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Uplift Capacity Of Inclined Strip Anchors in c-ϕ Soils

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Introduction

Anchors are primarily designed and constructed to resist outwardly directed loads imposed on the foundation of a structure. A few theories are available to obtain uplift capacity of inclined strip anchors in sand (Meyerhof, 1973; Hanna et al., 1988). Meyerhof (1973) treated the determination of uplift capacity of inclined strip anchor as a passive earth pressure problem. Using the passive earth pressure coefficients provided by Caquot and Kerisel (1948) for inclined walls, expressions for gross pullout load are provided. Effect of cohesion was considered approximately and surcharge effect was not considered. Hanna et al. (1988) also treated this problem as a passive earth pressure problem and used coefficients provided by Caquot and Kerisel (1948). Model test results were made use to decide the variation of wall friction angle along the depth and an expression for gross pullout load was suggested. Effect of surcharge and cohesion were not considered.

In this paper, a generalized approach has been suggested to estimate the uplift capacity of strip anchors in c-ϕ soils subjected to surcharge. This approach considers the problem as that of passive earth pressure. Uplift capacity has been expressed in terms of uplift capacity factors from limit equilibrium analysis. The values of uplift capacity factors are obtained from earth pressure coefficients derived and provided in Tables. Details of the proposed theory for the determination of uplift capacity of strip anchors and the results obtained from this theory are given in the subsequent sections.

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Uplift Capacity Analysis

Consider an inclined strip anchor of width B, making an angle β with the horizontal (Fig.1). Let D be the depth of embedment measured along the anchor rod length. The failure surfaces (GH and AI) are considered as logarithmic spirals. It is assumed that the failure surfaces make an angle of η (= $45-\phi/2$) with the horizontal at the ground surface, where ϕ is the angle of internal friction of the soil. AE and GF are treated as imaginary retaining wall faces. The ground surface IH is subjected to uniform surcharge pressure of q. The imaginary retaining wall faces GF and AE have inclined heights of D_1 and D_2 respectively. The vertical height of GF and AE are denoted by D_1' and D_2' respectively. The forces acting on the central soil block AEFG are shown in Fig.2. P_{pc1}, P_{pq1} and $P_{p\gamma 1}$ are respectively the cohesion, surcharge and unit weight components of passive force acting on the face GF. P_{pc2}, P_{pq2} and $P_{p\gamma 2}$ are the corresponding forces on the face AE.

Assumptions

The following assumptions are made in the uplift capacity analysis.

(a) Soil is homogeneous.

(b) Presence of anchor rod is not considered in the uplift capacity analysis.

(c) Suction below the plate is neglected.

