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Investigations on Uplift Behaviour of Plate Anchor in Reinforced Sand Bed

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ABSTRACT

Two series of pullout loads tests were conducted in anchors embedded in submerged sand in this study. First series of tests were in unreinforced sand and the second series of test were in submerged sand reinforced with single layer of geogrid. The geogrid was positioned directly on the anchor and its width ratio was varied (Br/B = 2, 3 and 4). Other parameters varied in both monotonic and cyclic mode of loading were embedment ratio of anchor (H/B=2, 3 and 4) and density (loose, medium and dense conditions). All the cyclic load tests were conducted for the cyclic load ratio of 60%. From the results of study it was found that the load -displacement response of unreinforced and reinforced sand for a given density and depth of embedment are similar except higher peak and residual loads due to the inclusion of geogrid reinforcement. Both peak and residual pullout loads increased with width ratio of reinforcement for the densities and embedment ratios studied in this investigation. In the case of cyclic load, the displacement of anchor was increased with decreasing rate and reached almost a constant value after 350 cycles. The post cyclic peak pullout load was marginally higher than the peak pullout load of monotonic condition for all the comparable test conditions.

KEYWORDS: Sand, anchors, pullout test, cyclic load, geogrid

INTRODUCTION

An anchor is a foundation system that is capable of resisting tensile force with the support of surrounding soil in which anchor is embedded. It is used in various civil engineering structures as a structural member, primarily to resist uplift loads and overturning moments; and to ensure the structural stability. A wide variety of anchor systems (plate, belled, under reamed pile, pedestal, pyramid, grillage and helical anchors) have been developed in order to satisfy the increase in demand for foundations to resist the pullout loads.

Researchers proved that the uplift capacity can be improved by grouping the anchors, increasing the unit weight of back fill, depth of embedment and the size of anchor. Innovation of geosynthetics in the field of geotechnical engineering as reinforcement found to be possible alternative in enhancing anchor capacity. Its behaviour on anchor system was first documented by Subbarao et al. (1988). Polypropylene strip as ties was found to increase the uplift capacity of anchors. Selvadurai (1993) studied the performance of uplift capacity of buried pipelines by the use of geogrid in sand bed. The increase in uplift capacity of the reinforced system was around 100% and also reported that reinforcement increased the pullout load with increase in displacement indicating an improvement in ductility of the system. Krishnaswamy and Parashar (1994) studied the uplift behaviour of plate anchors embedded in cohesive and cohesionless soil media, with and without geosynthetics. Placing the geosynthetics directly on the anchor foundation was proved to be beneficial in achieving maximum increase in the uplift capacity. Further they reported that two layers of geogrid reinforcement does not increase the uplift capacity predominantly. Ilamparuthi and Dickin (2001 a and b) carried out an extensive study on the behaviour of belled pile anchors in reinforced sand bed and formulated a hyperbolic theory for the breakout factor. Ravichandran et al. (2004) studied the behaviour of rectangular plate anchors in the unreinforced and reinforced (horizontal and vertical) sand bed. Vertical reinforcement showed higher increase in the uplift capacity of the anchors than the horizontal reinforcement, since vertical reinforcement was found to attribute better interlocking resistance than that of the horizontal reinforcement. Kingshri et al. (2005) carried out two series of tests to understand the influence of stiffness and opening size of geosynthetic reinforcement on the enhancement of uplift capacity of rectangular anchor. First series of tests were on combination of geocomposite and geogrid and the second series of tests were on two layers of geogrid as reinforcements and concluded that the performance of geocomposite & geogrid two layer combination was found to be effective in resisting uplift force than two combined layers of geogrids. Limited work was reported on the effect of submergence under uplift loading. Andreadis et al. (1981), Ghaly et al. (1991), Krishnaswamy and Parashar (1992), Ilamaparuthi (2004) are some among the few known researchers in this field. Krishnaswamy and Parashar (1992) performed the test in reinforced sand bed and others in unreinforced conditions. Further the research on the effect of cyclic load on anchor embedded against pullout is very rare in reinforced sand bed.

The behaviour of anchors in submerged sand subjected to cyclic loading is a complex interaction problem involving the sand, water, anchor and the loading pattern. Although quite a good amount of research has been done to understand the behaviour of plate anchors under monotonic loading, the effects of cyclic loading on anchor behaviour has drawn little attention from the investigators particularly in sand. A review of these works indicates that due to lack of sufficient information the design of anchors under repeated loading is generally based on high factor of safety. Keeping this in view in this paper, an attempt has been made to study the behaviour of plate anchors in submerged sand under monotonic and cyclic loads.

