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Study On Uplift Behavior of Single Belled Anchors in Multiple Regression Analyses

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Abstract: *This trial study clarifies the elevate limits of single belled stay models in homogeneous and two-layered (lesser thick sand is hidden higher thick sand) sand bed to assess the commitment of installation proportions of 3, 4 and 5, breadth proportions of 0.28, 0.33, 0.38 and 0.46, and ringer edges of 45, 54, 63 and 72°. Higher elevate limits are accomplished in layered sand contrasted with homogeneous sand store in each model in any case the estimations of implant proportions, distance across proportions and ringer edges. Also, it has been seen that elevate limits in the two sorts of sand layers are expanded with higher installation proportions, lesser distance across proportions and more extreme chime points. An undertaking is made to set up six quantities of different relapse conditions which would have the option to foresee breakout factors inside determined cutoff points. These conditions are checked with scarcely any current test outcomes which are not utilized in building up those conditions, and the blunders in 76.67% and rest 23.33% of predicted values of breakout factors are inside the scopes of +08.35 to and +11.48 to dependent on watched aftereffects of present examination.*
Key words: *Uplift capacity, Homogeneous sand, Layered sand, Breakout factors, multiple regression equations.*

I. Introduction

For radar tower, television line tower, power pole and road-side signposts etc. the imbalance horizontal forces are mainly due to severe wind velocity, hence, the resultant uplift load and overturning moments at their foundations are fundamental design considerations to ascertain their types, shapes and sizes. Belled anchors may be an attractive and economy-friendly alternative to resist resultant pull-out forces in foundation systems.

The uplift capacity of belled anchors is influenced by embedment depth, size of diameter and bell angle as observed by Dickin and Leung (1990, 1992), Pal (1992), Ghosh and Bera (2010), Bera and Banerjee (2013), Bera (2014) and Nazir et al. (2014) [3,5,6,12,13,15,16]. But these findings are based on homogeneous sand only. The experimental, numerical and mathematical studies were also conducted on plate anchors having a wide vatity of sizes at a different embedment depths by Dickin and Laman (2007), Vanita et al. (2007), Mittal and Mukherjee (2013), and Sujatha and Balamurugan (2014) [10,11,14,17].

The behavior of anchors in the layered sand was experimentally studied by Bouazza and Finlay (1990) [2] on laboratory models. Kumar (2003) [9] conducted a numerical study on the uplift capacity of anchors by introducing velocity hydrograph in failure mechanism. Sakai and Tanaka (1990) [4] documented pictorial observation of failure mechanism in the two-layered sand. The existing literature is having a dearth of data on uplift capacities and insufficient to provide a clear understanding on the comparison of uplift behaviors due to changes in embedment ratios and belled anchor characteristics buried in the different types of sand strata.

The present study aims to explore the comparison in the uplift behavior of belled anchors in homogeneous and layered (i.e., lesser dense sand is underlying higher dense sand) buried sand with variation in several embedment ratios and anchor characteristics on the basis of the experimental study. An attempt is also made to establish multiple regression models to predict the breakout factors as a function of embedment ratios, diameter ratios, bell angles and portions of embedment depth in the lower layer.

II. Testing Set-Up, Materials And Models

2.1. Sand, Model Anchors and Testing Tank

Two different types of dry sands are collected from the local market and these are designated as Sand I (S_I) and S_{II}). Fig. 1 shows grain size distribution curves of sand samples. The placement density of S_I and S_{II} are (γ_I) 15.60 and (γ_{II}) 16.90 kN/m^3 respectively. The angle of internal friction of S_I and S_{II} are recorded to be (ϕ_I) 33.0° and (ϕ_{II}) 39.5° respectively. The physical properties are obtained in accordance with ASTM standards and presented in Table 1.

The details of bell angles (β), shaft diameter (D_S) and bell diameter (D_b) of bell anchors are presented in Table 2 [column (i), (ii) and (iii)]. These are fabricated from a solid rounded bar of mild steel, and the shaft and bell part is welded internally. At top most part of all models, a small hollow cylindrical arrangement is welded with internal threading to hold the proving ring smoothly. Near to the top of cylindrical arrangement, two numbers of horizontally projected short steel strips are welded at 180° to each other to hold a couple of dial gauges gently.

The inner dimensions of the testing tank are 600 mm (L) × 600 (W) mm in plan area and 700 mm in height and supported by a steel frame. Its four sides are enclosed by pieces of plaxi-glass of 12 mm thick. The testing tank is sufficiently sized to be free from boundary effects.

2.2. Sand Bed Preparation for Models

The details of the thickness of layers are explained in Table 2 [column (viii) and (ix)] for layered sand deposit. S_I of constant thickness (L_I) of 168 mm is underlying S_{II}. Over S_I, S_{II} is poured for rest of the predetermined height and properly finished with level surface. From that surface total embedment depth upto anchor-base is rechecked. The placement density of S_I and S_{II} are achieved by raining technique (Bouazza and Finlay, 1990 and Dickin and Leung, 1990) [2, 3], and height of free fall is fixed to be 700 mm in both the cases and a soil tray is used manually to fill the testing tank. For both homogeneous and layered sand bed preparation, at first a compacted sand bed (S_I) of 10 mm thick is properly finished with the horizontal surface before installing the models over the bed.

2.3. Experimental Set-Up and Test Procedures

The Fig. 2 shows the schematic diagram of the experimental set-up. The loading frame is fabricated by steel channels, and its base is bolted to the ground for stability. The horizontal beam of reaction frame belongs to the nut and ball-bearing arrangement. A pulling shaft as screw jack passes through the nut and based on ball-bearing arrangement act on the principle of nut and screw motion. The bottom of the shaft is connected with the model along with proving ring. Vertical movement of the shaft is controlled by manually rotational circular wheel fixed with a nut. The clockwise motion of wheel helps the models to move upward. The dial gauges of 0.01 mm accuracy are attached properly with magnetic bases which are fitted on steel bars placed over the top of the model tank. The proving ring of 1.0 kN capacity records the gross uplift capacity of model anchors, and the corresponding displacement of the anchors are recorded from deflection in dial gauges. A similar pattern of experimental set-up and test procedures had also been adopted by Pal (1992), Ghosh and Bera (2010), Bera and Banerjee (2013) and Bera (2014) [6,12,13,15].

