz, 0.5 Hz, 0.8 Hz and 1 Hz, each applied with 2 mm, 5 mm, 8 mm and 10 mm amplitudes.

Square horizontal anchor plates of size 50 mm, 75 mm and 100 mm have been considered for the analysis. The ultimate pull out load has been considered to be the peak load corresponding to a displacement equal to each of the considered maximum amplitudes of a given frequency for the first cycle in the current study to account for the resonance effect between soil and the applied cyclic loading.

A typical variation of ultimate pull-out load with different amplitudes of 0.2 Hz frequency for various embedment ratios (H/B) and plate size 100 mm × 100 mm in unreinforced and reinforced soil have been shown in Figs. 6(a) and (b) respectively. Figures show that, in general, the patterns are almost linear and identical in behaviour irrespective of the anchor plate size. For all the conditions, it has been observed that at any stage of loading, the anchor plates embedded in reinforced clay result in larger pull-out load compared to that obtained for unreinforced case for the all depths of embedment and position of reinforcement because as the anchor is pulled out from the reinforced soil the additional frictional forces developed between the soil and geosynthetic reinforcement results in increase in pull-out load. Furthermore figures also show that the pull-out loads increase with the increase in displacement amplitude applied to the anchor plates. Moreover, for both reinforced and unreinforced clay, the pull-out load of the anchor plates increases with the increase in the embedment ratio. Similar observations was found for all the different plate sizes and input frequencies.

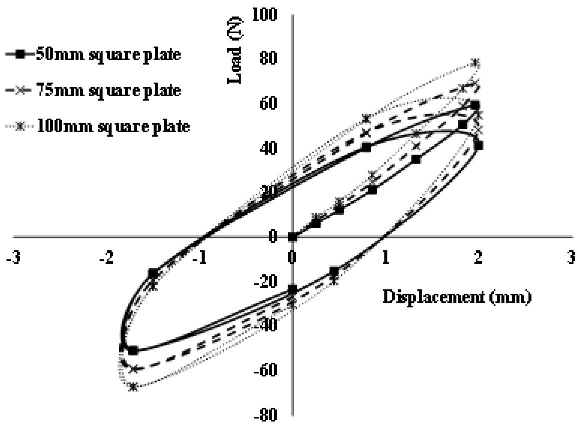


Fig. 7 Load-displacement behaviour for different size plates with 2 mm amplitude and embedment ratio (H/B) of 2 for a loading frequency of 0.2 Hz

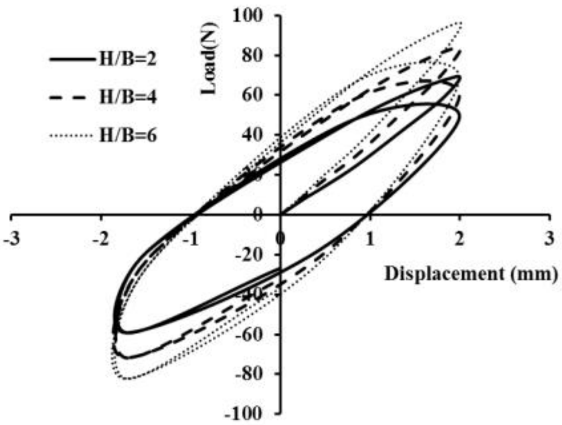


Fig. 8 Load displacement behaviour for different embedment ratio for 2 mm amplitude and loading frequency of 0.2 Hz for plate size of 75 mm × 75 mm

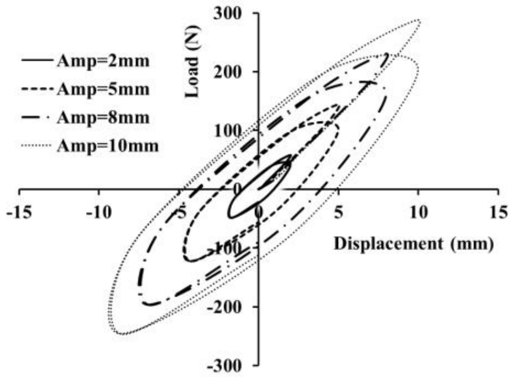


Fig. 9 Load displacement behaviour for different amplitudes with loading frequency of 0.2 Hz and embedment Ratio (H/B) of 1 for plate size of 50 mm × 50 mm