TEST PROGRAM

The test program involved monotonic and cyclic pullout tests on rectangular anchor of size 50 mm×350mm×5mm (L/B=7, L=Length and B=Width of anchor) at embedment ratios (H/B, where H=Depth of embedment and B=width of anchor) of 2, 3 and 4 in dense (γ'=10.81kN/m3), medium dense (γ'=10.41kN/m3) and loose (γ'= 9.47kN/m3) sand beds under submerged condition. Submergence of sand was achieved by allowing water to flow from the bottom of the bed to top and water level of 50mm above the top level of sand bed was maintained in all the tests. Model anchors were tested on two modes namely, unreinforced and reinforced systems. All the tests were carried in submerged conditions. In this study the parameter investigated are depth of embedment (H), unit weight of sand bed (γ) and width of reinforcement (Br).

The arrangement of the test set up for monotonic and cyclic loading is shown in the Plate 1. This setup consists of a loading frame of 10kN capacity with a hydraulic jack arrangement other than pressure cylinder, timer and monitoring devices required for cyclic load. The anchor was placed inside the model tank of size 740 mm x 740 mm x 560 mm and the anchor was pulled monotonically through the loading yoke connecting the proving ring, the hydraulic jack and the anchor. In the case of cyclic load tests, embedded plate anchors in submerged sand were subjected to a constant cyclic load ratio of 60% (intensity of cyclic load to peak pullout load of anchor under monotonic loading condition) and uniform rectangular cyclic loading of 6 seconds time period. The anchors were subjected to a maximum of 1000 cycles. At the end of cyclic load, pullout tests were conducted to find out the post-cyclic pullout capacity of anchors. In this investigation one way vertical cyclic pullout load on anchors were imparted through a pneumatic loading apparatus developed in house by the authors and its arrangement is as shown in Plate 1. Stress controlled cyclic loading tests were conducted as it is more appropriate for simulating field conditions. In this system, a predetermined cyclic pull was applied on the model anchor at the desired frequency. The cyclic load on the anchor was applied using a double acting pneumatic power cylinder which was connected to the anchor rod by a chain of required length. The piston of the pneumatic power cylinder is actuated by regulated filtered compressed air, passing through a solenoid valve system controlled by an electronic timer. Desired cyclic load to the anchor is imparted by regulating pressure and setting loading and unloading time intervals in the timer. A strain gauge load cell of 3 kN connected to the pullout arrangement was used to monitor the cyclic and post cyclic pullout loads. The displacement of the anchor was measured using a dial gauge having least count of 0.01mm and a travel of 50mm. Monitoring devices were used for measuring load and displacements.

Plate 1: Test set up for monotonic and cyclic loads

Properties of sand and reinforcement material

The sand used in this study was tested for index properties. It contains traces of fines with medium and fine sand contents of 80% & 19% respectively. Its minimum and maximum void ratios are 0.497 and 0.897 respectively. Its specific gravity is 2.69 and is classified as poorly graded sand (SP) as per unified soil classification. A NETLON (CE-121) geogrid was used as reinforcement in all the tests. Its aperture shape and size are Diamond and 8mm x 6 mm respectively. Thickness of reinforcement at the joint is 3.1 mm and its maximum strength is 7.68 kN/m.

BEHAVIOUR OF ANCHOR UNDER MONOTONIC LOADING

Response of width ratio (Br/B) on pullout loads

Fig 1 shows the pullout response of anchors for an embedment ratio of 4 and reinforcement width ratios of 2, 3 and 4 in medium dense sand bed. In the figure, the effect of width ratio of reinforcement of was compared with unreinforced condition. The load-displacement response of anchor in reinforced sand was almost identical to that of unreinforced sand except that the pullout load was higher for a given displacement of anchor.

