BEARING CAPACITY OF RECTANGULAR FOOTING RESTING OVER GEOGRID REINFORCED SAND UNDER ECCENTRIC LOADING

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ABSTRACT

A number of works have been carried out for the evaluation of a ultimate bearing capacity of shallow foundation, supported by geogrid reinforced sand and subjected to centric load. Few experimental studies have been made on the calculation of bearing capacity of shallow foundation on geogrid-reinforced sand under eccentric loading. The ultimate bearing capacity of eccentrically loaded square footings can be computed by knowing the ultimate bearing capacity of square footing under central load and a reduction factor (RkR) for reinforced condition. The reduction factor is developed based on the results of laboratory model tests on geogrid reinforced soil. The ultimate bearing capacity of eccentrically loaded rectangular footing resting over geogrid reinforced sand can be calculated by knowing the ultimate bearing capacity of rectangular footing resting over reinforced sand bed and subjected to central vertical load by using reduction factor (RkR). An equation for reduction factor for rectangular footing resting over geogrid reinforced sand is developed based on laboratory model test results.

Keyword: Ultimate Bearing Capacity, Reinforced Sand Bed, Eccentric Loading

INTRODUCTION:

Foundation is the lower most hidden but very important part of any structure whether it is onshore or offshore structure. It is the part which receive huge amount of load from superstructure and distribute it to ground. So the foundation should be strong enough to sustain the load of superstructure. The performance of a structure mostly depends on the performance of foundation. Since it is a very important part, so it should be designed properly Design of foundation consists of two different parts: one is the ultimate bearing capacity of soil below foundation and second is the acceptable settlement that a footing can undergo without any adverse effect on superstructure. Ultimate bearing capacity means the load that the soil under the foundation can sustain before shear failure; while, settlement consideration involves estimation of the settlement caused by load from superstructure which should not exceed the limiting value for the stability and function of the superstructure. Ultimate bearing capacity problem can be solved with the help of either analytical solution or experimental study. First one can be studied using theory of plasticity or finite element method, while the second is reached through performing laboratory model test.

OBJECTIVE OF PRESENT STUDY :

The objective of the present study is a) To conduct load tests on model rectangular footings resting over reinforced sand bed subjected to vertical eccentric load. b) Different layers of geogrids are used as reinforcement c) To develop the empirical correlation for bearing capacity of eccentrically loaded footings on reinforced sand by knowing the bearing capacity of footing under centric load.

EQUIMENTS AND MATERIALS: SAND

Characteristics of Sand

Property	Value
Specific gravity *(G)*	2.64
Effective particle size (D_{10})	0.33mm
Mean particle size (D_{50})	0.455mm
(D_{60})	0.47mm
(D_{30})	0.42mm
Coefficient of uniformity (C_u)	1.424
Coefficient of curvature (C_c)	1.137
Maximum unit weight	14.87 kN/m^3
Minimum unit weight	13.42kN/m^3
Angle of internal friction (ϕ degree)	40.9^0
Maximum void ratio (e_{max})	0.929
Minimum void ratio (e_{min})	0.741

GEOGRID ***Properties of the geogrid :***

Parameters	Value
Polymer	Polypropylene Pp
Tensile strength at 2% strain	7 *KN/m*
Tensile strength at 5% strain	14 *KN/m*
Aperture size (W)	39*39 mm
Aperture shape	Square
Rib width (w)	1.1 mm
Junction strength	95%

EQUIPMENT USED: static loading unit, proving ring, dial gauge, model footing

MODEL TEST PROCEDURE

Equipment setup

Theoretical bearing capacity of the sand bed is calculated using Meyerhof's bearing capacity formula. Now this ultimate load is applied on the footing in 8 steps. Load to be applied in one steps is calculate by dividing the ultimate load by number of steps and then load in one step is again dividing by least count of proving ring used during the test to calculate the number of division in each step. Since the test is stress controlled, the load calculated in one step is applied on the footing and corresponding settlement is measured by taking average reading of both dial gauge fitted at two diagonally opposite corner of footing. After taking the reading on proving ring and dial gauge, load applied is calculated by multiplying the number of division on proving ring by it's least count and corresponding settlement is calculated by multiplying the dial gauge reading by it's least count i.e. 0.01. Now the load-settlement curve is drawn and using double tangent method, experimental bearing capacity is extracted.

