Numerical analysis of uplift capacity of strip plate anchors in reinforced and unreinforced cohesionless soils

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ABSTRACT: In this study, the effect of the reinforced soil condition on uplift capacity of strip anchor plates is investigated with three dimensional numerical analyses. The analyses were performed both on dense and loose sand using different sizes strip anchors plates (B=L=0.5m-0.75m-1.00m) for different embedment ratios, (D_f/B=1-3-5). The geogrid element was modeled as a reinforcement in the analyses and the "Hardening Soil Model" was used as a soil model. The parameters investigated are the first reinforcement layer position, number of reinforcement layers, and length of the reinforcement layers. The results proved that the reinforcement had a considerable effect on the uplift capacity of the strip anchor plates in sand. Also, the improvement in bearing capacity of strip anchor plates in sand was found to be strongly dependent on the embedment ratio, and relative density of sand. The failure mechanism of strip plate anchors which are subjected to uplift forces was investigated in both reinforced and unreiforced soil conditions in order to observe the effect of reinforcement on failure mechanism. Based on the three dimensional finite element analyses, optimum values of the geogrid parameters for maximum reinforcing effect are discussed and suggested.

Keywords: plate anchors, sand, uplift capacity, geogrid, finite element method

1 INTRODUCTION

There are some kind of structures subjected to uplift forces and overturning moments such as transmission towers, anchored bulkheads, marine structures, traffic signs, submerged pipelines, tunnels etc. In these cases, foundations may be supported by tension elements as an economical solution in order to tolerate effects of relevant forces and moments. One of the tension elements is anchor plates which are generally fixed to structures and are embedded to sufficient soil depths to provide adequate amounts of support within required safety limits. Plate anchors are light structural members employed to withstand uplift forces. They are generally made of steel, precast concrete, poured concrete or timber and may be formed into shapes such as square, rectangular, circular and strip (Keskin 2015).

In geotechnical engineering, it has been conducted a variety of experimental and theorical studies in order to determine the uplift capacity for recent fifty years. Meyerhof ve Adams (1968) proposed a theory to describe uplift capacity by way of empirical equations. The theory was accepted rational propose for subject of uplift capacity. Figure 1 reveals the failure mechanism of continuous foundation under the ultimate uplift force, Q_u (Das 2009). Meyerhof and Adams (1968) described the uplift capacity for strip anchors as;

$$Q_u = W + K_u.\gamma.D_f^{\,2}.\tan\phi \tag{1}$$

where K_u = nominal uplift coefficient, D_f = embedment depth, and ϕ = angle of friction.

Geddes *et al.* (1996), conducted model tests in which vertical directional uplift force was applied to determine the uplift capacity of a group of square anchor plates embedded in sand bed and in different configurations. Model tests were carried out with single embedment ratio (D_f/B = 4) in dry sand with constant density. The uplift capacity of the anchor plates increased by a critical value due to the increase in the distance between the plates. It is also stated that the group productivity of the anchors increases with the relatively small increases in the ratio (*s/B*), where *s* = distance between anchors, and *B* = anchors width.

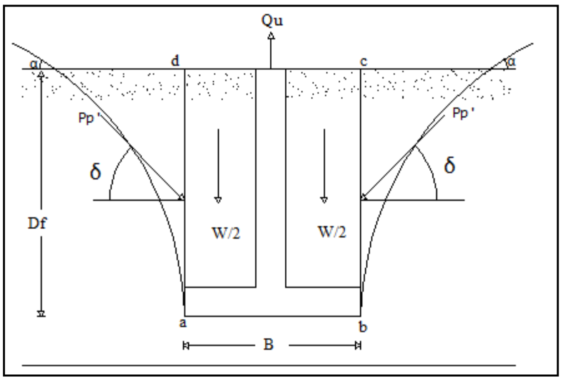


Figure 1. Continuous foundation subjected to uplift (Das 2009)

Patra *et al.* (2004), investigated the uplift capacity of the broad-base anchor plate embedded in the layered and homogeneous sand under axial and inclined uplift loads. According to the results obtained studies, the uplift capacity of the anchor plate increased due to the increase of the embedment ratio and base width. Also it was seen that the uplift capacity was affected by inclined loading.

