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Research Paper

A Review on Pull-Out Capacity of Helical Anchors in Clay And Sand

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ABSTRACT: *Helical anchors have been used widely in engineering application .They can be used to provide structural stability against axial compression ,uplift and lateral forces. In recent years, helical anchor foundations have become more widely used in many countries. Earth anchors are primarily designed to resist outwardly directed loads (pull out loads) imposed on structure such as foundations, earth retaining structures, and slopes. Anchors transfer these outwardly directed loads to deep soil and rock strata. Generally anchors are used to resist reactions which are greater than the self weight of the structure. These reactions may be due to lateral wind forces, earth pressures, uplift force due to expansive soils etc. Buried anchors have been used for thousands of years to stabilize lightweight structures like tents. Nowadays earth anchors of various types are used for uplift resistance of transmission towers, utility poles, aircraft moorings, submerged pipelines, and tunnels. They are also used for tieback resistance of earth retaining structures, waterfront structures, at bends in pressure pipelines, and when it is necessary to control thermal stresses. The paper observed that the ultimate uplift capacity is dependent on the relative undrained/drained shear strength of cohesionless soil, the depth ratio of embedment and soil thickness ratio. The pull out capacity of helical anchors increases with increase in the number of helixes, spacing between the helixes, embedment depth as well as the oblique while compared to that of oblique pull.*

Keywords: *Clay, Helical anchor, Pullout test, Screw anchor, Sand.*

I. INTRODUCTION

The earliest helical anchor created by a blind English brick maker names Alexander Mitchell for designing a foundation support of a lighthouse in 1833. The concept of “screw pile” was very successful in the designing but the development of helical plate foundation was not progress (Chance, 2004). Until 1950’s, a power-installed screw anchor for resisting tension load was found in US and this type of anchor was starting popular and widely used in the construction site. The helical anchor formed by a steel shaft which one or more helical plates welded to the shaft to create a “screw anchor”. Helical anchors are primary designed and constructed to provide the uplift resistance to the foundation of a structure. General review consists of research papers on various aspects of investigations on helical anchors like their pullout capacity in clay and sand, stress displacement relationships, stresses and strains induced around them during installation and pullout, effect of submergence and surcharge, effect of pitch, embedment, spacing of plate, behavior in group etc. Analysis in different papers incorporates different methods of analysis like numerical, analytical, empirical or experimental and theoretical or mathematical model.

Ghaly and Hanna (1991) provided remarkable studies on the failure surface developed due to helical anchors embedded in sands; Mooney et al. (1985) provided theoretical methodology for determining uplift capacity of anchors in clay which was further extended by Rao and Prasad(1993) depending upon the spacing of the helical plates; Ghaly, Hanna and Ranjan(1992) showed the effect of submergence and surcharge on the pullout capacity of anchors further Ghaly and Hanna(1991) investigated upon the stresses induced in the soil on installation and uplift of anchor; Hanna, Ayadat and Sabry(2006) determined pullout capacity, radius of influence on the assumption of log spiral failure surface; Tsuha, Aoki, Rault, Thorel and Garnier(2012) evaluated the efficiencies of helical anchor plates in sand by centrifuge model tests; Wang, Merifield and Gaudin(2013) investigated uplift behavior of helical anchors in clay by large deformation finite element analysis and centrifuge tests; paper by Mittal and Mukharjee(2014) presents empirical estimation of pullout capacity of group of anchors.