Table 1 Properties of Sand I (S_I) and Sand II (S_{II})

Physical Properties	Test Results	
	(S_I)	(S_{II})
Medium sand, (%)	93.50	77.00
Fine sand (%)	6.50	23.00
Silt and clay (%)	1.05	1.50
Effective grain size, D_{10}, (mm)	0.7	0.23
Coefficient of curvature, C_c	0.91	1.33
Coefficient of uniformity, C_u	1.00	3.26
Name of soil (USCS)	SP	SW
Specific gravity, G_s	2.67	2.69
Minimum void ratio, e_{min}	0.63	0.49
Maximum void ratio, e_{max}	0.88	0.79
Void ratio, at $\gamma_{expt l}$, $e_{expt l}$	0.71	0.58
Minimum density, γ_{min} (kN/m^3)	14.20	15.00
Maximum density, γ_{max} (kN/m^3)	16.50	18.20
Relative density D_r, (%)	64.38	63.94

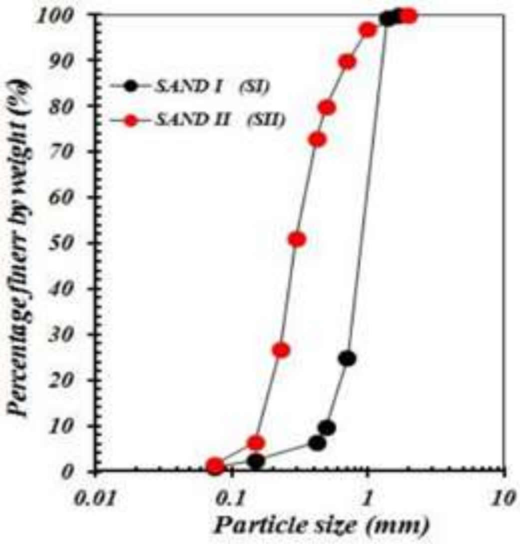


Figure 1 Grain size distribution for Sand I (S_I) and Sand II (S_{II})

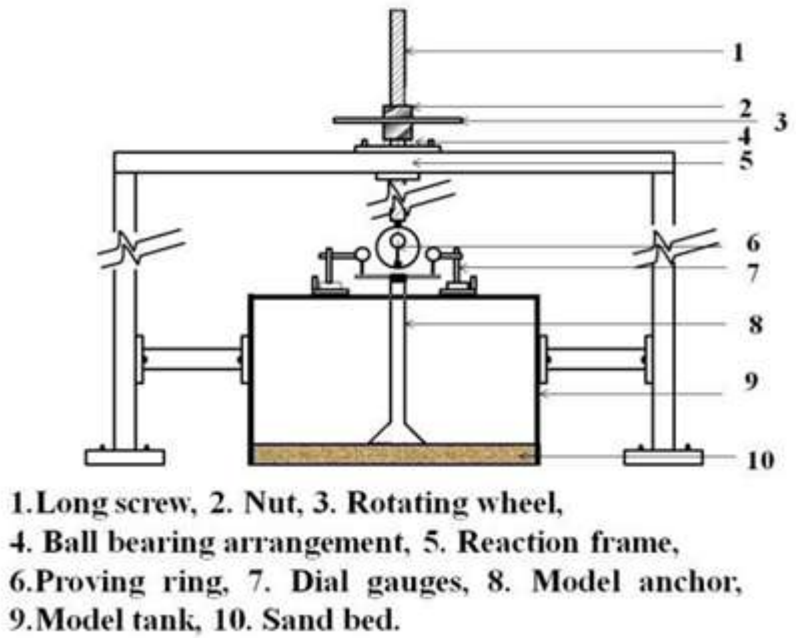


Figure 2 Schematic diagram of experimental set-up

2.4. Experimental Programme

To carry out experimental investigations on the uplift behavior of single belled anchors in buried sand, the following variable parameters are considered:

- Embedment ratios (L/D_b): 3, 4 and 5;
- Diameter ratios (D_S/D_b): 0.28, 0.33, 0.38 and 0.46;
- Bell angles (β): 45°, 54°, 63° and 72°; and
- Sand types: (i) homogenous sand deposits and (ii) layered sand deposits.

For this study, in total [{2×(3×4×4)}-4] = 92 tests are performed.

III. Model Designations

In Table 2, columns (iv), (v) and (vi) present the details of model identifications, embedment depth (L) and embedment ratios. In Table 2 [column (vii) and (x)] the detail designations of models are presented for homogeneous and layered sand deposits. In order to represent any model, a common coding system maintained consists of five sections. The first, second, third, fourth and fifth part specifies the model (M), β, D_S/D_b, L/D_b and type of sand deposit respectively. When a model is having β of 45°, D_S/D_b of 0.28 at L/D_b of 5, and its 37% and 63% of total embedment depth are embedded in S_I (bottom layer) and S_{II} (top layer) respectively, then it is designated as M:45-0.28-5-($0.37S_I+0.63S_{II}$). A model is represented as M:63-0.28-4-(S_I) indicates that the model belongs to β of 63°, D_S/D_b of 0.28 at L/D_b of 5 and it is fully embedded in S_I.

Table 2 Detail of models and their designations based on homogeneous and layered sand deposits

β (°) (i)	D_s (ii)	D_b (iii)	Model identifications (iv)	L (mm) (v)	L/Db (vi)	Designations based on L/D_b and S_I (vii)	L_I/L (viii)	LII/L (ix)	Anchor designations based on L/D_b, S_I and S_{II} (x)
45	26	56	M:45-0.46	168	3	M:45-0.46-3-(S_I)	1.00	0.00	M:45-0.46-3-(S_I)
				224	4	M:45-0.46-4-(S_I)	0.75	0.25	M:45-0.46-4-($0.75S_I+0.25S_{II}$)
				280	5	M:45-0.46-5-(S_I)	0.60	0.40	M:45-0.46-5-($0.60S_I+0.40S_{II}$)
45	26	68	M:45-0.38	204	3	M:45-0.38-3-(S_I)	0.82	0.18	M:45-0.38-3-($0.82S_I+0.18S_{II}$)
				272	4	M:45-0.38-4-(S_I)	0.62	0.38	M:45-0.38-4-($0.62S_I+0.38S_{II}$)
				340	5	M:45-0.38-5-(S_I)	0.49	0.51	M:45-0.38-5-($0.49S_I+0.51S_{II}$)
45	26	80	M:45-0.33	240	3	M:45-0.33-3-(S_I)	0.70	0.30	M:45-0.33-3-($0.70S_I+0.30S_{II}$)
				320	4	M:45-0.33-4-(S_I)	0.53	0.47	M:45-0.33-4-($0.53S_I+0.47S_{II}$)
				400	5	M:45-0.33-5-(S_I)	0.42	0.58	M:45-0.33-5-($0.42S_I+0.58S_{II}$)
45	26	92	M:45-0.28	276	3	M:45-0.28-3-(S_I)	0.61	0.39	M:45-0.28-3-($0.61S_I+0.39S_{II}$)
				368	4	M:45-0.28-4-(S_I)	0.46	0.54	M:45-0.28-4-($0.46S_I+0.54S_{II}$)
				460	5	M:45-0.28-5-(S_I)	0.37	0.63	M:45-0.28-5-($0.37S_I+0.63S_{II}$)
54	26	56	M:54-0.46	168	3	M:54-0.46-3-(S_I)	1.00	0.00	M:54-0.46-3-(S_I)
				224	4	M:54-0.46-4-(S_I)	0.75	0.25	M:54-0.46-4-($0.75S_I+0.25S_{II}$)
				280	5	M:54-0.46-5-(S_I)	0.60	0.40	M:54-0.46-5-($0.60S_I+0.40S_{II}$)
54	26	68	M:54-0.38	204	3	M:54-0.38-3-(S_I)	0.82	0.18	M:54-0.38-3-($0.82S_I+0.18S_{II}$)
				272	4	M:54-0.38-4-(S_I)	0.62	0.38	M:54-0.38-4-($0.62S_I+0.38S_{II}$)
				340	5	M:54-0.38-5-(S_I)	0.49	0.51	M:54-0.38-5-($0.49S_I+0.51S_{II}$)
54	26	80	M:54-0.33	240	3	M:54-0.33-3-(S_I)	0.70	0.30	M:45-0.33-3-($0.70S_I+0.30S_{II}$)
				320	4	M:54-0.33-4-(S_I)	0.53	0.47	M:45-0.33-4-($0.53S_I+0.47S_{II}$)
				400	5	M:54-0.33-5-(S_I)	0.42	0.58	M:45-0.33-5-($0.42S_I+0.58S_{II}$)