Dickin and Laman (2007), were investigated the uplift capacity of strip anchors embedded in cohesionless soil by performing finite elements method and model experiments. As a result of the studies, it was seen that the uplift capacity increased with the embedment ratio and the density of sand.

Bildik and Laman (2011), conducted model tests to determine the uplift capacity of anchor plates embedded in cohesionless soil. In the model tests, the effects of embedment depth, anchors geometry and density of sand on the uplift capacity were investigated by using square and rectangular anchor plates. According to the results obtained from the model tests, a general equation has been obtained from the breakout factor-embedment ratio curves both loose and dense sand conditions.

Emirler *et al.* (2015), numerically analyzed the behavior of uplift capacity of square anchor plates embedded in layered soils. As a result, it was found that the behavior of uplift capacity was significantly influenced by the embedment depth and layer thickness.

In this study, the uplift capacity of strip anchors plates in sand was investigated numerically with and without geogrid reinforcement. Analyses were performed by using commercially available computer program PLAXIS 3D Tunnel. In the analyses, the effects of a variety of geogrid parameters such as the effect of the depth of the single layer of geogrid, number of geogrid layers, vertical spacing of geogrid layers and the length of geogrid layers were investigated as a main purpose and the optimum vaules of these parameters were obtained. Also the uplift capacity of strip anchors were obtained for three different size and two relative densities (D_r = 35% - 85%) by used optimum parameters.

2 FINITE ELEMENT ANALYSES

Series of three-dimensional finite element analyses on a model plate anchor-soil system were carried out in order to provide insights into the uplift behaviour within the soil mass. The finite element analysis was performed using the commercial program *PLAXIS 3D Tunnel* (version 2.0). In the numerical study, only a quarter of the plate anchor was modeled using symmetry conditions at the plate anchor centerline, to reduce the calculation time. The sand soil was modeled as *Hardening Soil* material model. After the geometry was created, boundary conditions were determined and finite elements mesh was generated at medium mesh coarseness. Also, the anchor plate was modeled as plate elements and the geogrid elements used as a reinforcement. The analyses were carried out using a three dimensional model in sand with two different densities. Values of parameters used in the numerical investigation are shown in Table 1. Shear strength and stiffness parameters representing sand conditions derived from series of drained triaxial compression tests. The 3D finite element mesh used for analyses is shown in Fig. 2.

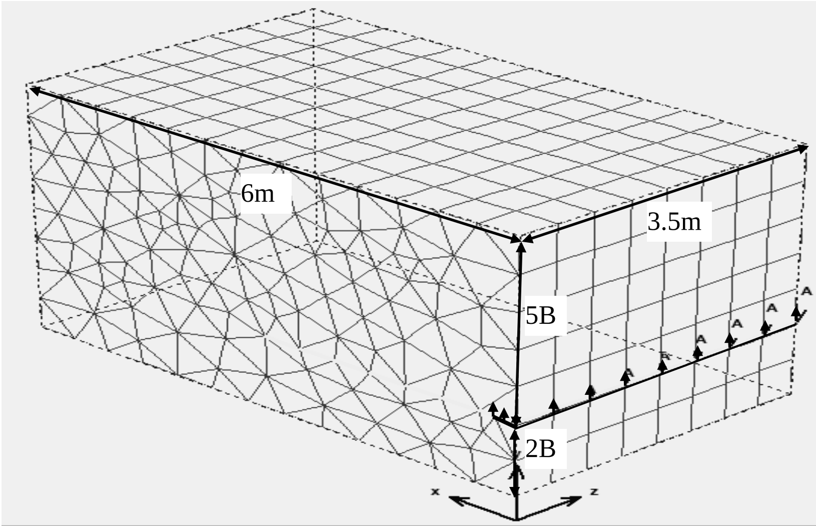


Figure 2. Geometric model and finite element mesh generation

Table 1. HS model parameters

Parameters	**(D_r = %35)**	**(D_r = %85)**
Unit weight, γ (kN/m^3)	15.4	17.0
E_{50} (kN/m^2)	21600	30000
E_{ur} (kN/m^2)	64800	90000
E_{oed} (kN/m^2)	21600	30000
Poisson's ratio, ν (-)	0.25	0.25
Internal friction angle, ϕ (°)	39	44
Cohesion, c (kN/m^2)	0.5	0.5
Dilatation angle, ψ (°)	9	14
Ref. Stress value, P_{ref}, kN/m^2	100	100
Earth pressure coefficient, K_0 (-)	0.43	0.33
Failure ratio, R_f, (-)	0.90	0.90