Some figures 1, 2, 3, 4 show various uses of anchor pile

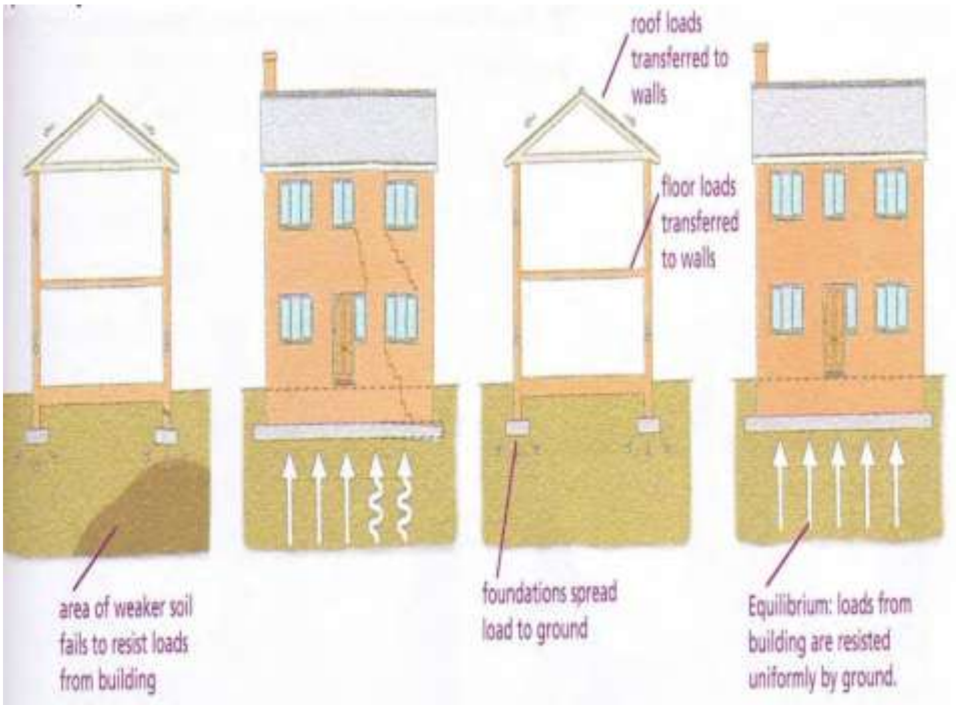


Figure 1: Using the anchors in foundations

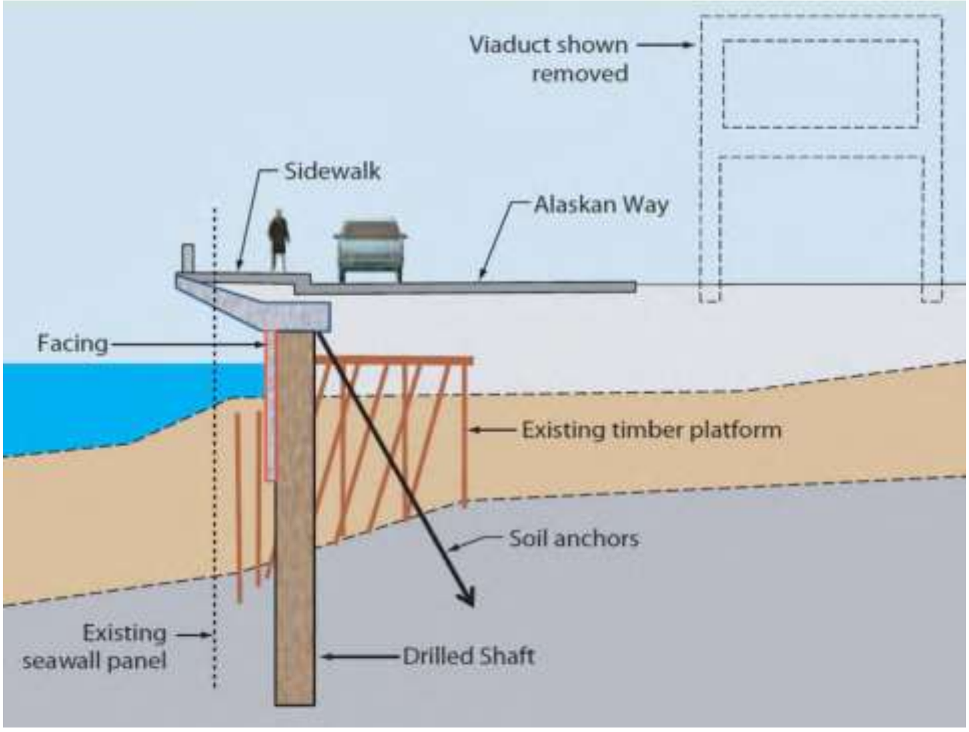


Figure 2: Using Soil Anchors In Seawall

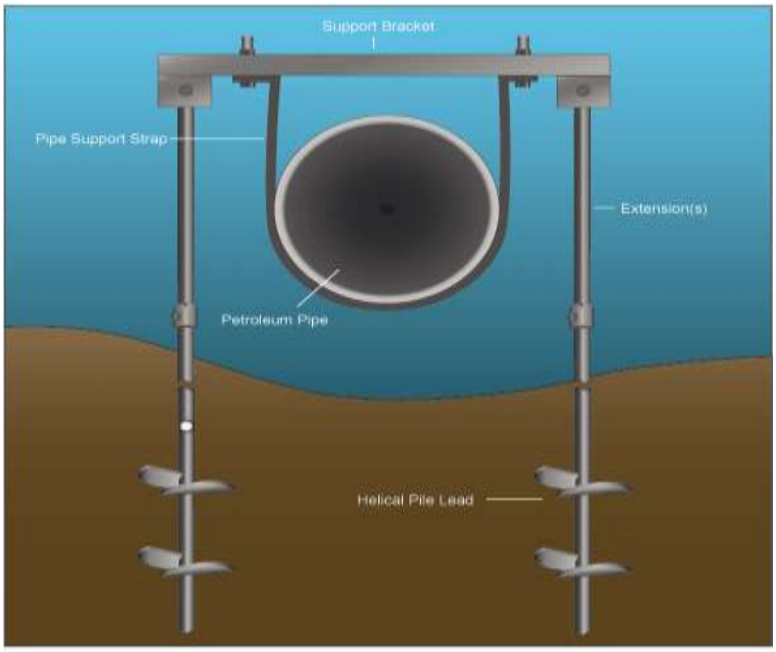


Figure 3: using the soil anchor in pipelines

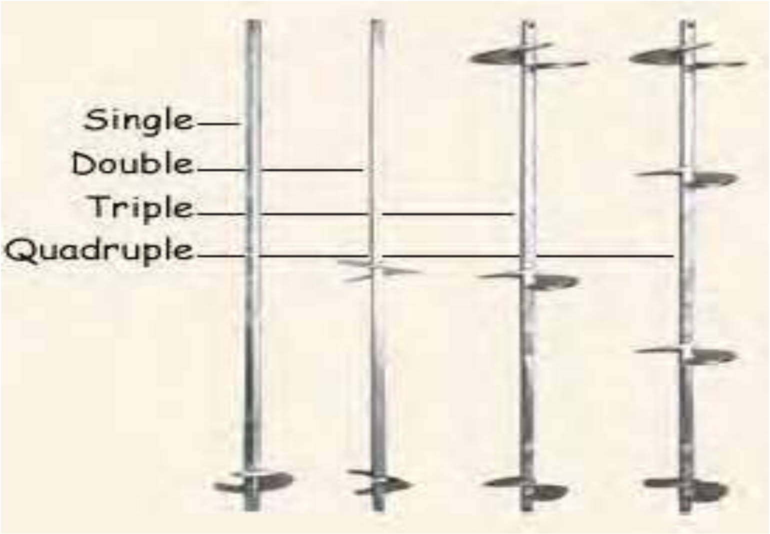


Figure 4: screw anchors

II. TYPES OF ANCHOR PILE

At present time, earth anchors can be divided into these categories: plate anchors, direct embedment anchors, helical anchors, grouted anchors, anchor piles and drilled shafts, suction caisson and drag anchors, and geo-anchors. But the earlier and most popular form of anchors used in soil for resisting vertically directed uplifting loads were screw or helical anchors. Helical anchors consist of a steel shaft with one or more helices attached to it, known as single or multiple helical anchors respectively. For multi helix anchors the pitch and center to center spacing of the helices can be varied so that upper helices follow the lower ones, this minimizes disturbance of the surrounding soil. They are screwed into the ground using hydraulic torque motors. In addition to resist tensile loads these anchors can also supply additional bearing capacity to the foundation developed at helix soil interface. They can also be used to repair existing foundations with marginal disruption to the surrounding soil or installed to serve as a new foundation. Helical foundations are often used on ecologically delicate or limited-access sites due to negligible disturbance to the natural environment. Helical foundations are used commonly in areas that have highly expansive soils that affect foundations built within the active zone. The active zone of soil is