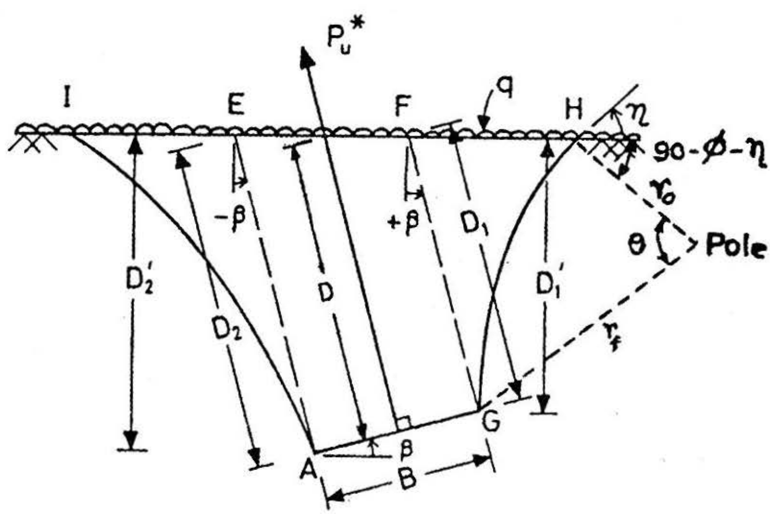

FIGURE 1 : Inclined Strip Anchor in c-ϕ Soil

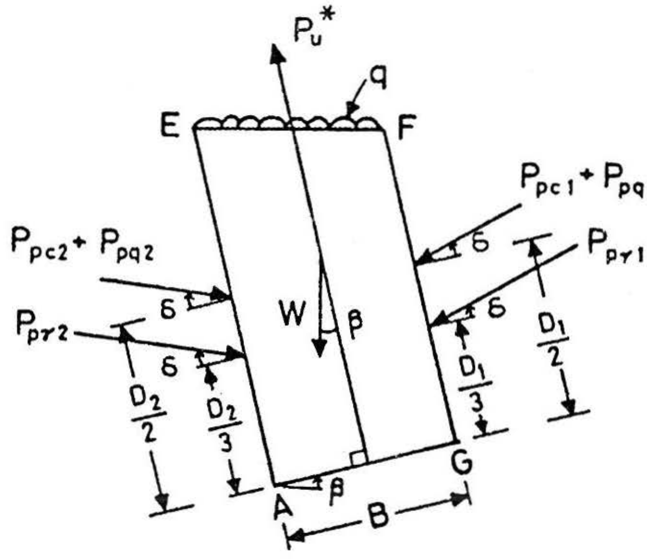

FIGURE 2 : Forces Acting on the Central Soil Block AEFG

(d) The passive force is divided into three components P_{pc}, P_{pq} and $P_{p\gamma}$. Independent effects of cohesion, surcharge and unit weight are considered. P_{pc} and P_{pq} are assumed to act at mid height and $P_{p\gamma}$ is assumed to act at 1/3rd height from the base.

(e) The wall friction along the imaginary retaining wall faces AE and GF are assumed to be 2/3rd of frictional angle (Meyerhof and Adams, 1968).

Uplift Capacity Factors

Consider Figs.1 and 2. The passive forces P_{pc1}, P_{pq1} and $P_{p\gamma1}$ acting on face GF can be obtained by considering the equilibrium of soil mass GFH. Similarly, the passive forces P_{pc2}, P_{pq2} and $P_{p\gamma2}$ acting on the face AE are obtained by applying equilibrium conditions to soil mass AEI. Considering the equilibrium of forces acting on the central soil block AEFG along the pull direction, the gross pullout load P_u^* is established.

$$P_u^* = \left[P_{pc1} + P_{pc2} + P_{pq1} + P_{pq2} + P_{p\gamma1} + P_{p\gamma2}\right]\sin\delta + W\cos\beta + qB \qquad (1)$$

where W is the weight of the soil block AEFG.

The normal components of passive earth pressures are expressed as follows:

$$P_{pc1}\cos\delta = 2cD_1^1 K_{pc1} \tag{2a}$$

$$P_{pc2}\cos\delta = 2cD_2^1 K_{pc2} \tag{2b}$$

$$P_{pq1}\cos\delta = qD_1^1 K_{pq1} \tag{2c}$$

$$P_{pq2}\cos\delta = qD_2^1 K_{pq2} \tag{2d}$$

$$P_{p\gamma 1}\cos\delta = \tfrac{1}{2} K_{p\gamma 1}\gamma\left[D_1^1\right]^2 \tag{2e}$$

$$P_{p\gamma 2}\cos\delta = \tfrac{1}{2} K_{p\gamma 2}\gamma\left[D_2^1\right]^2 \tag{2f}$$

The earth pressure coefficients connected with cohesion are K_{pc1} and K_{pc2}; connected with surcharge are K_{pq1} and K_{pq2} and connected with unit weight are $K_{p\gamma 1}$ and $K_{p\gamma 2}$. c is the cohesion and γ is the unit weight.

From the geometry of Fig.2,

$$\left.\begin{aligned} D_1 &= D - \frac{B}{2}\tan\beta \\ D_2 &= D + \frac{B}{2}\tan\beta \end{aligned}\right\} \tag{3}$$

$$\left.\begin{aligned} D_1^1 &= D_1\cos\beta \\ D_2^1 &= D_2\cos\beta \end{aligned}\right\} \tag{4}$$

Substituting from Eqn.3 into Eqn.4,

$$\left.\begin{aligned} D_1^1 &= D\cos\beta - \frac{B}{2}\tan\beta\cos\beta \\ D_2^1 &= D\cos\beta + \frac{B}{2}\tan\beta\cos\beta \end{aligned}\right\} \tag{5}$$

Substituting from Eqn.2 into Eqn.1, defining the net ultimate uplift capacity q_{unet}^* as

$$q_{unet}^* = \frac{P_u^* - W\cos\beta}{B} \tag{6}$$

$$q^*_{unet} = 2c\tan\delta\left[K_{pc1}\frac{D_1^1}{B}+K_{pc2}\frac{D_2^1}{B}\right]+q\tan\delta\left[K_{pq1}\frac{D_1^1}{B}+K_{pq2}\frac{D_2^1}{B}\right]$$
$$+1+\frac{1}{2}B\gamma\tan\delta\left[K_{p\gamma1}\frac{\left(D_1^1\right)^2}{B}+K_{p\gamma2}\frac{\left(D_2^1\right)^2}{B}\right] \quad (7)$$

