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Bearing Capacity of Square Footing on Sand Reinforced With Single Layer Woven Geotextile

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***Abstract*— In the present paper a series of model footing tests has been performed on sand reinforced with single layer of woven geotextile. From the experiment it is found that with increase in depth of first layer of reinforcement beneath the footing (u) to width of the footing (B) ratio, the values of ultimate bearing capacity (qru) of footing as well as bearing capacity of footing (qrs) at any settlement (s) of reinforced sand increases and reaches a peak value at certain u / B ratio after that it is decreased. In the present investigation optimum values of u / B ratio is obtain around 0.3. The value of bearing capacity of footing on reinforced sand is enhanced with increase in relative density (Dr) under study irrespective of any u/B values and s/B values under study. On the basis of the present model tests data an empirical model has been developed to predict the qrs in terms of bearing capacity of footing at any settlement of unreinforced sand (qs), s/B, u/B, and Dr.**

***Index Terms*— Relative density, bearing capacity, reinforcement, geotextile, empirical model.**

I. INTRODUCTION

Many attempts have been made by the several investigators to increase the soil bearing capacity (BC) in last few decades. Mixing of fly ash, lime, cement, etc. with soil are few examples, adopted by some researchers to enhance the BC of the soil. At present reinforced earth (introduction of reinforcement such as metal strip, geotextile sheets, geogrids, or some other similar fiber type material into the soil) techniques is widely used in construction of subgrade for roads, railway tracks and beneath the footing to reduce the settlement and also for improvement of bearing capacity. Binquet and Lee [1,2] were the pioneers to study on BC of footing on reinforced sand beds. Since then a number of experimental and numerical studies on bearing capacity of footing on reinforced sand have been conducted by several researchers. Akinmusuru and Akinbolade [3] studied the model square footing tests on a homogeneous sand bed reinforced with fibre strips. A series of laboratory BC of model strip footing tests on both reinforced and unreinforced sand has been performed by Fragaszy and Lawton [4]. Guido et.al. [5] carried out series of model footing tests on sand reinforced with geotextile sheet. Omar et al. [6] carried out laboratory model test on the rectangular footing on geogrids reinforced sand. Yetimoglu et al.[7] presented an experimental investigation on BC of rectangular footing on the geogrid reinforced sand. Adams and Collin [8] conducted large-scale model footing load tests on the geosynthetic reinforced sand. Shin and Das [9] studied the BC of strip foundation on geogrids reinforced sand. Dash et al. [10] presented the results of strip footing on geocell mattress reinforced sand. Latha and Somwanshi [11] studied the BC of square footings on geosynthetic reinforced sand. Abu-Farsakh et al. [12] conducted the laboratory model tests to study the behavior of footing on geosynthetic-reinforced sand. Deb and Konai [13] studied the BC of geotextile reinforced sand with varying fine friction. Moghaddas Tafreshi et al. [14] presented an analytical model for predicting the settlement of circular footings on non-cohesive soils reinforced with multi-layered geocell. Badakhshan and Noorzad [15] studied the load eccentricity effects on the behaviour of circular footings resting on a geogrids reinforced sand bed. Azzam and Nasr [16] conducted a number of loading tests were carried out on model shell footing with and without a single layer of reinforcement. They also verified their experimental results by using PLAXIS program, a finite element software. Kazi et al. [17] studied the behaviour of an embedded strip footing on the sand reinforced with geotextile. Harikumar et al. [18] conducted a series of model footing test on sand bed reinforced with plastic multi-directional-reinforcements. Both laboratory modeling tests and numerical studies on both types of footings (circular and square) that rests on geosynthetic reinforced sand bed carried out by Badakhshan and Noorzad [19]. From above studies, it has been observed that with the inclusion of reinforcement into the sand there is a considerable increase in load carrying capacity of footing on the sand system. From the findings of the several researchers it is found that the BC of footing on reinforced sand depends on number of factors such as N, location of first layer reinforcement beneath the footing (u), vertical spacing of reinforcement layers (S_v), length of reinforcement (l), relative density of soil (D_r) etc. However, the study of BC of footings on reinforced sand considering the relative density of sand (D_r) is scarce. In this paper, an attempt has been made to study the effect of D_r of sand and location of first layer reinforcement beneath the footing (u), on BC of footing on the single layered reinforced sand. An attempt has also been made to develop an empirical model to estimate BC of footing at any settlement (q_{rs}) in terms of D_r and (u / B).

II. MATERIALS

In the present work, sand has been chosen as foundation medium and woven geotextile sheet as reinforcement.

A. Sand

In the present paper, sand has been collected from, Burdwan district, West Bengal, India. The engineering properties of sand such as grain size distribution, specific gravity, permeability and also relative density tests have been performed in the geotechnical engineering laboratory, IIEST, Shibpur. The particle diameter versus percent finer curve for sand is shown in Fig.1 shows. From the curve (Fig.1) the values of C_u and C_c has been determined and also presented in the curve. In accordance with IS 1498 [20] the above sand may be classified as SP. The value of specific gravity of the sand is 2.661. In general to know the state (denseness and looseness) of sand relative density (D_r) has been determined. The maximum and minimum density of sand have been performed in accordance with IS 2720, Part14 [21]. The values of maximum density and minimum density as obtained in the present investigation are 1.722 and 1.408 respectively. Values of the angle of internal friction (ϕ) have been obtained from conventional laboratory direct shear tests. The respective values of ϕ corresponding D_r are presented in the Fig.2.