Significantly affected by seasonal fluctuations in moisture content. Expansive clay will shrink and swell with increasing and decreasing moisture contents, respectively, and often causes serious damage to foundations that are not designed and constructed to mitigate these effects. By embedding the helical plate below the depth of active seasonal movements, helical anchors can act as a bearing medium unaffected by the fluctuations in seasonal moisture (Pack, 2006).

III. DESIGN CRITERIA FOR HELICAL ANCHORS

Rao and Prasad (1993) intends to extend the work of Mooney et al. (1985) (who was among the first few who suggested design criteria for helical type of anchors in clay and silt). Mooney et al. assumed cylindrical failure surfaces between the top and bottom surfaces, however the authors considers the effect of spacing of helical plates and derived equations for pullout by conducting model tests. Four model anchors designated A1, A2, A3 and A4 were tested with spacing ratio (spacing of helical plates/diameter of helical plates) of 4.6, 2.3, 1.5 and 1.1 respectively. The spacing between top and the bottommost plate was constant i.e. only number of plates between the top and bottom one were varied to change the spacing ratio. Embedment ratio was taken to be zero to eliminate the bearing effect of the top most plate. Size of the tank was sufficient to minimize side effects according to Mooney et al. (1985). Arrangement was made to eliminate suction below the bottom helical plate. The tests were conducted at five different consistency Indices of soil.