Simplifying and using Eqn.5,

$$q^*_{unet} = cF_c+qF_q+\frac{1}{2}B\gamma F_\gamma \quad (8)$$

The uplift capacity factors F_c, F_q and F_γ are given by,

$$F_c = 2\lambda\tan\delta\cos\beta\left(K_{pc1}+K_{pc2}\right)$$
$$+\tan\delta\cos\beta\tan\beta\left(K_{pc2}-K_{pc1}\right) \quad (9)$$

$$F_q = 1+\lambda\tan\delta\cos\beta\left(K_{pq1}+K_{pq2}\right)$$
$$+\frac{1}{2}\tan\delta\cos\beta\tan\beta\left(K_{pq2}-K_{pq1}\right) \quad (10)$$

$$F_\gamma = \lambda^2\tan\delta\cos^2\beta\left(K_{p\gamma1}+K_{p\gamma2}\right)$$
$$+\frac{1}{4}\tan\delta\cos^2\beta\tan^2\beta\left(K_{p\gamma1}+K_{p\gamma2}\right)$$
$$+\lambda\tan\delta\cos^2\beta\tan\beta\left(K_{p\gamma2}-K_{p\gamma1}\right) \quad (11)$$

The embedment ratio λ is defined as,

$$\lambda = \frac{D}{B} = \frac{D_1+D_2}{2B} \quad (12)$$

The coefficients K_{pc1}, K_{pq1} and $K_{p\gamma1}$ are passive earth pressure coefficients with respect to positive wall batter angle $(+\beta)$, where as K_{pc2}, K_{pq2} and $K_{p\gamma2}$ are the corresponding coefficients for negative wall batter angle $(-\beta)$ (wall batter angle β is positive when the top of the wall is leaning away from the backfill). These passive earth pressure coefficients are obtained by limit equilibrium method using logarithmic spiral failure surface (for

TABLE 1 : Passive Earth Pressure Coefficients K_{pc} ($\delta = -2/3\phi$)

ϕ	β						
	-30	-20	-10	0	10	20	30
5	2.77	1.71	1.26	1.02	0.85	0.71	0.60
10	2.72	1.71	1.28	1.04	0.85	0.71	0.59
15	2.65	1.70	1.28	1.03	0.84	0.69	0.57
20	2.58	1.69	1.28	1.01	0.82	0.66	0.54
25	2.50	1.66	1.26	0.98	0.78	0.63	0.51
30	2.41	1.63	1.22	0.94	0.74	0.59	0.47
35	2.31	1.58	1.16	0.88	0.68	0.54	0.43
40	2.20	1.51	1.09	0.81	0.62	0.49	0.38
45	2.09	1.41	1.00	0.73	0.55	0.43	0.34
50	1.96	1.28	0.89	0.64	0.48	0.37	0.29

TABLE 2 : Passive Earth Pressure Coefficients K_{pq} ($\delta = -2/3\phi$)

ϕ	β						
	-30	-20	-10	0	10	20	30
5	1.39	1.23	1.14	1.09	1.08	1.11	1.19
10	1.63	1.40	1.26	1.18	1.14	1.15	1.21
15	1.89	1.57	1.38	1.26	1.20	1.18	1.22
20	2.16	1.75	1.49	1.33	1.23	1.19	1.21
25	2.44	1.93	1.60	1.39	1.26	1.20	1.20
30	2.74	2.09	1.68	1.42	1.27	1.18	1.17
35	3.05	2.24	1.75	1.44	1.26	1.15	1.12
40	3.34	2.37	1.79	1.44	1.23	1.11	1.07
45	3.62	2.47	1.81	1.41	1.18	1.05	1.00
50	3.87	2.52	1.78	1.35	1.11	0.97	0.92

$\delta/\phi = -2/3$) and are presented in Tables 1, 2 and 3. Nayak (2000) has shown that the error involved in the superposition of earth pressure components is only marginal, less than 9%. He has also shown that $K_{p\gamma}$ values from limit equilibrium approach using logarithmic spiral surfaces are very close to those provided by Kerisel and Absi (1990).