3 RESULTS AND DISCUSSION

The uplift capacity for the various arrangements of reinforcement, sand conditions, and embedment depth is discussed. In the analyses, a peak value is never observed. In this case choosing a single value of uplift capacity may be extremely subjective. In this study, the ultimate uplift capacity and corresponding displacement were defined as occurring at the point where the displacements began to take place under essentially constant load. In order to observe increasing of uplift capacity due to using geogrid, the term of uplift capacity ratio (*UCR*) was assumed:

$$UCR = \frac{Q_{ur}}{Q_u} \tag{2}$$

where Q_{ur} and Q_u are the ultimate uplift capacity for the reinforced and the unreinforced soils, respectively.

In this study, ten series of analyses were performed to investigate the inclusion effect of the geogrid layers on the plate anchor behaviour. Analyses were carried out to find out the best location, length, and configuration of the geogrid layers that give the maximum improvement in plate anchor response. Also, the effects of embedment depth and the relative density of sand on the behaviour of plate anchor were investigated. Each series of analyses was performed to study the effect of one parameter while the other variables were kept constant. Fig. 3 and Table 4 summarize all test programs with constant and variable parameters used.

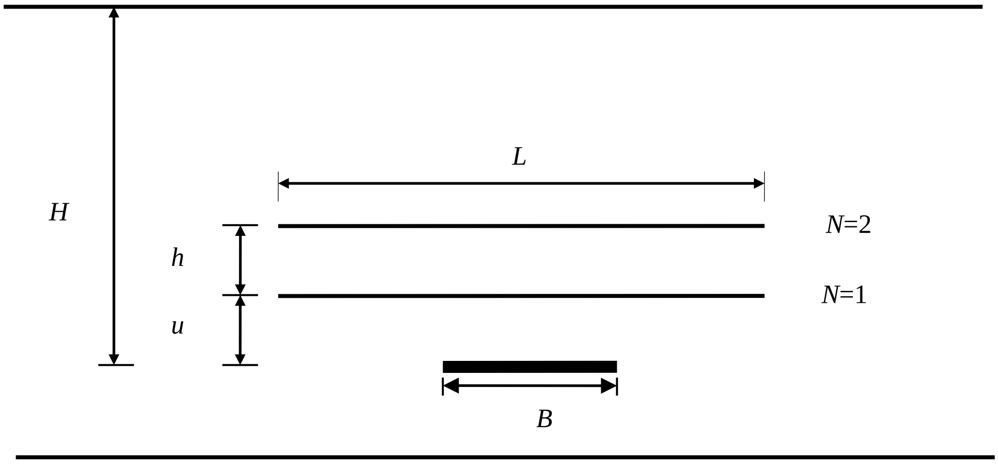


Figure 3. Geometric parameters

Table 2. Analyses plan

Series	Constant Parameters	Variable Parameters
I	*B*=0.5m, unreinforced	D_r=%35, %85
II	*B*=0.75m, unreinforced	D_r=%35, %85
III	*B*=1.00m, unreinforced	D_r=%35, %85
IV	*B*=0.5m, D_r=35%, *N*=1, *L/B*=24	*u/B*=0.03, 0.04, 0.05, 0.06, 0.08
V	*B*=0.5m, D_r=35%, N=2, *L/B*=24, *u/B*=opt.	*h/B*=0.02, 0.04, 0.06, 0.08
VI	*B*=0.5m, D_r=35%, *N*=1, *u/B*=opt.	*L/B*=2, 4, 6, 8
VII	D_r=35%, *N*=1, *u/B*=opt., *L/B*=opt.	*B*=0.5m, 0.75m, 1.00m
VIII	D_r=85%, N=1, *u/B*=opt., *L/B*=opt.	*B*=0.5m, 0.75m, 1.00m
IX	D_r=35%, *B*=0.5m, *N*=1, *u/B*=opt., *L/B*=opt.	*H/B*=1, 3, 5
X	D_r=85%, *B*=0.5m, *N*=1, *u/B*=opt., *L/B*=opt.	*H/B*=1, 3, 5

where *B* = width of strip plate anchor, *u* = depth of the first reinforcement layer, *h* = vertical spacing between geogrid layers, *L* = length of geogrid layers, *H* = embedment depth, and, *N* = number of geogrid layers.

