Uplift behavior of horizontal anchor plates buried in geosynthetic reinforced slopes

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Uplift behavior of horizontal anchor plates located near to sandy earth slopes with and without geosynthetic reinforcement has been investigated in model tests. Several configurations of reinforcement layers were used to reinforce the sandy soil over anchor plates. Many factors, such as relative density of sand, embedment depths, the location of plate relative to the slope crest, along with geosynthetic parameters including size, type, number of layers and the proximity of layer to the plate have been studied in a scale model. The failure mechanism and the associated rupture surface were observed and discussed. Test results showed that using geosynthetic reinforcement has a significant effect in improving the uplift capacity of anchorage plate. However, it was found that inclusion of one layer placed resting directly on top of the anchor plate was more effective in enhancing the anchor capacity than reinforcing the slope itself. Based on test results, critical values were discussed and recommended.

يتناول هذا البحث دراسة معمليه لسلوك ألوح رباط أفقية مقامة في تربة رمليه ذات ميل تم زيادة مقاومتها بشرائح التسليح الجيوتكنيكية. و قد تم دراسة أنظمة التسليح المختلفة لاختيار أفضل طريقه منهم على قوة شد الرباط . أيضا تم دراسة أهم العوامل المؤثرة على سلوك لوح الرباط وهي كثافة التربة و عمق لوح الرباط من سطح الأرض الطبيعي والمسافة بين لوح الرباط وقمة ميل التربة . كذلك تأثير عوامل التسليح المختلفة و تشمل طول الشرائح و عددها و نوعها و قربها من طول الرباط. تم ملاحظة و مناقشة شكل الانهيار و تحركات التربة المصاحبة له. و قد تم عرض و مناقشة نتائج التجارب المعملية في صورة جداول و منحنيات توضح تأثير العوامل المختلفة.

Keyword: Horizontal anchor plate, Reinforced sand, Model test, Geogridd, Geotextiles, Uplift resistance

1. Introduction

Horizontal anchors are often used to resist uplift tensile forces acting on the foundations of structures such as free standing, guyed lattice towers, television and transmission towers, tension cables for suspension bridges, underground reservoirs below water table, floating platforms, and pipe line under water. Such structures are often subjected to wind loading or uplift water loads which results in pullout forces much greater than the weight of the structure itself. In such cases an economic design solution may be achieved by embedding the anchor in the ground to sufficient depth so that they can resist the pullout forces with adequate safety. The pullout response of anchor plate depends on many factors such as the soil type, relative density, the size of anchorage, the depth of embedment, and the vertical pressure on soil. The uplift capacity theories are based on the formation of the failure surface above the plate under the action of uplift loads and may be broadly classified into three categories: gravity anchors, plate anchors, and anchor piles. The capacity of a buried anchor essentially comprises the weight of soil within the failure zone above the anchor, the frictional resistance along the failure surface and the self-weight of the anchor. The choice of anchor type depends on the magnitude and type of loading, type of structure and subsoil conditions. However, anchor plates are most widely used as they represent an economical alternative to gravity anchors and other embedded anchor piles for resisting uplift forces.

Several researchers have investigated the influence of different parameters on the pullout capacity of horizontal anchors in sand. Conventional laboratory model studies at unit gravity, by Meyerhof and Adams [1], Hanna et al. [2], Das and Seeley [3 - 4], Andreadis et al. [5], Sutherland et al. [6], Murray and Geddes [7], Ghaly et al. [8], Ilamparuthi et al. [9], Ghaly and Hanna, [10], etc.) have established a reasonably good understanding of anchor behavior. Also, centrifugal modeling tests by (Ovesen [11], Tagaya et al. [12], Dickin [13], Dickin and Leung [14] etc.) have provided data on anchors and enlarged base piles under stress levels similar to that experienced by full scale prototypes. Also several numerical studies have been carried out on the behavior of anchors (Chattopadhyay et al. [15], Dickin [13], Meyerhof and Adams [1], Hanna et al. [2], Meyerhof [16], Das and Seeley [3-4], Murray and Geddess [7], Tagaya et al. [12], and Trautmann and Kulhawy [17].

Increasing use of anchors to resist and sustain uplift forces may be achieved by increasing the size and depth of an anchor and/or the improvement of soil in which these anchors are embedded. In restricted situations increasing the size and depth of an anchor may be not economical compared with other alternatives. On the other size, soil improvement can be attained by the inclusion of soil reinforcement to resist larger uplift forces. However, few investigations on the behavior of horizontal plates in a reinforced soil bed under uplift loads were reported. Subbarao et al. [18] studied the improvement in pullout capacity by using geotextiles as ties to reinforced concrete model anchors embedded in sand. Selvadurai [19-20] reported significant enhancement, of the order of 80% to 100%, in the uplift capacity of pipelines embedded in fine and coarse-grained soil beds reinforced by inclusion of geogrids immediately above the pipeline in an inclined configuration. Krishnaswamy and Parashar [21] studied the uplift behavior of circular plates and rectangular plates embedded in cohesive and cohesionless soils with and without geosynthetic reinforcement and reported that the geocomposite reinforcement offered higher uplift resistance than both geogrid and geotextile reinforcement. Ilamparuthi and Dickin [22] investigated the influence of soil reinforcement on the uplift behavior of model belled piles embedded in sand. A cylindrical gravel-filled geogrid cell was placed around the enlarged pile base. It was reported that pullout resistance increases with the increase in geogrid cell diameter, sand density, pile bell diameter and embedment.

