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BEARING CAPACITY OF REINFFORCED LAYERED SOIL BED WITH INCLINED REINFORCEMENT

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Abstract:
The objective of the present investigation is M30, M40 grades concrete has been considered. Compressive strength and Flexural strength of conventional as well as self-compacting concrete were investigated. The Development of this strength with different age of curing is investigated. The properties of recycled aggregate differed from those natural aggregate. For the production of concrete for both conventional and self-compacting concrete, these recycled aggregates are replaced by normal concrete, always in ascending order of 10%, 20%, 30%. However, these changes did not affect the properties of the recycled aggregate, both in the normal case and in the self-compaction of the concrete. However, in the case of self-compacting concrete, it has been observed that the quality of the concrete deteriorates after a certain percentage of recycled aggregate with natural aggregate. The high water absorption of the recycled aggregate is ensured by the process before wetting, whereby the recycled aggregate becomes functional as a natural inert substance.

***Keywords**: Compressive strength, Tensile Strength, Flexural Strength.*

I. INTRODUCTION

In Geosynthetic Reinforced soil bed, the tensile force mobilized due to the interfacial friction developed between the soil and reinforcement results in increased bearing capacity of soil. In a research work, the bearing capacity equation was formulated by Meyerhof assuming punching shear mode of failure for the strip footing placed at depth (D) in dense sand layer which is overlying on homogeneous soft clay [1]. In the available literature, an analytical equation was developed by considering the stress distribution from replaced sand layer, contribution from

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membrane action of reinforcement and shear layer effect. The analysis was carried out to formulate an equation for the ultimate bearing capacity (q_u) of the strip footing on sand bed overlying soft clay with geotextile as reinforcement at sand clay interface. Mathematical modeling of strip footing on horizontal reinforced soil bed compares well with the experimental results [2], [3]. Madhav and Umashankar studied analysis of inextensible sheet reinforcement subjected to transverse displacement/force linear sub grade reaction. This approach presents a new method to predict the pull-out resistance of inextensible sheet reinforcement subjected to transverse force assuming a linear sub grade response. The stability analysis was carried out by considering the non axial failure instead of a axial failure. The non axial failure involves the transverse force in addition to the axial pull which is the practical phenomenon and this new approach named as kinematics of failure [4]. Rajashekar Reddy performed an analytical study for bearing capacity of strip footing resting over two-layered (Cohesive Non Swelling (CNS) soil bed overlying soft clay) reinforced soil bed by considering the kinematics of failure. The geosynthetic reinforced material was placed in an inclined position with the horizontal in CNS due to which there was an increase in overburden pressure along the inclined reinforcement. Hence, additional shear stresses were observed above the inclined portion leading to increase in bearing capacity of footing compared to the horizontal reinforcement (coventional method) [5]. An analytical solution developed by Mandal and Manjunath for sand bed reinforced with inclined reinforcement beneath the strip footing .Limited experimental studies are available with vertical/inclined reinforcement in soil bed. Hence, in this paper, model tests were conducted on square footing resting on reinforced soil bed overlying soft clay with different reinforcement inclinations and a comparison was made between the analytical and experimental work.

2. EXPERIMENTAL WORK

2.1. Program

The model tests were conducted at laboratory in a tank of dimension 100cm X 100cm X 60cm. The tests are carried out on a square footing of 15cm width resting on a single geotextile reinforced CNS soil bed of thickness equal to width of footing (H=B) overlying on soft clay. The geotextile reinforcement has been placed at a depth, u(B/4) from bottom surface of the footing with an inclination of reinforcement, α (0°, 5°, 10° and 15°) and the reinforcement is inclined from the edges of footing as shown in Figure 1. A negligible strength flexible sheet was used as separator at the interface of CNS and soft soil. The parametric study with the length of reinforcement L_r(2B, 2.5B and 3B) and unit weight of CNS soil bed γ_d(20kN/m^3, 19kN/m^{3}and 18kN/m^3) are studied for the inclination of reinforcement, α =10°.