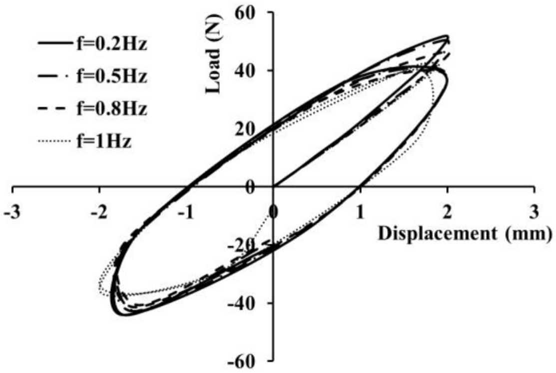


Fig. 10 Load displacement behaviour for different loading frequencies with 2 mm amplitude and embedment ratio (H/B) of 1 for plate size 50 mm × 50 mm

4.1 Effect of size of the anchor plate

Three square horizontal anchor plates of size 50 mm, 75 mm and 100 mm have been considered in the present study. It has been observed from Fig. 7 that the pull out capacity increases by about 40% with increase in the size of square anchor plate from 50 mm to 100 mm. The patterns are same for both unreinforced soil and reinforced soil.

4.2 Effect of embedment ratio

It can be observed from Fig. 8 that for the given amplitude and frequency of cyclic loading, as the embedment ratio increases the pull out load also increases which is in agreement with the study by Ravichandran *et al.* (2008). Similar conclusions can be made for different sizes of anchor plates. Moreover, for the unreinforced and reinforced conditions, the pull-out load increase with the increase in the embedment ratio. In general it can be said that the pull-out load for all the plate anchors has been found to increase by more than 100% for the embedment ratio varying from 1 to 6.

4.3 Effect of cyclic loading amplitude and frequency

Fig. 9 shows the load displacement behaviour of 50 mm × 50 mm anchor plate with H/B = 1. It can be observed that for a constant frequency of 0.2 Hz, the increase in amplitude from 2 mm to 10 mm increases the pull out load by more than 100%. This is in line with the observation reported by most of the researchers (Yu *et al.* 2015).

Fig. 10 plots the load displacement behaviour for a 50 mm square anchor plate subjected to a cyclic load of 2 mm amplitude for different frequencies. It can be noticed that 0.2 Hz frequency generates the higher pull out load than the 1 Hz frequency for the same amplitude for first cycle i.e. the pull out load decreases by about 20% with increase in cyclic loading frequency from 0.2 Hz to 1 Hz.

4.4 Effect of position of reinforcement above anchor plate

The variation of the breakout factors with H′/H ratio where H′ is the distance from anchor plate to the reinforcement and H is the embedment depth of anchor plate has been studied for the frequency of 0.2 Hz, embedment ratio (H/B) varying from 2 to 6 and Bg/B ratio of 4 (Fig. 11). It has been observed that the effect of reinforcement on the pull-out load is predominant when the reinforcement is placed closed to the plate. It can also be inferred that the reinforcement placed at 0.25 times the embedment depth of anchor gives higher pull out load for all the cases which is in agreement with Krishnaswamy and Parashar (1994). Similar observation can be obtained for all the different plate sizes.

