Indian Geotechnical Journal, 38(2), 2008, 156-170

Uplift Behaviour of Strip Anchor in Sand and Reinforced Sand Beds

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Introduction

There are many structures in Civil engineering where the requirement to resist pullout forces acting on embedded foundations are inevitable. Typical of such structures are tent-type roofs, television and transmission towers, chimneys, cooling towers, cable for suspension bridges and marine structures such as floating platform, tension leg platform, offshore mobile drill rig and guyed towers. The structures on land are often subjected to wind loading which results in pullout forces much greater than the weight of the structure itself. In case of marine structures in addition to wind forces they are subjected to wave forces with substantial pullout forces even of the order of 20,000 to 70,000 kN (Le Tirant, 1979). To resist uplift forces of this magnitude, massive sized area of foundation is required. An economical alternative to massive sized foundation is a light weight foundation provided by anchors. Anchors are structural elements that can take a variety of forms. These include plate anchors of different shapes, screw anchors, belled piles and grillage foundations. Even though different types of anchors are in use, the direct embedded anchors such as plate and pile anchors are among those which essentially rely for their capacity on the resistance of soil in which they are embedded. The capacity of buried anchor comprises essentially of the weight of soil within the failure zone above the anchor, the frictional resistance along the failure surface and self weight of anchor. Situation wherein individual footings at shallow depth cannot provide required uplift capacity, it can be achieved by increasing the foundation size, depth of embedment, density of back fill and grouping of anchors. A further, potentially more economical alternative involves the incorporation of some form of reinforcement in soil around the anchor foundations. The present investigation deals with essentially the behaviour of anchor, buried in loose, medium and dense sand beds with and without reinforcement subjected to vertical pull.

Published literature (1960s) was primarily concerned with large size field tests on anchor for transmission line towers [(Giffels et al. (1960), Ireland (1963) and Adams and Hayes (1967)]. Many experimental and analytical studies have been reported in this area of research by several investigators, notably Majer (1955), Balla (1961), Baker and Kondner (1966), Meyerhof and Adams (1968), Das and Seeley (1975 a and b), Ovesen (1981), Sutherland et al.(1982), Tagaya et al. (1983 and 1988), Murry and Geddes (1987), Dickin and Leung

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(1990 and1992), Ghalay et al.(1991 a and b), Ilamparuthi and Muthukrishnaiah (1999), Ilamparuthi et al. (2002) and others. Here it may be noted that all these studies were in the context of anchors embedded in unreinforced soil mass. However, a few studies have been reported in the area of anchors embedded in reinforced soil mass by Subbarao et al. (1988), Krishnasamy and Prashar (1991), Ilamparuthi and Dickin (2001 a and b), Swamisaran and Rao (2002) and others.

Johnston (1986) studied the pullout resistance of TENSAR geogrids. Subbarao et al. (1988) reported the improvement in pullout capacity by using geotextiles as ties to anchors embedded in sand bed. Results indicated that anchors with geotextile ties offered greater uplift resistance than those without ties. Selvadurai (1989 and 1993) reported that 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 it was reported that reinforcement increased pullout load with increase in displacement indicating an improvement in ductility of the system. Krishnaswamy and Prashar (1994) studied the uplift behaviour of plate anchor embedded in cohesive and cohesionless soil media with and without geosynthetics. Placing the geosynthetics directly on the top of anchor was proved to be beneficial in achieving maximum increase in the uplift capacity. Further they reported that the effect of double layer 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 geogrid-cell reinforced sand bed and formulated a hyperbolic theory for the breakout factor. Swamisaran and Rao (2002) have studied the uplift behaviour of square and circular anchor embedded in sand at embedment ratio of 2,3 and 4 by introducing single and multiple layers of reinforcement having width of 3 times breadth of anchor. Results indicated that pullout capacity of anchor is maximum when the reinforcement is kept at top of the plate anchor in single reinforcement and decrease as the distance of the reinforcement position from top of the plate increases and uplift capacity increases from single layer of reinforcement to double layer of reinforcement, while the pullout capacity increases only marginally with third layer of reinforcement. However the works reported in literature on the uplift behaviour of anchors in reinforced soil bed are very limited. Further little is known about the mechanism by which the load transfer takes place between soil and reinforcement. Hence in this experimental investigation an attempt is made to study the behaviour of anchors embedded in sand beds with and without geogrid.