				276	3	M:54-0.28-3-(S_I)	0.61	0.39	M:45-0.28-3-($0.61S_I+0.39S_{II}$)
54	26	92	M:54-0.28	368	4	M:54-0.28-4-(S_I)	0.46	0.54	M:45-0.28-4-($0.46S_I+0.54S_{II}$)
				460	5	M:54-0.28-5-(S_I)	0.37	0.63	M:45-0.28-5-($0.37S_I+0.63S_{II}$)
				168	3	M:63-0.46-3-	1.00	0.00	M:63-0.46-3-(S_I)
63	26	56	M:63-0.46	224	4	(S_I) M:63-0.46-4-	0.75	0.25	M:63-0.46-4-($0.75S_I+0.25S_{II}$)
				280	5	(S_I)	0.60	0.40	M:63-0.46-5-
						M:63-0.46-5-(S_I)			($0.60S_I+0.40S_{II}$)
				204	3	M:63-0.38-3-(S_I)	0.82	0.18	M:63-0.38-3-($0.82S_I+0.18S_{II}$)
63	26	68	M:63-0.38	272	4	M:63-0.38-4-(S_I)	0.62	0.38	M:63-0.38-4-($0.62S_I+0.38S_{II}$)
				340	5	M:63-0.38-5-(S_I)	0.49	0.51	M:63-0.38-5-($0.49S_I+0.51S_{II}$)
				240	3	M:63-0.33-3-(S_I)	0.70	0.30	M:63-0.33-3-($0.70S_I+0.30S_{II}$)
63	26	80	M:63-0.33	320	4	M:63-0.33-4-(S_I)	0.53	0.47	M:63-0.33-4-($0.53S_I+0.47S_{II}$)
				400	5	M:63-0.33-5-(S_I)	0.42	0.58	M:63-0.33-5-($0.42S_I+0.58S_{II}$)
				276	3	M:63-0.28-3-(S_I)	0.61	0.39	M:63-0.28-3-($0.61S_I+0.39S_{II}$)
63	26	92	M:63-0.28	368	4	M:63-0.28-4-(S_I)	0.46	0.54	M:63-0.28-4-($0.46S_I+0.54S_{II}$)
				460	5	M:63-0.28-5-(S_I)	0.37	`0.63	M:63-0.28-5-($0.37S_I+0.63S_{II}$)
				168	3	M:72-0.46-3-(S_I)	1.00	0.00	M:72-0.46-3-(S_I)
72	26	56	M:72-0.46	224	4	M:72-0.46-4-(S_I)	0.75	0.25	M:72-046-4-($0.75S_I+0.25S_{II}$)
				280	5	M:72-0.46-5-(S_I)	0.60	0.40	M:72-0.46-5-($0.60S_I+0.40S_{II}$)
				204	3	M:72-0.38-3-(S_I)	0.82	0.18	M:72-0.38-3-($0.82S_I+0.18S_{II}$)
72	26	68	M:72-0.38	272	4	M:72-0.38-4-(S_I)	0.62	0.38	M:72-0.38-4-($0.62S_I+0.38S_{II}$)
				340	5	M:72-0.38-5-(S_I)	0.49	0.51	M:72-0.38-5-($0.49S_I+0.51S_{II}$)
				240	3	M:72-0.33-3-(S_I)	0.70	0.30	M:72-0.33-3-($0.70S_I+0.30S_{II}$)
72	26	80	M:72-0.33	320	4	M:72-0.33-4-(S_I)	0.53	0.47	M:63-0.33-4-($0.53S_I+0.47S_{II}$)
				400	5	M:72-0.33-5-(S_I)	0.42	0.58	M:72-0.33-5-($0.42S_I+0.58S_{II}$)
				276	3	M:72-0.28-3-(S_I)	0.61	0.39	M:72-0.28-3-($0.61S_I+0.39S_{II}$)
72	26	92	M:72-0.28	368	4	M:72-0.28-4-(S_I)	0.46	0.54	M:72-0.28-4-($0.46S_I+0.54S_{II}$)
				460	5	M:72-0.28-5-	0.37	0.63	M:72-0.28-5-

	(S_I)	$(0.37S_I+0.63S_{II})$

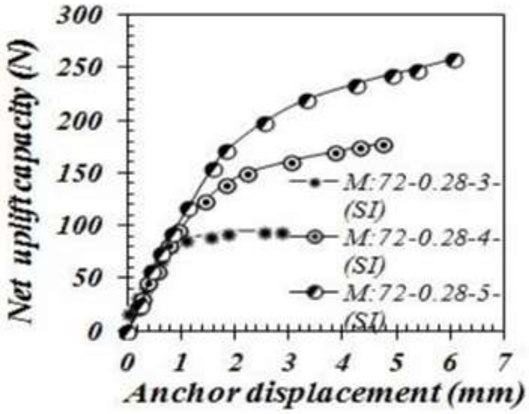
IV. Observations On Load-Displacement Behaviours

Fig. 3 represents typical curves of net uplift capacity vs. anchor displacement relation for models M:72-0.28 in the homogenous sand. In homogeneous deposit of sand, initially, the curves are linear representing true elastic response in the very early stage when increments in uplift resistance are higher than the vertical displacements; after that the curve takes the shape of pseudo-elastic pattern resembles curvilinear and finally produces elasto-plastic response with the rapid growth of the plastic region as well as high rate of deformation. The behaviour of curves is similar in nature as demonstrated by Vanita et al. (2007), Bera (2014) and Sujatha and Balamurugan (2014) [11,15,17].

Fig. 4 represents typical curves of net uplift capacity vs. anchor displacement relation for models M:54-0.33 in the layered sand. In general, in the layered deposit of sand, more or less curvi-linear shape is noticed in very early stage, and it may be due to the bottom layer of sand. After that in all curve, there is a sudden higher rate of increment in uplift capacity at a very lower rate of upward displacement. This type of uplift capacity vs. anchor displacement behavior is dominated by the higher and lower limit of densities in the top and bottom layers of sand deposit respectively. A Similar pattern of relationship in net uplift capacity vs. anchor displacement curves was reported by Stewart (1985) [1] for plate anchors installed in soft clay underlying comparatively dense sand.