TABLE 3 : Passive Earth Pressure Coefficients $K_{p\gamma}$ ($\delta = -2/3\phi$)

ϕ	β						
	-30	-20	-10	0	10	20	30
5	1.39	1.23	1.14	1.09	1.09	1.12	1.19
10	1.64	1.40	1.26	1.19	1.15	1.16	1.21
15	1.89	1.58	1.39	1.27	1.21	1.19	1.23
20	2.16	1.75	1.50	1.35	1.25	1.22	1.23
25	2.44	1.93	1.61	1.41	1.29	1.23	1.22
30	2.74	2.10	1.71	1.46	1.31	1.22	1.20
35	3.05	2.27	1.79	1.50	1.31	1.21	1.16
40	3.35	2.41	1.86	1.52	1.30	1.17	1.12
45	3.65	2.54	1.90	1.51	1.27	1.13	1.06
50	3.93	2.63	1.91	1.49	1.23	1.07	0.99

For horizontal strip anchor ($\beta = 0$) in horizontal ground (for which $K_{pc1} = K_{pc2} = K_{pc}$, $K_{pq1} = K_{pq2} = K_{pq}$ and $K_{p\gamma1} = K_{p\gamma2} = K_{p\gamma}$), the expressions for uplift capacity factor reduce to,

$$F_c = 4\lambda K_{pc} \tan\delta \tag{13}$$

$$F_q = 1 + 2\lambda K_{pq} \tan\delta \tag{14}$$

$$F_\gamma = 2\lambda^2 K_{p\gamma} \tan\delta \tag{15}$$

For square and circular anchors, Meyerhof and Adams (1968) rep[illegible]d the critical embedment ratio λ_{cr} to vary from 2.5 to 11 for ϕ values ran[illegible]ng from 25° to 48°. Meyerhof (1973) reported that for strip anchors these critical values are about 1.5 times those for square or circular anchors. Further Meyerhof (1973) observed that anchor inclinations will reduce λ_{cr} values. The critical embedment ratios for general c-ϕ soils have not yet been established. Qualitatively, it is known that the λ_{cr} values for c-ϕ soils can not be very high as for dense sands. In this paper the uplift capacity factors have been calculated upto $\lambda = 10$, a value arbitrarily fixed. The values of uplift capacity factors for $\beta = 0°$, 10°, 20° and 30° are presented in Tables 4 to 7. It is observed from Tables 4 to 7 that the uplift capacity factors F_c, F_q and F_γ increase with the increase in ϕ and λ. Variation of F_γ is much more compared to the variation of F_c and F_q.

TABLE 4 : Uplift Capacity Factors for λ = 2, 4, 6 and 10 when β = 0°

ϕ	F_c				F_q				F_γ			
	λ = 2	λ = 4	λ = 6	λ = 10	λ = 2	λ = 4	λ = 6	λ = 10	λ = 2	λ = 4	λ = 6	λ = 10
5	0.48	0.95	1.43	2.38	1.25	1.51	1.76	2.27	0.51	2.03	4.57	12.70
10	0.97	1.94	2.92	4.86	1.55	2.10	2.66	3.76	1.11	4.45	10.01	27.82
15	1.45	2.91	4.36	7.26	1.89	2.78	3.67	5.44	1.79	7.17	16.12	44.79
20	1.91	3.83	5.74	9.57	2.26	3.52	4.78	7.30	2.56	10.24	23.04	63.99
25	2.35	4.69	7.04	11.74	2.66	4.33	5.99	9.32	3.38	13.51	30.39	84.43
30	2.74	5.47	8.21	13.69	3.07	5.13	7.20	11.34	4.25	17.00	38.26	106.28
35	3.04	6.07	9.11	15.18	3.48	5.97	8.45	13.42	5.18	20.71	46.59	129.41
40	3.25	6.51	9.76	16.27	3.89	6.79	9.68	15.46	6.11	24.43	54.96	152.67
45	3.37	6.74	10.12	16.86	4.26	7.51	10.77	17.28	6.97	27.90	62.77	174.36
50	3.37	6.73	10.10	16.84	4.55	8.10	11.65	18.76	7.84	31.36	70.56	196.00