In summary, most of the studies in the literature are mainly focused on the capacity of horizontal anchors embedded in unreinforced soil mass with horizontal ground surface. However, a few studies have been reported in the area of anchors embedded in reinforced soil. On the other hand, to the knowledge of the author, hardly any effort has been made so far to investigate the performance of horizontal anchors placed on geosynethic reinforced slopes. Therefore, the effect of soil reinforcement on slope stability and rupture surface of the soil and hence the anchor capacity is not clear. The present study provides insight into the effect of soil reinforcement on the response of horizontal strip anchors embedded adjacent to sloped ground surface. The main objective of the research is to study the optimum number, sizes and the best location of geosynthetic inclusion for enhancing the ultimate uplift capacity of anchor plates along with the influence of embedment depth, soil density and the proximity of the anchor to slope crest.

2. Laboratory model tests

2.1. Model box

Fig. 1 shows a schematic view of the scale model experimental apparatus used in the study. It consists of two main elements; the test box and the loading system. The test box, having inside dimensions of 1.00 m x 0.50 m in plan and 0.5 m in depth is made from steel with the front wall made of 20 mm thickness glass and is supported directly on two steel columns. These columns are firmly fixed in two horizontal steel beams, which are firmly clamped in the lab ground using 4 pins. The glass side allows the sample to be seen during preparation and sand deformations to be observed during testing. The tank box was built sufficiently rigid to maintain plane strain conditions by minimizing the out of plane displacement. To ensure the rigidity of the tank, the back wall of the tank was braced on its outer surface with two steel beams fitted horizontally at equal spacing. The inside walls of the tank are polished smooth by attaching fiber glass to minimize side friction with the sand as much as possible by attaching fiber glass onto the inside walls. An overall assessment of the performance of the tank was carried out to check the plane strain conditions. Measurements of the out of plane displacement of the tank sides were made by means of dial gauges with accuracy of 0.001 mm. The worst case of loading was used to assess the tank behavior. The three fixed walls, and the glass wall were found to be sufficiently rigid. No measurable movements were observed and it was concluded that the value of any movement, if there was any, were less than 0.001 mm which means that the out of plane strain was less than 0.0002 %. The loading system consisted of a 3.0 mm diameter steel cable which was attached to the center of the anchorage plate using an eye bolt passing through two pulley and end vertically with a load hanger**.**

2.2. Model anchor

Plane strain anchor plate was used in the experimental work to study the effect of soil reinforcement on the uplift behavior of anchor plates. Strip model plates made of steel with 498 mm in length; 6.0 mm in thickness and 80 mm in width were made with a hole –3.0 mm in diameter- in the center and used in the study. The plates were positioned on the sand with the length of the plate running the full width of the tank. The length of the plate was made almost equal to the width of the tank in order to prevail plane strain conditions within the test set-up. The two ends of the anchor plate were polished smooth to minimize the end friction effects. The load is transferred to the plate through a cable attached at its center as shown in fig.1

2.3. Test materials

The sand used in this research is medium to coarse sand, washed, dried and sorted by particle size. It is composed of rounded to sub-rounded particles. The specific gravity of the soil particles was measured according to ASTM standards 854. Three tests were carried out producing an average value of 2.65. The maximum and the minimum dry unit weights of the sand were found to be 19.95 and 16.34 kN/m^3 and the corresponding values of the minimum and the maximum void ratios are 0.305 and 0.593, respectively. The particle size distribution was determined using the dry sieving method and the results are shown in fig. 2. The effective size (D_{10}), the mean particle size (D_{50}), uniformity coefficient (C_u), and coefficient of curvature (C_c) for the sand were 0.15 mm, 0.50 mm, 4.07 and 0.77, respectively.

In order to achieve reasonably homogeneous sand beds of reproducible packing, controlled pouring and tamping techniques were used to deposit sand in 50 mm thick layers into the model box. In this method the quantity of sand for each layer, which was required to produce a specific relative density, was first weighed and placed in the tank and tamped until achieving the required layer height. The experimental tests were conducted on samples prepared with average unit weights of 17.44, 18.15 and 19.10 kN/m^3 representing loose, medium-dense and dense conditions, respectively. The relative densities of the samples were 35 %, 55 % and 80 %, respectively. The estimated internal friction angle of the sand determined from direct shear tests using specimens prepared by dry tamping at the same relative densities were 34°, 37.5° and 43° respectively.

2.4. Soil reinforcement

Two types of geosynthetics (one is geogrid and the other is geotextile) were used in this research. Typical physical and technical properties were obtained from manufacturer's data sheet and are given in table 1 and 2. A hole equal to the cable diameter was punched at the center of the geotextile layer to pass the cable through.

2.5. The experimental setup and test program

An extensive test program was carried out to study the uplift behavior of an anchor plate located near the reinforced earth slope.