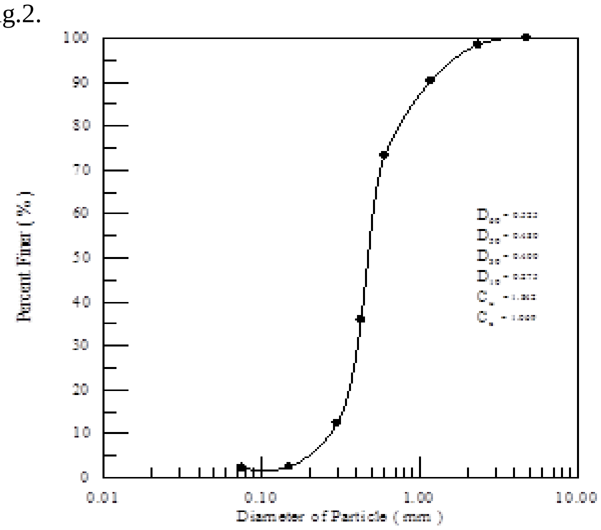

Fig.1 Grain size distribution curve for sand

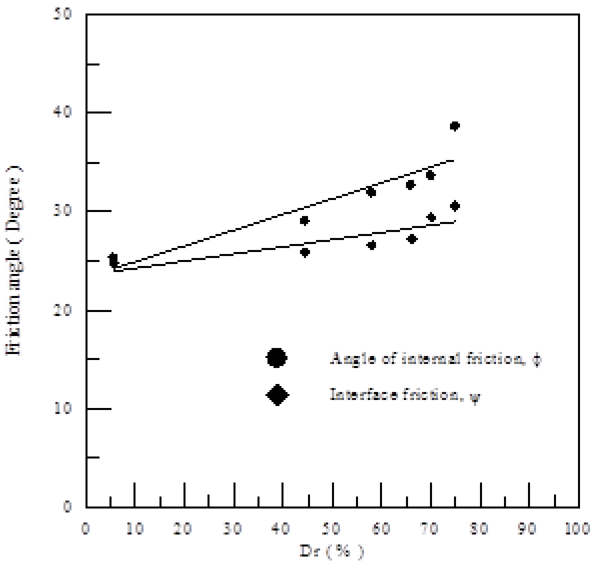

Fig.2 Friction angle versus relative density of sand curve

B. Geotextile

In the present investigation woven geotextile sheet has been used as reinforcement.Fig.3 shows the photo plate of the geotextile sheet. Engineering properties of geotextiles such as mass per unit area, thickness, apparent opening size, and wide width tensile strength have been conducted in accordance with ASTM D5261 [22], ASTM D5199 [23], ASTM D4751 [24], and ASTM D4595[25] respectively in the Geotechnical Engineering Laboratory in the IIEST Shibpur, West Bengal, India. The values of respective properties of the geotextile are presented in Table 1.

Table 1 Engineering properties of geotextiles

Physical Properties		Experimental Value
Mass per unit area (gm/sq.m)		237
Thickness (mm)		0.55
Apparent Opening Size (mm)		0.250
Breaking Strength (kN/m)	Warp	42.8
	Weft	40.2
Elongation at Break (%)	Warp	20.12
	Weft	19.44
Initial tangent modulus (kN/m)	Warp	2.77×10^2
	Weft	2.42×10^2

Fig.3 Photo plate of geotextile sheet

Table 2 Plan of work for model footing tests

Series	Type of foundation medium	Relative density (%)	Depth of reinforcement (u/B)
A	Unreinforced	5.4,4.4,58.4, 66.7,70.3,75.3	-
B	Reinforced	5.4, 44.4,58.4,66.7,70.3,75.3	0.1, 0.2, 0.3, 0.4, 0.5, 0.7, 0.9, 1.1, 1.3, 1.5 and 2.0

C. Interface Friction

One of the important parameters is the interface friction in the reinforced earth. To evaluate the interface friction (ψ) a series of direct shear tests have been performed on sand-geotextile-sand in the geotechnical engineering laboratory of IIEST, shibpur, India. The vertical normal stresses are 50-, 100-, 150- and 200 kN/m^2 applied on the shear box for conducting direct shear tests in different sets for both the cases, determination of interface friction angle (ψ) and also the angle of internal friction(ϕ). The ψ value has been calculated from the normal stress versus shear stress at failure curves. The values of ψ versus D_r of sand curve are presented in the Fig2. From the figure (Fig.2) it is observed that with an increase in D_r the values of ϕ as well as ψ value increases. Punetha et al.[26] also reported the similar types of results that with the increase in D_r of sand the coefficient of friction of sand geotextile interface increases. From the figure (Fig. 2) it is also found that the rate of increase of values of ψ is lower than the ϕ value. The reason could be the fact that with the increase in relative density, the interlocking between the sand particles of sand bed without geotextile is higher than the sand particle and geotextile sheet in the sand-geotextile-sand composite.