TABLE 5 : Uplift Capacity Factors for λ = 2, 4, 6 and 10 when β = 10°

ϕ	F_c				F_q				F_γ			
	$\lambda = 2$	$\lambda = 4$	$\lambda = 6$	$\lambda = 10$	$\lambda = 2$	$\lambda = 4$	$\lambda = 6$	$\lambda = 10$	$\lambda = 2$	$\lambda = 4$	$\lambda = 6$	$\lambda = 10$
5	0.49	0.97	1.46	2.42	1.25	1.51	1.76	2.27	0.51	2.02	4.54	12.60
10	0.99	1.97	2.95	4.91	1.55	2.11	2.66	3.76	1.10	4.38	9.85	27.34
15	1.49	2.96	4.43	7.38	1.87	2.74	3.61	5.34	1.79	7.14	16.04	44.52
20	1.98	3.94	5.90	9.82	2.28	3.54	4.81	7.35	2.55	10.16	22.82	63.32
25	2.43	4.84	7.24	12.05	2.70	4.38	6.07	9.44	3.41	13.54	30.42	84.37
30	2.84	5.65	8.46	14.08	3.13	5.24	7.36	11.59	4.32	17.16	38.54	106.86
35	3.16	6.29	9.42	15.67	3.58	6.13	8.69	13.81	5.27	20.90	46.91	130.05
40	3.42	6.81	10.19	16.96	4.01	7.00	9.99	15.96	6.26	24.83	55.71	154.41
45	3.57	7.10	10.62	17.67	4.43	7.83	11.23	18.03	7.24	28.66	64.29	178.14
50	3.60	7.15	10.70	17.79	4.78	8.53	12.27	19.76	8.18	32.37	72.58	201.07

TABLE 6 : Uplift Capacity Factors for λ = 2, 4, 6 and 10 when β = 20°

ϕ	F_c				F_q				F_γ			
	λ = 2	λ = 4	λ = 6	λ = 10	λ = 2	λ = 4	λ = 6	λ = 10	λ = 2	λ = 4	λ = 6	λ = 10
5	0.55	1.08	1.61	2.67	1.26	1.51	1.77	2.28	0.49	1.95	4.37	12.11
10	1.10	2.17	3.23	5.36	1.57	2.13	2.69	3.81	1.08	4.27	9.57	26.52
15	1.64	3.23	4.81	7.98	1.92	2.83	3.75	5.57	1.78	7.00	15.67	43.36
20	2.18	4.27	6.36	10.55	2.33	3.64	4.95	7.57	2.59	10.13	22.64	62.58
25	2.68	5.26	7.84	12.99	2.80	4.56	6.32	9.84	3.50	13.66	30.51	84.24
30	3.17	6.20	9.24	15.32	3.29	5.53	7.77	12.24	4.51	17.52	39.07	107.77
35	3.59	7.03	10.47	17.34	3.83	6.58	9.33	14.82	5.64	21.84	48.64	134.07
40	3.95	7.73	11.50	19.05	4.39	7.68	10.96	17.53	6.80	26.26	58.41	160.82
45	4.19	8.18	12.17	20.16	4.96	8.78	12.60	20.24	8.07	31.04	68.99	189.78
50	4.28	8.36	12.44	20.60	5.49	9.80	14.12	22.74	9.33	35.77	79.41	218.26

TABLE 7 : Uplift Capacity Factors for λ = 2, 4, 6 and 10 when β = 30°

ϕ	F_c				F_q				F_γ			
	$\lambda = 2$	$\lambda = 4$	$\lambda = 6$	$\lambda = 10$	$\lambda = 2$	$\lambda = 4$	$\lambda = 6$	$\lambda = 10$	$\lambda = 2$	$\lambda = 4$	$\lambda = 6$	$\lambda = 10$
5	0.74	1.42	2.10	3.46	1.26	1.52	1.78	2.30	0.47	1.83	4.10	11.33
10	1.46	2.80	4.15	6.83	1.59	2.16	2.74	3.89	1.06	4.11	9.15	25.22
15	2.15	4.12	6.08	10.02	1.98	2.93	3.88	5.78	1.79	6.84	15.19	41.80
20	2.80	5.36	7.93	13.05	2.44	3.82	5.21	7.97	2.65	10.07	22.32	61.26
25	3.42	6.54	9.66	15.91	2.98	4.87	6.76	10.53	3.71	13.97	30.87	84.54
30	3.98	7.62	11.25	18.51	3.61	6.07	8.54	13.47	4.88	18.27	40.27	110.07
35	4.50	8.59	12.69	20.88	4.32	7.44	10.55	16.79	6.27	23.32	51.26	139.85
40	4.95	9.43	13.92	22.90	5.12	8.96	12.79	20.47	7.84	29.02	63.66	173.36
45	5.37	10.23	15.09	24.81	6.00	10.62	15.24	24.48	9.62	35.39	77.48	210.59
50	5.68	10.80	15.93	26.18	6.94	12.40	17.86	28.77	11.58	42.38	92.60	251.57

Correction To Gross Pullout Load P_u^*

In the estimation of the gross pullout load P_u^*, equilibrium of the forces along the pull direction is satisfied, where as equilibrium of the forces along the normal to the pull direction and the moment equilibrium conditions are not satisfied. Therefore the estimation of P_u^* will be in error and it needs to be corrected. The imbalance of the forces along the normal to the pull direction can be corrected by applying an equivalent surcharge q_e on the ground surface. The detailed procedure of applying the correction to P_u^* is given below.