3.1 *Effect of first geogrid layer depth*

The tests in this series were performed to determine the relation of uplift capacity to depth ratio, u/B. For the tests, the values of *N*, and *L* were kept constant as *N*=1 and *L*=24*B*. The width of the plate anchor was *B*=0.5m, the relative density of sand was D_r=35% and the embedment ratio was *H/B*=5. The *u/B* ratios were varied from 0.03 to 0.08. Figure 4 shows the relation of *UCR* to *u/B* obtained from finite element analyses. It can be seen from the figure that the effect of the depth to the first reinforcement layer on uplift capacity is clearly significant. Figure 4 shows that, maximum improvement in the uplift capacity of plate anchor is achieved when the geogrid layer is placed directly on top of the anchor plate. The improvements in the uplift capacity of plate anchor decrease as the distance between the geogrid layer and the plate anchor increases. At larger depths of embedment the contribution to the load transfer mechanism caused by the presence of the reinforcement reduces significantly. For *u/B* values of greater than 0.03, the entire system behaves more or less like unreinforced sand.

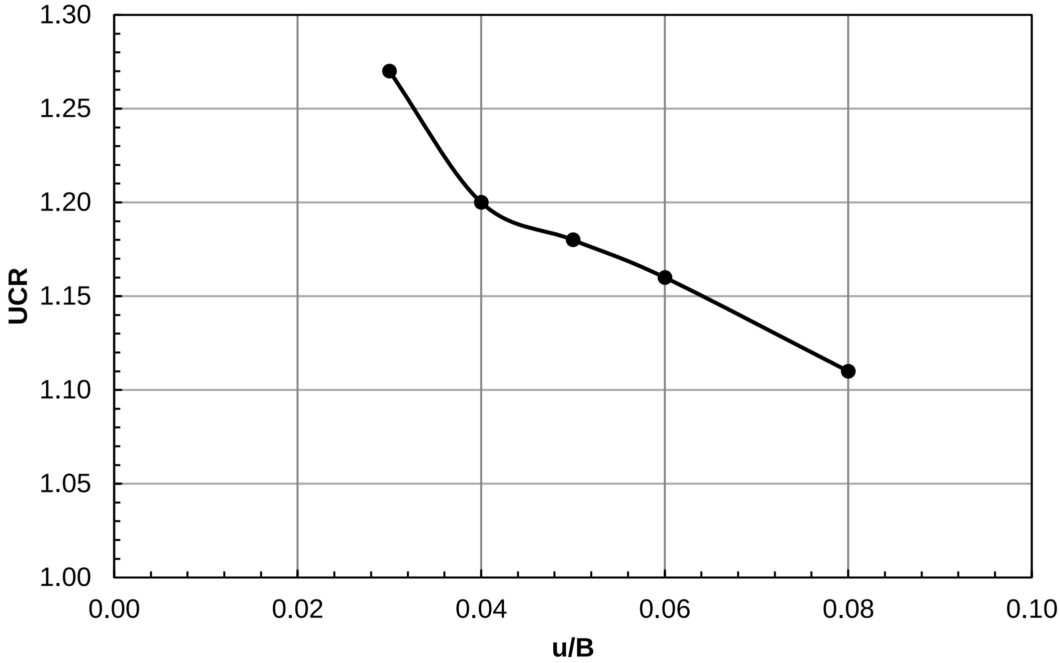


Figure 4. Variation of *UCR* with *u/B*

3.2 *Effect of vertical spacing of geogrid layers*

The effect of vertical spacing of reinforcement layers (h) on uplift capacity was investigated using two layers of geogrid reinforcement with a top layer spacing of u=0.03B. For the analyses, the plate anchor width was B=0.5m, the relative density of sand was D_r=35%, embedment ratio was H/B=5 and length of reinforcement L was kept constant as 24B. The vertical spacing ratios of reinforcement were varied from 0.02 to 0.08. Figure 5 shows the variation of *UCR* with h/B. It can be seen from the Figure 5 that there is no considerable increase in *UCR* with using two geogrid layers. It can be said that the addition of more layers of reinforcement after the first did not contribute much to the uplift capacity improvement.