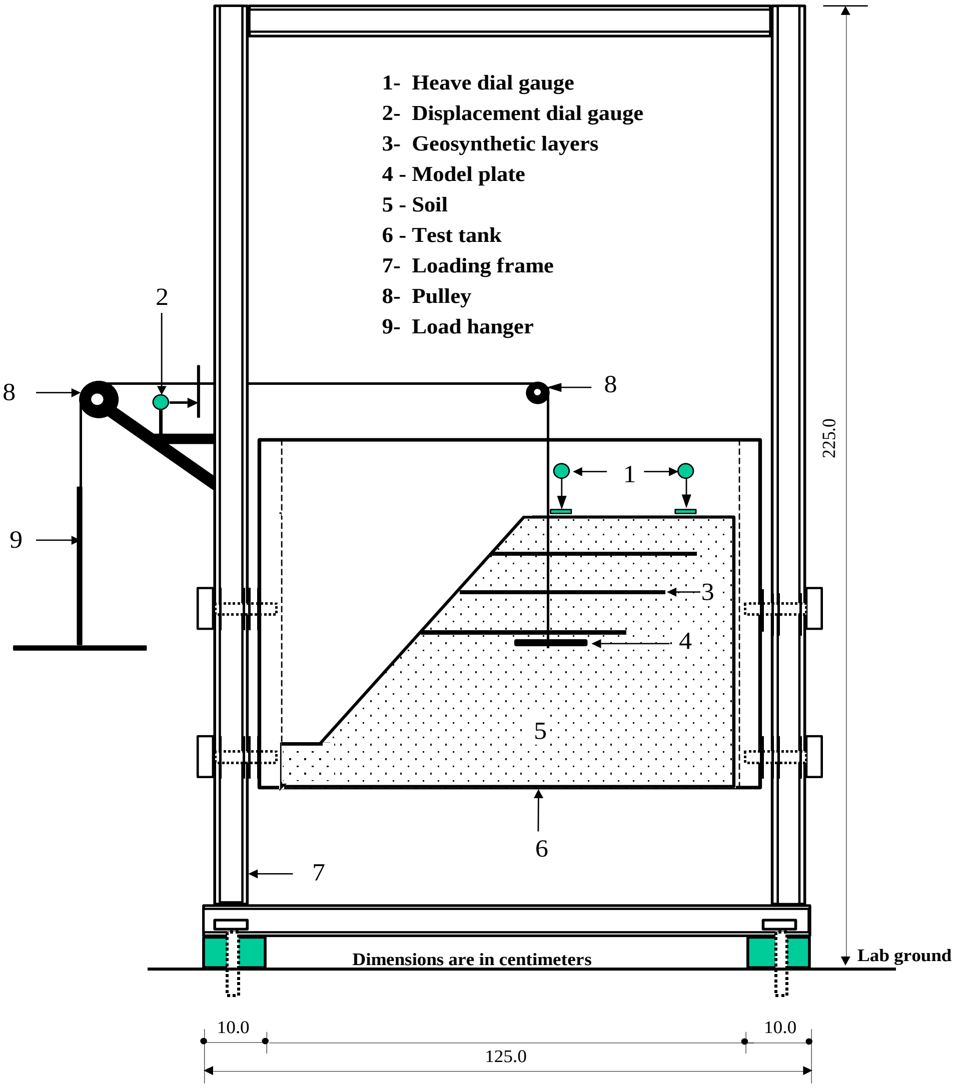

Fig. 1. Schematic view of the experimental apparatus.

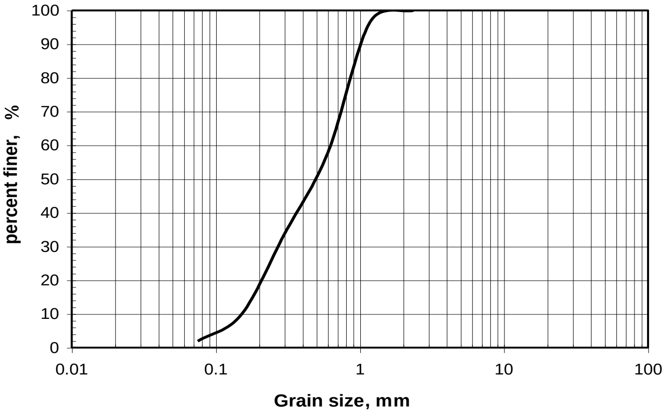

Fig. 2. Grain size distribution of the used sand.

Table 1
Engineering properties of geogrid

Structure		Bi-oriented geogrids	
Aperture shape		Rectangular apertures	
Aperture size,	mm x mm	27 x 37	
Weight,	g/m^2	210	
Polymer type		Polypropylene	
Tensile strength		MD	TD
At 2 % strain	kN/m	4.5	6.6
At 5 % strain	kN/m	9.5	13.5
At Peak Tensile strength	kN/m	13.0	20.5
Yield point elongation	%	16.0	13.0

Table 2
Engineering properties of geotextile

Type		Woven geotextile
Puncture		668 N
Apparent opening size		0.425 mm
Roll size		4.57 m x 91.5 m
Polymer type		Polypropylene
Tensile strength		1400 x 1335 N
Wide width tensile strength at 5 % strain,	kN/m	12.9 x 22.8 kN/m
Wide width tensile strength	kN/m	35 x 35 kN/m
Wide width elongation		10 x 8 %
Elongation		15 x 15 %

350 mm in height model sand slopes were constructed in 50 mm layers with the bed level and slope observed through the front glass wall. On reaching the predetermined level of anchor plate, it was placed on position and a layer of sand is poured and tamped. On reaching the reinforcement level, a geosynthetic layer was placed and the next layer of sand was poured and tamped. One to three geosynthetic layers 500 mm in width (the full width of the tank) were placed with different lengths. The preparation of the sand bed above the reinforcement was continued in tamped layers up to the level required for a particular depth of embedment. Minimum depth of sand of 110 mm was maintained below the anchor plate. Great care was given to level the slope face using special rulers so that the relative density of the top surface was not affected. All tests were conducted with an artificially made slope of 1 (V): 1.5 (H) with new sheets of geosynthetic used for each test. The anchor plate displacements were measured using 50 mm travel dial gauge accurate to 0.001 mm mounted outside the box measuring the lateral displacements of a piece of metal firmly fixed to the wire as shown in fig. 1. Sand displacements (heave) at the ground surface were observed using two dial gauges measuring the deformations of two 15mm diameter plastic contact plates carefully placed on sand surface. Finally the load is applied incrementally until reaching failure. Each load increment was maintained constant until the plate vertical displacement had stabilized.