Experimental Investigation

A loading frame designed to resist a vertical pullout capacity of 50kN and a rectangular steel tank of inner dimensions of 1.2mx0.5mx0.6m high, were used for conducting the laboratory tests. Overall view of the experiment facility fabricated for this purpose is shown in Figure 1. The anchor with and without reinforcement is shown in Figure 2. The pullout of anchor was effected at the rate of 1.25mm/min using hydraulic jack of 100kN capacity. A proving ring of 10kN was used to measure applied pullout force and two dial gauges having least count of 0.01mm were used to measure displacement of anchor. A uniformly graded clean Palar river sand (SP) was used in all the experiments.

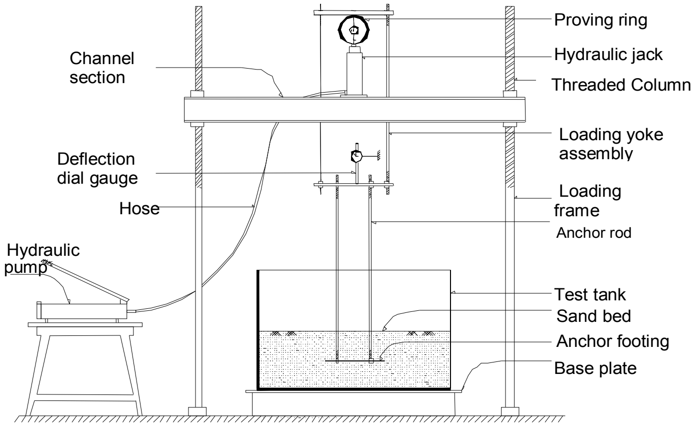

Fig. 1 Schematic Diagram of Loading Frame and Testing Arrangement

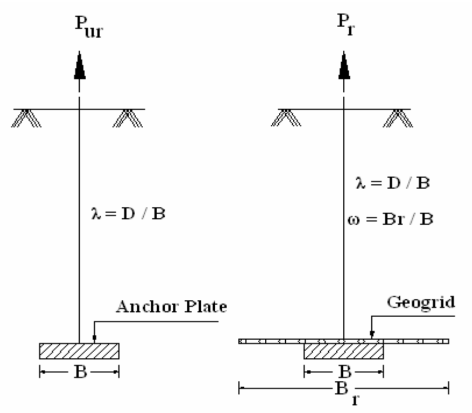

Fig. 2 Arrangement of Anchors in Reinforced Anchor System

Properties of the test sand are as follows:

γ_{dmax} = 18.19kN/m^3; e_{max} = 0.831; d_{10} = 0.28mm;
γ_{dmin} = 14.41kN/m^3; e_{min} = 0.45; and G = 2.69

Experiments were conducted in three homogeneous sand beds of chosen densities. Controlled pouring and tamping technique were adopted to achieve loose (φ=33˚), medium dense (φ=38˚) and dense (φ=43˚) sand beds of relative densities 0.34, 0.71 and 0.85 respectively. The model anchor of size 50mm x 350mm was fabricated from 5mm thick mild steel plate. The reinforcement used was a geogrid having tensile strength of 7.7kN/m and diamond shape aperture opening of size 8mm x 6mm. The size of the geogrid mesh was kept as 2, 3 and 4 times of the width of anchor plate. In total 36 tests were conducted in nine series by varying density of sand bed (loose, medium dense and dense), embedment ratio, (λ) =D/B (D= depth of anchor, B = width of anchor) and reinforcement width ratio, (ω) = B_r / B (B_r = width of reinforcement; B = width of anchor). In Table 1 the range of parameters considered for conducting test in the laboratory on anchor are presented. The condition of ω equal to '0' refers to unreinforced anchor condition.