III. PLAN OF MODEL TEST

Plan of the model footing tests has been chalked out in two series (A & B) are presented in Table 2. In the series, 'A' model footing tests have been performed with the varying D_r of unreinforced sand to determine the effect of relative density on BC of footing unreinforced sand. To know the effect of relative densities and u/B on bearing capacities of model square footing on single layered reinforced sand series B has been planned. The relative density varies from 5.4 % to 75.3 % for both unreinforced and reinforced case. The value of u / B ratio varies from 0.1 to 2 for each relative density of footing on the reinforced sand.

IV. EXPERIMENTAL SETUP AND TEST PROCEDURE

The experimental investigation has been carried out in Geotechnical Engineering Laboratory of the civil engineering department of IIEST, Shibpur. A series of model footing tests have been conducted in the tank of internal dimension 600mm × 600mm in plan and 400 mm in depth. In the present investigation, tank size was kept as 6 times the size of the footing to have a minimum influence of the test tank boundaries on the results of bearing capacity of footing. Fig.4 shows the schematic diagram of the test set up used in the present investigation. The model square footing has been made of steel with dimension 100 mm (B) × 100 mm (B) × 10 mm (thickness). The dry sand was placed in the test tank by sand raining technique. In case of tests with reinforced sand beds, geotextile sheet of size 600mm × 600mm has been placed at predetermined depths while preparing the sand bed. Then the sand layer was finished by the same procedure (sand raining techniques) up to the designed level. After preparing the bed, the surface was leveled and the footing was placed above the sand bed (Fig.4). The applied loads were measured using a calibrated proving ring. In general, the test was continued till the load increment between two successive readings is either negligible or zero (Ghosh et al. [27]). However, in the present investigation readings were taken up to 50 mm settlement in all tests for comparison (footings on reinforced sand and footing on unreinforced sand) purposes. To determine the accuracy of the experimental results particularly in lower relative density some of the tests have been repeated twice. After completion of the tests load versus settlement, curve has been plotted.

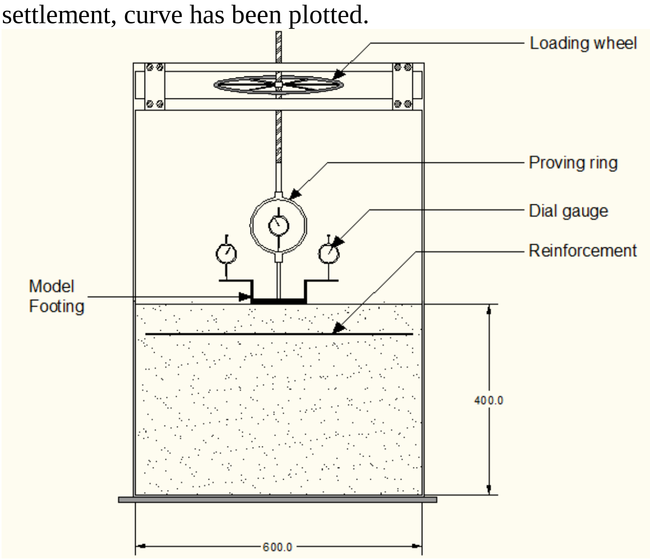

Fig 4 Schematic diagram of test set up

V. RESULTS AND DISCUSSIONS

Figs.5-7 shows the typical load versus settlement curve with varying u / B ratio for relative densities (D_r) 58.4 - , 66.7-and 75.3 % respectively. Figs 8-9 shows the plots of q_{ru} versus u / B ratio curve with varying the relative density and BCR_{ru} ($\frac{q_{ru}}{q_u}$) versus u / B ratio curve with varying relative density respectively. q_{rs} versus u / B ratio curve with varying (s/B) ratio for Dr=75.3 % are shown in Fig.10. Fig.11 shows the plots of BCR_{rs}($\frac{q_{rs}}{q_s}$) versus u / B ratio curve with varying (s/B) ratio for D_r=75.3%. Fig.12 shows the comparison of experimental UBC values and theoretical UBC of 100 mm square footing on the unreinforced sand for different relative densities of sand. Figs.13-14 shows the q_{ru} versus Dr (%) curve with varying (u / B) ratio and BCR_{ru} versus D_r (%) curve with varying (u / B) ratio respectively. Figs15-16 shows the plots of q_{rs} versus D_r (%) curve with varying (s / B) ratio at u / B =0.3 and BCR_{rs} versus Dr (%) curve with varying (s / B) ratio at u / B =0.3 respectively.

Based on the model footing test results presented herein, discussions are made highlighting the effects of the following parameter item wise:

- s /B ratio
- u / B ratio
- Relative density

A. *Effect of S / B Ratio on BC of Footing on Sand Reinforced With Single Layered Geotextile*

Settlement of footing on geotextile reinforced soil one of the important governing factor. Figs.5-7 show the plots of load versus settlement curves with varying u / B ratio for relative densities 58.4-, 66.7- and 75.3 % respectively. From the all three figures (Figs.5-7) it is found that with an introduction of geotextile layer into the sand bed the BC of footing on reinforced soil improves but after certain s / B ratio irrespective of relative density. The reason may be as explained by Guido et al. [5] to get maximum benefit from a geotextile full functioning as reinforcement, sufficient deformation of the fabric is requird to mobilize its tensile stress. They also found that footing on geotextile reinforced sand produced beneficial results after a measureable settlement take place.