Initially, the configuration of soil reinforcement inclusion was examined to choose the most effective one in terms of anchor plate capacity. In the first one, geosynthetic layers were placed to reinforce the sandy slope itself as shown in fig. 3-a. Upon analyzing test results, it was found that inclusion of one layer at the top of anchor plate is more effective in increasing the plate resistance than reinforcing the slope itself using three layers. Therefore, the second pattern of reinforcement using only one layer of inclusion placed in symmetric position shown in fig. 3-b was chosen to carry out the test program. A total of 41 tests in fifteen series were performed on anchor plate embedded in both reinforced and non-reinforced sand slopes of various densities. Initially, the behavior of anchor plate with different number of geosynthetic layers (N), to reinforce the slope itself was studied in series 1 and 2. Next, four series of tests (3 to 6) were performed to study the effects of the other reinforcement parameters on the anchor plate behavior. These parameters include the length of geosynthetic layer (L), the vertical distance between one geosynthetic layer and the anchor plate (x) and geosynthetic type as shown in fig. 3-b. Then, three different depths of embedment H, giving embedment ratios, H/B, of 1, 2 and 2.5 which fall under the categories of shallow anchors and three different locations of the anchor plate relative to slope crest (b) were studied in series (7 to 12). Finally, three series of tests (13 to 15) were conducted to study the effect of the relative density of ground slope (R_d) for both geogrid and geotextile reinforcement. Table 3 summaries all the tests program with both the constant and varied parameters illustrated. Several tests were repeated at least twice to verify the repeatability and the consistency of the test data.

3. Results and discussion

The ultimate uplift capacity of the horizontal anchor plate with and without soil reinforcement P_u and P_o was obtained from the load displacement curves. The anchor capacity improvement due to soil reinforcement is represented using a non-dimensional factor, called the Anchor Capacity Ratio (ACR) to assist in comparing the test results. This factor is defined as the ratio of the anchor ultimate capacity with soil reinforcement ($P_{u\ \mathrm{reinforced}}$) to the anchor ultimate capacity in tests without soil reinforcement (P_o). The anchor displacement (S) is also expressed in non-dimensional form in terms of the anchor width (B) as percentage ratio (S/B, %). The ultimate pullout capacity of the anchor is obtained from the load- displacement curve as the point where the slope of the load settlement curves first reach zero or steady minimum value. Test results for different studied parameters are given in tables 4 to 7. These results are discussed in the following sections.

3.1. Effect of number of geosynthetic layers

Seven tests (1-7) were performed to study the effect of slope reinforcement with various number of geosynthetic inclusion on the behavior of the anchor plate located at slope crest (b/B=0) and at embedment depth=2B. In reinforced tests, geosynthetic layers were placed at equal vertical spacing of 0.5B with the first layer placed resting on the plate (x/B=0). The variations of anchor capacities with S/B for various number of geosynthetic layers for different type of reinforcement are plotted in fig. 4. The figure clearly shows that the anchor behavior much improve with slope reinforcement. Also, it can be seen that inclusion of geotextile layers is much better than that of geogrid. However, the load-displacement ratio curves for different number of layers illustrate that the number of layer has no significant effect on the anchor response. In fact the inclusion of one layer of geogrid resting directly on top of the plate approximately enhance the same effect of inclusion of three layers. Similar conclusion

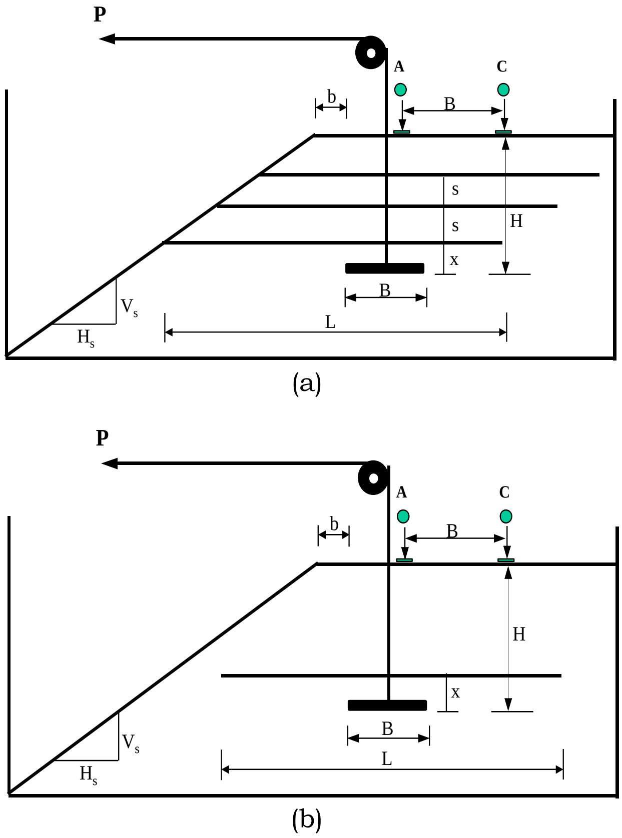

Fig. 3. Geometric parameters of anchor plate-reinforced sand slope model;
(a) slope reinforcement, and
(b) one symmetric layer inclusion.