Test Results:

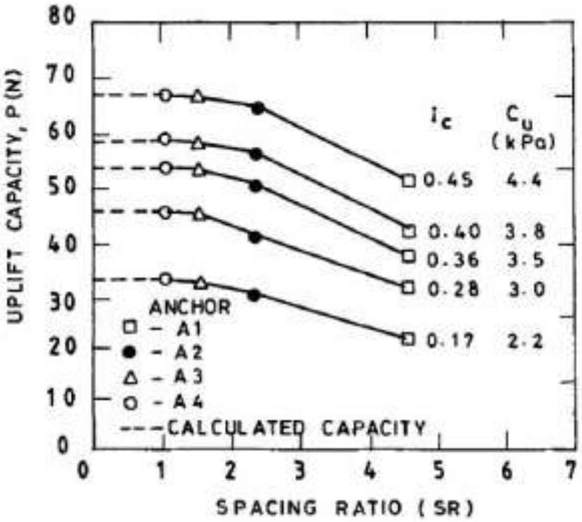


Figure 5: Variation of P of Anchors with SR at Different IC Values

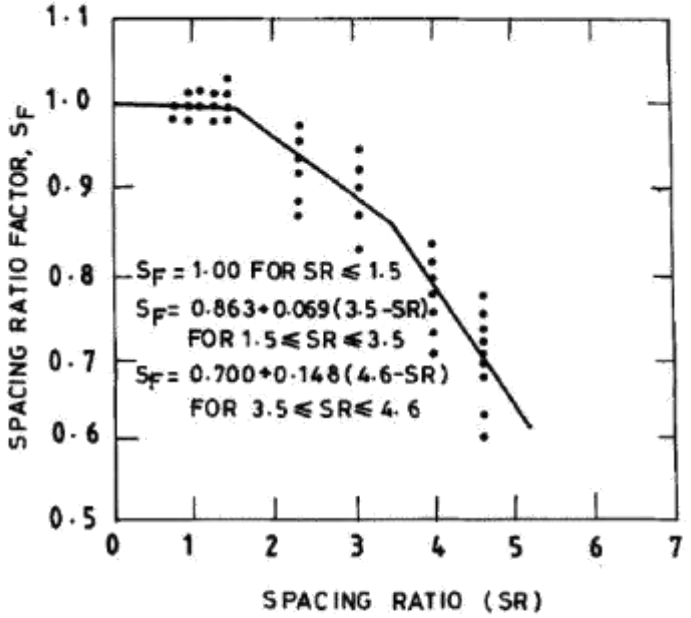


Figure 6: Variation of Sf with S.R.

We defined Spacing ratio factors SF to modify basic pull out capacity of multi plate helical anchors with zero embedment ratios given by Mooney et al.

$$Pu = \pi DLCu$$

$$SF = \text{experimental } (P)/Pu$$

Different values of Spacing ratio factors are defined by authors for different spacing ratios of anchors. Finally authors concluded that for spacing ratios beyond 1.5, the failure surfaces are not cylindrical and for such cases also, formulations to predict the capacities were suggested.