Table 1 Values of Parameters Considered for Test on Anchor

Soil Condition	*Embedment Ratio (λ)*	*Reinforcement Width Ratio (ω)*
Loose(LO)	2,3 and 4	0, 2, 3 and 4
Medium dense(M)	2,3 and 4	0, 2, 3 and 4
Dense(D)	2,3 and 4	0, 2, 3 and 4

Experimental Procedure

The sand bed was prepared in layer of 50mm from the bottom of the tank to the base level of anchor by adopting controlled pouring and tamping technique. The anchor model with and without reinforcement was placed in position and preparation of sand bed was continued until the required embedment was reached. For loose sand bed condition, sand pouring technique was adopted. The anchor was then pulled continuously at the rate of 1.25mm/min. The pullout load and displacement of anchors were recorded upto an anchor displacement of 40mm at regular time intervals.

Results and Discussions

The peak pullout load and corresponding displacement obtained from pullout response curves for all the tests conducted in reinforced and unreinforced sand beds are presented in Table 2.

Table 2 Pullout Resistance of Strip Anchors in Unreinforced and Reinforced Sand beds

Sand bed condition	*λ*	*ω = 0*		*ω = 2*		*ω = 3*		*ω = 4*	
		P_{ur} (N)	δ_{ur} (mm)	P_r (N)	δ_r (mm)	P_r (N)	δ_r (mm)	P_r (N)	δ_r (mm)
Dense (ϕ=43°)	2	102.2	2.0	185.3	2.5	217.3	3.5	242.8	4.0
	3	198.1	2.5	332.3	3.0	357.8	4.0	383.4	3.5
	4	357.8	3.0	536.8	4.0	549.5	4.0	562.3	3.5
Medium (ϕ=38°)	2	76.7	2.5	140.6	2.0	172.5	3.0	204.5	3.0
	3	153.4	3.0	255.6	3.0	293.9	3.0	332.3	3.0
	4	293.9	3.5	460.1	3.0	498.4	3.5	536.8	4.5

Table 2 Contd. Pullout Resistance of Strip Anchors in Unreinforced and Reinforced Sand beds

Sand bed condition	*λ*	*ω = 0*		*ω = 2*		*ω = 3*		*ω = 4*	
		P_{ur} (N)	δ_{ur} (mm)	P_r (N)	δ_r (mm)	P_r (N)	δ_r (mm)	P_r (N)	δ_r (mm)
Loose	2	57.5	5.0	102.2	8.0	134.2	9.0	166.1	9.0
(ϕ=33°)	3	108.6	8.0	185.3	9.5	236.4	10.0	287.5	9.5
	4	204.5	9.0	351.4	12.0	409.0	11.0	472.9	10.5

Behaviour of Anchor in Sand with and without Reinforcement

The pullout response curves for dense and loose sand bed are shown in Figure 3 to Figure 8 for different λ and ω values. The shape of the curve in dense sand bed shows that rapid increase in pullout load with increase in displacement. Beyond the peak load, they tend to decrease gradually before reaching the residual phase. The shape of the load – displacement curves for all embedment ratios are more or less similar with variation in peak pullout loads and the corresponding displacements. Similar characteristics have been reported by previous researchers Trautmann et al. (1985), Dickin and Leung (1990) and Ilamparuthi (1991). The load – displacement responses showed two distinct behaviour irrespective of density of sand bed. The responses obtained from the tests in unreinforced dense and medium dense sands resembles to typical stress – strain behaviour of those sands, that is, mainly three phase. Whereas the tests on anchors in loose sand resulted in a typical behaviour, that is, two phase behaviour of loose sand.

The three phase behaviour is characterized by

i. pre-peak behaviour, exhibiting a rapid increase in load;

ii. post – peak behaviour, exhibiting a rapid load reduction with increase in displacement and

iii. residual behaviour, associated with moderate decrease in load at larger displacements.