In both cases at the collapsed stage, ultimate strength mobilisation ($Q_u(S_I)$) and $Q_u(S_I+S_{II})$) is lower than the rate of increment in vertical displacement. The net ultimate uplift capacity ($Q_u(S_I)$ and $Q_u(S_I+S_{II})$) is presented as

$$Q_U(S_I) = \mathbf{Q_g(S_I) - w_M} \tag{1}$$
$$Q_U(S_I + S_{II}) = \mathbf{Q_g(S_I + S_{II}) - w_M} \tag{2}$$



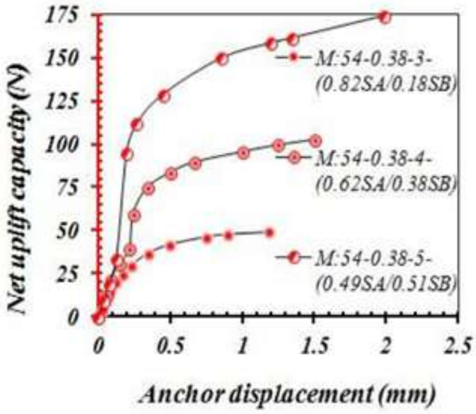


Figure 3 Net uplift capacity vs. displacement curve for M:72-0.28 in homogeneous sand deposits at varying L/D_b

Figure 4 Net uplift capacity vs. displacement curve for M:54-0.33 layered sand deposits at varying L/D_b

V. Discussions

On the basis of experimental data, the comparison on the net ultimate uplift capacities ($Q_{u.}(S_I)$ and $Q_u(S_I+S_{II})$) of belled anchors in homogeneous and layered sands strata in reference with L/D_b, D_S/D_b and β, the following discussions are made.

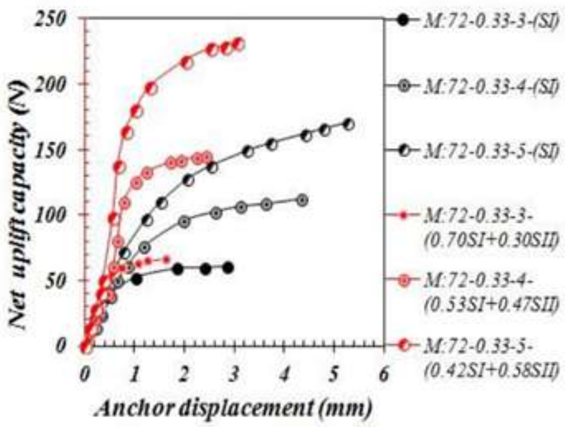
5.1. Comparison on Net Uplift Capacity and Uplift Capacity vs. Anchor Displacement Curves of Belled Anchors in Homogeneous and Layered Sands

Fig. 5 represent the net uplift capacity vs. displacement relation for model M:72-0.33 in homogeneous and layered sand deposits. In layered sand for the same model, the net uplift capacity vs. anchor displacement curves show more upward movement than that of homogeneous sand as the thickness of S_{II} gradually increases with higher L/D_b. $Q_u(S_I+S_{II})$ are higher than $Q_{u.}(S_I)$ for the same model, irrespective of L/D_b, D_S/D_b and β. In case of layered sands, when arrangement in thickness within two layers are distributed as $(0.75S_I+0.25S_{II})$, $(0.82S_I+0.18S_{II})$ and $(0.70S_I+0.30\ S_{II})$ (the distribution in thickness is dependent on L/D_b and D_S/D_b values), the increment in values of $Q_u(S_I+S_{II})$ are within 2 to 10% than $Q_u(S_I)$, and for any other arrangement in thickness of sand within the bottom and top layer in layered sands $Q_u(S_{I+}S_{II})$ increased within 20 to 50% than $Q_u(S_I)$ for the same models and this finding is consistent for β within the specified range of this present study. When the higher dense sand is overlying lesser dense sand then it contributes to attain higher uplift capacity due to increase in normal stresses, interface stresses and compaction residual stresses (Bera 2014)

Hence, in this study, the layered sand where the overlying denser sand by virtue of its higher γ_{II} and ϕ_{II} value attribute to gain higher uplift capacities by the formation of larger wedges than those form in the homogeneous deposit; as a result, more tensile load necessitates for lifting larger breakout wedge upward.

5.2. Comparison on Uplift Capacity of Belled Anchors in Homogeneous and Layered Sands due to Variation in Embedment Ratios

The net ultimate uplift capacity vs. embedment ratio relation has been presented in typical Fig. 6. It has been revealed from the figure that for the same model the rate of increase in $Q_u(S_{I+}S_{II})$ is higher than $Q_u(S_I)$ as the value of L/D_b changes gradually from 3 to 4 and 4 to 5. In this same figure, it has also been noticed that each 54° belled anchors have achieved gradually higher $Q_u(S_I)$ and $Q_u(S_I+S_{II})$ due to increase in L/D_b from 3 to 4 and from 4 to 5, and this trend is consistent regardless the values D_S/D_b of 0.28, 0.33,0.38, and 0.46. For a model possessing D_S/D_b of 0.46 and β of 63° due to increase in L/D_b from 3 to 5, $Q_u(S_I)$ and $Q_u(S_{I+}S_{II})$ increased from 21.71 to 64.33 N and from 21.71 to 78.02 N respectively. Dickin and Leung (1990), Ilamparuthi and Dickin (2001), Vanitha et al. (2007) [3,8,11] in case of plate anchors, and Bera (2014) and Nazir et al. (2014) [15,16] for belled anchors had noticed that uplift capacity significantly increased at higher embedment ratio in homogeneous sand deposits. This phenomenon is attributed due to the reasons (i) larger contact area between the anchor and sand (Ghosh and Bera, 2010) [12] and (ii) deeper embedment of the anchor (Bera and Banerjee 2013) [13]. In this present study, for a certain value of D_b, higher L/D_b indicates deeper anchor installation which implies larger overburden pressure for any type of sand deposit. It may also be remarked that with higher embedment ratios overburden pressure becomes significantly larger when higher dense sand of increasing thickness is overlying lesser dense sand of fixed thickness. The same model when installed in layered sand deposit, overlying S_{II} of higher γ_{II} and ϕ_{II} values may create larger wedge than that of homogeneous sand; consequently, for the lifting of larger weight of breakout wedge upward, the more tensile load is required.