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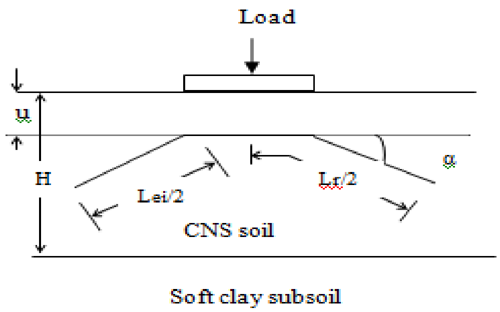

Figure 1: Inclined reinforcement in foundation

2.2. Materials and Properties

2.2.1. Cohesive Non-Swelling (murrum) soil: CNS soil has been selected as soil bed for the study and the properties of CNS soil are shown in Table 1.

Table 1. Properties of CNS soil

Sl. No.	Property Name	Value
1.	Specific Gravity	2.67
2.	Liquid Limit (%)	31
3.	Plastic Limit (%)	20
4.	Plasticity Index (%)	9
5.	OMC% (Optimum Moisture Content)	9.5
6.	Maximum Dry Density (kN/m^3)	20
7.	Grain Size Distribution	
8.	Soil classification	SC

2.2.2. Clay soil: The soft clay soil containing moisture content of 37% is proposed to use as subsurface soil and the properties of clay soil are mentioned in Table 2.

Table 2. Properties of Clay soil

Sl. No.	Test name	Test value
1.	Specific Gravity	2.72
2.	Liquid Limit (%)	50.8
3.	Plastic Limit (%)	23.4
4.	Plasticity Index (%)	27.4
5.	Free Swell Index (%)	100
6.	UCS @ 37% W.C (kN/m^2)	31.8
7.	Grain Size Distribution	

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8.	Soil Classification	CH

2.2.3. Geotextile Reinforcement: GEOFIL HF800 is a polypropylene geotextile (Figure .2) used as reinforcement and the properties are given in Table 3.

Table 3. Properties of Geotextile

Sl . No.	Property	Value
1.	Type of Geotextile	GEOFILL HF800 woven
2.	Tensile strength (kN/m)	65
3.	Thickness (mm)	1.18

Figure .2 woven geotextile reinforcement

Table. 4 Interface friction angle between the reinforcement and CNS soil

Sl. No.	Unit weight of CNS Soil(kN/m^3)	Angle of internal Friction (^{0})	Interface friction angle between soil and geotextile (^{0})
1.	20	43	32
2.	19	39	29
3.	18	36	27

2.3. Preparation of Soil Bed

Soft clay soil with 37% water content is placed up to 15cm in 5 layers in the test tank. A negligible strength flexible sheet placed above the soft clay as separator, CNS soil has been placed and compacted with required density and leveled in 3 layers i.e., up to B/4 depth from bottom of footing. After this, compacted soil is trimmed to achieve angle of inclination, α and specific length of reinforcement as shown in Fig.2.

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Figure . 3. Inclined Profile in CNS Soil

The geotextile reinforcement is placed on prepared slope then the soil is compacted to the required density over geotextile and leveled. The remaining depth of soil placed and leveled to get thickness of soil H (= B). Load tests were conducted on square footing placed at centre of tank using hydraulic jack as shown in Fig.3.

2.4. Test results

The ultimate bearing capacity was calculated using the double tangent method

2.4.1. Effect of inclined reinforcement on bearing carrying capacity of footing

Fig. 4 Depicts the stress Vs Settlement curve of reinforced CNS soil with γ_d=20kN/m^3 for different inclinations of geotextile reinforcement (α = 0°, 5°, 10° and 15°) placed at a depth of B/4 from the bottom of footing and length of reinforcement, L_r= 3B.

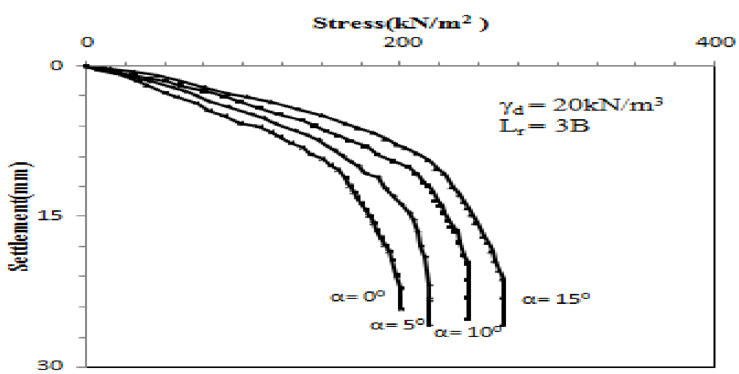

Figure 4. Stress Vs Settlement curve for different inclinations of the reinforcement (α) in soil bed.

