Pullout behavior of plate anchors in geotextile reinforced soft clay

Arunashis Majumder[1], Ratul Roy[2], Subhadeep Banerjee [3], Sibapriya Mukherjee [4] and
Sumit Kumar Biswas [5]

[1] PhD Research Scholar, Jadavpur University, Kolkata 700032, West Bengal
[2] PG Student, Jadavpur University, Kolkata 700032, West Bengal
[3] Associate Professor, IIT Madras –Chennai 600036, Tamilnadu
[4] Professor, Jadavur University, Kolkata 700032, West Bengal
[5]Associate Professor, Jadavpur University, Kolkata 700032, West Bengal

Abstract. Different types of anchors are used for offshore and onshore structures to resist uplift forces. In case of soft clay the uplift capacity may be increased with geotextile reinforcements. In the present study an attempt has been made to find uplift capacity of model plate anchors of sizes 50mm×50 mm and 75mm×75 mm, in reinforced and unreinforced soil with embedment ratios of 1, 2 and 3. Properties of clay and geotextile have been appropriately obtained by carrying out relevant laboratory tests. Model anchor tests have been carried out by applying monotonic loads through pulley arrangement and recording displacements using Linear Variable Differential Transformer (LVDT). To supplement the experimental results, numerical analyses have been carried out using ABAQUS software, simulating experimental models with similar plate sizes and embedment ratios. The experimental results agree well with the numerical ones. The geotextile layer has been considered to be placed for an extent of four times the anchor width at a distance of 0.25 times the embedment depth from the bottom of the anchor. It has been observed that pullout capacity increases with increase of plate size on an average by 113% for unreinforced clay when the plate size increases from 50mm to 75mm. For 50 mm plate with embedment ratio equal to 1 the improvement has been found to be 25% and the same has been found to be 36% and 31% for embedment ratio 2 and 3 respectively. This improvement has been found to be higher for larger plate sizes.

Keywords: Plate Anchor, Embedment Ratio, ABAQUS, Geotextile

1 Introduction

The foundations of many civil engineering structures are subjected to vertical or inclined tensile loads. To endure such loads, horizontal plate anchors are extensively used both in onshore and offshore structures. Different types of anchorages are used in the field depending on the size and type of loading, the type of structure to be supported, the importance of the structures and the conditions of the subsoil. The ultimate strength of these anchors depends on the shape and size of the anchor, the depth of anchorage, the characteristics of the surrounding soil, inclination of the tensile load, type and extent of geotextile used for reinforcement etc. When the depth of anchor is shallow, excavation costs less to accommodate the anchor, and control of pit placement is easier and safer. However, in order to withstand the tensile load, the size of the excavation area and the depth of excavation must be adjusted depending on the size of anchor plate and depth of penetration or both. Many researchers have already worked in this field relating to anchor and pullout behavior of anchor since last few decades. Rowe and Davis (1982) reported results from two dimensional finite element analyses of continuous vertical and horizontal plate anchors. It was observed that anchors with horizontal axis exhibited higher collapse load than vertical anchors for similar conditions. Soil dilatancy was found to have a significant effect on the pull out capacity of both types of anchors. Merifield et al. (2003) estimated the ultimate pullout capacity of different shapes of anchor in clay using a new three dimensional numerical procedure based on finite element formulation of the lower bound analysis theorem. They found that anchoring capacity of the strip anchor increased when the overburden pressure reached a limiting value reflecting the change from shallow to deep anchoring behavior. Bhattacharya et al. (2008) investigated the uplift capacity of square plate anchors in reinforced kaolin and the maximum uplift capacity was obtained when the geotextile layer is placed at a depth of 0.25 times the embedment depth.Anguiano et al. (2012) performed laboratory testing on circular plate anchors and also performed numerical analysis using Mohr-coulomb soil model under plane strain and axisymmetric conditions. Since their numerical results overestimated their experimental ones.Jesmani et al. (2013) developed the model based on the failure mechanism deduced from laboratory testing and utilize the Mohr-Coulomb yielding criteria. Finally, a new theory has been introduced to predict the pullout capacity of any anchor plates with different inclination angles and various depths, without any computer analysis and just by using the new proposed theory.Yu et al.(2015) studied the effect of cyclic loading on the bearing capacity of plate anchors in clay and they found that the ultimate pullout capacity of the plate anchor decreases as the accumulated plastic shear strain did not grow due to strain softening of clay under cyclic loading. Beirne et al. (2017) investigated the field data from reduced scale anchor tests at two sites to validate a new release to rest model for dynamically installed anchors. They stated that although dynamically installed anchors were an attractive and often a cost effective anchoring solution, their global acceptance had been somewhat hampered by uncertainties on achieving the targeted embedment depth in the sea-bed. Raghuram et al.(2018) conducted plate load tests on unreinforced expansive clay beds and clay beds reinforced with Granular Pile Anchor (GPA) and geogrid-encased GPA to compare their compressive load response. It was found from the tests that the expansive clay beds reinforced with geogrid-encased GPA showed higher load-carrying capacity and improved compressive load response compared with GPA and unreinforced beds. Biradar et al.(2019) studied the load-displacement behaviour of anchors for various embedment ratios with and without reinforcement. The pull out load, corresponding to a displacement equal to each of the considered maximum amplitudes of a given frequency, was expressed in terms of a dimensionless breakout factor. The pull out load for all anchors was 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 was proposed by carrying out regression analysis on the data obtained from numerical simulations.