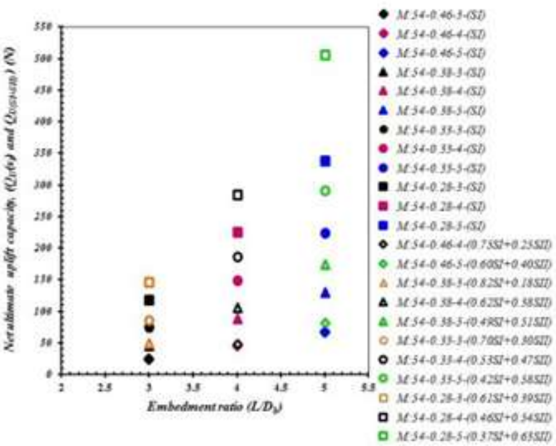


Figure 5 Net uplift capacity vs. displacement curve for M:72-0.33 in homogeneous and layered sands deposit at L/D_b of 3, 4 and 5

Figure 6 Net ultimate uplift capacities ($Q_u(S_I)$ and $Q_u(S_I+S_{II})$) for 54° belled anchors (having D_S/D_b of 0.28, 0.33,0.38, and 0.46) in homogeneous and layered sand deposits at L/D_b of 3, 4 and 5

5.3. Comparison on Uplift Capacity of Belled Anchors in Homogeneous and Layered Sands due to Variation in Diameter Ratios

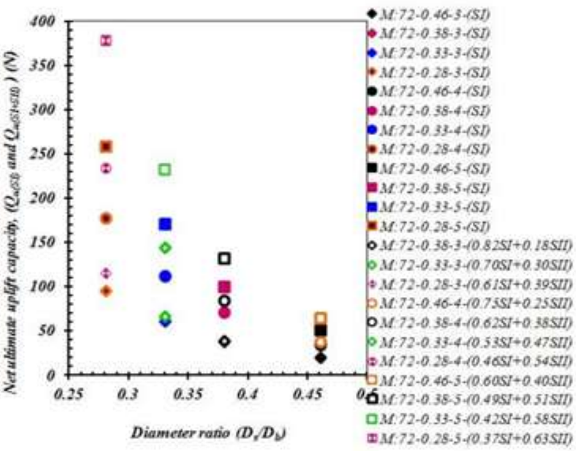
The net ultimate uplift capacity vs. diameter ratio relation has shown in typical Fig.7. From the figure, it has been observed that for the same model the rate of increase in $Q_u(S_I+S_{II})$ is higher than $Q_u(S_I)$ when the value of D_S/D_b changes gradually from 0.46 to 0.38, from 0.38 to 0.33 and from 0.33 to 0.28. In this same figure it is also noticed that M:72-0.46, M:72-0.38, M:72-0.33 and M:72-0.28 have achieved progressively higher $Q_u(S_I)$ and $Q_u(S_I+S_{II})$ and this trend is consistent regardless the values L/D_b of 3, 4 and 5. For models at L/D_b ratio of 5 and

β of 63°, due to a decrease in D_S/D_b ratios from 0.46 to 0.28, $Q_u(S_I)$ and $Q_u(S_I+S_{II})$ increased from 64.33 to 313.89 N and from 78.02 to 480.16 N respectively. The reasons to attain higher values of $Q_u(S_I+S_{II})$ than

$Q_{u.}(S_I)$ has already been discussed in § 5.2 Comparison on Uplift Capacity of Belled Anchors in Homogeneous and Layered Sands due to Variation in Embedment Ratios. Dickin and Leung (1990), Pal (1992), Ilamparuthi and Dickin (2001), Bera (2014) and Nazir et al. (2014) [3,6,8,15,16] in dry sand observed that uplift capacities were considerably increased by lesser diameter ratio in homogeneous sand deposit. For particular D_S with an increase in D_b, the D_S/D_b ratios decrease. In the present study, it is noticed that at certain L/D_b ratio, gradually lesser D_S/D_b ratios implies increased embedment depth and hence, higher overburden pressures prevail on the larger anchor bases and larger breakout wedges are generated irrespective of sand type.

5.4. Comparison on Uplift Capacity of Belled Anchors in Homogeneous and Layered Sand due to Variation in Bell Angles

The uplift capacity vs. bell angle relation has been presented in typical Fig. 8. It is noticed from the figure that for the same model the rate of increase in $Q_u(S_I+S_{II})$ is higher than $Q_u(S_I)$, irrespective the values of β 45°,54°,63° and 72°. In this same figure it has also been observed that each belled anchor belonging to D_S/D_b of 0.28 and due to increase in β from 45 to 72°, $Q_u(S_I)$ and $Q_u(S_I+S_{II})$ indicate a descending pattern, regardless the values L/D_b of 3, 4 and 5. In the present study, it is also observed that when β increased from 45 to 63° and from 63 to 72°, almost all the values of uplift capacities are decreased by 7 to 10% and by 17 to 22% respectively, in both the types of sand deposits. For anchors having D_S/D_b ratio of 0.28 and L/D_b ratio of 4 due to increase in β from 45 to 72°, $Q_u(S_I)$ and $Q_u(S_I+S_{II})$ decreased from 234.84 to 177.06 N and from 297.89 to 213.14 N respectively. The reasons to attain higher values of $Q_u(S_I+S_{II})$ than $Q_{u.}(S_I)$ has already been discussed in § 5.2 Comparison on Uplift Capacity of Belled Anchors in Homogeneous and Layered Sands due to Variation in Embedment Ratios. The decreasing pattern in the behaviour of uplift capacity was noticed by Nazir et al. (2014) [16] for bell anchor angle of 30 to 60° installed in homogeneous dry sand deposit in a conventional test using physical modelling. Dickin and Leung (1992) [5] reported the variation in uplift behaviour of anchors having β within a range of 22 to 72° in centrifugal modeling test in homogeneous sand bed and noticed that when β was 72°, there was a rapid decrease in uplift capacities in comparison to those found for 62° belled anchor; in the present study also similar observation has been noticed.



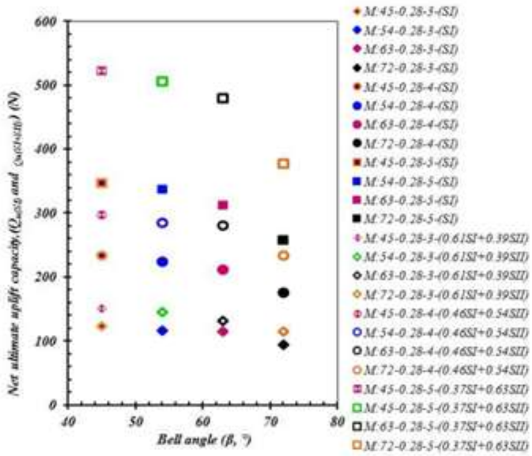


Figure 7 Net uplift capacities ($Q_u(S_I)$ and $Q_u(S_I+S_{II})$) for 72° belled anchors **(**at L/D_b of 3, 4 and 5) in homogeneous and layered sand deposits possessing D_S/D_b of 0.28, 0.33,0.38, and 0.46

Figure 8 Net ultimate uplift capacities ($Q_u(S_I)$ and $Q_u(S_I+S_{II})$) for anchors belonging to D_S/D_b of 0.28 at varying bell angles in homogeneous and layered sand deposits **(**at L/D_b of 3, 4 and 5)