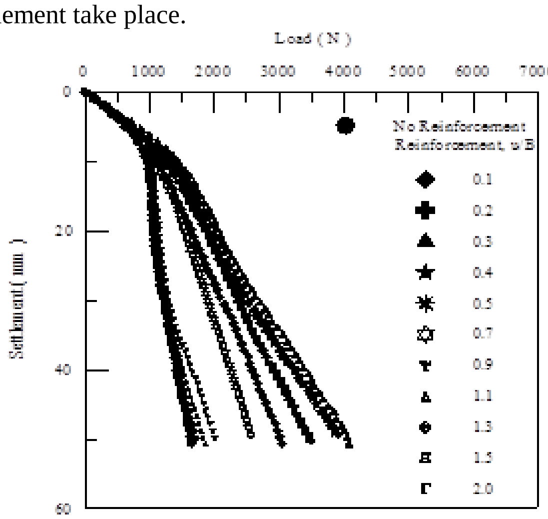

Fig.5 Load versus settlement curve for relative density (D_r = 58.4 %) with varying u / B ratio.

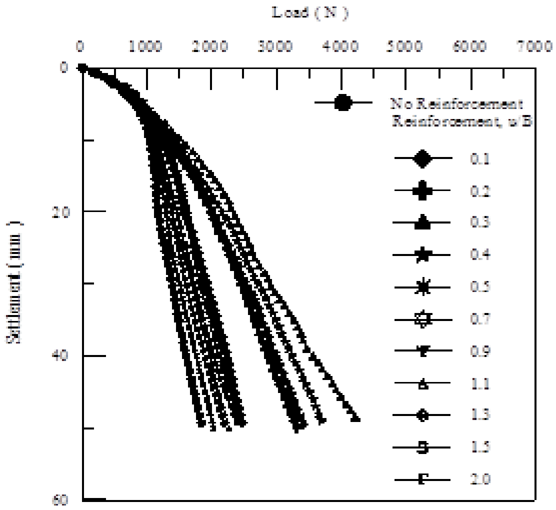

Fig.6 Load versus settlement curve for relative density (D_r = 66.7 %) with varying u / B ratio.

B. Effect of u / B ratio on BC of footing on sand reinforced with single layered geotextile

u / B ratio is one of the important governing parameters for footing on single layered or multilayered reinforced soil. Figs.8-9 shows the UBC (q_{ru}) of footing on reinforced sand versus u / B ratio curve with varying relative density and bearing capacity ratio($BCR_{ru} = \frac{q_{ru}}{q_u}$) of footing versus u / B ratio curve varying relative density respectively. From both the curve it is found that the optimum values of u/B ratio is 0.3 for all relative density within the range of 58.4 % to 75.3 %. Figs.10-11 show the BC (q_{rs}) of footing at any s / B ratio on reinforced soil versus u / B ratio curve with varying s / B ratio and BC ratio ($BCR_{rs} = \frac{q_{rs}}{q_s}$) of footing at any s / B ratio versus u / B ratio curve varying s / B ratio respectively. From both the curve it is also found that optimum values of u/B ratio is 0.3 at any settlement. The reason as explained by Ghosh et al. [27] in case of footing on reinforced pond ash that particular u/ B ratio (u/B = 0.3125) the overburden was just sufficient to develop the maximum frictional resistance. Abdrabbo et al. [28] also found the optimum value of u / B ratio is 0.3 in case of footing on the reinforced sand.

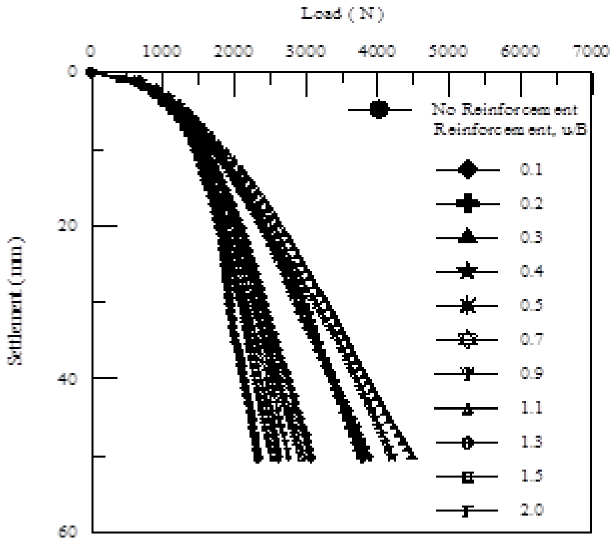

Fig.7 Load versus settlement curve for relative density (D_r = 75.3 %) with varying u / B ratio.