Consider an inclined strip anchor shown in Fig.3. The gross pullout load P_u^* is obtained by satisfying the equilibrium of all forces (acting on the central block AEFG) along the pull direction.

The normal component of the passive force acting on GF is given by,

$$P_{p1n} = \left(P_{pc1} + P_{pq1} + P_{p\gamma 1}\right)\cos\delta \tag{16}$$

$$P_{p1n} = 2cD_1^1 K_{pc1} + qD_1^1 K_{pq1} + \frac{1}{2} K_{p\gamma 1}\gamma\left(D_1^1\right)^2 \tag{17}$$

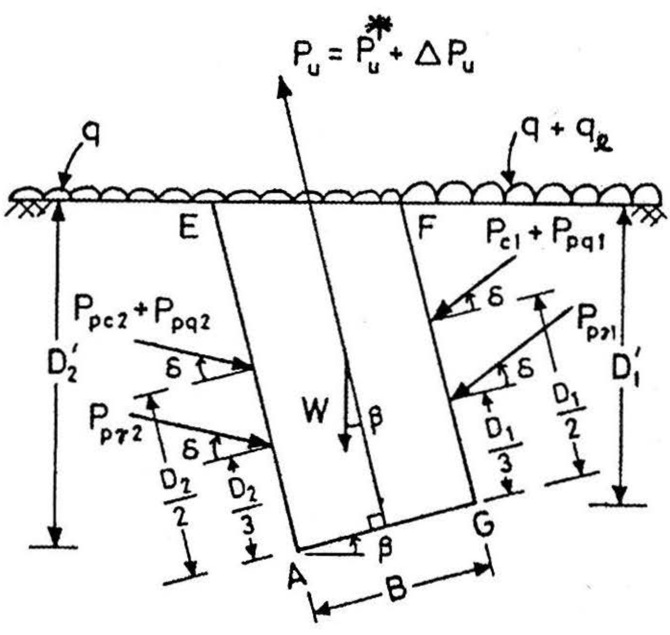

FIGURE 3 : Correction to Gross Pullout Load P_u^*

The normal component of the passive force acting on AE is given by,

$$P_{p2n} = \left(P_{pc2} + P_{pq2} + P_{p\gamma 2}\right)\cos\delta \tag{18}$$

$$P_{p2n} = 2cD_2^1 K_{pc2} + qD_2^1 K_{pq2} + \frac{1}{2}K_{p\gamma 2}\gamma\left(D_2^1\right)^2 \tag{19}$$

where, D_1^1 and D_2^1 are as given in Eqn.5.

Consider the forces acting on central block AEFG in the direction normal to GF and AE.

Forces acting from right to left,

$$P_{n_{R-L}} = P_{p1n} + W\sin\beta \tag{20}$$

Forces acting from left to right,

$$P_{n_{L-R}} = P_{p2n} \tag{21}$$

But, $P_{n_{R-L}} \neq P_{n_{L-R}}$ (22)

To balance the forces along the normal direction, an equivalent surcharge of intensity q_e should be applied either to the right of G (if $P_{n_{R-L}} < P_{n_{L-R}}$) or to the left of E ($P_{n_{L-R}} < P_{n_{R-L}}$). Equivalent surcharge q_e is given by,

$$q_e = \frac{\left(P_{n_{L-R}} - P_{n_{R-L}}\right)}{D_1' K_{pq1}} \qquad \text{if } P_{n_{R-L}} < P_{n_{L-R}} \tag{23}$$

or

$$q_e = \frac{\left(P_{n_{R-L}} - P_{n_{L-R}}\right)}{D_2' K_{pq2}} \qquad \text{if } P_{n_{L-R}} < P_{n_{R-L}} \tag{24}$$

The increase in pullout load due to the additional surcharge q_e is given by,

$$\Delta P_u = \left|P_{n_{L-R}} - P_{n_{R-L}}\right|\tan\delta \tag{25}$$

The corrected gross pullout load P_u is given by,

$$P_u = P_u^* + \Delta P_u \tag{26}$$

Thus using Eqns.20, 21, 25 and 26, for any value of β, i, ϕ, λ (= D/B), c, q and γ, the corrected pullout load P_u can be estimated.