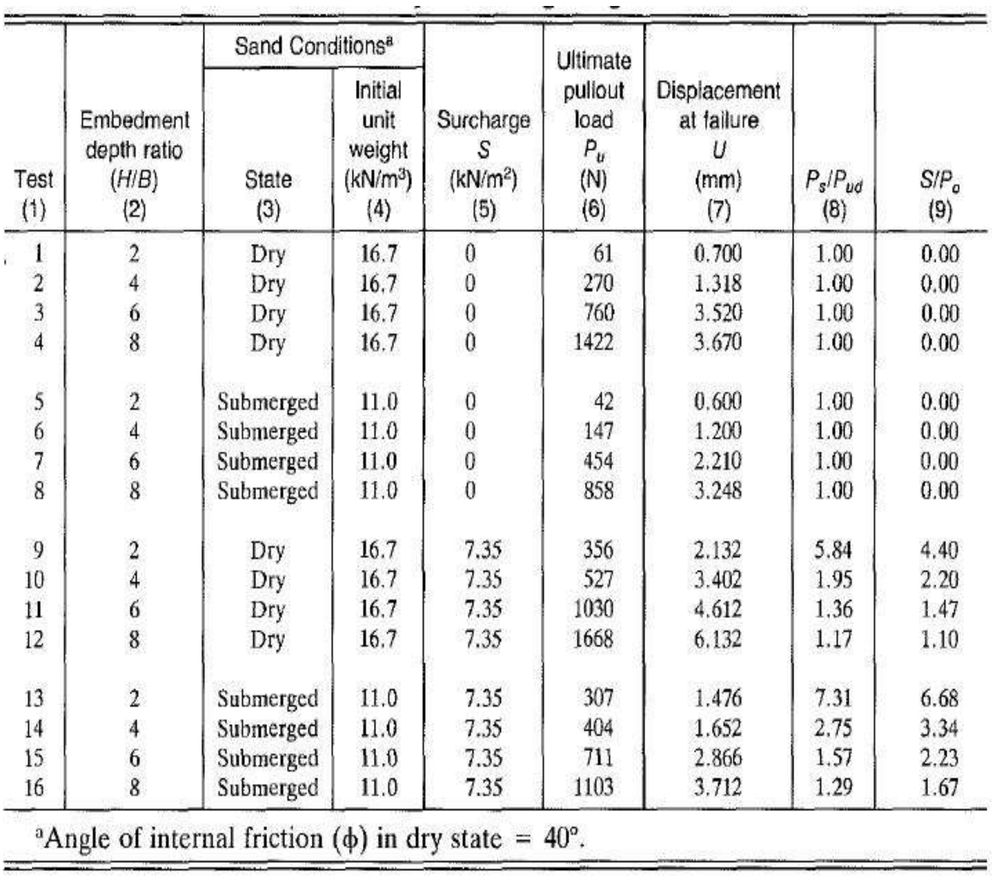
3.1 Effect of surcharge and submergence of anchors:

Ghaly et al. presented effect of surcharge and submergence of anchor. Non dimensional equations presenting the parameters affecting the uplift capacity of a single helical anchor and the applied surcharge intensity were proposed. It has been shown that the negative effect of submersion on the anchor's pullout capacity can be offset by applying surcharge on the sand surface.

Model anchor used for testing had the same dimensions as that used by Ghaly et al. 1991. Tests were done in a water proof tank to prevent leakage during the tests on submerged sands. Surcharge intensity was applied to the surface of the sand after installing the anchor and before applying the uplift force.

Test results:

Table 1: Various Test Results



Test (1)	Embedment depth ratio (H/B) (2)	Sand Conditions[a] State (3)	Initial unit weight (kN/m³) (4)	Surcharge S (kN/m²) (5)	Ultimate pullout load P_u (N) (6)	Displacement at failure U (mm) (7)	P_s/P_{ud} (8)	S/P_o (9)
1	2	Dry	16.7	0	61	0.700	1.00	0.00
2	4	Dry	16.7	0	270	1.318	1.00	0.00
3	6	Dry	16.7	0	760	3.520	1.00	0.00
4	8	Dry	16.7	0	1422	3.670	1.00	0.00
5	2	Submerged	11.0	0	42	0.600	1.00	0.00
6	4	Submerged	11.0	0	147	1.200	1.00	0.00
7	6	Submerged	11.0	0	454	2.210	1.00	0.00
8	8	Submerged	11.0	0	858	3.248	1.00	0.00
9	2	Dry	16.7	7.35	356	2.132	5.84	4.40
10	4	Dry	16.7	7.35	527	3.402	1.95	2.20
11	6	Dry	16.7	7.35	1030	4.612	1.36	1.47
12	8	Dry	16.7	7.35	1668	6.132	1.17	1.10
13	2	Submerged	11.0	7.35	307	1.476	7.31	6.68
14	4	Submerged	11.0	7.35	404	1.652	2.75	3.34
15	6	Submerged	11.0	7.35	711	2.866	1.57	2.23
16	8	Submerged	11.0	7.35	1103	3.712	1.29	1.67

[a] Angle of internal friction (ϕ) in dry state = 40°.

It is clearly seen that pullout capacity increases with the increase in surcharge and decreases with submergence, however the effect of surcharge decreases with the depth. Relations between non dimensional parameters were derived from the test results and was presented in graphical and mathematical form as shown below