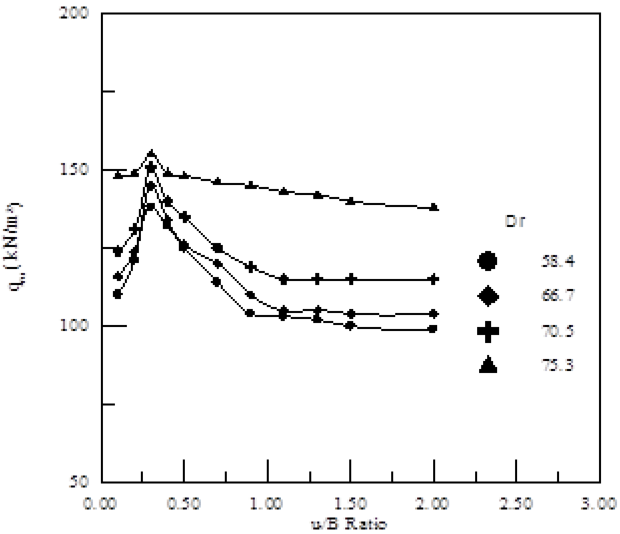

Fig.8 q_{ru} versus u / B ratio curve with varying relative density

C. Effect of relative density on BC of footing on sand reinforced with single layers of geotextile sheet

Relative density is one of the important parameters to know the consistency of coarse grained soil. Higher relative density represents denser soil formation whereas lower relative density means loose soil. In the present work, a series of model footing tests have been performed with varying relative density 5.4 % to 75.3 % to achieve the wide variety of soil condition such as loses state to densest states for both unreinforced sand and reinforced sand. Fig.12 shows the comparison of UBC (q_u) obtained from present experiment and UBC of 100 mm square footing on unreinforced sand based on different BC theories versus varying relative densities curve. From the figure (Fig.12) it is found that the experimental value of bearing capacity obtained for higher relative density (greater than 58.4 %) is in between the bearing capacity obtained based on Meyerhof [30] and bearing capacity obtained based on IS: 6403 [31]. However, for lower relative density (less than 58.4%) the experimental value of bearing capacity is slightly higher than the bearing capacity obtained based on different established BC theories. Fig.13 shows the plots of q_{ru} versus D_r (%) curve with varying (u / B) ratio. From the figure, it is found that with an increase in relative density the value of ultimate bearing capacity increases. It is may be due to that higher relative density means more densification of sand geotextile composite as a result of higher UBC. A similar trend also found in case of q_{rs} versus D_r (%) curve with varying (s / B) ratio curve (Fig.15). Fig.14 shows the BCR_{ru} versus Dr (%) curve with varying (u / B) ratio. From the figure, it is found that with an increase in relative density the values of BC ratio with respect to ultimate bearing capacity decreases for all u / B ratio. It is may be due to that with an increase in relative density of sand geotextile composite the values of friction ratio ($f = \frac{\psi}{\phi}$) decreases. Fig.16 shows the similar trend in case of BCR_{rs} versus D_r (%) curve with varying (s / B) ratio at u / B =0.3. Abdrabbo et al. [28] also reported that the effect of reinforcement was more prominent in a lower D_r of sand.

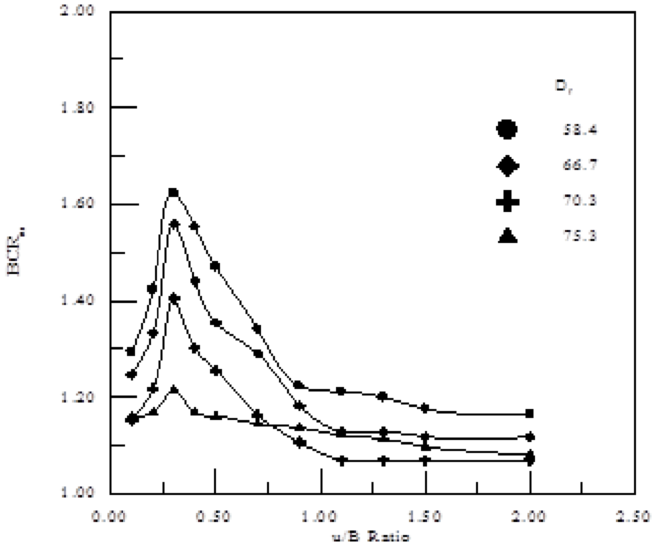

Fig.9 BCR_{ru} versus u / B ratio curve with varying relative density

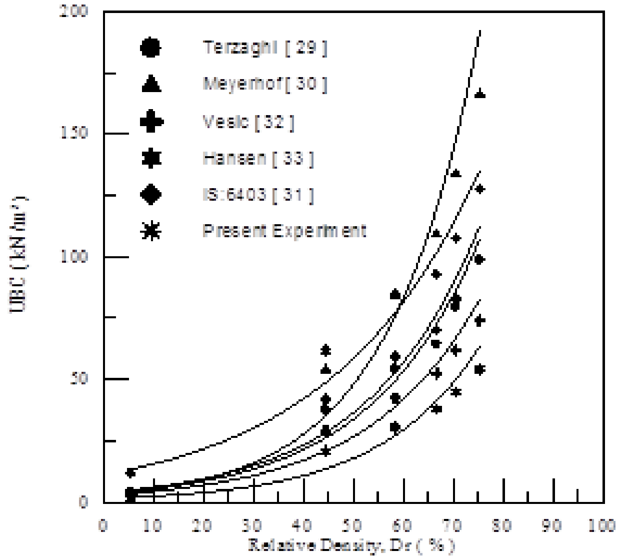

Fig.12 Comparison of experimental ultimate bearing capacity values and theoretical of 100 mm square footing on unreinforced sand for different relative densities of sand