In the present study, an attempt has been made to study the pullout behavior of horizontal square anchor plates with respect to the plate size, embedment depth and reinforcement. It has been found from both experimental and numerical studies that for all plate sizes and embedment ratios, the pullout capacity increases due to inclusion of geotextile as a reinforcing material. The increase in embedment ratio increases the pullout capacity for a certain size of anchor plate. Increase in plate size for a certain embedment depth also increases the pullout capacity.

2 Materials and their Properties

Materials used in the present study are: (i) Soil for foundation bed, (ii) Geotextile for reinforcement and (iii) Anchor plate made of Mild Steel. Their properties have been presented below.

i) Soil

Routine tests have been carried out on locally available clayey soil in Soil Mechanics and Foundation Engineering Department, Jadavpur University. Soil used, in this study, has been collected from a nearby land situated at Jadavpur, West Bengal, India. Table 1 presents the properties of the clay.

Table 1. Properties of the clay.

Materials	Cohesion (T/m^2)	L.L	P.L	OMC	Φ
Clay	2.5 (at OMC)	37.7%	23.8%	14%	5^0

ii) Geotextile

Tests have been conducted on geotextile material to determine the thickness (ISO 9863), mass per unit area (ISO 9864), Apparent opening size (ISO 12956). Tensile Strength at 10% elongation (ISO 10319) as well as the breaking load has also been estimated. Table 2 presents the properties of geotextile.

Table 2. Properties of geotextile

Materials	Thickness (mm)	Mass per unit area (gm/m^2)	Tensile Strength (kN/m)	Elongation at maximum load
Geotextile	0.36	146	27.6	28.6%

iii) Mild Steel For Anchor Plates

For the ongoing investigation square anchor plates made of mild steel have been used. To determine the properties of the mild steel Tension Test was conducted with a round tensile specimen made from mild steel and tested in Universal Testing Machine at a strain rate of 0.05 mm/sec. Table 3 presents the properties of mild steel used to fabricate anchor plates.

Table 3 Properties of Anchor

Materials	Young's Modulus	Mass per unit volume (kg/m^3)	Poisson's Ratio(μ)
Anchor	200GPa	7850	0.33

3 Experimental Study

The experimental study was done by carrying out model anchor tests

3.1 Test program

The test programs for model anchor tests in unreinforced and reinforced clay have been shown in Table 4(a) and Table 4 (b) respectively.

Table 4(a) Test Programme- For Unreinforced Clay (UR)

Type	Test Name	Plate Size	(H/B)
UR	50_UR_(H/B=1)	50^{mm}x50^{mm}	1
	50_UR_(H/B=2)		2
	50_UR_(H/B=3)		3
	75_UR_(H/B=1)	75^{mm}x75^{mm}	1
	75_UR_(H/B=2)		2

Table 4(b) Test Programme-For Reinforced Clay (RE)

Type	Test Name	Plate Size	(H/B)	*(H'/H)	**(Bg/B)
RE	50_RE_(H/B=1)	50^{mm}x50^{mm}	1	0.25	4
	50_RE_(H/B=2)		2		
	50_RE_(H/B=3)		3		

*H'=Height of geotextile from anchor bottom

**Bg=Extent of geotextile, B=Anchor width

3.2 Model Anchor Test

The aim of this investigation is to find out uplift capacity of anchors embedded in both unreinforced and reinforced clay using square anchors. Reinforcement in clay has been provided with geotextile sheet placed at a position having a fixed ratio with the embedment depth within the embedded clay bed. From the observed capacity, the behavioral aspects of the anchors in reinforced clay have been studied in terms of various parameters involved. The detailed test set up is illustrated in Fig.1 below.