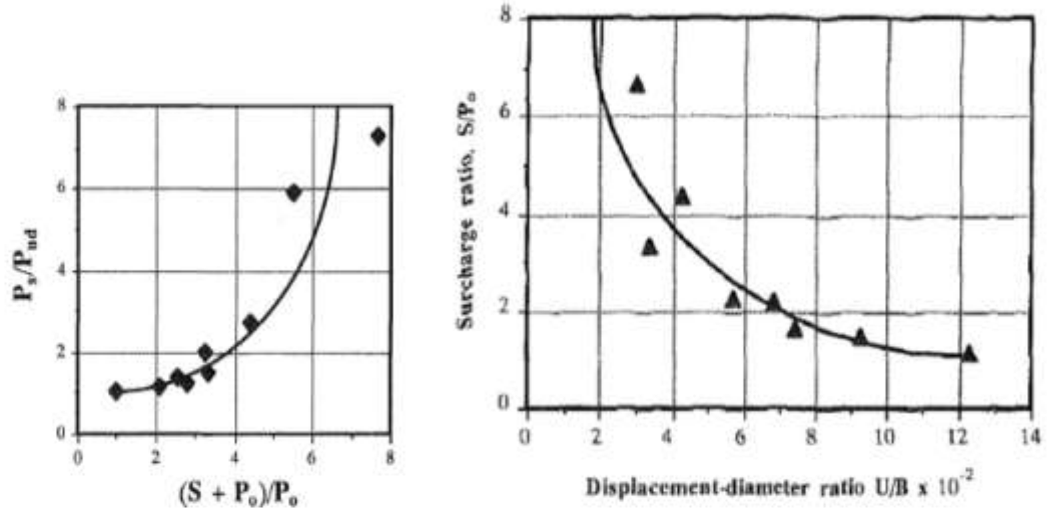


Figure 7: (a) Pullout-Load Ratio versus Total Surcharge-Overburden-Pressure Ratio
(b) Surcharge ratio V/S Diameter displacement ratio
y = a.10bx

Where a and b = constants; x = (S + Po)/Po; and y =Ps/Pud. From data provided by test results, a = 0.72 and b = 0.14. Hence (S + Po)/Po is the total overburden ratio and Ps/Pud is the ratio of uplift force with surcharge and without surcharge. The value of Pud can be computed from any of the available theories reported in literature. The upward displacement at failure (U) can be calculated from the above equation according to the required ratio of Ps/Pud. Also, for a given limit of upward displacement, the corresponding surcharge intensity can be calculated. Ghaly also concluded that in difficult soils where deep anchor installation is difficult, surcharge effect could considerably increase the pullout capacity moreover it could also overcome the effect of submergence of soil.

IV. PULL OUT CAPACITY AND LOAD DISPLACEMENT RELATIONSHIP

Hanna et al. (2007) presented analytical models to predict the pullout capacity and the load–displacement relationship for shallow single vertical helical and plate anchors in sand. The models were developed based on the failure mechanism deduced from laboratory testing and utilize the limit equilibrium technique. Expression was given to estimate the critical depth for a given anchor/soil conditions, which separates deep from shallow anchors. Furthermore, the radius of influence of a individual anchor on the ground surface is established, and accordingly, the spacing between anchors can be determined to avoid anchors interactions between anchors. The proposed theory compared well with the theories and the experimental data available in the literature.

4.1 Theoretical Model

The sand was assumed to be homogeneous, isotropic and behaves as a rigid-perfectly plastic material. In additional, the anchor's helix and plate were assumed to be thin and rigid and in full contact with the surrounding sand and the frictions between the sand and the tie-rod and the blade surfaces are ignored. The weight of the anchor is considered negligible. Failure surface was assumed to be logarithmic spiral: (as shown in the figure)

$$Z=a.\ln(r)+b$$

Here the parameters Z, a, b are as defined in the given figure. The constant a, depends on soil friction angle ϕ and the ratio [H/B]. Values of a and b are determined by boundary conditions. The pullout capacity can be calculated as:

$$Qu=Tv+W$$

Where W is the weight of the sand within the failure surface and Tv is the vertical component of the frictional resistance along the failure surface.