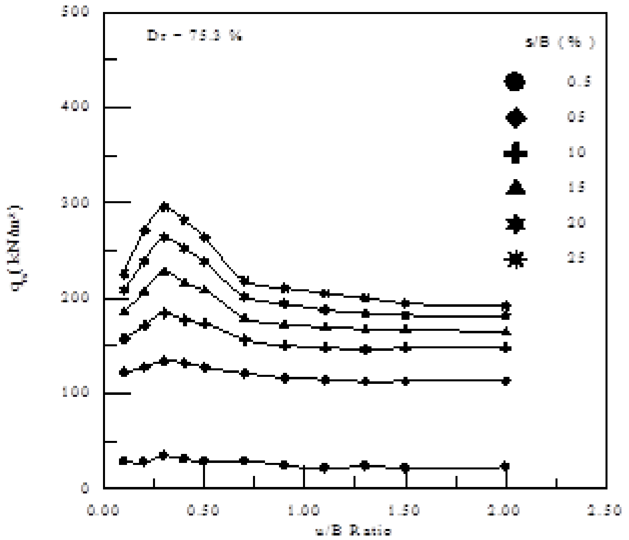

Fig.10 q_{rs} versus u / B ratio curve with varying (s/B) ratio for Dr=75.3 %

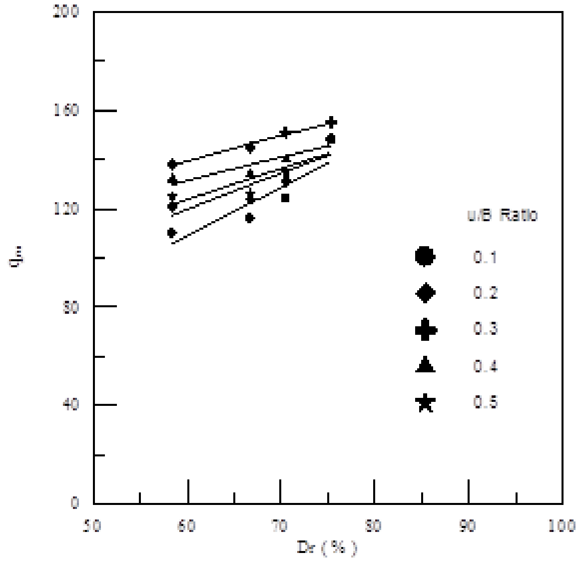

Fig.13 q_{ru} versus D_r (%) curve with varying (u / B) ratio

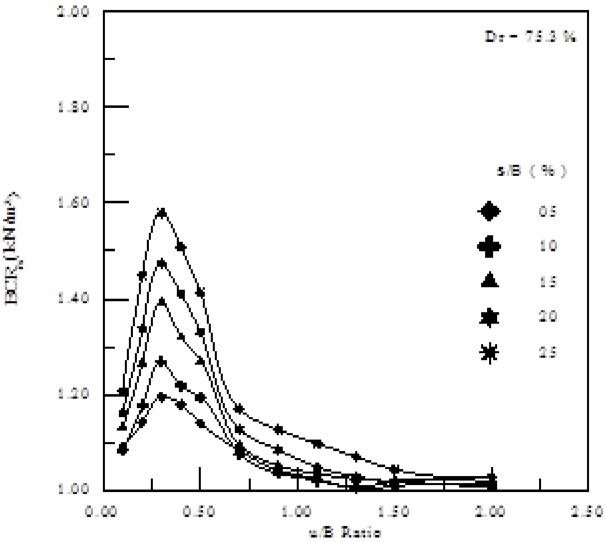

Fig.11 BCRrs versus u / B ratio curve with varying (s/B) ratio for D_r=75.3%

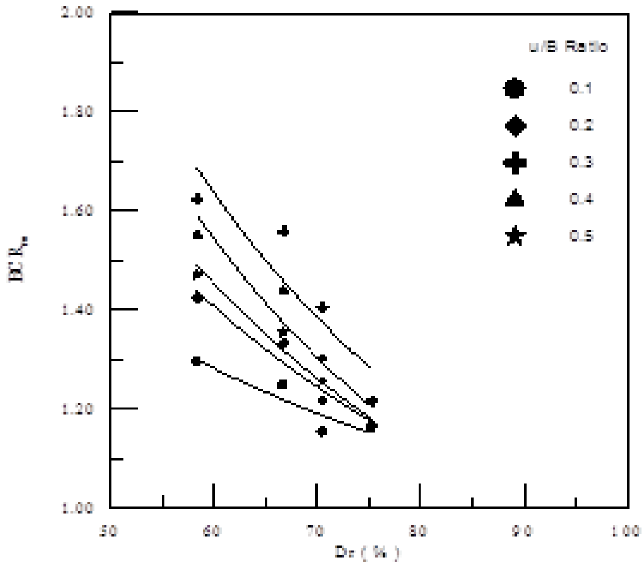

Fig.14 BCR_{ru} versus D_r (%) curve with varying (u / B) ratio

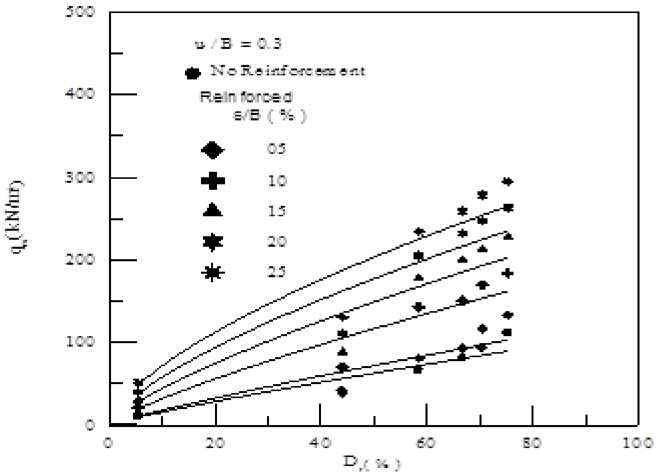

Fig.15 q_{rs} versus D_r (%) curve with varying (s / B) ratio at u / B =0.3

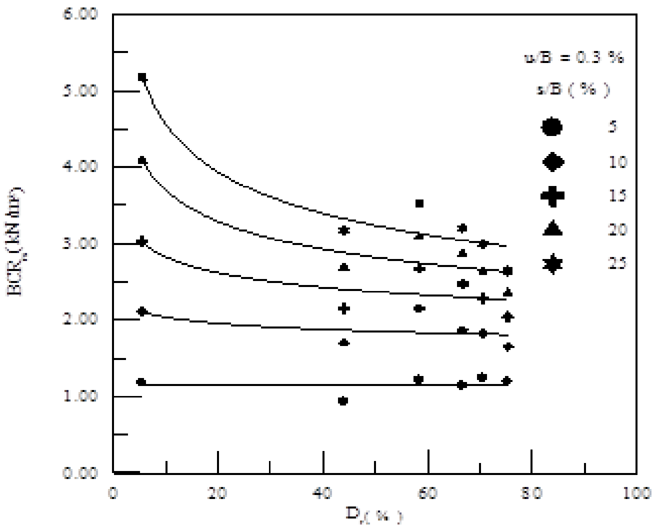

Fig.16 BCR_{rs} versus D_r (%) curve with varying (s / B) ratio at u / B =0.3

VI. NUMERICAL MODEL

The UBC of footing on sand reinforced with woven geotextile sheet depends on a number of governing parameter viz., D_r, u / B ratio, N , l/ B, f f etc. Till date, no simple correlations are available on BC of footing on the reinforced sand in terms of different governing parameters. In the present investigation, an empirical correlation has been proposed. The BC of footing on single layered geotextile reinforced sand mainly depends on D_r, u /B ratio, q_s and s/B. In the present paper proposed model has been developed by considering above mention four parameters (D_r, u /B ratio, q_s and s/B) only. From the scatter plot matrix of the present data point and also previous experience [35], an empirical model may be proposed as follows:

$$q_{rs} = \alpha_0 \times q_s^{\alpha_1} \times \left(\frac{s}{B}\right)^{\alpha_2} \times \alpha_3^{\left(\frac{u}{B}\right)} \times (D_r)^{\alpha_4} \quad \text{……..………..(1)}$$

By using log linear transformation the above equations may be written as:

$$\log q_{rs} = \log \alpha_0 \times \alpha_1 \log q_s \times \alpha_2 \log\left(\frac{s}{B}\right) \times \left(\frac{u}{B}\right) \log(\alpha_3) \times \alpha_4 \log(D_r) \quad \text{……………………………………………..(2)}$$