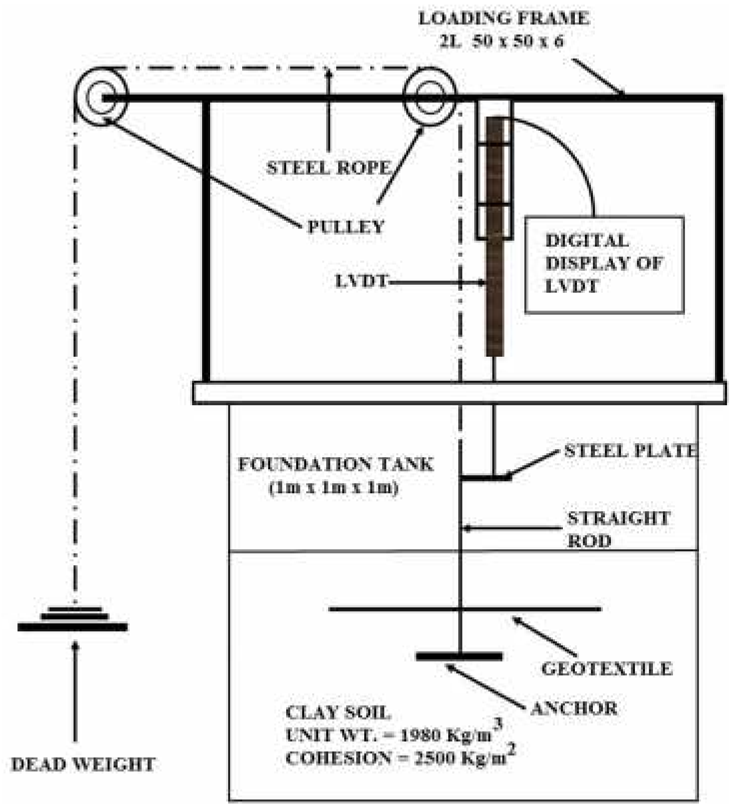

Fig. 1. Experimental Set up for model anchor test

3.3 Test Procedure

Pullout tests for the two different size square anchor plates have been carried out under different embedment condition for unreinforced as well as for reinforced case. For all the model tests mild steel foundation tank of size $1^{m} \times 1^{m} \times 1^{m}$ has been used. In the present investigation square anchor plates of mild steel have been used. For carrying out model test, pullout load has been applied through dead weights with different increments given as 180 gm, 360 gm, 575 gm, 1412 gm, 1960 gm, 2270 gm and 4500 gm. During pullout test, anchor plate has been attached with a 10 mm diameter shaft through a slotted hole at the middle of anchor plate, which, in turn, has been tied with the steel wire used for pulling arrangement through pulley mechanism. During preparation of embedment soil after placement of anchor, the loading arrangement has been supported with a minimum load to keep the anchor-shaft assembly in proper alignment. For the present study water content for preparation of bed was fixed at OMC + 4 %, as it would simulate soft clay condition that would require improvement through the use of plate anchors. The compaction of the clay bed has been done appropriately with required number of hammer blows as was obtained by calibration earlier. It has been done to make the desired degree of compaction so that density of clay may reach the required density at the moulding water content. During the test, when soil bed and anchor plate have become ready in position, loads have been increased with successive increment in load system. With each increment of load, the corresponding displacement has been noted. The load increment is continued until indicated by observed failure or the displacement exceeds 10% of plate width. The load- displacement curve has been plotted with the observed data and the corresponding ultimate load has been found using double tangent method from the load displacement curve.

4 Numerical Modeling

To obtain the vertical pullout capacity of the anchor plate finite element software ABAQUS v 6.14 has been used for both unreinforced and reinforced soil. Numerical analysis has been carried out based on 2D plain strain condition**.**For discretization of soil a 4-noded quadrilateral plane strain elements has been adopted for the analyses. Material non-linearity has been taken into account by considering the Mohr-Coulomb plasticity model. The anchor plate and geotextile have been modeled as 2-D wire elements. In case of geotextile material a linear elastic model has been adopted with the compressive strength reduced to zero as it cannot take any compressive loads. A prescribed displacement of 10% plate width has been applied in order to get the load displacement behavior of the anchor plate and this continued for all the sizes of plates and different embedment ratio values. Slave surface has been considered for soil and the Mastered surface considered for anchor. The selected dimensions of the model are large enough to accommodate the stress contour well within the domain. The size of the mesh and mesh coarseness were determined by running trial models to optimize the mesh size with computational time. Mesh refinement was done by trial in case of interface elements to consider no-slip condition. Interaction at the soil-anchor interface is formulated considering soil as slave surface and anchor as master surface with node to surface discretization due to the rigidity of anchor material. Separation of anchor plate from initial slave surface has been allowed with non-linear stiffness effects in normal behavior. The first analysis step is Initial, which is the default that is already there. For the model, a load step has been added. Among many types of loads that can be added a static, general load has been chosen, and the NLGEOM command was turned on. This module allowed for defining Soil-Structure Interaction properties at the interface of soil and anchor plate as well as for the soil geosynthetic interface. Loads, boundary conditions, and fields have been created in the Load module. The step has been created to calculate the pullout load required for a prescribed displacement of anchor plate for monotonic loading.