The two phase behaviour is characterized by gradual increase in pre-peak behaviour followed by a very slowly decreasing residual post-peak behaviour. The load-displacement behaviour of anchor with reinforcement is no way different from that of unreinforced condition except for the slow rate at which resistance builds up. Initially, irrespective of density, the pullout load increases rapidly with displacement upto certain displacement beyond which it decreases suddenly with increase in displacement. As the displacement increases further, gradual decrease of resistance was observed. However, the rate of decrease of resistance in the residual phase is lesser than in unreinforced sand. The shape of the load-displacement curve of reinforced sand bed irrespective of depth of embedment and density of sand bed can be characterized as three phase behaviour. The fluctuations in the load –

displacement behaviour in loose sand bed at higher displacements are attributed to the collapse and flow of sand towards the gap created below the strip anchors.

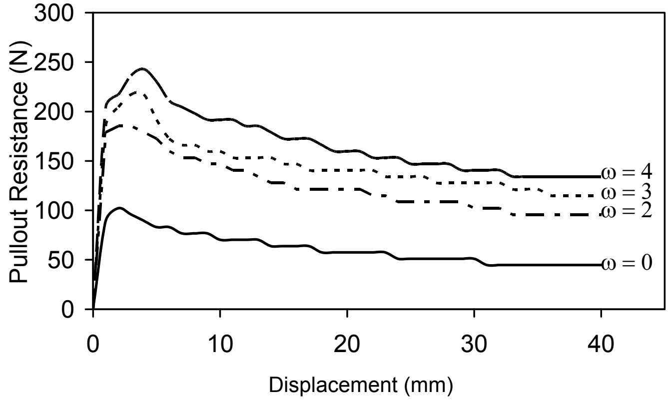

Fig. 3 Load - Displacement Behaviour of Strip Anchor at λ=2 in Dense Sand

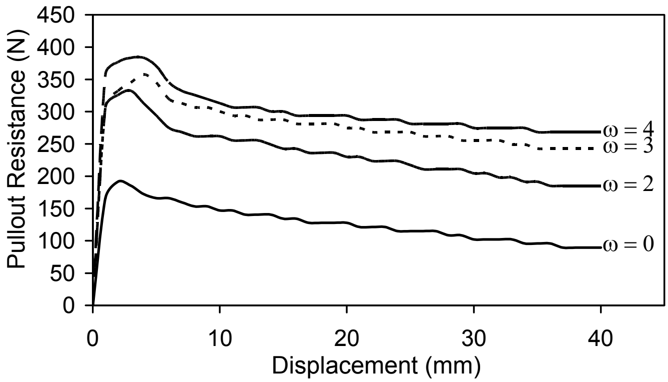

Fig. 4 Load - Displacement Behaviour of Strip Anchor at λ=3 in Dense Sand

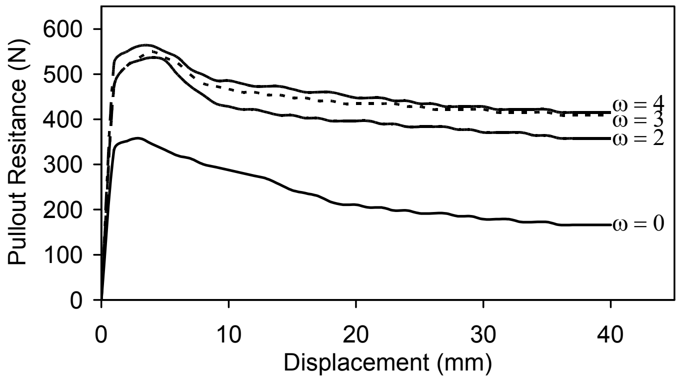

Fig. 5 Load - Displacement Behaviour of Strip Anchor at λ= 4 in Dense Sand

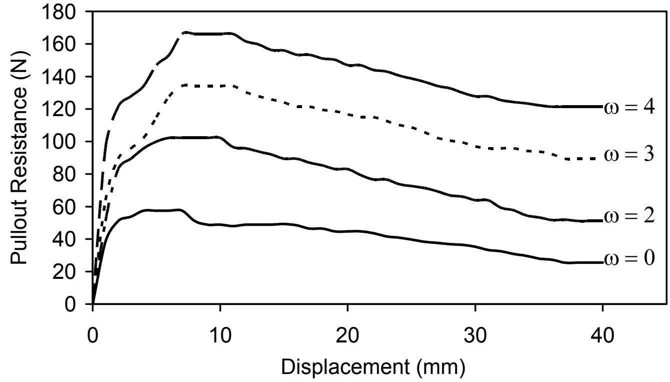

Fig. 6 Load - Displacement Behaviour of Strip Anchor at λ=2 in Loose Sand

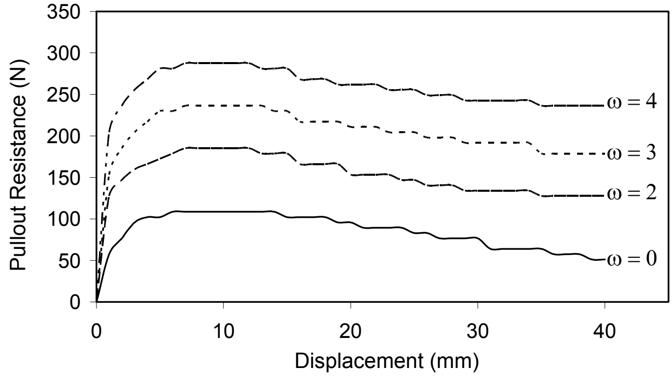

Fig. 7 Load - Displacement Behaviour of Strip Anchor at λ=3 in Loose Sand

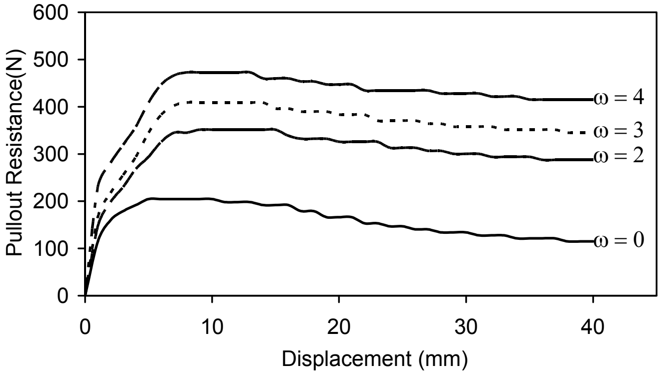

Fig. 8 Load - Displacement Behaviour of Strip Anchor at λ=4 in Loose Sand

Influence of Embedment Ratio on Anchor Capacity

Design of anchor foundation system requires higher peak resistance to axial tension. This resistance depends on various parameters and one of the major parameters that controls the pullout capacity of anchor is the embedment ratio. The peak pullout loads (P_{ur} and P_r) recorded in the tests conducted in various sand beds for different embedment ratios are presented in Table 2 along with corresponding displacement at peak