For the case of pure sand (c = 0) without surcharge effect (q = 0), the error analysis is carried out for a typical case of λ = 3 and B = 1. A total of four cases of β has been considered. The equivalent surcharge q_e and increase in the gross pullout load (correction to P_u^*) ΔP_u is calculated using the procedure explained above. It is expressed as a percentage of gross pullout load P_u^*. The results of this analysis are tabulated in Table 8. It is found from Table 4 that the correction to pullout load (shown in last column of Table 4) is less than 5% for three of the four cases studied (β = 0°, 10°, 20°). The correction for the case of β = 30° is about 35%.

It is also possible to obtain expression for corrected values of uplift capacity factors (denoted by F_c^1, F_q^1 and F_γ^1).

$$P_u = P_u^* + \Delta P_u \qquad \text{if } P_{n_{R-L}} < P_{n_{R-L}}$$

Resolving the forces along pull direction and using Eqns.20, 21 and 25,

$$P_u = \left\{P_{p2n} \tan\delta + P_{p1n} \tan\delta + W\cos\beta + qB\right\} \\ -\left\{P_{p2n} \tan\delta - P_{p1n} \tan\delta - W\sin\beta\tan\delta\right\} \tag{27}$$

$$P_u = 2P_{p2n} \tan\delta + W\cos\beta + qB - W\sin\beta\tan\delta \tag{28}$$

TABLE 8 : Correction to P_u^* for B = 1 m and λ = 3

β (deg.)	ϕ (deg.)	γ (kN/m³)	P_{p1n} (kN)	P_{p2n} (kN)	$P_{p1n} + W\sin\beta$ (kN)	q_c (kN/m²)	ΔP_u (kN)	$\Delta P_u/P_u^*$ (in %)
0	30	15	98.55	98.55	98.55	0	0	0
10	30	15	90.85	105.41	98.66	1.75	2.45	2.10
20	30	15	81.80	110.44	97.19	2.12	4.82	4.12
30	30	15	49.61	166.68	72.11	34.42	34.42	35.04

Corrected net ultimate uplift capacity,

$$q_{unet} = \frac{P_u - W\cos\beta}{B} \tag{29}$$

The corrected uplift capacity factors are given by,

$$F_c^1 = 4K_{pc2}\tan\delta\left[\lambda\cos\beta + \frac{1}{2}\sin\beta\right] \tag{30}$$

$$F_q^1 = 2K_{pq2}\tan\delta\left[\lambda\cos\beta + \frac{1}{2}\sin\beta\right] + 1 \tag{31}$$

$$F_\gamma^1 = 2K_{p\gamma2}\tan\delta\left[\lambda^2\cos^2\beta + \frac{1}{2}\sin^2\beta + \lambda\sin\beta\cos\beta\right] - 2\lambda\sin\beta\tan\delta \tag{32}$$

For the case of $P_{n_{L-R}} < P_{n_{R-L}}$, proceeding in a similar way the expression for corrected uplift capacity factors are,

$$F_c^1 = 4K_{pc1}\tan\delta\left[\lambda\cos\beta - \frac{1}{2}\sin\beta\right] \tag{30}$$

$$F_q^1 = 2K_{pq1}\tan\delta\left[\lambda\cos\beta - \frac{1}{2}\sin\beta\right] + 1 \tag{31}$$

$$F_\gamma^1 = 2K_{p\gamma1}\tan\delta\left[\lambda^2\cos^2\beta + \frac{1}{2}\sin^2\beta - \lambda\sin\beta\cos\beta\right] - 2\lambda\sin\beta\tan\delta \tag{32}$$

Comparison with the Experimental and Theoritical Results

Three typical comparisons are made considering experimental results of Murray and Geddes (1989), Ranganath (1993) and the theoretical results of Meyerhof (1973).

Murray and Geddes (1989) conducted pull out load test on inclined strip anchor with B = 0.0508 m, $L/B = 10$ and $\beta = 22.5°$ where, L is the length of the anchor plate. In the proposed theory the corrected gross pullout load P_u is used for calculating $P_u/(\gamma AD)$. Table 9 shows their experimental results and the values obtained as per the present theory (after applying

TABLE 9 : Comparison of $P_u/\gamma AD$ Obtained from the Proposed Theory with the Expt. Data of Murray and Geddes (1989) for $\beta = 22.5°$, $\phi = 43.6°$, $\gamma = 16.8\ kN/m^3$, $c = 0$, $q = 0$