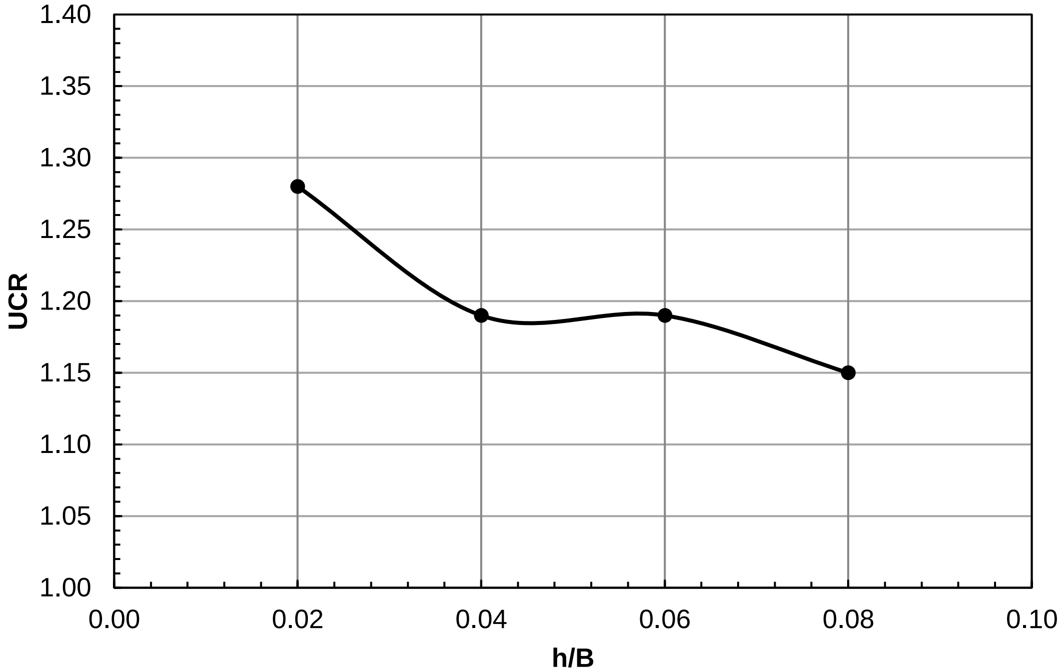


Figure 5. Variation of *UCR* with *h/B*

3.3 *Effect of length of geogrid layers*

This series of analyses were carried out to investigate the effect of the reinforcing element length on *UCR*. In these analyses, the lengths of the geogrid layers were varied from 2*B* to 8*B*. For the analyses, the values of *u/B* and *N* were kept constant as 0.03 and 1, respectively. Figure 6 shows the variation of *UCR* with length of reinforcement, *L*. It can be seen from the figure that uplift capacity ratios obtained from analyses increase rapidly with increasing reinforcement layer length, and remains relatively constant for *L*=6*B*.