pullout loads. The load displacement behaviour from all the test conditions has been indicative of a direct increase in the peak loads to corresponding displacements as the embedment ratio is increased, that is, the anchor being placed at increased depth, within the range of study. The load increased rapidly with displacement initially and reached the peak value. The increase in displacement of anchor beyond the level of displacement corresponding to peak load has resulted in sudden reduction in the pullout resistance. The load exhibited residual behaviour at very large displacements (= 10 times the displacements corresponds to peak load) compare to that at peak load. The variation of peak pullout load with embedment ratio of strip anchor in three different densities of unreinforced sand bed (P_{ur}) and reinforced sand bed(P_r) conditions are shown in Figure 9 and Figure 10 respectively. The increase in peak pullout load increases with increase in embedment ratio for both reinforced and unreinforced condition but the rate of increase of peak pullout load in reinforced sand bed is more when compared to unreinforced sand bed condition. The magnitude of peak pullout load increased non-linearly with depth of embedment. The increase in the pullout resistance is attributed to frictional resistance mobilized on the surface of reinforcement included which in turn alter the volume of sand involved in the failure mechanism that is much higher than that in unreinforced condition. It was observed during the experiment that the reinforcement placed on the top of the anchor was lifted partly from its position along with the anchor. Due to this, the soil above the anchor in this part is also pulled out and hence offered resistance against pulling. However certain portion of the reinforcement was in perfect contact with the soil and tries to pull towards the anchor which develops the frictional resistance both at top and the bottom surfaces of the reinforcement. This frictional resistance offers additional resistance to anchor against pull out and also prevents the lifting of reinforcement. This phenomenon is observed throughout the test during the process of pulling and occurred continuously and simultaneously.