D/B	$P_u/\gamma AD$	
	Proposed theory	Expt. Results of Murray and Geddes (1989)*
2	3.8	3.4
3	5.1	4.6
4	5.8	5.6
5	7.7	7.2
6	9.0	7.9

* As read from their graphs

TABLE 10 : Comparison of $P_u/\gamma AD$ Obtained from the Proposed Theory with the Expt. Results of Ranganath (1993) for c = $7.85\ kN/m^2$, $\phi = 17.5°$, $\gamma = 12.16\ kN/m^3$, $B = 0.05$ m, $q = 0$

λ	Expt. Values	Meyerhof and Adams (1968)	Proposed theory
4	12.8	28.00	12.96
5	16.7	28.30	13.28
6	16.8	28.61	13.49

correction). Table 10 shows the comparison of $P_u/(\gamma AD)$ with the experimental results of Ranganath (1993) for horizontal anchors in c-ϕ soils. There is reasonable comparison of results.

The corrected uplift capacity factors F_γ^1 obtained from the proposed theory are compared with that obtained from theory of Meyerhof (1973) for sands. The results are shown in Table 11 for anchor inclinations of 10° and 20°, considering λ = 2, 6 and 10. It is found from the Table 11 that the results are comparing reasonably well. The proposed theory can consider the effect of cohesion and surcharge also.

Summary and Conclusions

A generalized approach for the determination of uplift capacity of inclined strip anchors in c-ϕ soils subjected to surcharge is proposed. This

TABLE 11 : Comparison of Uplift Capacity Factors F_γ^1 with that Obtained from Theory of Meyerhof (1973)

ϕ	$\beta = 10°$			$\beta = 20°$		
	$\lambda = 2$	$\lambda = 6$	$\lambda = 10$	$\lambda = 2$	$\lambda = 6$	$\lambda = 10$
20	2.9 (3.0)	25.1 (25.2)	69.3 (70.0)	3.2 (3.2)	27.0 (24.3)	74.3 (65.1)
30	5.0 (5.2)	44.0 (44.2)	121.6 (121.4)	6.0 (5.5)	50.1 (41.8)	135.2 (111.9)
40	7.6 (7.7)	67.5 (66.1)	182.7 (181.6)	9.6 (8.7)	79.7 (65.8)	213.3 (176.2)
45	8.9 (9.0)	77.7 (76.9)	214.5 (211.2)	11.6 (10.3)	96.7 (80.0)	258.6 (214.3)

(Values in brackets are Meyerhof's F_γ values)

problem is treated as a passive earth pressure problem. The passive earth pressure coefficients K_{pc}, K_{pq} and $K_{p\gamma}$ are obtained using limit equilibrium approach considering logarithmic spiral failure surface. The net ultimate uplift capacity of strip anchors is expressed in terms of uplift capacity factors F_c, F_q and F_γ and the expressions are derived for the same. For various anchor inclinations and embedment ratios, the values of uplift capacity factors are established for the ready practical use. The detailed procedure of applying correction to gross pullout load is presented. In addition to comparing well with the available experimental results and theoretical approaches, the proposed theory can clearly consider the effect of cohesion and surcharge also.

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Notations

A = Area of anchor plate;

B = Width of anchor plate;

c = Unit cohesion;

D = Embedment depth measured along the anchor rod length;

F_c = Uplift capacity factor with respect to cohesion;

F_c' = Corrected uplift capacity factor woth respect to cohesion;

F_q = Uplift capacity factor with respect to surcharge;

F_q' = Corrected uplift capacity factor with respect to surcharge;

F_γ = Uplift capacity factor with respect to unit weight;

F_γ' = Corrected uplift capacity factor with respect to unit weight;

K_{pc} = Passive earth pressure coefficient with respect to cohesion;

K_{pq} = Passive earth pressure coefficient with respect to surcharge;

$K_{p\gamma}$ = Passive earth pressure coefficient with respect to unit weight;

L = Length of anchor plate;

P_{pc} = Cohesion component of passive force;

P_{pq} = Surcharge component of passive force;

$P_{p\gamma}$ = Unit weight component of passive force;

P_u^* = Gross uplift load (uncorrected);

P_u = Corrected gross uplift load;

q = Surcharge pressure acting over the ground surface;

q_u = Corrected net ultimate uplift capacity;

q_u^* = Net utlimate uplift capacity (uncorrected);

W = Weight of soil mass above the anchor plate of width B;

ϕ = Angle of internal friction;

η = Angle made by the failure surface with the horizontal at the ground surface;

γ = Unit weight of soil;

δ = Angle of wall friction;

β = Angle made by the anchor plate with the horizontal.