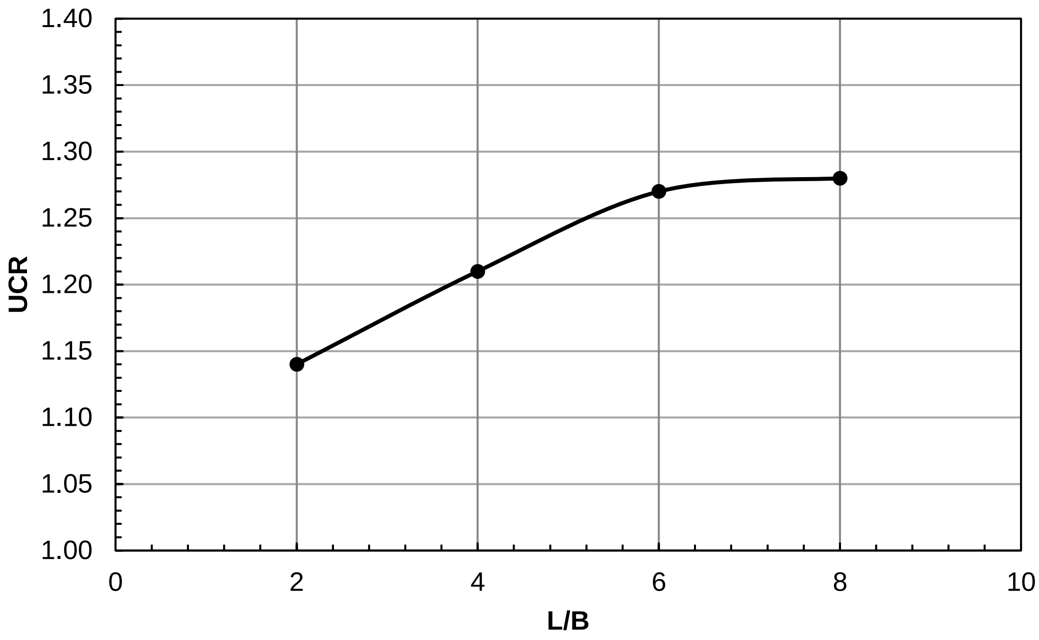
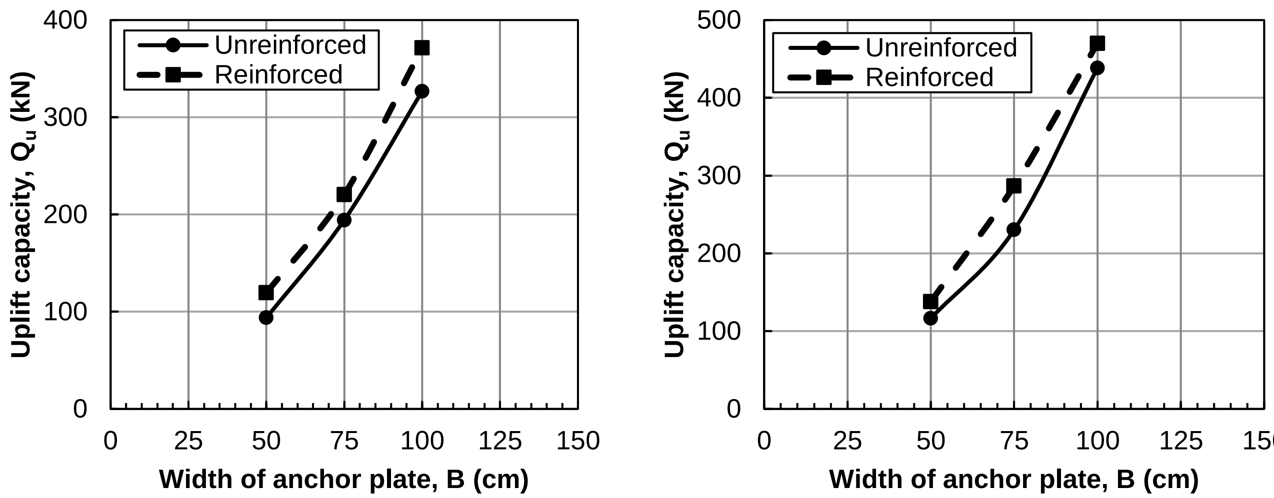


Figure 6. Variation of *UCR* with *L/B*

3.4 *Effect of plate anchor width and relative density of sand*

In order to investigate the effect of relative density of sand and plate anchor width on uplift capacity, series of finite element analyses were performed. In the analyses, two different densities (D_r=35% and 85%) and three different plate anchors width (*B*=0.5m-0.75m and 1.00m) were used. In these analyses, the values of *u/B* was *0.03, N* was 1, and the length of the geogrid layer was used 6*B*. Figs.7a and 7b show the ultimate uplift capacities obtained from analyses with relative densities of D_r=35% and 85% for strip plate anchors of *B*=0.5m, 0.75m, and 1.00m, respectively. It can be seen from Fig. 7a and 7b, the uplift capacity increase with an increase in relative density and anchor width.