Table 3
Model tests program

Series	Constant parameters	Variable parameters
1	b/B=0, H/B=2, x/B=0, L/B=7, s/B=0.5, R_d=80%, geogrid	N= 0,1, 2, 3
2	b/B=0, H/B=2, x/B=0, L/B=7, s/B=0.5, R_d=80%, geotextile	N= 0,1, 2, 3
3	b/B =0, H/B =2, x/B =0, N=1, R_d =80%, geogrid	L/B=2, 3, 4, 5, 6, 7
4	b/B =0, H/B =2, x/B =0, N=1, R_d =80%, geotextile	L/B=2, 3, 4, 5, 6, 7
5	b/B=0, H/B=2, L/B=5, N=1, R_d=80%, geogrid	x/B=0, 0.5,1.0,1.5
6	b/B=0, H/B=2, L/B=5, N=1, R_d=80%, geotextile	x/B=0, 0.5,1.0,1.5
7	b/B=0, R_d=80%, non-reinforced	H/B= 1, 2, 2.5
8	b/B=0, x/B =0, L/B =5, N=1, R_d=80%, geogrid	H/B= 1, 2, 2.5
9	b/B=0, x/B =0, L/B =5, N=1, R_d=80%, geotextile	H/B= 1, 2, 2.5
10	H/B=2, R_d=80%, non-reinforced	b/B= 0, 1, 2
11	H/B=2, x/B =0, L/B =5, N=1, R_d=80%, Geogrid	b/B= 0, 1, 2
12	H/B=2, x/B =0, L/B =5, N=1, R_d=80%, Geotextile	b/B= 0, 1, 2
13	b/B=0, H/B =2, non-reinforced	R_d= 35, 55, 80 %
14	b/B=0, H/B =2, x/B=0, L/B =5, N=1, geogrid	R_d= 35, 55, 80 %
15	b/B=0, H/B =2, x/B=0, L/B =5, N=1, geotestile	R_d= 35, 55, 80 %

Note: See fig. 3 for definition of the variable. Plate width (B) is always constant = 80 mm

Table 4
Pullout load (N) for plates located in reinforced slopes with different N (Series 1 to 2)

Test results	N			
	0	1	2	3
Geogrid	171.7	284.5	283.05	286.94
Geotextile	171.7	401.1	410.7	407.23

Table 5
Pullout load (N) for plates with one layer of geosynthetic of various L/B, and x/B (Series 3 to 6)

Test results	L/B						x/B			
	2	3	4	5	6	7	0	0.5	1.0	1.5
Geogrid	200.1	225.6	264.87	280.1	283.07	284.5	280.1	255.06	225.63	181.9
Geotextile	247.2	290.5	350.18	384.2	394.22	401.1	384.2	309.3	265.22	243.16

Table 6
Pullout load (N) for plates located at different H/B and various b/B (Series 7 to 12)

Test results	H/B			b/B		
	1	2	2.5	0	1	2
Non-reinforced	88.29	171.7	284.49	171.7	206.1	209.93
Geogrid	177.13	280.1	441.75	280.1	308.04	311.45
Geotextile	239.13	384.2	620.21	384.2	412.29	406.21

Table 7
Pullout load (N) for plates located in different relative densities (Series 13 to 15)

Test results	Relative density		
	Loose sand	Medium dense	Dense sand
Non-reinforced	105.6	152.05	171.7
Geogrid	242.08	264.87	280.1
Geotextile	341.7	354.3	384.2

when studying anchors of different shapes under horizontal ground surface was given by Subbarao et al. [18] and Krishnaswamy and Parashar [21] that, the provision of single layer of reinforcement close to the anchor is more effective than the use of multiple layers. Therefore, it was concluded that, in terms of anchor capacity, using one layer of geosynthetic layer is better and more economic than reinforcing the slope itself with several layers. Hence, it was decided to carry out the test program on the response of anchor plates adjacent to sandy slope using one layer of geosynthetic placed in symmetric state over the plate.

3.2. Effect of geosynthetic layer length

Two series of tests using only one layer of both geogrid or geotextile placed resting directly on the plate were performed to study the effect of the inclusion of one geosynthetic layer of various lengths on the behavior of anchor plate. Fig. 5 shows the variation of anchor capacities-displacement ratio for anchor plates located adjacent to slope crest (b/B=0) in dense sand. The anchor capacity increases with the increase of geogrid layer size. However, these improvements in anchor uplift capacity are accompanied with an increase in the displacement ratio. For anchors with geosynthetic inclusions, maximum uplift resistance is attained at a displacement ratio of 8-10%. The variation of ACR for the various layer lengths of geogrid and geotextile are plotted in fig. 6. The longer the layer size is, the greater is the improvement in anchor capacity. Same trend can be seen for both geosynthetic types with obvious effect of geotextile more than that of geogrid. However, this increase in the anchor resistance of the plate with layer length is significant until layer length equal to 5.0 times anchor width beyond which further increase in the layer length does not show significant contribution in increasing the load carrying capacity.