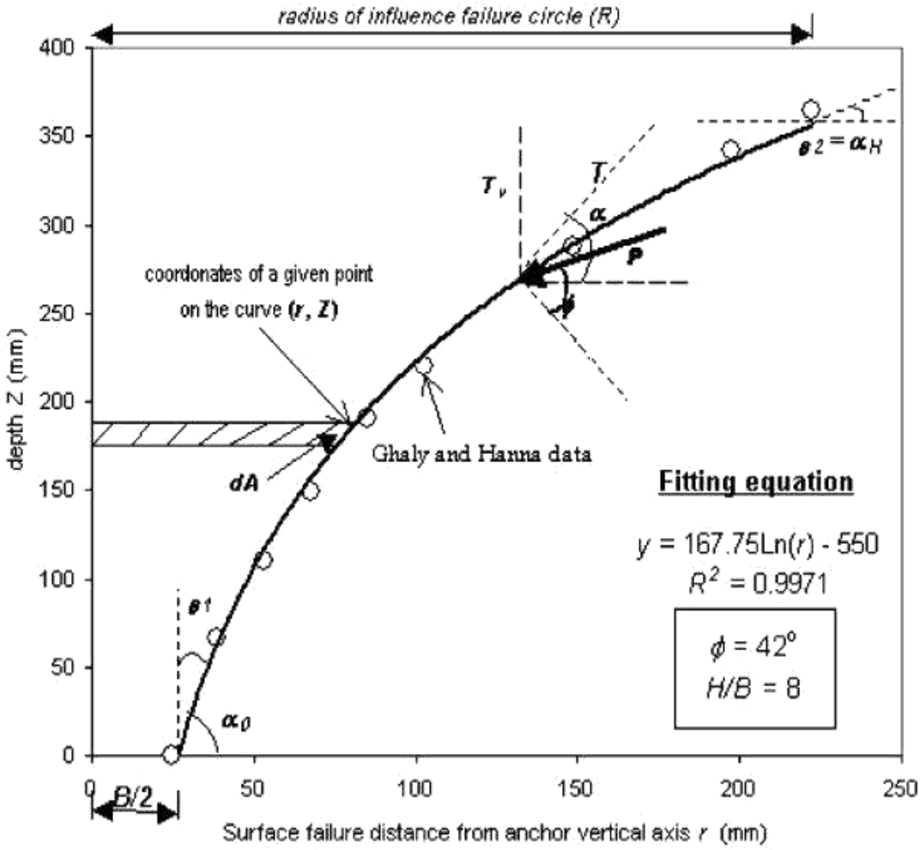


Figure 8: Typical logarithmic spiral rupture surface of shallow anchors

Test results:
Pullout load was derived as

$$Q_u = \bar{A} \cdot e^{\frac{2H}{a}} + \bar{B} \cdot e^{(k_2+1)\frac{H}{a}} - \bar{C} \cdot e^{(k_2+3)\frac{H}{a}} + \bar{D}$$

Where,

$$\bar{A} = \frac{\pi}{8} \cdot \gamma \cdot B^2 \cdot a$$

$$\bar{B} = \pi \cdot B \cdot k_1 \cdot \left(\frac{B}{2a}\right)^{k_2} \cdot \frac{a^2}{(k_2+1)^2} \cdot \gamma \cdot \sin\varphi$$

$$\bar{C} = \frac{1}{8}\pi \cdot k_1 \cdot \left(\frac{B}{2a}\right)^{k_2} \cdot \frac{B^3}{(k_2+3)^2} \cdot \gamma \cdot \sin\varphi$$

$$\begin{aligned}\bar{D} = {} & \frac{1}{8}\pi \cdot k_1 \cdot \left(\frac{B}{2a}\right)^{k_2} \cdot \frac{B^3}{a^2} \cdot \gamma \cdot \sin\varphi \\ & \cdot \left(\frac{a^2}{(k_2+3)^2} + \frac{a}{(k_2+3)} \cdot H\right) - \pi \cdot B \cdot k_1 \cdot \left(\frac{B}{2a}\right)^{k_2} \\ & \cdot \gamma \cdot \sin\varphi \cdot \left(\frac{a^2}{(k_2+1)^2} + \frac{a}{(k_2+1)} \cdot H\right)\end{aligned}$$

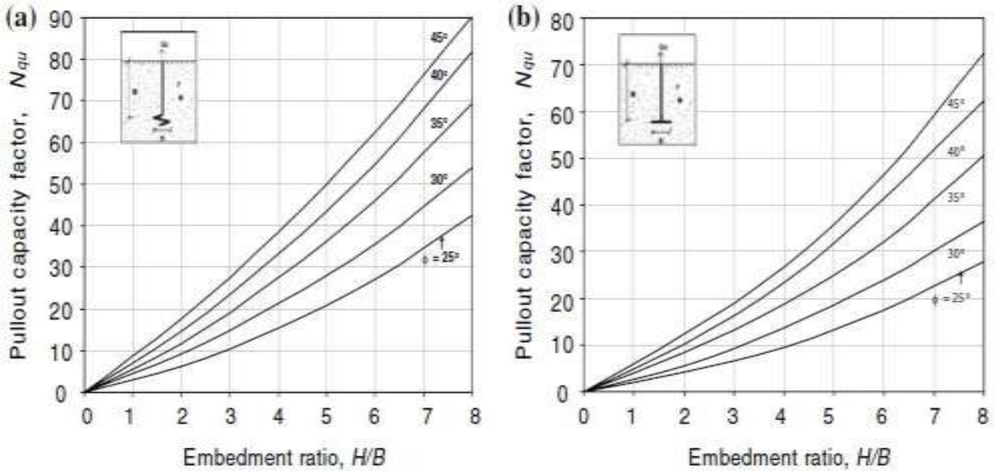


Figure 9: (a) Design chart for pullout capacity factor (Nqu) computation (helical anchors). (b) Design chart for pullout capacity factor (Nqu) computation (plate anchors)