VI. Breakout Factor

Net ultimate uplift capacities ($Q_u(S_I)$ and $Q_u(S_I+S_{II})$) are presented as breakout factor, non-dimensionalised by density (γ_I or both γ_I and γ_{II}), embedment depth (L or both L_I and L_{II}), and belled base area (A_b). For homogeneous sand deposit, breakout factors ($N_{u.obs.}(S_I)$) are expressed in the following form:

$$\mathbf{N_{U.obs.}(S_I)} = \frac{Q_U(S_I)}{\gamma A_b L} \tag{3}$$

For layered sand deposit, breakout factors ($N_{u.obs.}(S_I+S_{II})$) can be extended as follows:

$$\mathbf{N_{U.obs.}(S_I + S_{II})} = \frac{\mathbf{Q_U(S_I + S_{II})}}{\mathbf{A_b(\gamma_I L_I + \gamma_{II} L_{II})}} \tag{4}$$

To form the regression models with observed breakout factors ($N_{u.obs.}(S_I)$ and $N_{u.obs.}(S_I+S_{II})$) for β of 45°, 54°, 63° and 72° these are notified as $N_{u.obs.(45°)}$, $N_{u.obs.(54°)}$, $N_{u.obs.(63°)}$ and $N_{u.obs.(72°)}$ respectively. When anchors are having β values of 45°, 54° and 63° then observed breakout factors are indicated as $N_{u.obs.(45°,54°,63°)}$ and similarly, anchors are possessing β values of 45°, 54°, 63° and 72° the breakout factors are noted as

Nu.obs.(45°,54°,63°,72°).

VII. Multiple Linear Regression Models

7.1. Significance of Multiple Regression Coefficients as a Whole and Partial Multiple Regression Coefficients

As conferred by Draper and Smith (1998) [7], multiple linear regression is a predictive analysis, to explain the relationship between one continuous dependent variable and two or more independent variables, and the assessment of regression equations can be made through estimation of R^2, R^2_{adj} and E_s. The significance of multiple regression coefficients as a whole and the significance of partial regression coefficients can be evaluatedthrough „F" test and „t" test. In this study, the level of significance (α) of requisite hypothesis is taken as 0.05.

In general, „F" test in regression compares the fits of different linear equations. The „F" test can assess multiple coefficients, simultaneously unlike„t" test that can assess only one regression coefficient at a time. This test indicates the acceptance probability of the assumed model to predict data. According to the null hypothesis all the partial regression coefficients, ξ_1, $\xi_2 \ldots \xi_p$ are equal to zero. i.e., H_0: $\xi_1 = \xi_2 = \ldots = \xi_p = 0$. According to the alternative
hypothesis, H_a: at least one of the values of ξ is non-zero.

Decision Criteria:
Reject Ho, if Fcal > F (1- α, p-1, n-p); and

Accept Ho, if Fcal ≤ F (1- α, p-1, n-p).
$F_{(1-\alpha, p-1, n-p)}$ is chosen from F table for level of significance, α = 0.05.

If the null hypothesis is not accepted in case of „F" test, then„t" test should be conducted to assess the contribution of individual variables to explicate the dependent variable. From the t statistics, if any regression coefficient is found to be insignificant, and then a new regression equation should be anticipated by eliminating the previous sequence of independent variables.

Decision Criteria:
Reject Ho, if tcal > t(1-α/2, n-p) or tcal < -t(1-α/2, n-p); and
Accept Ho, if –t(1-α/2, n-p) ≤ tcal ≤ t(1-α/2, n-p)
$t_{(1-\alpha/2, n-p)}$ is chosen from t table for the level of significance, α as 0.05.

7.2. Multiple Regression Models proposed by using the values of $N_{u.obs.(45°)}$, Nu.obs.(54°), Nu.obs.(63°) and Nu.obs.(72°)

Based on each 19 set of observed scattered data of $N_{u.obs.(45°)}$, $N_{u.obs.(54°)}$, $N_{u.obs.(63°)}$ and $N_{u.obs.(72°)}$, the Eqs. (5), (6), (7) and (8) have been established to predict $N_{u.pred.(45°)}$, $N_{u.pred.(54°)}$, $N_{u.pred.(63°)}$ and $N_{u.pred.(72°)}$ respectively as a function of L/D_b, D_s/D_b, and f:

$$N_{U.pred.(45^0)} = 3.54 + 1.67\left(\frac{L}{D_b}\right) - 4.19\left(\frac{D_S}{D_b}\right) - 2.96(f) \quad (5)$$

$$N_{U.pred.(54^0)} = 4.00 + 1.57\left(\frac{L}{D_b}\right) - 5.82\left(\frac{D_S}{D_b}\right) - 2.69(f) \quad (6)$$

$$N_{U.pred.(63^0)} = 3.87 + 1.48\left(\frac{L}{D_b}\right) - 4.61\left(\frac{D_S}{D_b}\right) - 2.97(f) \quad (7)$$

$$N_{U.pred.(63^0)} = 2.93 + 1.17\left(\frac{L}{D_b}\right) - 2.78\left(\frac{D_S}{D_b}\right) - 2.40(f) \quad (8)$$

These eqs. (5), (6) (7) and (8) are developed for 45°, 54°, 63° and 72° belled anchors respectively and for each equation the values of L/D_b and D_s/D_b are within the ranges of 3 to 5 and 0.28 to 0.46 respectively; the values of f is 1 in homogeneous sand deposit and f is within the ranges of 0.37 to 0.82 when S_I is underlying. To know the efficiency of the eq. (5), the values of R^2, R^2_{adj} and E_s have been found out and these are 0.961, 0.953 and 0.392 respectively. In the equation (6) the values of R^2, R^2_{adj} and E_s are calculated and these are 0.956, 0.947 and 0.395 respectively. In the equation (7) the values of R^2, R^2_{adj} and E_s are calculated as 0.968, 0.961 and 0.339 respectively. In the equation (8) the values of R^2, R^2_{adj} and E_s are 0.961, 0.952 and 0.262 respectively. The calculated value of $F_{cal(45°)}$, $F_{cal(54°)}$, $F_{cal\ (63°)}$ and $F_{cal(72°)}$ are 123.57,107.58,150.38 and 120.19 respectively; these four values of $F_{cal\ (45°)}$, $F_{cal\ (54°)}$, $F_{cal\ (63°)}$ and $F_{cal\ (72°)}$ are greater than tabulated F (0.95, 2, 54) = 3.168.