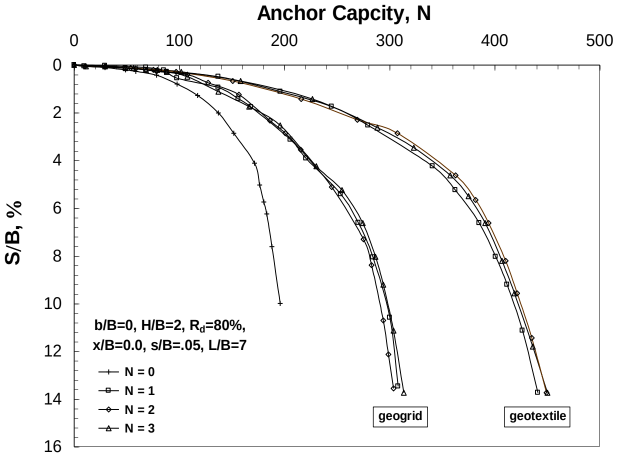

Fig. 4. Typical variations of anchor capacities with S/B for various N of geosynthetic layers (series 1, 2).

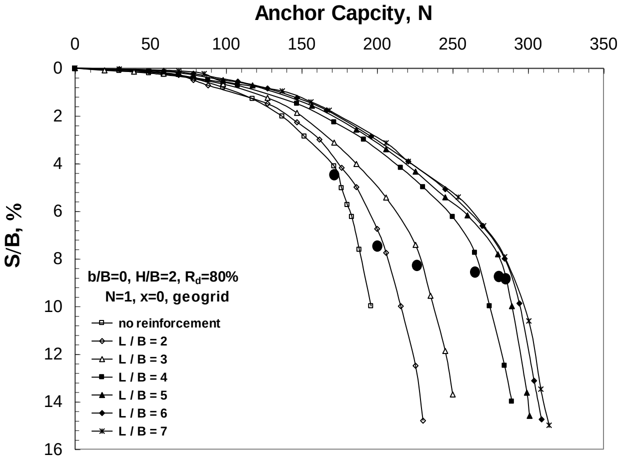

Fig. 5. Typical variations of anchor capacities with S/B for various lengths of geogrid layers (series 3).

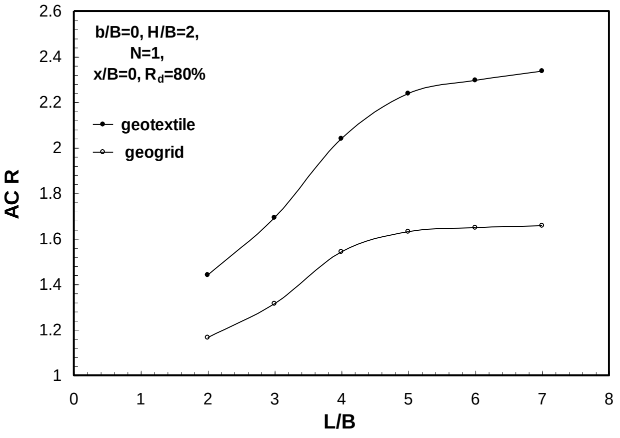

Fig. 6. Variation of ACR with L/B of geosynthetic layer.

anchorage length beyond the failure surface is essential for reinforcing layers to maximize the transferred shear stresses to unstressed area of soil. Hence, a wider failure wedge develops leading to longer failure surface. Therefore, not only the mobilized weight of soil within the failure wedge but also the shear resistance acting along the failure surface area increase leading to greater anchor capacity. The improvement in anchor capacity with inclusion of geotextile is more than that of geogrid and can be attributed to the large surface area of contact between geotextiles and soil particles which were pushed to move vertically. On the other hand, the effect of geogrid on the anchor capacity is less than that of geotextile due to its wider mesh openings, which offer less area of contact with the soil.

3.3. Effect of geosynthetic layer proximity to the anchor

Two series of tests (5 and 6) were performed on anchor plates located at slope crest (b/B=0) with inclusion of one geosynthetic layer placed at various distances of 0, 0.5B, B and 1.5B over the anchor plate. Fig. 7 shows the variation of ACR with x/B for the two types of reinforcement. The improvements in anchor capacity decrease as the geosynthetic layer is placed a way of the plate. Maximum gain in anchor capacity is attained when the layer is placed resting directly on top of the anchor plate. Same trend of anchor response can be seen for both geotextile and geogrid. This is consistent with the recommendation reported by Krishnaswamy and Parashar [21] in which reinforcement is placed directly above the anchor resulted in a higher uplift resistance than the mobilized value at any other levels. Similar conclusion was given by Selvadurai, [20] that, the inclusion of single layers of stratagrids immediately above the pipeline in an inclined configuration give the max improvement in the uplift resistance in both fine- and coarse-grained soils. This may be explained that the closeness of geosynthetic layer with adequate anchorage length to the anchor plate offers greater resistance to anchor displacement leading to greater failure wedge and larger failure surface area.

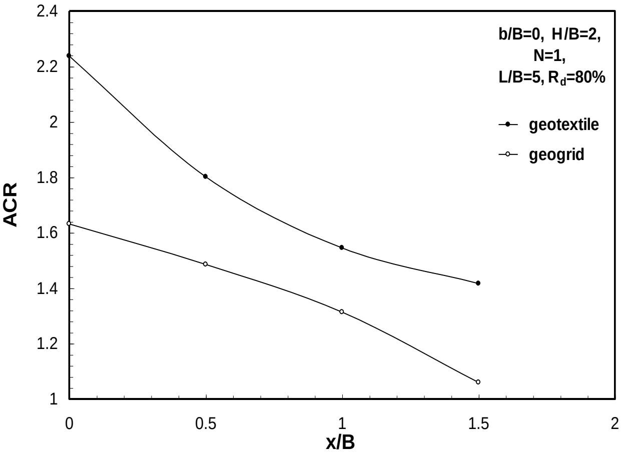

Fig. 7. Variation of ACR with x/B.