However pullout capacity can also be determined by the graphical relation derived using above equations by the author for helical anchor as well as plate anchor (It should be mentioned herein that the values of the constant a for plate anchors were deduced by trials and error from using the pullout capacity results of Ilamparuthi et al. (2002).

Values of critical depth Hc which distinguish between deep and shallow anchors were also derived

For shallow anchors

$$H<H_c = B \cdot (0.4\varphi - 5)$$

For deep anchors

$$H>B \cdot (0.4\varphi - 3)$$

The value of R (radius of influence) can be derived as,

$$R = \frac{B}{2} \cdot e^{\frac{H}{a}}$$

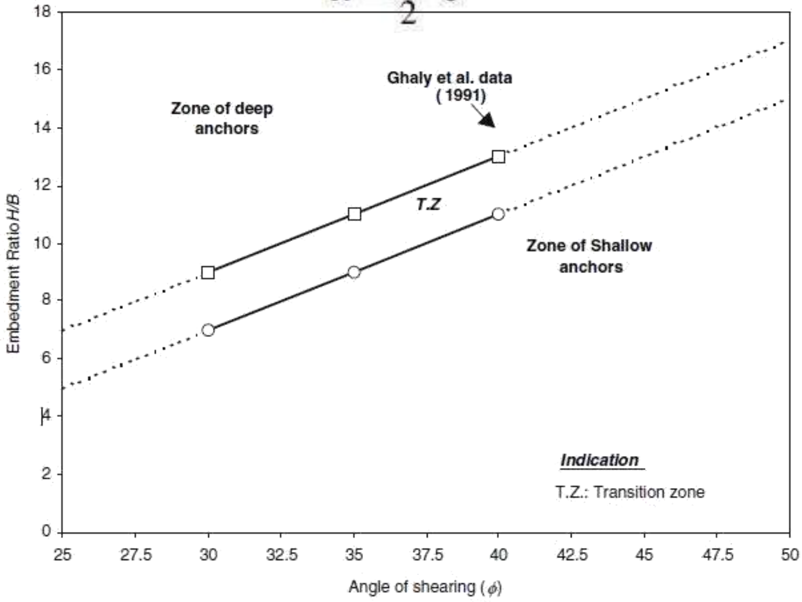


Figure 10: Variation of critical height Hc with soil friction angle ϕ and anchor width

Accordingly, spacing between anchors can be established to avoid overlap of the stress zones of these anchors. In case of overlap, group action should be taken into consideration in determining the capacity of individual anchors.

The predicted values by the proposed theory compared well with the experimental and field data of single and multi helix, plate anchors and belled piles in loose and medium-dense sand. Discrepancies were noted between the calculated and the measured results for these anchors in dense sand, which believed due to the dilatancy effect at shallow depths.

V. CONCLUSION

Earth anchors are primarily designed to resist outwardly directed loads (pull out loads) imposed on structures such as foundations, earth retaining structures, and slopes. Anchors transfer these outwardly directed loads to deep soil and rock strata. Pullout capacity helical anchors in clay and sand, stress displacement relationships, stresses and strains induced around them during installation and pullout, effect of submergence and surcharge, effect of pitch, embedment, spacing of plate, behavior in group etc. Pullout capacity of helical anchors is a function of many parameters. There is vast literature available on the theoretical, experimental and numerical analysis of effect of these parameters on the pullout capacity of anchors. Since anchors are mostly installed in groups, so the pitch and center to center spacing of the helices can be varied that upper helices follow the lower ones, this minimizes disturbance of the surrounding soil. Pullout capacity of helical anchors is a function of (i) the type of soil and its density; (ii) bearing capacity of plate material; (iii) adhesion between the plate and shaft with the soil; (iv) interaction between bearing elements; (v) embedment depth of the anchor and (vi) the shaft angle of anchor.

A more rigorous three dimensional analysis is planned to compare the pullout capacity of single anchor and the group of anchors and factors affecting it. Displacement defined pullout test was performed on the multi-strip anchor defined in the section. Vertical displacement of 0.1 meter was applied uniformly on the anchor.

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