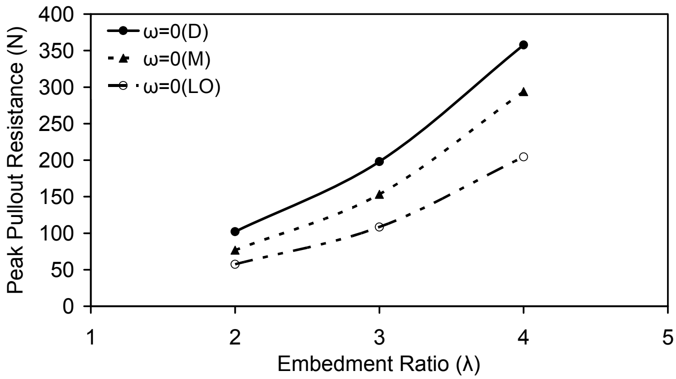

Fig. 9 Variation of P_{ur} with λ of Strip Anchor in Sand

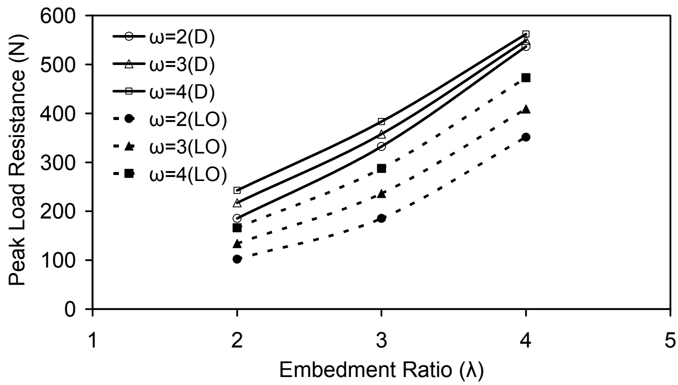

Fig. 10 Variation of P_r with λ of Strip Anchor in Reinforced Sand

Influence of Width Ratio of Reinforcement on Anchor Capacity

The effect of width ratio of reinforcement on pullout resistance is compared in Figure 11. From the graph it is observed for the width ratios tested that the pullout resistance increased linearly with width ratio of reinforcement. Similar characteristic behaviour up to 5times the width ratio of reinforcement has been reported by Krishnaswamy and Prashar (1994) for rectangular anchors of L/B = 2 to 5 (L = length of the anchor and B = width of the anchor). The observed linear increase in resistance with increase in width ratio of reinforcement may be attributed to higher frictional resistance in the case of wider geogrid reinforcement. The peak pullout load in dense sand is higher than that in loose sand, which is due to the increased particle interlocking between the reinforcement and sand. However for the embedment ratio more than 3, the rate of increase of pullout resistance is reduced particularly for the dense sand condition. The displacement required to mobilize peak shearing resistance in the sand is less than the deformation required to mobilize higher resistance in geogrid reinforced sand. The reduction in resistance offered by the soil at higher displacements is more than compensated by the resistance offered by the geogrid, hence the pullout resistance is higher in reinforced condition compared to unreinforced condition. The increase in pullout resistance for reinforced condition is compared with unreinforced condition (Pullout resistance ratio = (P_r/P_{ur})) and it is shown in Figure 12. In reinforced condition the pullout resistance is increased with reinforcement width ratio in all densities of sand tested compared to unreinforced condition. However, improvement in pullout resistance due to reinforcement is reduced with embedment ratio of anchor irrespective of the density of sand bed.