4.1 List of numerical cases

The lists of numerical cases for unreinforced and reinforced clay have been shown in Table 4(c) and 4(d) respectively.

Table 4(c) Numerical cases- For Unreinforced Clay(UR)

Type	Test Name	Plate Size	(H/B)	Test Name	Plate Size	(H/B)
UR	50_UR_(H/B=1)	50^{mm}x50^{mm}	1	75_UR_(H/B=1)	75^{mm}x75^{mm}	1
	50_UR_(H/B=2)		2	75_UR_(H/B=2)		2
	50_UR_(H/B=3)		3	75_UR_(H/B=3)		3

Table 4(d) Numerical cases- For Reinforced Clay (RE)

Type	Test Name	Plate Size	(H/B)	(H'/H)	(Bg/B)
RE	50_RE_(H/B=1)	50mmx50mm	1	0.25	4
	50_RE_(H/B=2)		2		
	50_RE_(H/B=3)		3		
	75_RE_(H/B=1)	75mmx75mm	1		
	75_RE_(H/B=2)		2		
	75_RE_(H/B=3)		3		

In each of the numerical cases the load displacement curve has been plotted and the corresponding ultimate load has been found using double tangent method from the load displacement curve as has been done for experimental cases.

5 Results and discussions

5.1 Load Settlement curve

Typical experimentally and numerically obtained load settlement curves have been shown in figure 2(a) and 2(b). Failure loads are obtained by double tangent method.

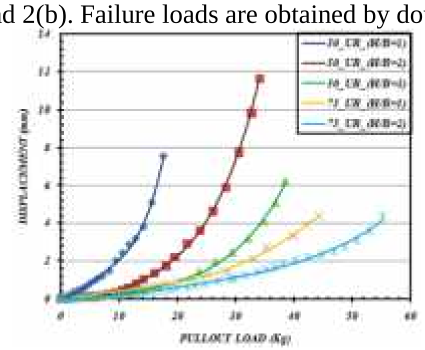

Fig.2(a). Typical experimental Load Settlement curves

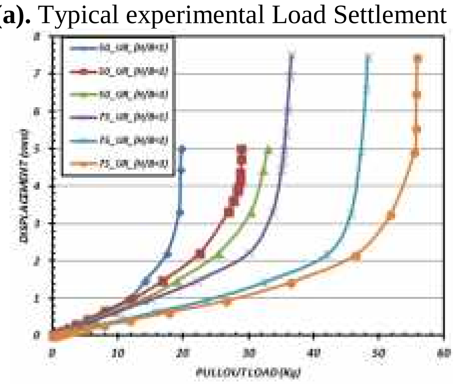

Fig.2 (b). Typical numerical Load Settlement curves

After obtaining all curves numerical and experimental results are furnished in Table 5 along with deviation of numerical results with respect to experimental results.

Table 5 Comparison between Experimental and Numerical Results

Type	Plate Size(B)	Embedment Ratio (H/B)	Pullout Load (Kg)		
			Experimental	Numerical	Deviation with respect to Experimental(%)
UR	50x50	1	14	18	-28.57
		2	24	24	0
		3	29	29	0
UR	75x75	1	30	34	-13.33
		2	40	46	-15.00
RE	50x50	1	17.5	20	-14.28
		2	30	26	13.33
		3	38	33	13.16

It is observed from the table that in unreinforced case the value of pullout capacities obtained from numerical investigations overestimates that of model tests with maximum deviation of 28% for 50 mm plate with H/B =1. For reinforced conditions results obtained from numerical investigation underestimates the pullout capacity owing to the fact that material nonlinearity for geotextile material was not considered in numerical modeling. For 50 mm plate with embedment ratio 1 the respective numerical results overestimates pullout capacity by 15% but for embedment ratio 2 and 3, numerical analysis underestimates pullout capacity by 13%.

5.2. Influence of different parameters on ultimate pullout capacity

Based on the results obtained from the experimental and numerical modeling, attempts have been made to study the influence of plate size, reinforcement and embedment depth on pullout capacity. Those aspects have been illustrated through figure 3, which shows a plot between ultimate pullout capacity and embedment ratio for all the cases considered during experimental and numerical studies.