3.4. Effect of embedment depth

Nine tests were carried out to study the response of anchor plates placed at embedment depth of 80, 160 and 200 mm presenting embedment ratios, H/B of 1, 2 and 2.5 which fall under the category of shallow anchors (series 7 to 9). Table 6 shows that the pullout load increases significantly with the anchor embedment depth for both reinforced and non-reinforced cases. Also, inclusion of one layer of geotextile over anchor plate located at embedment depth H/B=2 gives 35% greater than the capacity of same anchor plate embedded at deeper depth (H/B=2.5) without reinforcement. Therefore, In cases where the structural design requires large pullout resistance, soil reinforcement can be considered as an economic solution and used to obtain the design anchor capacity instead of increasing the embedment depth or anchor size. The variation of ACR against normalized embedment ratio H/B are plotted in fig. 8. Despite of the increase in anchor capacity loads, the ACR decreases with the increase of H/B. Same trend can be seen for both geogrid and geotextile reinforcement. The same trend of observation that ACR decreases with H/B was reported by Ilamparuthi and Dickin [9] who studied the effect gravel-filled geogrid cell on the uplift of belled piles.

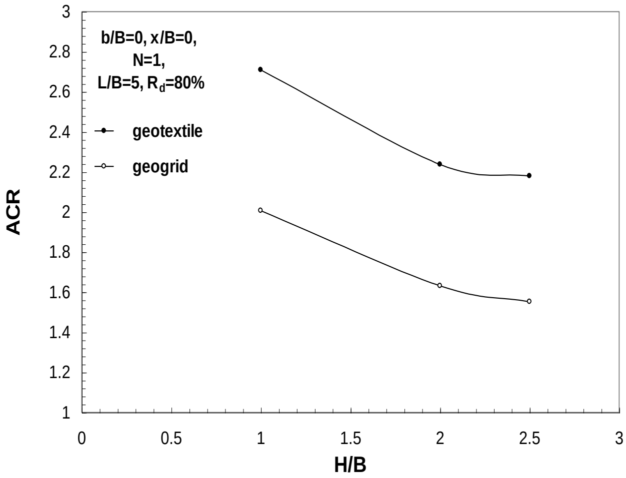

Fig. 8. Variation of ACR with H/B.

3.5. Effect of the plate location relative to slope crest

In order to study the effect of the closeness of the anchor plate to the crest of the ground slope (b/B) on the anchor response, nine tests were carried out with all the parameters kept constant and b/B ratios of 0.0, 1.0, and 2.0. Test results in table 6 shows that, anchor capacity decreases as the anchor location moves closer to the slope crest. The same trend can be observed for both reinforced and non-reinforced slopes. Fig. 9 shows the variation of the ACR against the b/B ratio for the two cases. As the plate location moves away from crest, the improvement of anchor load becomes less although the anchor capacity increase. This decrease in the ACR is obvious until a value of about b/B = 1.0 after which the effect the slope on anchor plate can be neglected. However, the location of the plate after which the effect of the slope on the anchor response vanish is dependent on several factors such as embedment depth, the slope angle and the anchor size. The tests conducted in this study are not adequate to determine critical value of b/B after which the effect of slope can be neglected.

3.6. Effect of soil density

Two series of tests on anchor plate located at the crest of sandy slopes (b/B=0) were performed in order to study the effect of soil density on the plate behavior. The ultimate capacity of anchor plate are given in table 7 and the variations of the ACR against the relative density for both geogrid and geotextile inclusions are plotted in fig. 10. The test results clearly show that the increase in soil density results in greater uplift capacity of anchors with and without geosynthetic inclusions. A gain in the anchor capacity as much as 3.24 times that located in un-reinforced loose sand is obtained when one layer of geotextile is placed at the top of anchor plate. However, the figure shows that the greater the soil density is, the lower is the improvement in anchor resistance.

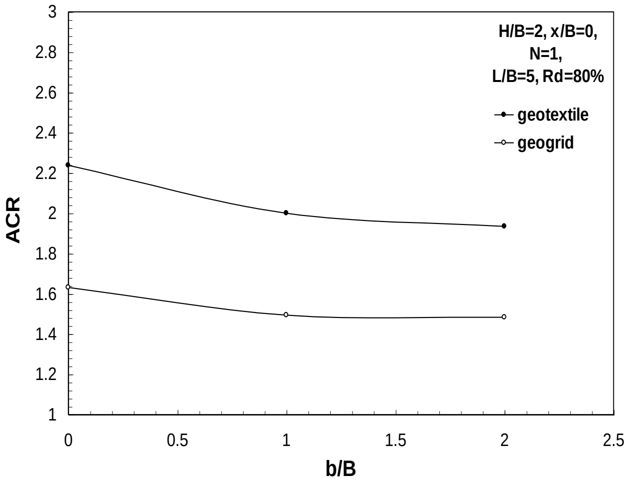

Fig. 9. Variation of ACR with b/B.