Model test series

The sequence of the model test series

Number of Test	Number of Geogrid Layer (N)	B/L	e/B
1 - 8	0	0.5, 0.33	0.00, 0.05, 0.10, 0.15
9 - 16	2	0.5, 0.33	0.00, 0.05, 0.10, 0.15
16 - 24	3	0.5, 0.33	0.00, 0.05, 0.10, 0.15
24 - 32	4	0.5, 0.33	0.00, 0.05, 0.10, 0.15

RESULTS AND ANALYSIS :

Bearing capacity of unreinforced sand : Results of load test have been plotted in term of load-settlement curve as shown in Figures below for footing size 20cm×10 (B/L = 0.5) and 30cm×10 (B/L = 0.33) respectively. From the graph, it is observed that ultimate bearing capacity decreases as eccentricity width ratio (e/B) increases and also the total settlement at failure load decreases as eccentricity width ratio (e/B) increases. By comparing the graph shown in Figure and Figure, it can also be concluded that as the width to length ratio (B/L) decreases, load carrying capacity of footing increases.

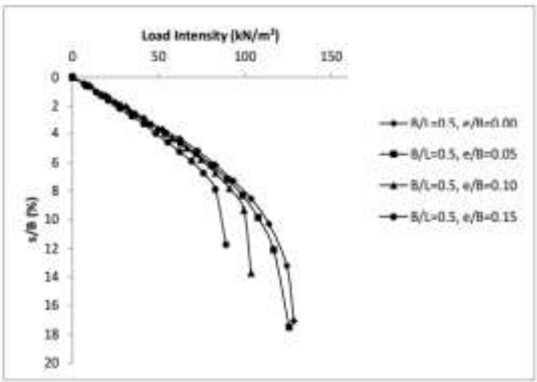


Figure Load-settlement curve of unreinforced sand bed (B/L=0.5)

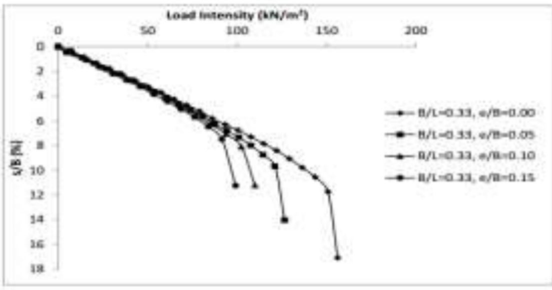


Figure Load-settlement curve of unreinforced sand bed (B/L=0.33)

From the load-settlement curve shown in Figure and Figure ult imate load carrying capacity of both B/L ratio i.e. 0.5 & 0.33 and for all eccentricity has been calculated using tangent intersection method. The result has been tabulated in Table for B/L=0.5 & 0.33 respectively and compared with theoretical value of load carrying capacity given by different authors. The variation of theoretical bearing capacity with eccentricity calculated by using different formula along with experimental results has been plotted in Fig for B/L=0.5 and B/L=0.33.

Theoretical bearing capacity of unreinforced sand bed for B/L=0.5

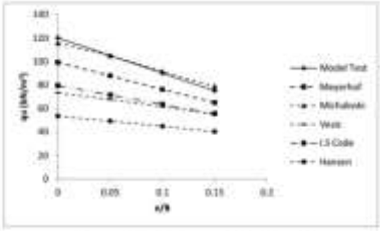


Figure Variation in q_u with e/B (B/L=0.5)

S. No	e/B	D_f/B	φ = 40.9°					
			Model Test q_u KN/m²)	Meyrhof (1953) q_u (kN/m²)	Michalowski (1997) q_u (kN/m²)	Vesic (1973) q_u (kN/m²)	I.S. 6403 (1981) q_u (kN/m²)	Hansen (1970) q_u (kN/m²)
1	0	0	120	99.17	115.65	73.28	79.42	53.46
2	0.05	0	105	87.79	104.77	67.59	71.47	49.24
3	0.1	0	90	76.12	91.52	61.57	63.54	44.83
4	0.15	0	75	69.94	78.67	55.13	55.59	40.22

Variation in qu with e/B (B/L=0.33)