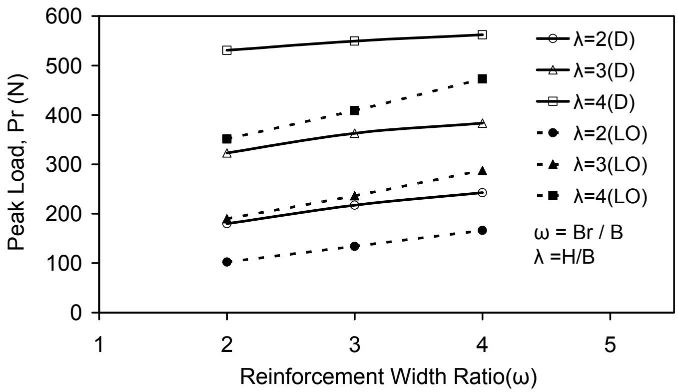

Fig. 11 Variation of Peak Pullout Resistance with Reinforcement Width Ratio(ω)

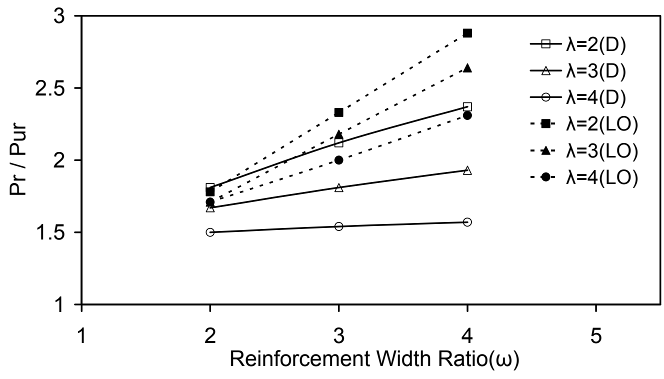

Fig. 12 Variation of Pullout Resistance Ratio with Reinforcement Width Ratio (ω)

Effect of Angle of Shearing Resistance on Anchor Capacity

Influence of angle of shearing resistance on peak pullout load is studied in Figure 13 and Figure 14 for unreinforced and reinforced conditions respectively. In unreinforced condition the peak pullout load increases almost linearly with angle of shearing resistance for a given embedment ratio and the rate of increase is higher for deeper embedment. The effect of density is more pronounced at embedment ratio 4 than at embedment ratio 2 and 3. Similar trend was observed in reinforced condition also. However, the difference in peak pullout resistances between the width ratio of reinforcements 2,3 and 4 are marginal for the deeper embedment and dense sand condition. The increase in density of soil results in higher pullout capacity of anchors both with and without reinforcement. Swamisaran and Rao (2002) have investigated on a similar line for square and circular anchors and reported a similar trend.

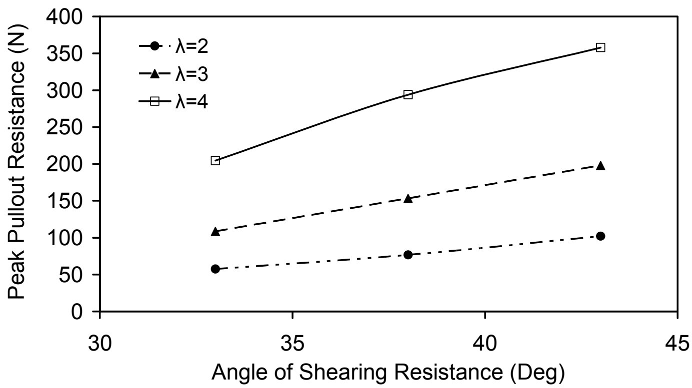

Fig. 13 Peak Pullout Resistance Vs Angle of Shearing Resistance (Unreinforced)