7.3. Multiple Regression Model proposed by using the values of $N_{u.obs.(45°,54°,63°)}$

This multiple regression model is proposed by using the data of $N_{u.obs.(45°,54°,63°)}$ as the observed uplift capacities are very close to each other for anchors having β values of 45°,54°

and 63°. Based on 63 set of observed data of $N_{u.obs.(45°,54°,63°)}$ the Eq. (9) has been developed to predict $N_{u.pred.(45°,54°,63°)}$ where L/D_b, D_s/D_b, β and f are the independent variables:

$$N_{U.pred.(45^0 54^0 63^0)} = 5.23 + 1.58\left(\frac{L}{D_b}\right) - 4.07\left(\frac{D_S}{D_b}\right) - 0.03(\beta) - 2.94(f) \quad (9)$$

eq. (9) is applicable when L/D_b and D_s/D_b are within the ranges of 3 to 5 and 0.28 to 0.46 respectively; the values of f is 1 in homogeneous sand deposit and f is within the ranges of 0.37 to 0.82 when S_I is underlying. The values of R^2, R^2_{adj} and E_s are 0.965, 0.963 and 0.338 respectively. The value of $F_{cal\ (45°,\ 54°,\ 63°)}$ = 418.70 and this is greater than F (0.95, 3, 248) = 2.645.

7.4. Multiple Regression Model proposed by using the values of $N_{u.obs.(45°,54°,63°,72°)}$

The use of 84 sets of scattered data of $N_{u.obs.(45°,54°,63°,72°)}$ has assisted in developing Eq. (10) to predict $N_{u.pred.(45°,54°,63°,72°)}$ where L/D_b, D_s/D_b, β and f are the independent variables:

$$N_{U.pred.(45^0 54^0 63^0 72^0)} = 4.22 + 1.69\frac{L}{D_b} - 3.64\frac{D_S}{D_b} - 0.06(\beta) - 0.37(f) \quad (10)$$

The eq. (10) is applicable for L/D_b, D_s/D_b and β which are within the ranges of 3 to 5, 0.28 to 0.46 and 45 to 72° respectively; the values of f is 1 in homogeneous sand deposit and f is within the ranges of 0.37 to 0.82 when S_I is underlying. The values of R^2, R^2_{adj} and E_s are 0.833, 0.824 and 0.722 respectively. The calculated value of $F_{cal(\ 45°,54°,63°,72°)}$ = 98.36 and this is greater than tabulated F (0.95, 3, 332) = 2.637.

The independent variables, coefficients, standard error, t statistics of all the parameters and values of $t_{critical}$ for eqs. (5) to (10) has been presented in Table 3.

Table 3 Independent variables, coefficients, standard error, t statistics and $t_{critical}$ of all the parameters from eqs. (5) to (10)

Eq. (5)					Eq.(6)				
Parameters	**Coefficients**	**Standard error**	**t statistics**	**tcritical = t(0.975,54)**	**Parameters**	**Coefficients**	**Standard error**	**t statistics**	**tcritical = t(0.975,54)**
L/D_b	+1.67	0.11	14.54	2.01	L/D_b	+1.57	0.11	13.78	2.01
D_S/D_b	4.19	1.43	2.93		D_S/D_b	5.82	1.39	4.18	
f	2.96	0.41	7.13		f	2.69	0.42	6.35	
Eq. (7)					Eq.(8)				
Parameters	**Coefficients**	**Standard error**	**t statistics**	**tcritical = t(0.975,54)**	**Parameters**	**Coefficients**	**Standard error**	**t statistics**	**tcritical = t(0.975,54)**
L/D_b	+ 1.48	0.10	14.62	2.01	L/D_b	+ 1.17	0.08	15.29	2.01
D_S/D_b	4.61	1.21	3.80		D_S/D_b	2.78	1.00	2.78	
f	2.97	0.36	8.16		f	2.40	0.29	8.35	
Eq. (9)					Eq.(10)				
Parameters	**Coefficients**	**Standard error**	**t statistics**	**tcritical = t(0.975,248)**	**Parameters**	**Coefficients**	**Standard error**	**t statistics**	**tcritical = t(0.975,332)**
L/D_b	+1.58	0.05	29.79	1.980	L/D_b	+ 1.69	0.10	17.25	1.978
D_S/D_b	4.07	0.65	6.23		D_S/D_b	3.64	1.04	3.50	
β	0.03	0.01	5.54		β	0.06	0.01	7.71	
f	2.94	0.20	15.08		f	0.37	0.10	3.72	

The eqs. (5) to (10) of the present study may be followed for full-scale models of the same ratio as used in this study. Experimental studies on the models are conducted in laboratory in the sand only. This particular study may be directly used for the densities, values of L/D_b, D_s/D_b, β and f as used in this study. Due to the paucity of data in the relevant literature, these equations cannot be verified with previous data. These multiple regression equations are verified by other data of the present study, which are not used for development of these correlations. These equations may be checked before application due to a wide range of prevailing variations in-field soil properties.

Table 4 Comparison of observed breakout factor and predicted breakout factor by using Eqs. (5) to (10)

Comparison on	**Source**	**L/D_b**	**D_S/D_b**	**β**	**f**	**Nu.obs.**	**Nu.pre.**	**Errors (%)**
Comparison on Nu.obs.(45°) and Nu.pre.(45°) by using Eq.(5)	**Source**	**L/D_b**	**D_S/D_b**		**f**	**Nu.obs.(45°)**	**Nu.pre.(45°)**	**Errors (%)**
	Present study	3	0.33		1.00	4.37	4.21	+ 03.72
		4	0.46		0.75	5.75	6.07	05.61
		4	0.28		0.46	7.47	7.69	+ 02.88
		5	0.38		1.00	6.97	7.34	05.28
Comparison on Nu.obs.(54°) and Nu.pre.(54°) by using Eq.(6)	**Source**	**L/D_b**	**D_S/D_b**		**f**	**Nu.obs.(54°)**	**Nu.pre.(54°)**	**Errors (%)**
	Present study	4	0.46		1.00	5.55	4.91	+ 11.48
		5	0.38		0.49	8.70	8.32	+ 04.36
		4	0.33		0.53	7.16	6.93	+ 03.16
		5	0.38		1.00	6.73	6.95	03.25
Comparison on Nu.obs.(63°) and Nu.pre.(63°) by using Eq.(7)	**Source**	**L/D_b**	**D_S/D_b**		**f**	**Nu.obs.(63°)**	**Nu.pre.(63°)**	**Errors (%)**
	Present study	5	0.46		1.00	5.98	6.18	03.33
		4	0.38		1.00	5.53	5.07	+ 08.35
		3	0.33		0.70	4.21	4.71	11.87
		4	0.28		0.46	7.05	7.13	01.18
Comparison on Nu.obs.(72°) and Nu.pre.(72°) by using Eq.(8)	**Source**	**L/D_b**	**D_S/D_b**		**f**	**Nu.obs.(72°)**	**Nu.pre.(72°)**	**Errors (%)**
	Present study	3	0.38		1.00	3.19	2.98	+ 06.47
		4	0.28		1.00	4.64	4.43	+ 04.49
		5	0.46		0.60	5.73	6.06	05.78
		5	0.33		0.42	7.04	6.85	+02.63
Comparison on Nu.obs.(45°54°63°) and Nu.pre.(45°54°63	**Source**	**L/D_b**	**D_S/D_b**	**β**	**f**	**Nu.obs.(45°54°63°)**	**Nu.pre.(45°54°63°)**	**Errors (%)**
	Present study	5	0.46	45	0.60	7.66	8.10	05.73
		3	0.38	54	0.82	4.20	4.34	03.30
		4	0.33	63	0.53	6.54	6.70	02.38