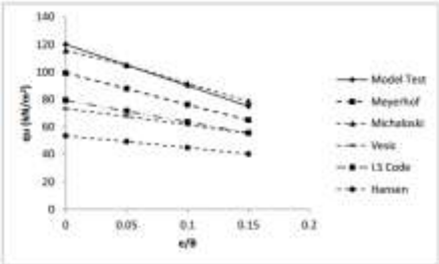


Figure Variation in q_u with e/B (B/L=0.5)

S. No	e/B	D_f/B	φ = 40.9°					
			Model Test q_u (KN/m²)	Meyrhof (1953) q_u (kN/m²)	Michalowski (1997) q_u (kN/m²)	Vesic (1973) q_u (kN/m²)	I.S. 6403 (1981) q_u (kN/m²)	Hansen (1970) q_u (kN/m²)
1	0	0	125	92.83	111.45	79.65	86.37	58.07
2	0.05	0	110	82.1	98.51	72.49	77.73	52.87
3	0.1	0	94	72.34	85.97	65.13	69.09	47.57
4	0.15	0	80	62.18	73.14	58.27	60.45	42.57

Theoretical bearing capacity of unreinforced sand bed for B/L=0.33

BEARING CAPACITY OF GEOGRID REINFORCED SAND: model test result

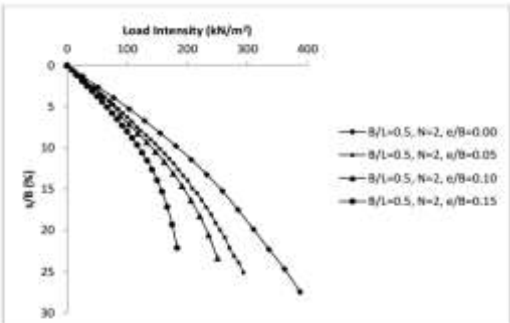


Figure Load-settlement curve for B/L=0.5 & N=2 and different e/B ratio

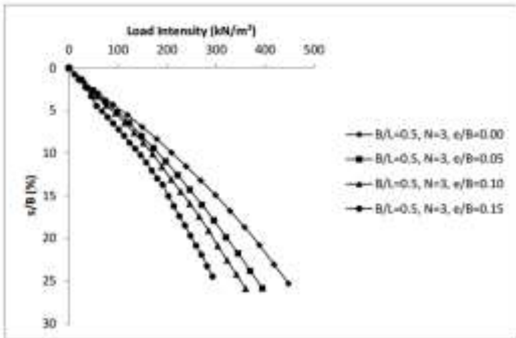


Figure Load-settlement curve for B/L=0.5 & N=3 and different e/B ratio

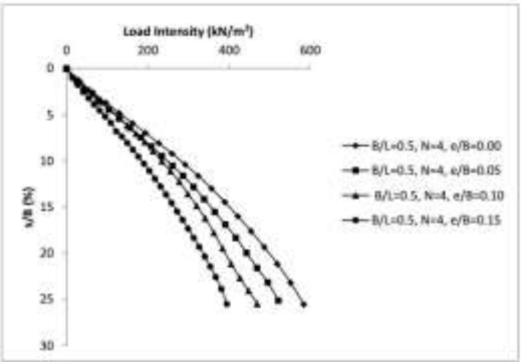


Figure Load-settlement curve for B/L=0.5 & N=4 and different e/B ratio

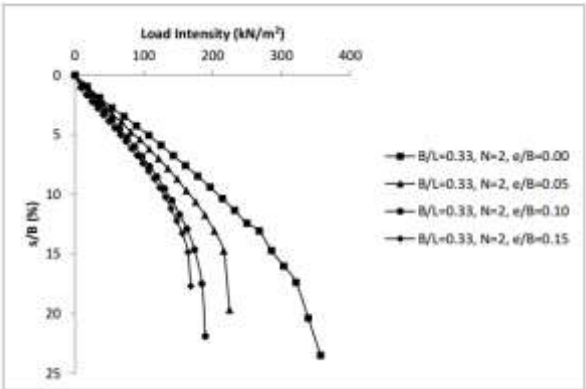


Figure Load-settlement curve for B/L=0.33 & N=2 and different e/B ratio

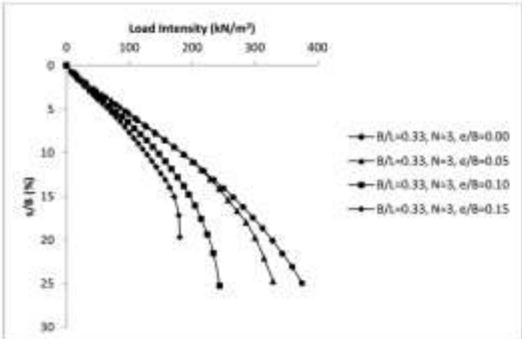
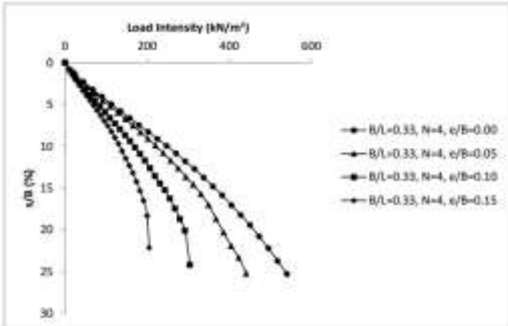