It is also observed that the bearing capacity of square footing on CNS soil bed increases with increasing the reinforcement inclination (α). This increase in bearing capacity may be contributed due to mobilization of the bond resistance with the increasing overburden pressure acting on the reinforcement beyond the footing edge, increased tangential stresses by normal stress component with inclination of reinforcement and additional bond stresses mobilized due to transverse pull beneath the reinforcement. The bearing capacity increases by 26% with increase in the inclination of reinforcement from α = 0° to 15°.

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2.4.2. Effect of reinforcement length on bearing capacity of footing

The effect of the reinforcement length on bearing capacity of square footing are shown below in Fig. 5 for different unit weights of CNS soil bed. The model plate load tests were conducted for the length of reinforcement L_r = 3B, 2.5B and 2Bat 10^0 inclination of reinforcement with the unit weights of CNS soil bed $\gamma_d = 20kN/m^3$.

The Fig. 5 shows the stress Vs settlement curve of square footing resting on CNS soil bed having the unit weight γ_d= 20kN/m^3 with 10° inclination of reinforcement.

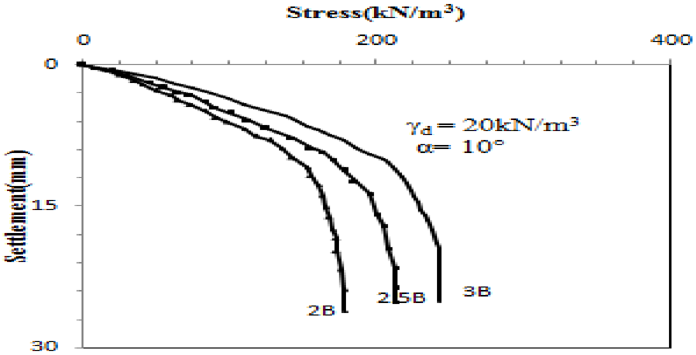

Figure .5 Stress Vs Settlement curve of Reinforced Soil Bed with different lengths of reinforcement

From the above graph it was observed that the bearing capacity of CNS soil bed has increased by 30% with increase in the length of reinforcement (L_r) from 2B to 3B. The increased length of reinforcement gives more confining area along with the inclination of reinforcement, increase in overburden pressure on reinforcement with the length, increases in tangential stress as the consequence of normal stress and the increase in upward transverse force will mobilise additional bond resistance along the length of reinforcement against pull out which leads to increase in strength of reinforced foundation bed.

2.4.3. Variation of bearing capacity of square footing with the unit weight of CNS soil bed

Fig. 6 shows the graphical representation of the model plate load tests of square footing for 3B length of reinforcement at 3 different unit weight of CNS soil bed (γ_d= 18kN/m^3, 19kN/m^3 and 20kN/m$^{3)}$. The reinforcement was placed in the CNS soil at a depth of u=B/4 from the surface bed and with 10^0 inclination of reinforcement. The load carrying capacity of footing is increases with increase in the unit weight of CNS soil bed as expected, which also leads to increase in overburden pressure on the inclined reinforcement which results in enhanced tangential stresses and the additional stresses due to transverse resistance from bottom of the reinforcement, which is finally contributes the increased load carrying capacity of the footing. And that the improvement of the bearing capacity of square footing is observed as 27% with the increase in unit weight CNS soil bed from 18kN/m^{3}to 20kN/m^3.

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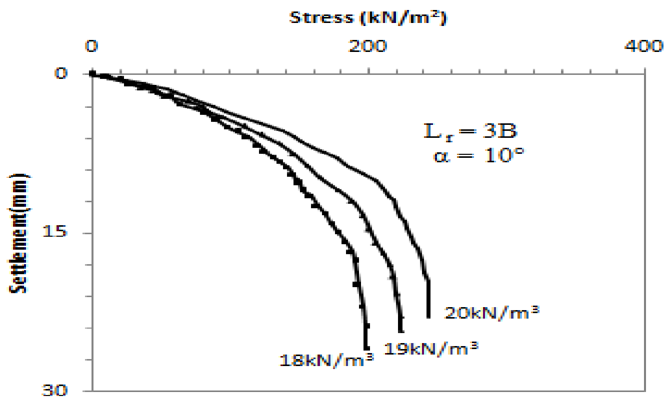

Figure. 6 Stress Vs Settlement curves at different unit weights of soil bed of 3B length.