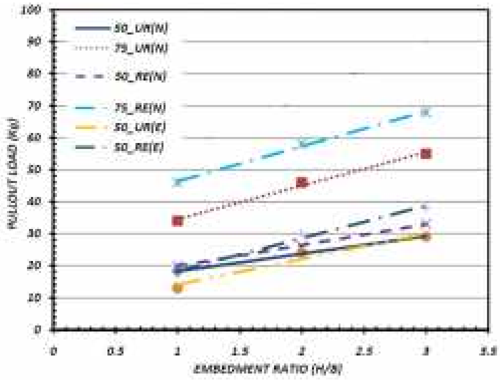

Fig.3. Pullout capacity vs embedment ratio

5.2.1 Plate Size

Two square horizontal anchor plates of size 50 mm and 75 mm have been considered in the analysis. It is observed from fig 3 that as the plate size increases for same embedment ratio, the pull out capacity also increases, when other parameters remain the same.
Effect of plate size on pullout capacity can be observed by comparing pullout load for 50 mm square anchor plate with H/B = 3 and 75 mm square anchor plate with H/B =2. This comparison shows that the pullout capacity obtained with 75 mm plate is about 213% of that obtained for 50mm plate. This increase in pullout capacity for higher plate sizes having same depth of embedment may be attributed to involvement of more soil mass during pullout. Effect of plate size on pullout capacity shows similar trend for both numerical study and model test results. For similar depth of embedment, with increase in plate size, pullout capacity increases for both experimental and numerical studies.

5.2.2 Reinforcement

Effect of reinforcement on pullout capacity is observed as follows: (i) the pull-out load is higher in reinforced soil compared to the unreinforced soil for all depths of embedment for a given position of reinforcement. It can be explained 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 capacity. The increment of pullout capacity obtained due to inclusion of geotextile increased with increase in plate size when other parameters remain same. In the present investigation geotextile has been introduced with a fixed ratio with the width of plate and embedment depth; thus with increase in plate size the extent of geotextile increases. This leads to mobilization of shear strength along a greater zone around the anchor plate resulting in higher pullout capacity. It can be observed that model tests show 25% increment of capacity in reinforced case for 50mm plate with single embedment ratio (H/B=1), whereas the same has been reported to be 11 % from numerical investigation as furnished in Table 5.

5.2.3 Embedment Depth

The increase in pull out capacity due to increase in embedment ratio is agreeing well with the study by Bhattacharya et al. (2008). Even for the different sizes of plate anchor it holds good. In the unreinforced and reinforced conditions also the increase embedment ratio increases the pull out capacity. Following observations are made from the results obtained for pullout capacity from numerical and experimental investigations (i) With increase in embedment ratio for any particular plate size, pullout capacity increases both in unreinforced and reinforced condition as shown in fig 3 This increase in capacity is accounted on the basis of larger volume of soil resisting the upward axial movement of anchor leading to increased value of ultimate pullout load. (ii) Comparing results obtained from numerical analysis for 50mm X 50mm plate in unreinforced condition the increase in pullout capacity for H/B =2 is about 33% than that is obtained by H/B =1 and this increment is 61% for H/B =3 than H/B=1. Similar observations for 75 mm plate shows that the increase in pullout capacities for increase in embedment ratio from H/B =1 to H/B =2 and 3 are 47% and 66%

6 Conclusions

The following conclusions may be drawn from the present study:
(i) The load vs Displacement curves obtained from model tests and numerical investigations show good agreement in trend for similar test conditions.
(ii) The pullout capacity of the anchor plates has been found to increase with increase in embedment ratio. For 50 mm square anchor plate the increase in pullout capacity has been found to be 33% when embedment ratio changed from 1 to 2, and the same has been found to be 61% when embedment ratio changed to 3. For 75 mm plate this increase has been observed to be 47% and 66% when embedment ratio changed from 1 to 2 and 3 respectively. This increment of pullout capacity with higher embedment ratio was found to increase with increase in plate size.
(iii) The pullout capacity has been found to increase with increase in plate size. For 150 mm depth of embedment this increase was found to be 113% when the plate size changed from 50 mm to 75 mm.
(iv) Inclusion of geotextile as a reinforcing material increases pullout capacity for all plate sizes and embedment ratios. For 50 mm plate with embedment ratio equal to 1 the improvement has been found to be 25% and the same has been found to be 36% and 31% for embedment ratio 2 and 3 respectively. This improvement has been found to be higher for larger plate sizes.

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