4.5 Effect of extent of reinforcement

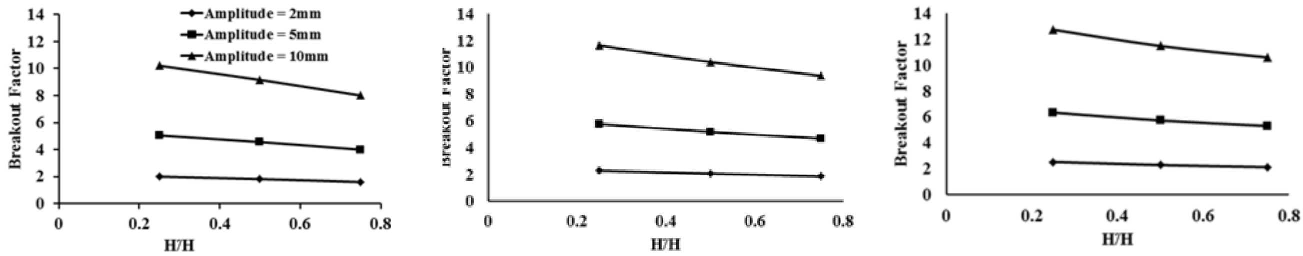
The variation of break out factor with Bg/B ratio where Bg is the width of reinforcement and B is the width of anchor plate has been studied for the frequency of 0.2 Hz, H′/H ratio of 0.25 and embedment ratio (H/B) of 2, 4 and 6 (Fig. 12). The increase in the extent of reinforcement increases the pull out load of anchor plate. This is owing to the fact that the anchorage length increment will generate higher frictional resistance along the soil-reinforcement interface. The similar observation has been reported by Ravichandran *et al.* (2008) and Choudhary *et al.* (2013). It has been observed that when the width of reinforcement becomes greater than 4 times the width of anchor plate, the increment in the pull out capacity is minimal. Hence it is economical to consider the width of reinforcement to be 4 times the width of the anchor plate.

4.6 Effect of reinforcement on displacement contours

The displacement contours obtained for 0.2 Hz frequency with 10 mm amplitude for 50 mm × 50 mm plate size and embedment ratio (H/B) of 2 have been shown in Fig. 13. It has been observed that inclusion of reinforcement reduces the displacement with the increase in pull out load.

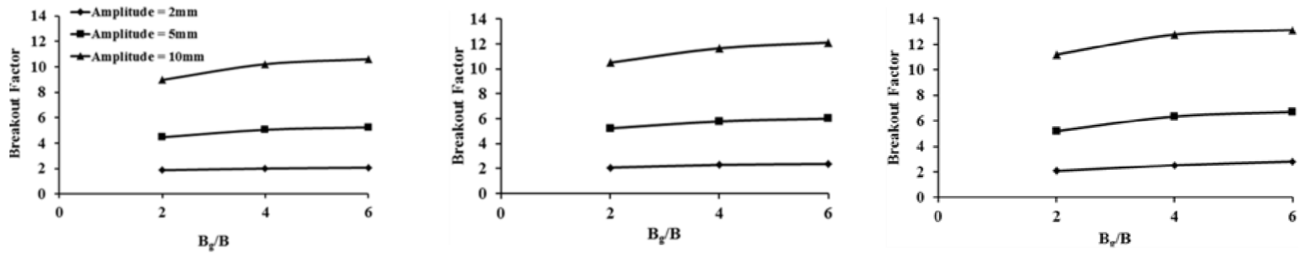
$$\frac{F}{AC_u} = -1.66 + 0.32\left(\frac{H}{B}\right) - 0.86\left(\frac{f}{f_s}\right) + 46.47\left(\frac{Amp}{B}\right) - 0.984\left(\frac{H'}{H}\right) + 0.35\left(\frac{B_g}{B}\right) \quad (2)$$

where F/AC_u is the non-dimensional breakout factor; F is the pull out capacity of plate anchor; A is the area of the anchor plate; C_u is the undrained cohesion; H/B is the embedment ratio of the plate; f/f_s is the frequency ratio;