From the present 656 numbers of experimental data points, multiple regression analysis has been performed. In the present investigation, multiple regression analysis has been carried out by using data analysis tool pack of MS Excel 2007.Values of the regression coefficients are also calculated by using data analysis tool pack of MS Excel 2007 and presented in Table 3. The values of $F_{critical}$ and $t_{critical}$ also determine from percentage points of the F-distribution table and percentage points of the t-distribution table [36] respectively. The final equation is presented below:

$$q_{rs} = 1.279716 \times q_s^{\ 0.936017} \times \left(\frac{s}{B}\right)^{0.108023} \times 0.822302^{\left(\frac{u}{B}\right)} \times (D_r)^{0.02627} \quad \text{……………………………………………(3)}$$

Where,
q_s = BC of footing on unreinforced soil, (kN/m^2),
s / B = settlement of the footing to width of footing ratio (%),
u / B = frist layers of reinforcement beneath the footing to width of footing ratio,
D_r= relative density (%).

Observed q_{rs} versus predicted q_{rs} obtained from Eq. 3are shown in Fig.17. From the figure (Fig.17) it is found that the 100% data within $\pm 25\%$ error. Co-efficient of determination (R^2) has been calculated to know the efficiency of the model and the corresponding value is 0.988. The significance of the co-efficients of the model as a whole *F* statistics has been calculated. Details of the regression methods, methods of calculation of *F* statistics, t-statistics etc. already presented by the author elsewhere (Bera et al.[35]). Now in the present investigation, the calculated value of F_{cal} = 14435 and this is greater than the tabulated $F_{critical} = F_{(4, 656, 0.95)}$ = 2.37. The significance of partial regression coefficient has been performed by calculating the t statistics. Table 3 presents the values of t statistics for all regression coefficients. From the table (Table3) it is found that all the variables showing the significant contribution to the model. Comparison of predicted bearing capacity at any settlement ($\widehat{q_{rs}}$) by using additional data, those are not used in developing the model (Eq^n 3) and corresponding observed q_{rs} are presented in Table 4. From the table, it is found that observed data is closed to the predicted data. The proposed model may be useful for the parameters, s/B, D_r, and u/ B, within the range of 0.25% - 25 %, 5.4% - 75.3%, and 0.1 to 0.3 respectively.