Figure Load-settlement curve for B/L=0.33 & N=3 and different e/B ratio



Figur Load-settlement curve for B/L=0.33 & N=4 and different e/B ratio

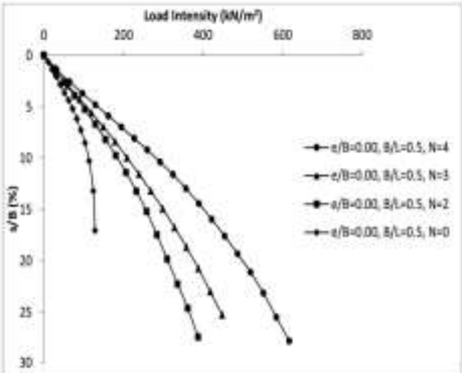


Figure Load-settlement curve for B/L=0.5 & e/B=0.00 with different N

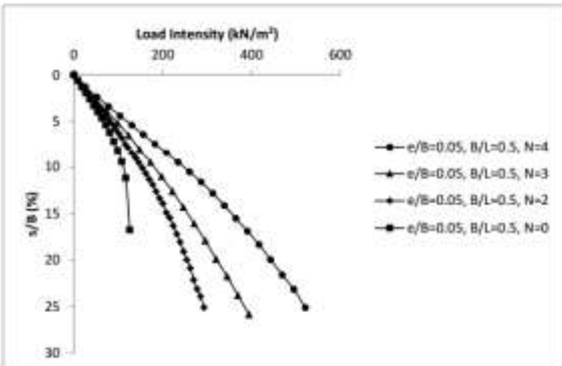


Figure .oad-settlement curve for B/L=0.5 & e/B=0.05 with different N

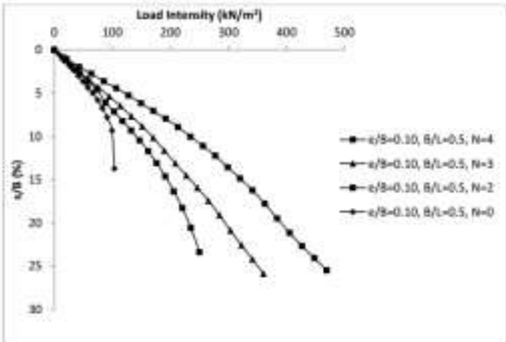


Figure Load-settlement curve for B/L=0.5 & e/B=0.10 with different N

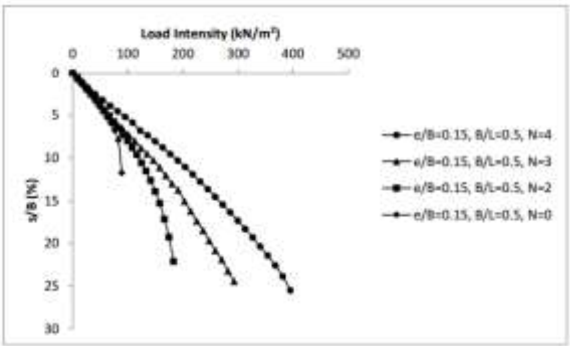


Figure Load-settlement curve for B/L=0.5 & e/B=0.15 with different N

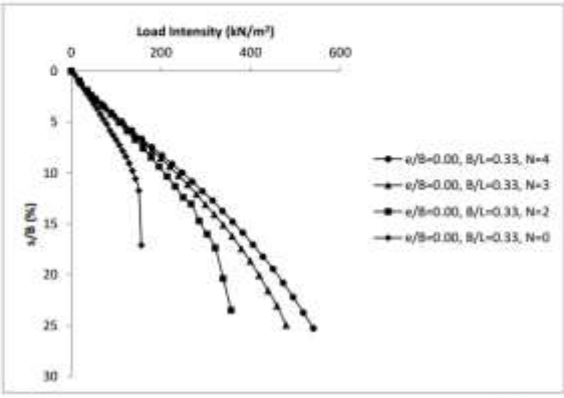


Figure Load-settlement curve for B/L=0.33 & e/B=0.00 with different N

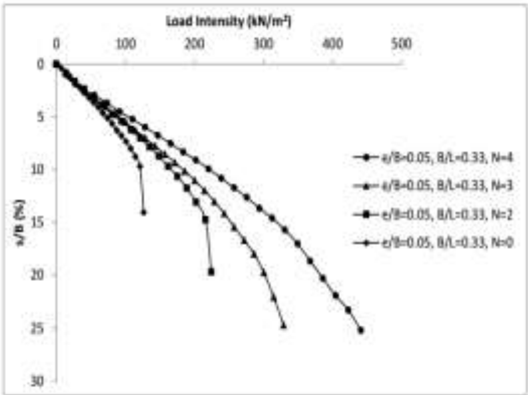


Figure Load-settlement curve for B/L=0.33 & e/B=0.05 with different N

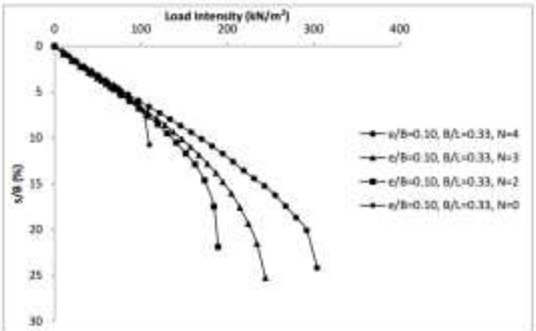


Figure Load-settlement curve for B/L=0.33 & e/B=0.10 with different N