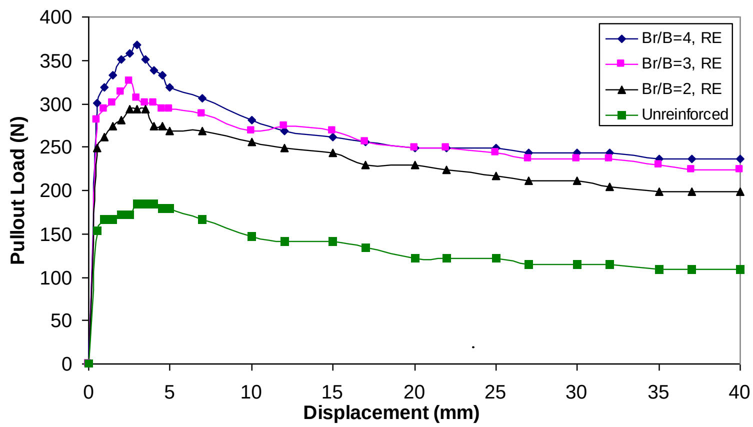


Figure 1: Pullout response on anchor in medium dense sand bed for H/B ratio 4

For the embedment ratio 4 the increase in peak pullout loads for Br/B ratio 2, 3 and 4 were 59%, 76% and 98% respectively over unreinforced sand bed condition. It was found that increase in peak pullout load values for corresponding width ratios of reinforcement were 59%, 118% and 171% for the anchor embedment ratio of 2. This variation in peak load indicates that the percentage increase in peak pullout load reduces with increase in embedment ratio. Though the magnitude of pullout resistance was high for deeper embedment, the contribution from the reinforcement to peak pullout load is better for the anchor embedded at shallower depth. Further, reinforcement increased the residual pullout load and let a gradual decrease in pullout load for further displacement of anchor after the peak pullout was reached. The increase in residual pullout load for the embedment ratio 2 was 166%, 200% and 433% for the width ratios of 2, 3 and 4 respectively in medium dense sand over unreinforced sand. The increase in residual pullout load due to the introduction of reinforcement reduced with increase in embedment ratio. For an embedment ratio of 4 and Br/B of 2, the increase was about 82% and this value was almost around 160% for embedment ratio of 2 and 3. Almost similar behaviour was observed in the case of tests in dense and loose sand conditions.

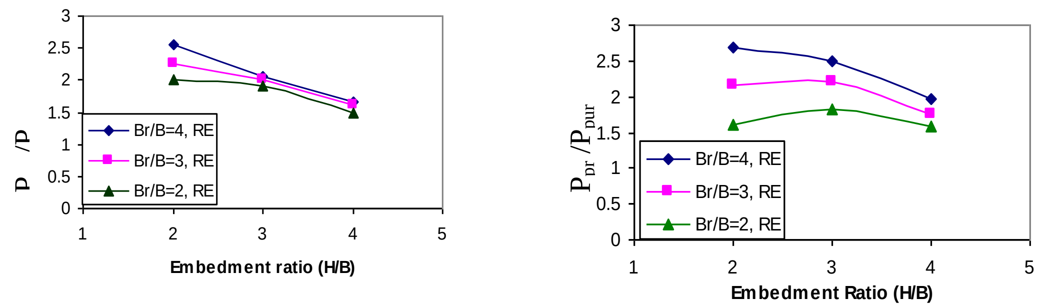
From the observations made in submerged sand bed condition, it was found that the reinforcement provides substantial increase in peak and residual pullout loads. The percentage increase in pullout load was higher in case of loose sand bed than in medium dense and dense sand bed. Increase in width ratio (Br/B) provides better improvement in peak and residual pullout loads for an embedment ratio 2 and 3 in medium dense sand. But this effect converges with increase in embedment ratio. The improvement was also found to decrease with increase in density of sand bed irrespective of depth of embedment and width ratio of reinforcement.

Response of depth of embedment on pullout loads

The ratio between peak pullout load of anchor embedded in reinforced (P_{pr})and unreinforced (P_{pur}) bed are presented for various embedment ratios in Fig. 2 for dense and medium dense conditions. It decreases with H/B ratio irrespective of width ratios of reinforcement and densities of sand bed. The P_{pr} /P_{pur} is maximum for the width ratio 4 and minimum for width ratio 2 irrespective of the depth of embedments studied. Further for a given H/B ratio, higher the density, lower is the peak pullout load ratio. The peak pullout loads in reinforced bed are 1.5 to 2.55 times the peak pullout load in unreinforced bed for the dense sand and the width ratio of 2. The corresponding ranges for medium dense condition are 1.58 to 1.83 respectively

BEHAVIOUR OF ANCHOR UNDER CYCLIC LOADING

Fig. 3 shows the cyclic response of anchors for the embedment ratio of 2 in medium dense sand bed. In the figure, the effect of width ratio of reinforcement was compared with unreinforced condition. The upward movement of anchor increases with the number of loading cycles. The anchor movement was high initially as observed in unreinforced sand. It was increasing with number of cycles and after 350 cycles the rate of movement of anchor was almost constant and also negligibly small. It was found that the anchor movement after 1000 cycles for Br/B ratio 3 and 4 were around 1.85 and 2.53 times the unreinforced condition for the embedment ratio of 2 and for the embedment ratio of 4 the respective anchor movements were 1.77 and2 times the unreinforced condition. Thus the movement of anchor decreases with embedment ratio as expected. However anchor movement was higher in denser bed despite the tests were conducted at CLR value of 60% because intensity of cyclic load was higher for denser condition