Table 3 Values of t statistics for different parameters of model (Eq^n.1)

Parameters	Coefficients	Standard Error	t- statistics	$t_{critical} = t_{(0.975, 656)}$
Intercept	$\log(\alpha_0)$= 0.107114	0.009	11.80924	1.960
q_s	α_1 =0.936017	0.0151	61.76833	
s/B	α_2 = 0.108023	0.009	10.88235	
u/B	$\log(\alpha_3)$ = -0.08497	0.003	-26.2805	
D_r	α_4= 0.026277	0.012	2.159957	

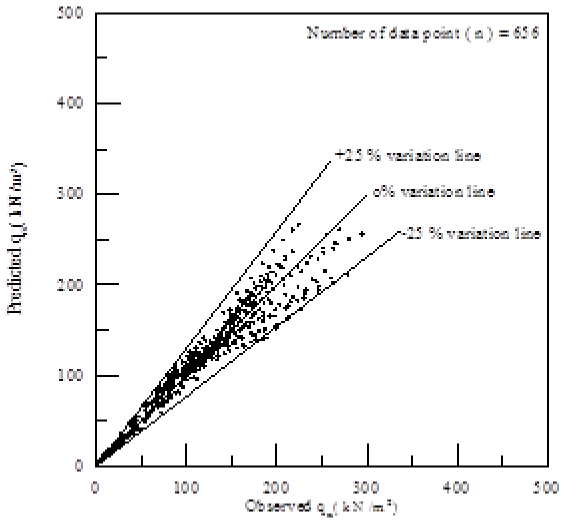

Fig.17 Predicted q_{rs} versus observed q_{rs}

Table 4 Comparison of $\widehat{q_{rs}}$ (predicted, using additional data not used in developing the model) and corresponding observed q_{rs}

References	q_s (kPa)	s/B	u/B	D_r (%)	$\widehat{q_{rs}}$ (kPa)	q_{rs} (kPa)
Authors File	18.43	12.5	0.4	5.4	24.85	24.64
Authors File	20.92	15	0.4	5.4	28.54	28.80
Authors File	27.44	25	0.7	5.4	36.66	45.75
Authors File	13.57	2	0.3	44.4	16.50	17.22
Authors File	76.61	15	0.4	44.4	101.66	89.96
Authors File	83.67	7.5	0.1	58.4	109.42	90.59
Authors File	95.70	10	0.1	58.4	128.00	112.19
Authors File	104.41	17.5	0.9	58.4	126.15	111.11
Authors File	105.95	20	0.9	58.4	129.75	113.57
Authors File	104.41	17.5	1.5	58.4	112.18	106.25
Authors File	105.95	20	1.5	58.4	115.38	106.60
Authors File	96.02	7.5	0.2	66.7	122.49	113.42
Authors File	105.08	10	0.2	66.7	137.48	134.56
Authors File	80.82	5	0.5	66.7	94.09	90.30
Authors File	96.02	7.5	0.5	66.7	115.50	116.48
Authors File	109.52	12.5	1.5	66.7	113.52	116.60
Authors File	113.43	15	1.5	66.7	119.64	121.20
Authors File	108.47	7.5	0.1	70.5	140.21	121.84
Authors File	119.41	10	0.1	70.5	158.25	137.93
Authors File	172.04	17.5	0.2	75.3	232.43	224.45
Authors File	178.82	20	0.2	75.3	244.49	239.20
Authors File	111.61	5	0.7	75.3	122.78	120.85
Authors File	132.22	7.5	0.7	75.3	150.33	140.10
Authors File	132.22	7.5	1.3	75.3	133.68	133.10
Authors File	145.00	10	1.3	75.3	150.33	145.71
Guido et.al. [5]	77.41	5.1	0.5	50	89.87	108.91
Guido et.al. [5]	76.33	4.7	0.5	50	87.92	102.25
Guido et.al. [5]	68.77	4	0.5	50	78.36	89.83

VII. CONCLUSIONS

Based on the experimental results and discussions made and also statistical analysis performed in the paper the following conclusions can be drawn:

- With introduction of geotextile sheet into the sand the bearing capacity of footing on geotextile reinforced sand enhances after certain s/B ratio irrespective of relative density of sand.
- With increase in u / B ratio the values of UBC of footing on reinforced sand as well as BC at any settlement of footing on reinforced sand enhances and optimum values of u/ B ratio is around 0.3 within the range of relative density of 5.4 % to 75.3 % .
- With increase in Dr value the values of UBC of footing on reinforced sand as well as BC at any settlement enhances.
- Interface friction of sand geotextile sand composite is decreased with increase in D_r under study.
- An empirical model has been developed to predict BC of footing (q_{rs}) at any settlement of geotextile reinforced sand in terms of q_s, s / B, D_r , and u / B ratio.
- The proposed model may be useful in the range of 5.4 % to 75.3 %, and 0.1 to 0.3 for D_r, and u / B ratio respectively.

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