°) by using Eq.(9)		3	0.38	45	1.00	4.16	4.09	+ 01.72
		5	0.46	54	1.00	6.26	6.64	06.13
		4	0.28	63	1.00	5.57	5.52	+ 00.94
Comparison on	**Source**	**L/D_b**	**D_S/D_b**	**β**	**f**	**Nu.obs.(45°54°63°72°)**	**Nu.pre.(45°54°63°72°)**	**Errors (%)**
Nu.obs.(45°54°63°72°)	Present	3	0.33	45	1.00	4.37	5.02	14.85
and	study	4	0.46	45	0.75	5.75	6.33	10.05
Nu.pre.(45°54°63°72°)		4	0.33	54	0.53	7.16	6.34	+11.41
by using Eq.(10)		5	0.38	54	1.00	6.73	7.68	14.07
		4	0.38	63	1.00	5.53	5.45	+ 01.50
		3	0.33	63	0.70	4.21	4.05	+ 03.81
		4	0.28	72	1.00	4.64	5.28	13.59
		5	0.46	72	0.60	5.73	6.45	12.63

In future, in a similar type of problem by the formation of correlations for any other set of sand densities, L/D_b, D_s/D_b, β,f and forming multiple regression equations within those definite ranges, it is possible to find out the predicted N_u. The present equations should be checked and modify accordingly when different soil profiles of a wide range of variation will be encountered at the site.

VIII. Concluding Remarks

Based on experimental results, discussions and multiple linear regression models the following concluding remarks may be highlighted:

- Belled anchors can achieve increased uplift capacities when lesser dense sand is underlying higher dense sand ($Q_u(S_I+S_{II})$) than those obtained in the homogeneous deposit of lesser dense sand ($Q_u(S_I)$) irrespective of L/D_b, D_s/D_b and β.
- With increase in the values of L/D_b the rate of increase in uplift capacities of belled anchors in layered sand ($Q_u(S_I+S_{II})$) is comparatively higher than those uplift capacities as observed in homogeneous deposit ($Q_u(S_I)$) for the same model, regardless the particular values of D_S/D_b and β.
- With decrease in the values of D_S/D_b from 0.46 to 0.28, the rate of increase in uplift capacities of belled anchors in layered sand ($Q_u(S_I+S_{II})$) is comparatively higher than those uplift capacities as obtained in homogeneous deposit ($Q_u(S_I)$) for the same model, regardless for the particular values of L/D_b and β.
- With increase in the values of β from 45° to 72°, the uplift capacities of belled anchors have been decreased from 23 to 29% in both layered and homogeneous deposits ($Q_u(S_I+S_{II})$ and $Q_u(S_I)$) for the same model, despite of the certain values of L/D_b and D_S/D_b. For the change of β value from 63 to 72°, both the values of $Q_u(S_I)$ and $Q_u(S_I+S_{II})$ are decreased at higher rate than those rates of decrement as observed for the change in β value from 45 to 63°.
- The 'F' test and 't' test results implied that the multiple regression equations are practically significant from the statistical point of view.
- Four numbers of multiple regression equations have been developed by $N_{u.obs.(45°)}$, $N_{u.obs.(54°)}$, Nu.obs.(63°) and Nu.obs.(72°). The errors on 87.50% values of Nu.pred.(45°), Nu.pred.(54°), Nu.pred.(63°) and Nu.pred.(72°) are within the range of 5.78 to +8.35 % based on Nu.obs.(45°), Nu.obs.(54°), Nu.obs.(63°) and Nu.obs.(72°).
- A multiple regression equation has been formed by $N_{u.obs.(45°,54°,63°,72°)}$. The use of this equation shows error on $N_{u.pred.(45°,54°,63°)}$ are within the ranges of +0.94 to 6.13% based onNu.obs.(45°,54°,63°).
- A multiple regression equation has been developed by $N_{u.obs.(45°,54°,63°,72°)}$. The use of this equation shows errors on $N_{u.pred.(45°,54°,63°,72°)}$ are within the range of +11.41 to 14.85 % based on Nu.obs.(45°,54°,63°,72°).

ABBREVIATIONS

E_s = Estimated standard error of regression statistics;

f = Portions of embedment depth of anchor in the lower layer;

$F_{cal\ (45°,\ 54°,\ 63°)}$ = Calculated values of F statistics in regression model prepared by Nu.obs.(45°,54°,63°);

$F_{cal\ (45°,\ 54°,\ 63°,72°)}$ = Calculated values of F statistics in regression model prepared by Nu.obs.(45°,54°,63°,72°);

$F_{cal(45°)}$, $F_{cal(54°)}$, $F_{cal(63°)}$ and $F_{cal(72°)}$ = Calculated values of F statistics in regression model prepared by Nu.obs.(45°), Nu.obs.(54°), Nu.obs.(63°) and Nu.obs.(72°);
H_0, ξ_1, ξ_2, ….. ξ_p = Regression coefficients;

n = Total number of observations in all groups;
$N_{u.obs.(45°)}$, $N_{u.obs.(54°)}$, $N_{u.obs.(63°)}$ and $N_{u.obs.(72°)}$ = Observed values of breakout factor for anchors having bell angles of 45°, 54°, 63° and 72° respectively;
$N_{u.obs.(45°54°63°)}$ = Observed values of breakout factor for anchors having bell angles of 45°, 54° and 63°;

$N_{u.obs.(45°54°63°72°)}$ = Observed values of breakout factor for anchors having bell angles of 45°, 54°,63° and 72°;
$N_{u.obs.}(S_I)$ = Observed breakout factor in S_I;
$N_{u.obs.}(S_I+S_{II})$ = Observed breakout factor when S_I is underlying S_{II};

$N_{u.pre.(45°)}$, $N_{u.pre.(54°)}$, $N_{u.pre.(63°)}$ and $N_{u.pre.(72°)}$ = Predicted values of breakout factor for anchors having bell angle of 45°,54°,63° and 72° respectively;

$N_{u.pre.(45°54°63°)}$ = Predicted values of breakout factor for anchors having bell angles of 45°, 54° and 63°;
$N_{u.pre.(45°54°63°72°)}$ = Predicted values of breakout factor for anchors having bell angles of 45°, 54°,63° and 72°;
p = Number of independent group;
$Q_g(S_I)$ = Gross ultimate uplift capacity observed in S_I;
$Q_g(S_I+S_{II})$ = Gross ultimate uplift capacity observed when S_I is underlying S_{II}; $Q_u(S_I)$ = Net ultimate uplift capacity observed in S_I;
$Q_u(S_I+S_{II})$ = Net ultimate uplift capacity observed when S_I is underlying S_{II}; R^2 = Coefficient of determination;
R^2_{adj} = Adjusted multiple coefficients of determination; USCS = Unified soil classification system and
W_M = Self-weight of models.

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