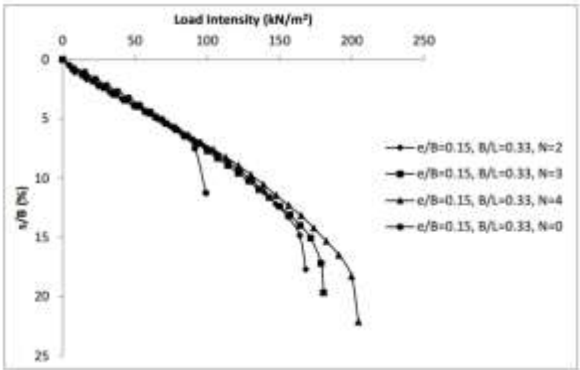


Figure Load-settlement curve for B/L=0.33 & e/B=0.15 with different N

rom the load-settlement curve shown in Figure , ultimate load carrying capacity of both B/L ratio (i.e. 0.33 & 0.5) and for all eccentricity has been calculated using tangent intersection method. The result has been tabulated in Table for e/B = 0, 0.05, 0.10 & 0.15 respectively with different number of geogrid layers. Theoretical ultimate bearing capacity for centrally loaded footing on reinforced sand has been calculated using formula given by Huang and Menq (1997) as shown in equation. This formulae reported by Huang and Menq (1997) corresponds to strip footing. A shape factor for rectangular footings on reinforced soil has been multiplied as per Huang and Menq (2000).

$$q_{uR(e=0)} = \left[0.5 - 0.1\left(\frac{B}{L}\right)\right](B + \Delta B)\gamma B N_\gamma + \gamma d N_q$$