3. ANALYTICAL STUDY

In this work, an analytical approach has been developed for calculating the bearing capacity of square footing resting on reinforced thin dense CNS soil bed with inclined reinforcement over homogeneous soft clay subsoil by assuming a punching shear failure.

From Meyerhof and Hanna (1978) given an analytical equation of the bearing capacity of rectangular footing of width = B and length=L placed at a depth of foundation D in a thin dense sand bed of thickness(D+H) overlying soft homogenous clay stratum considered a punching shear failure was,

$q_{rectangle}$ =

$$\left(1+0.2\frac{B}{L}\right)cN_c+\frac{\gamma H^2 K_s \tan\phi\left(1+\frac{2D}{H}\right)\left(1+\frac{B}{L}\right)}{B}+\gamma D \leq \gamma D N_q+\frac{1}{2}\left(1-\frac{0.4B}{L}\right)B\gamma N_\gamma$$

N_C= 5.14, Bearing capacity factor for clayey soil(ø=0)

C= Undrained cohesion of clay soil

γ= Unit weight of sand bed

K_s = co-efficient of punching shear resistance

ø = Angle of friction of sand layer

D = Depth of foundation

N_C, N_q = Bearing capacity factors for sandy soil corresponding to ø.

For square footing,

$$q_{u(square)} = 1.2cN_c + \frac{2\gamma H^2 K_s \tan\phi}{B} \leq 0.3B\gamma N_\gamma$$

Rajyalakshmi (2011)developed an equation for bearing capacity of square footing of width, B resting on reinforced foundation bed overlying a non-homogeneous soft clay bed by introducing the factors, ρ= rate of increase of undrained shear strength of clay deposit with depth and with F as the correction factor. The reinforcement was provided just above the interface of sand and clay soil. For

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homogeneous clay, ρ=0 and F=1 then, the bearing capacity equation of square footing resting on reinforced cohesion less soil bed over soft homogeneous clay stratum is obtained as,

$q_{ur(square)}$

$$= 1.2CN_c + \frac{2\gamma H^2 K_s \tan\phi}{B} + \frac{2\gamma H \tan\phi_r (L_r{}^2 - B^2)}{B^2}$$

ϕ_r= Interface angle of friction between sand and reinforcement
L_r = Length of reinforcement layer provided
H = Thickness of sand layer above the clay stratum

3.1.Problem definition

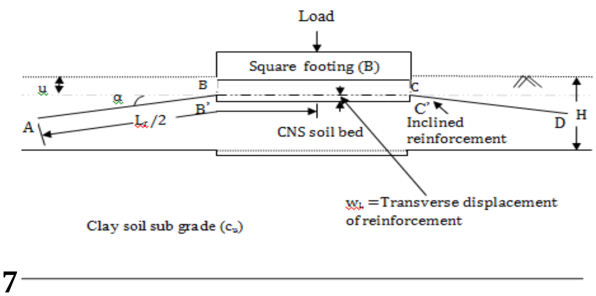

Figure. 7 Punching shear failure of footing with inclined reinforcement

A square footing of width B resting over the surface of CNS soil bed overlying a soft homogeneous clay soil with cohesion(c) and the thickness of the CNS soil bed was taken as H.

The layout ABCD in Fig. 7.1 presents a single layer of geotextile reinforcement of length L_r is provided at a depth u (=B/4) below the bottom of the footing. Here, the geotextile reinforcement is inclined downward at an angle of α from edges of footing such that the depth of free end of reinforcement from surface of foundation bed is $(u+((L_r - B)\sin\alpha/2)$.Here, γ and ø are the unit weight and angle of internal friction of CNS soil bed respectively and the cohesion this soil is neglected. It is assumed that, due to the applied load, a punching shear failure will takes place and as the consequence, the geotextile reinforcement below the footing will deformed to a shape of AB'C'D as shown in Fig. 7.