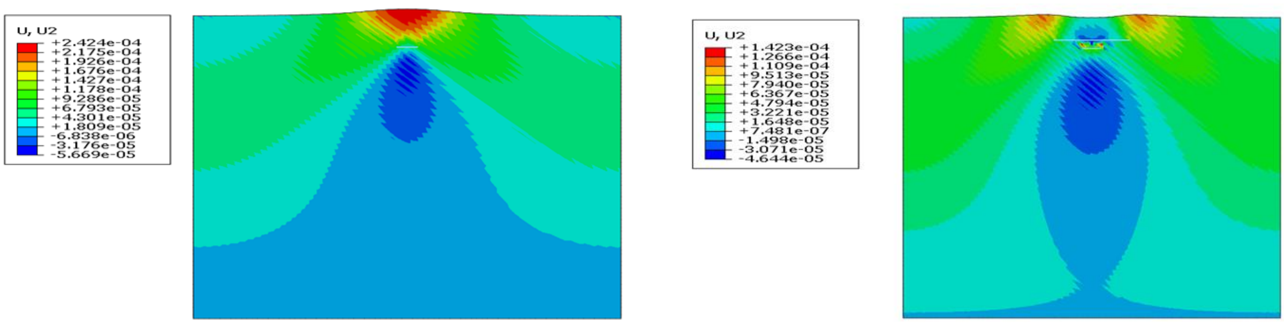
(a) H/B=2 (b) H/B=4 (c) H/B=6

Fig. 11 Breakout factor vs H/H Ratio (plate size of 50 mm × 50 mm) for loading frequency of 0.2 Hz with $B_g/B=4$



(a) H/B=2 (b) H/B=4 (c) H/B=6

Fig. 12 Breakout factor vs. B_g/B ratio (plate size 50 mm × 50 mm) for loading frequency of 0.2 Hz with H'/H=0.25



(a) Unreinforced soil (b) Reinforced soil

Fig. 13 Effect of reinforcement on displacement contours

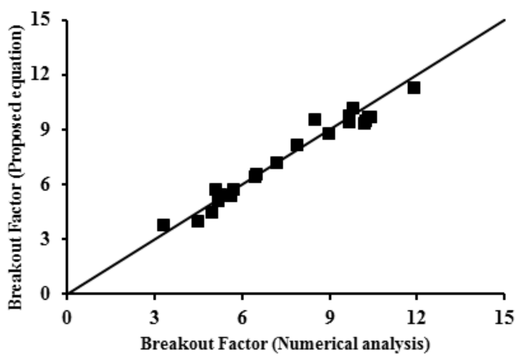


Fig. 14 Comparison of breakout factors as obtained from numerical analysis with that computed from proposed equation (Eq. (2))

Amp/*B* is the ratio of amplitude of cyclic load to the width of plate; H'/H is the relative position of the reinforcement; B_g/B is ratio of width of reinforcement to the width of plate. The multiple coefficient of determination (R^2), adjusted multiple coefficient of determination (R^2adj) and standard error (E_s) of the above model have been found as 0.946, 0.945 and 0.656 respectively. The breakout factors obtained from the numerical analysis as well as predicted from Eqn. 1 has been plotted in Fig. 14. It has been observed that for the embedment ratios up to 6, the breakout factors obtained from the numerical analysis agree well with that from Eq. 1; however there is a significant disparity observed for the anchor plates placed close to the ground surface.

5. Conclusions

The following conclusions can be drawn from the present analysis:

• The uplift capacity for all anchors has been found to increase by more than 100% with embedment ratio varying from 1 to 6. For lower embedment ratio, displacement contours reaches the ground surface.

• The uplift capacity increases by about 40% with increase in the size of square anchor plate from 50 mm to 100 mm.

• For the first cycle, the pull out capacity decreases by about 20% with increase in cyclic loading frequency from

0.2 Hz to 1 Hz.

• For a constant frequency, the increase in amplitude from 2 mm to 10 mm increases the pull out load by more than 100%.

• The maximum increase in capacity has been observed when the reinforcement is close to the plate, which is 0.25 times the embedment depth of anchor.

• The increment in the pull out capacity of the anchor is optimum when the width of reinforcement becomes 4 times the width of anchor plate.

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