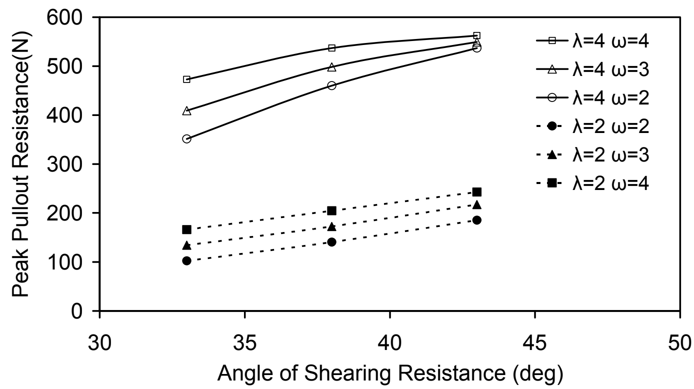

Fig. 14 Peak Pullout Resistance Vs Angle of Shearing Resistance(Reinforced)

Effect of Reinforcement on Residual Pullout Resistance

The relationship between residual resistance to peak resistance was studied and presented as a load ratio (Residual load / Peak load) in Figure 15 for the loose and dense sand conditions. The load ratio is higher for higher embedment ratio irrespective of the density of sand bed and width ratio of reinforcement. For a given embedment ratio, the load ratio is higher for higher width ratio of reinforcement, but the influence of width ratio is better in case of lower embedment ratios as well as in loose sand bed. Among the densities of sand bed in which anchors are tested, the load ratio is maximum in loose sand for a given embedment ratio and width ratio of reinforcement. This response shows clearly that inclusion of reinforcement above the anchor has not only increased the peak pullout resistance but also increased the residual resistance of the anchor. The reduction in the difference between peak and residual resistances (i.e. increase in load ratio) indicates that deeper embedment and wider width of reinforcement reduced the work softening behaviour of reinforced anchor. This response has major advantage particularly when the anchor is designed to withstand larger displacement and snap load. The reasons for high peak pullout resistance and sustained residual resistance are frictional resistance of reinforcement against pullout, confinement to the sand particles against sliding and restriction on free movement of the sand particles towards the gap created at the bottom of the anchor during pull.

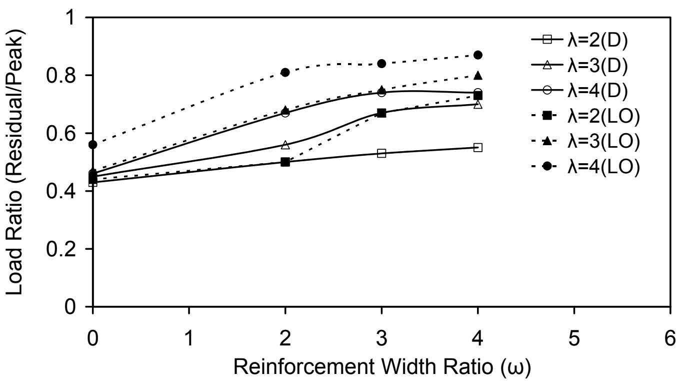

Fig. 15 Relationship between Load Ratio to Reinforcement Width Ratio(ω)

Conclusions

Based on the results obtained from the present experimental investigation on strip anchor embedded in different densities of reinforced and unreinforced sand beds, the following conclusions are drawn.

1. Pullout response of anchor in unreinforced and reinforced sand beds is three phase behaviour in general and is independent of embedment ratio. However the response is two phase in loose sand.

2. Peak pullout resistance increases linearly with width ratio of reinforcement irrespective of densities of sand and embedment ratios of

anchor analysed in this study. The minimum and maximum increase in pullout reistances due to reinforcement are 50% and 190% respectively. The maximum increase is for anchor embedded at shallow depth(λ=2) in loose sand. However peak pullout load increases non-linearly with embedment ratio both in reinforced and unreinforced sand conditions.

3. Inclusion of single layer of reinforcement increased both the peak and residual pullout resistances of anchor irrespective of density of sand bed, depth of embedment and width of reinforcement studied in this research. This is attributed to the frictional resistance mobilized between the reinforcement and sand at their interfaces and increase in the confinement to the sand around the anchor. This has restricted the movement(collapse) of sand particles, thus the difference between peak and residual resistance is less in reinforced sand than unreinforced sand.

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