(a) (b)

Figure 7. Variation of Q_u with *B* (a) D_r=35%, (b) D_r=85%

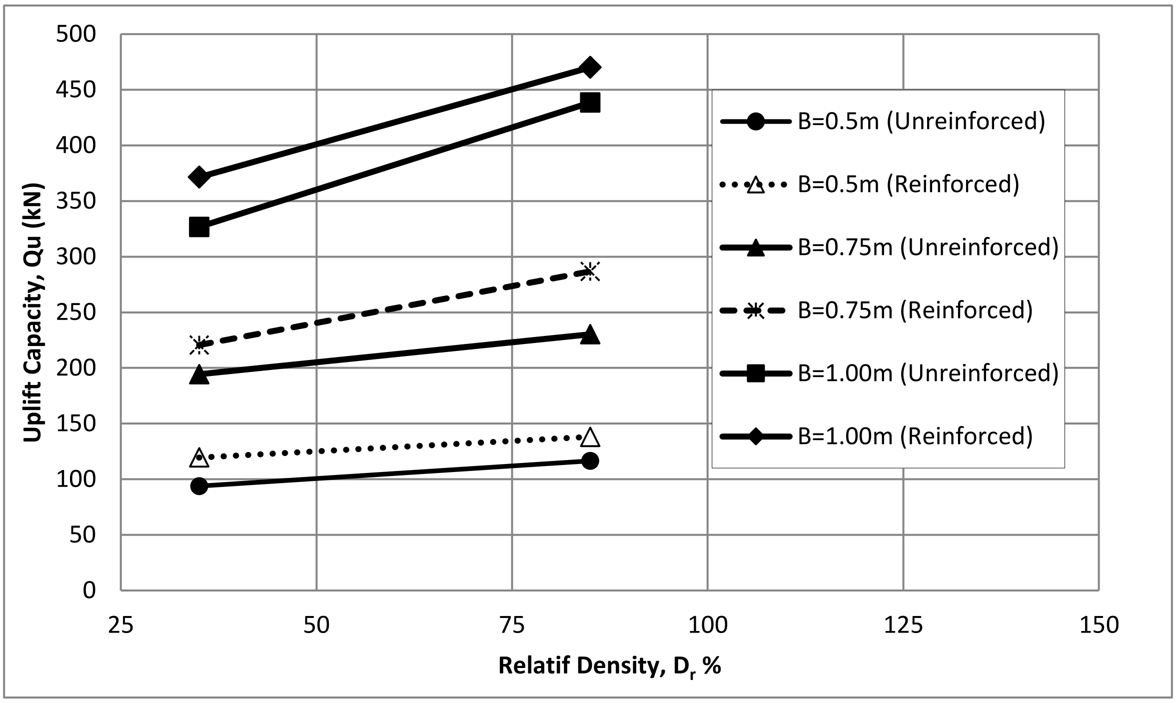


Figure 8. Variation of Q_u with D_r

Figure 8 shows the relationship between the uplift capacity and relative density of sand for various plate anchor width. From Figure 8, it is clear that, uplift capacity increases with an increase in relative density of sand for both reinforced and unreinforced cases.

3.5 *Effect of embedment ratio*

The analyses in this series were performed to determine the relation of uplift capacity, Q_u to embedment ratio, *H/B* for reinforced case. In the analyses, 0.5m strip plate anchor was used and the relative densities were D_r=35% and 85%. The *H/B* ratios were selected as 1.00, 3.00 and, 5.00. In the analyses, the values of *u/B* was *0.03, N* was 1, and the length of the geogrid layer was used 6*B*. From Figure 9, it can be seen that, ultimate uplift capacity, Q_u increases significantly with an increase in embedment ratio, *H/B*.