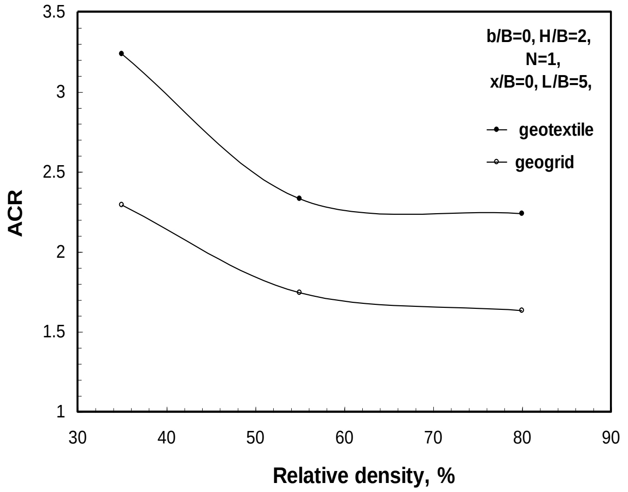

Fig. 10. Variation of ACR with the sand relative density.

4. Surface heave and failure wedge

Fig. 11 shows typical variations of anchor loads versus the vertical displacement of sand surface (heave) measured over the center of the anchor plate (series 3). In this series of tests, the anchor was placed at slope crest (b/B=0), at embedment depth H/B= 2 with one geogrid layer of various lengths. The figure demonstrates that using one layer of geogrid not only increases the anchor capacity but also increases the vertical heave of sand surface. Further, for the same load level, as the layer length decreases the sand surface displacements increase. Visual observation of slope surface (difficult to measure) showed that the area of the deformed sand surface on the slope surface increased as the layer length increased. Also, the surface area of heave extended further in other directions than that for the unreinforced case. The figure also shows that inclusion of layers of length more than five times the anchor width has a slight effect on the anchor response. Comparing the two dial gauges measurements demonstrated that the maximum heave occurs at the top center of the plate and decreased on both sides of anchor plate. Also it should be mentioned that in non-reinforced tests, failure occurred accompanied with rotation of the anchor plate in the clockwise direction. With inclusion of reinforcement, the rotations decrease with increase of layer length until L/B =5 in which the anchor exhibited the least rotation. In the series of different embedment depths, while the maximum upheaval and surface area of displacement decrease as the plates were embedded deeper in non-reinforced tests, increased area of heave with higher values of heave displacement were observed in reinforced tests. These observations confirm the development of larger failure wedge with larger soil mass mobilized within the failure wedge when reinforcement were included.

5. Limitations

The anchor plate adopted in this study is reduced to a certain scale while the used sand and geogrids were the same as that in the prototype. Therefore, the model plate or the soil, may not play the same role as in the prototype encountered in the field. In choosing both the geogrid and geotextile, the weakest types available in the local market were considered and studied. However, the used soil reinforcement can be considered high modulus for the scale of the problem and hence they represent behavior of higher modulus reinforcement. Therefore, despite we cannot rely on these tests to predict the exact quantitative behavior of a particular prototype, the study indicated the benefits can be obtained when using geosynthetic to reinforce sandy slopes on the uplift response of anchor plate. The results also provide a useful basis for further research using full-scale tests or centrifugal model tests and numerical studies leading to an increased understanding of the real behavior and accurate design in application of soil reinforcement.

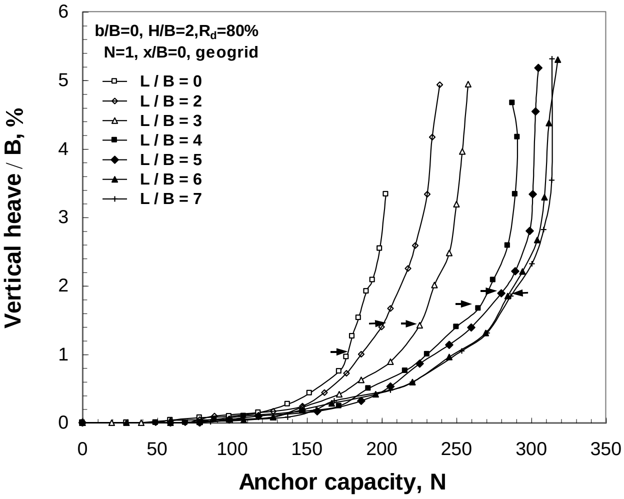

Fig. 11. Typical variation of anchor capacities versus (vertical heave/B) for various lengths of geogrid layers using dial gauge (A) (series 3).

6. Conclusions

Based on the experimental study carried out on model strip anchor plate embedded adjacent to earth slope at three sand densities with and without geosynthetic reinforcement, the following conclusions are drawn:

1. Inclusion of geosynthetic reinforcement in earth slope significantly increases the ultimate pullout resistance of anchors plate embedded adjacent to slope crest. However, geotextiles

are much better than geogrids in improving the anchor capacity.

2. In cases where design requirements necessitate large pullout resistance, soil reinforcement can be considered an economic solution and used to obtain the designed anchor capacity instead of increasing the embedment depth or anchor size.
3. In terms of anchor capacity, inclusion of one layer of geosynthetic over the anchor plate is more cost effective than slope reinforcement using multiple layers. The optimal location of one geosynthetic inclusion is that when resting directly on the anchor plate.
4. Anchor plate improvement is much dependent on geosynthetic layer length and increases significantly until value of (L/B=5.0) beyond which further increase in the layer length does not show significant contribution in the anchor capacity.
5. The proximity of anchor plate to the slope crest highly influences the anchor response. The closer the anchor to slope crest the greater would be the gain in anchor capacity.
6. Increased soil density and embedment depth results in greater uplift capacity without soil reinforcement. However, with geosynthetic inclusions, the greater the relative density or embedment depth the lower is the ACR.

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