Due to the varying overburden pressure on reinforcement, vertical stress is calculated for average depth of reinforcement u_{avg}, as,

$$u_{avg} = \frac{u + \left(u + \frac{(L_r - B)\sin\alpha}{2}\right)}{2} = u + \frac{\left(\frac{(L_r - B)\sin\alpha}{2}\right)}{2}$$

By resolving the over burden pressure into normal stress q_n and the tangential stress q_t to the alignment of reinforcement are;

$$q_n = [\gamma(u + \frac{0.5(L_r - B)\sin\alpha}{2})]\cos\alpha$$

$$q_t = [\gamma(u + \frac{0.5(L_r - B)\sin\alpha}{2})]*\sin\alpha$$

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The bond resistance (T_r), developed due to pullout of reinforcement contributed from both tangential and normal stresses are calculated as shown below

$$T_r = 2(q_n(L_r^2 - B^2)\tan\phi_r) + 2(q_t(L_r^2 - B^2))$$

$(L_r^2 - B^2)$ = effective area of the reinforcement

Normalizing the above equation by dividing with area of footing B^2 on both sides,

$$T_r/B^2 = 2\left(q_n \frac{(L_r^2 - B^2)}{B^2}\tan\phi_r\right) + 2\left(q_t\left(\frac{(L_r^2 - B^2)}{B^2}\right)\right)$$

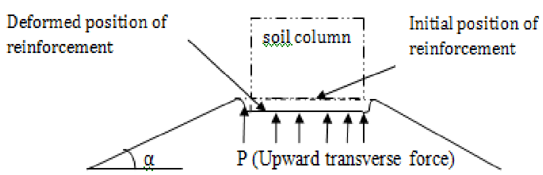
By substituting the q_n and q_t in the above equation

$$(T_r/B^2)$$

$$= 2\left\{\left[\gamma\left(\frac{u + (u + (L_r - B)\sin\alpha/2)}{2}\right)\right].\left[\frac{(L_r^2 - B^2)}{B^2}\right].[\tan\phi_r . \cos\alpha + \sin\alpha]\right\}.$$

3.2.Kinematic Analysis

Due to the punching effect of footing, the soil column below the footing moves downward along with the footing due to which the reinforcement gets displaced transversely downward below the footing and the reinforcement deformed into a new position AB'C'D from the original lay out as showed in Fig. 7.



Due to this downward movement of footing causes the reinforcement dragged towards the centre of footing, which will result in an upward normal stress on bottom of the reinforcement. In Fig. 8 below, P is the upward transverse force mobilised in the reinforcement due to kinematics of failure.

The transverse force P is calculated for the square footing as ,

$$P = \gamma u_{avg}((L_{ei} + B)L_{ei}).P^*$$

L_{ei} = half of effective length of reinforcement = $0.5L_e$

P* is the normalized transverse force in the geotextile reinforcement of effective length L_{ei}.

Rajashekar Reddy et al developed a graph to interpolate the P* value corresponding to normalized displacement(w_L/L) and interface friction angle of soil and geotextile, then the soil bed relative stiffness(μ) using a C- program;

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$$\mu = \frac{K_s L_e}{\gamma u}$$

The additional bond resistance mobilized on four sides of footing and the total T_{ar} taken as;

$$T_{ar} = 4\{[2q_n \tan\phi_r . ((L_{ei} + B)L_{ei}) + 2q_t . ((L_{ei} + B)L_{ie})]P^*\}$$

The total resistance mobilised against the pullout of reinforcement (T) is obtained

$$T = T_r + T_{ar}$$

after adding T_{ar} & T_{ar} and normalizing with B^2

$$T = [2[\gamma(u + \frac{0.5(L_r - B)\,sin\alpha}{2})cos\alpha . \tan\phi_r + \{2[\gamma(u + \frac{0.5(L_r - B)\,sin\alpha}{2})]sin\alpha]. [\frac{(L_r{}^2 - B^2)}{B^2} + 4P^* \frac{(L_{ei} + B)L_{ei}}{B^2}] \}$$