(*a*) Dense sand (*b*) Medium Dense sand

Figure 2: Variation of pullout load ratio with embedment ratio (H/B)

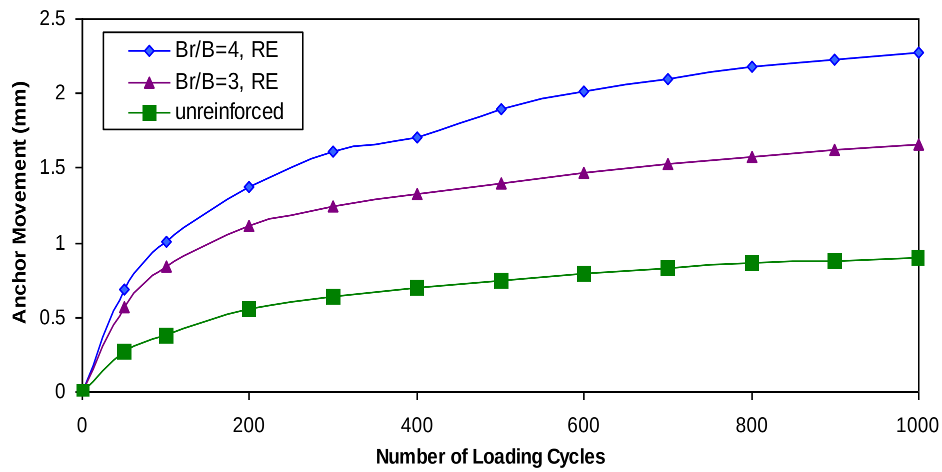


Figure 3: Cyclic response of anchors in medium dense bed for embedment ratio 2

The post cyclic pullout load and monotonic pullout load of anchors for Br/B ratio 3 and the embedment ratios 2, 3 and 4 were compared in the Table 1 for medium dense condition. It is clear from the results, the post cyclic pullout capacities are marginally higher (maximum 10% and average 6%) than monotonic pullout capacities and the displacement required to develop peak resistance in cyclic loading was also higher than that of monotonic pull. Marginal increase in capacity may be attributed to negative pore water pressure (suction pressure) at the base of the anchor. Ilamparuthi (1991) recorded negative pore water pressure at different levels of failed mass during pullout and also reported that the negative pore water pressures are higher for rapid pulling than strain rate of 0.5mm/sec. However post cyclic resistance was less when compared with the response of monotonic pull particularly for the displacements less than the displacement corresponds to peak pullout load of monotonic loading condition. Further, the rate of increase of resistance with displacement in the post cyclic phase was lesser than the monotonic pull. This may be attributed to gradual collapse movement of sand towards the gap created at the bottom of anchor during cyclic load, loss of resistance in sand due to adjustment of particles and change in the pore pressure.

Table 1: Comparison between monotonic and post cyclic peak pullout loads for Medium dense (Br/B=3)

Nature	H/B=2		H/B=3		H/B=4	
	P_u (N)	δ_u (mm)	P_u (N)	δ_u (mm)	P_u (N)	δ_u (mm)
Monotonic	118.2	3.0	210.9	3.0	325.9	2.5
Cyclic	128.4	4.9	224.2	5.6	337.0	6.1

CONCLUSIONS

The shape of the load-displacement curves for anchors embedded in reinforced and unreinforced beds are similar. However the rate of increase of pullout resistance (Pre-peak phase) is higher for reinforced condition.

The peak pullout load increases with embedment ratio and density of sand bed for both reinforced and unreinforced conditions and is higher for reinforced sand than unreinforced condition irrespective of density and embedment ratio. Friction along the reinforcement is the main contributing factor for the higher pullout capacity.

The increase in the width ratio (Br/B) of the reinforcement increased the pullout capacity of the anchor owing to the fact that the friction along the reinforcement increases with the increase in anchorage length of the reinforcement. The effect of reinforcement is more pronounced at lower embedment ratio and density irrespective of the width of reinforcement.

In case of cyclic loading, the upward movement of anchor per loading cycle decreases with increase in number of load cycles and the movement of anchor gets stabilized after 350 cycles. The displacements of anchor are increasing with increase in density and depth of embedment. Though the tests were conducted at same CLR value in all the densities, the movement is higher in denser beds because absolute cyclic load is higher for higher densities and deeper embedment.

The post cyclic peak pullout loads are marginally higher (< 10%) than monotonic peak pullout loads for all the three states of sand and embedment ratios in unreinforced and reinforced sand beds. But the displacement correspond to post cyclic peak pullout load is 1.5 to 2 times higher than the displacement of monotonic peak pullout load.

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