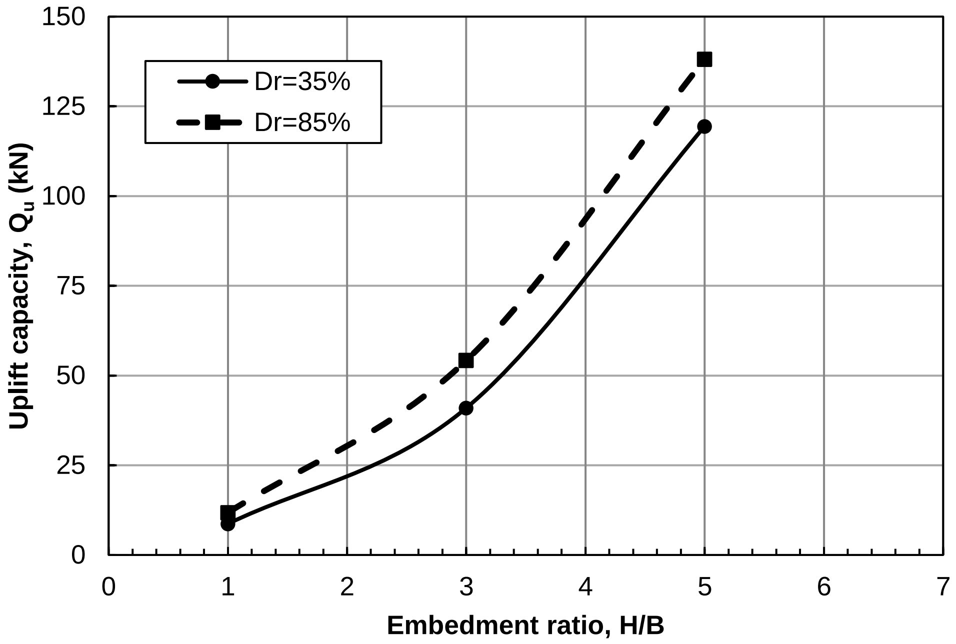


Figure 9. Variation of Q_u with *H/B*

3.6 *Failure mechanism*

The failure mechanism was examined based on the displacement contours obtained from numerical analysis. Figure 10a and 10b present displacement plots for unreinforced and reinforced cases at ultimate conditions, respectively. Fig. 10b shows that for unreinforced case, uplift loading of the plate anchor causes curved shear surface form beginning at the anchor and continue to develop until reaching the soil surface. The observed displacement contours at failure for reinforced case (Fig.10a) are distributed for greater width and depth than that in unreinforced case. Sand-geogrid interaction results in increasing the uplift capacity due to developed longer failure surface.

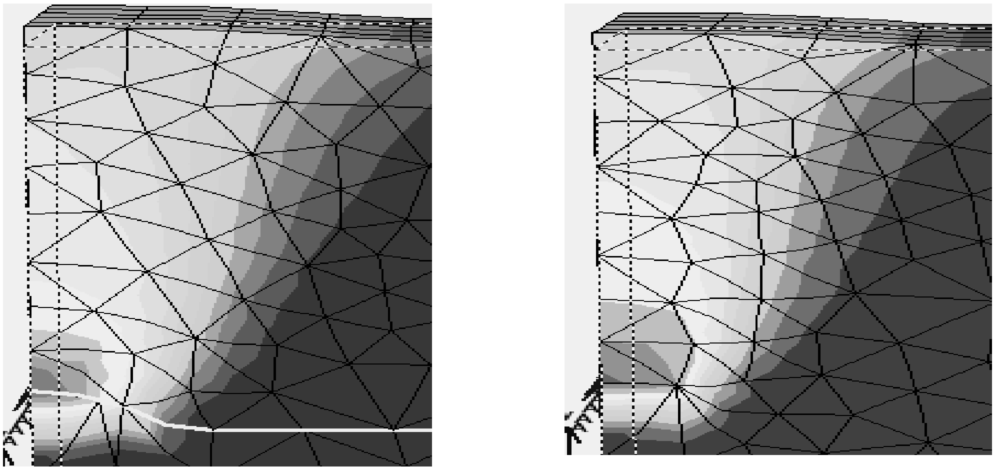


Figure 10. Displacement contours (a) reinforced case (b) unreinforced case

4 CONCLUSIONS

The uplift capacity of strip plate anchors in geogrid reinforced sand was investigated numerically. Based on the results, the following main conclusions can be drawn:

- A significant improvement in plate anchor performance in sand can be obtained by using geogrid reinforcements. Depending on the geogrid arrangement, ultimate uplift capacity values can be improved by up to approximately 1.30 times those of the unreinforced case.
- To obtain maximum benefit from the reinforcement, the optimum depth-footing width ratio (u/B) is 0.03 and addition of more than one layer of geogrid did not contribute much to the uplift capacity improvement. The optimum length of geogrid layer (L) that contribute to the increase of uplift capacity is found to be 6B.
- 3D numerical studies show that uplift capacity for strip plate anchors in sand increase with an increase in anchor embedment ratio, anchor plate width, and relative density of sand.

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