The analytical equation of square footing resting on reinforced CNS foundation bed overlying a soft Homogeneous clay stratum with inclined reinforcement considering the kinematics is,

$$q_{uirk} = 1.2CN_c + \frac{2\gamma H^2 K_s \tan\phi}{B} + [2[\gamma(u + \frac{0.5(L_r - B)\,sin\alpha}{2})cos\alpha . \tan\phi_r + \{2[\gamma(u + \frac{0.5(L_r - B)\,sin\alpha}{2})]sin\alpha]. [\frac{(L_r{}^2 - B^2)}{B^2} + 4P^* \frac{(L_{ei} + B)L_{ei}}{B^2}] \}$$

3.1.Analytical Results

The bearing capacity of square footing was calculated using the right above equation by taking the same parameters used in experimental studies and the results are tabulated below in Table 5.

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Table 5 analytical bearing capacity values

α (°)	γ kN/m³	K_s	L_{ei} (m)	μ	settlement W_L(mm)	P*	q_{urik} kN/m²
0	20	6.5	0.15	4636	8	7.32	190.79
5	20	6.5	0.15	5581	7.1	8.05	205.12
10	20	6.5	0.15	7413	5.2	9	216.5
15	20	6.5	0.15	8934	3.3	10.53	236.40
10	20	6.5	0.15	7413	5.2	9	216.50
10	20	6.5	0.1125	5113	7	7.75	191.45
10	20	6.5	0.075	3392	8.8	6.48	169.25
10	19	7.5	0.15	5307	5	6.98	194.05
10	19	7.5	0.1125	3710	7.4	5.9	175.99
10	19	7.5	0.075	2903	9.2	4.32	154.58
10	18	9	0.15	4480	5.3	5.61	175.48
10	18	9	0.1125	3200	7.5	3.86	159.63
10	18	9	0.075	2034	9.5	2.48	141.82

The value of normalized transverse force, P* was calculated corresponding to the relative stiffness (μ) of the reinforced bed, interface friction angle ($ø_r$) and for the settlement (W_L) corresponding to ultimate bearing capacity of each model test with the help of a C – Program.

4. COMPARISON OF RESUULTS

The bearing capacity of square footing on reinforced foundation bed with inclined reinforcement considering the kinematics and the normalised bearing capacity of the footing with the undrained compressive strength of clay were shown in table 6

Table 6. Comparison of analytical and experimental results

α (°)	γ (kN/m³)	L_r(m)	Analytical Results	Analytical results q_{urik} (Normalised)	Experimental results	Experimental results q_{urik} (Normalised)
0	20	0.45	190.79	12.24	183	11.73
5	20	0.45	205.12	13.15	198	12.69
10	20	0.45	216.50	13.87	215	13.7
15	20	0.45	236.40	15.16	234	15
10	20	0.45	216.50	13.87	215	13.7
10	20	0.375	191.45	12.27	188	12.05
10	20	0.3	169.24	10.85	165	10.57
10	19	0.45	194.05	12.43	187	11.98
10	19	0.375	171.99	11.025	166	10.64
10	19	0.3	154.60	9.91	149	9.55
10	18	0.45	175.48	11.248	170	10.89
10	18	0.375	156.63	10.23	150	9.61
10	18	0.3	141.82	9.09	135	8.65

The comparison of the both obtained experimental and analytical results of the square footing are well compared with in the percentage of error 1% to 5% may be due to the error in observation of readings and experimental work.

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5. CONCLUSIONS

The bearing capacity of the square footing increased with the inclination of reinforcement α compared to the horizontal reinforcement. The load carrying capacity has increased by 26% with increasing inclination of reinforcement, α from 0° to 15° for 3B length of reinforcement provided in CNS soil bed of unit weight 20kN/m^3. For constant inclination of reinforcement α =10^0, with increasing the length of the reinforcement from 2B to 3B, the bearing capacity of footing increased by 30% at 20kN/m^3 unit weight of CNS soil bed respectively. The bearing capacity of square footing increased by 27% with the increase in unit weight of CNS soil bed from γ_d =20kN/m^3 to 18kN/m^3 with 3B length of reinforcement provided at 10^0 inclination of reinforcement.
Hence, the inclined reinforcement in the foundation bed resulted in good improvement compared to the bearing capacity of the footing with horizontal reinforcement.

Future Scope

Bearing capacity of circular/rectangular footing on reinforced soil bed with inclined reinforcement

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