For the calculation of ultimate load carrying capacity of eccentrically loaded foundation on reinforced soil, the reduction factor method proposed Purkayastha and Char (1977) for the case of un-reinforced soil has been extended. The relationship can be written in line with Purkayastha and Char (1977) as shown in equation

$$\frac{q_{uR(e)}}{q_{uR(e=0)}} = 1 - R_{KR}$$

Where, $q_{uR(e)}$ is the ultimate bearing capacity of reinforced sand under eccentric loading; uR q is the ultimate bearing capacity of reinforced sand under centric loading and RKR is the reduction factor. Patra et. al. (2006) proposed reduction

factor (RKR) for strip footing on
reinforced soil in as shown in equation

$$R_{KR} = 4.97\left(\frac{d_f}{B}\right)^{-0.12}\left(\frac{e}{B}\right)^{1.21}$$

Bearing capacity of reinforced sand bed for e/B = 0

e/B=0			
N	B/L	$q_{uR(th)}$ (Huang & Menq, 1997) (kN/m^2)	$q_{uR(exp)}$ (kN/m^2)
2	0.33	198.16	225
	0.5	193.25	220
3	0.33	245.25	275
	0.5	239.36	270
4	0.33	292.33	380
	0.5	285.96	365

Bearing capacity of reinforced sand bed for e/B = 0.05

e/B=0.05			
N	B/L	$q_{uR(th)}$ (Huang & Menq, 1997) (kN/m^2)	$q_{uR(exp)}$ (kN/m^2)
2	0.33	170.59	201
	0.5	166.57	198
3	0.33	211.89	242
	0.5	207.97	238
4	0.33	254.56	323
	0.5	248.97	314

Bearing capacity of reinforced sand bed for e/B=0.10

e/B=0.10			
N	B/L	$q_{uR(th)}$ (Huang & Menq, 1997) (kN/m^2)	$q_{uR(exp)}$ (kN/m^2)
2	0.33	134.59	171
	0.5	131.45	165
3	0.33	169.71	195
	0.5	165.78	189
4	0.33	204.05	251
	0.5	200.12	237

5 Bearing capacity of reinforced sand bed for e/B=0.15

e/B=0.15		
B/L	$q_{uR(th)}$ (Huang & Menq, 1997) (kN/m^2)	$q_{uR(exp)}$ (kN/m^2)
0.33	94.17	140
0.5	91.82	132
0.33	121.93	151
0.5	119.19	140
0.33	149.1	182
0.5	146.16	164

ANALYSIS OF TEST RESULT

ANALYSIS OF RECTANGULAR FOOTING WITH B/L=0.5

Experimental reduction factor for eccentrically loaded footing resting on reinforced sand bed with B/L=0.5

$\frac{B}{L}$	$\frac{d_f}{B}$	$\frac{e}{B}$	$q_{uR(e)}$ (kN/m^2)	$\frac{q_{uR(e)}}{q_{uR(e=0)}}$	$R_{KR} = 1 - \frac{q_{uR(e)}}{q_{uR(e=0)}}$
0.5	0.6	0.05	198	0.90	0.10
0.5	0.6	0.10	165	0.75	0.25
0.5	0.6	0.15	132	0.60	0.40

$\frac{B}{L}$	$\frac{d_f}{B}$	$\frac{e}{B}$	$q_{uR(e)}$ (kN/m^2)	$\frac{q_{uR(e)}}{q_{uR(e=0)}}$	$R_{KR} = 1 - \frac{q_{uR(e)}}{q_{uR(e=0)}}$
0.5	0.85	0.05	238	0.88	0.12
0.5	0.85	0.10	189	0.70	0.30
0.5	0.85	0.15	140	0.51	0.49
0.5	1.1	0.05	314	0.86	0.14
0.5	1.1	0.10	237	0.65	0.35
0.5	1.1	0.15	164	0.45	0.55

ANALYSIS OF RECTANGULAR FOOTING WITH B/L=0.33

$\frac{B}{L}$	$\frac{d_f}{B}$	$\frac{e}{B}$	$q_{uR(e)}$ (kN/m^2)	$\frac{q_{uR(e)}}{q_{uR(e=0)}}$	$R_{KR} = 1 - \frac{q_{uR(e)}}{q_{uR(e=0)}}$
0.33	0.6	0.05	201	0.89	0.11
0.33	0.6	0.10	171	0.76	0.24
0.33	0.6	0.15	140	0.62	0.38
0.33	0.85	0.05	242	0.88	0.12
0.33	0.85	0.10	195	0.71	0.29
0.33	0.85	0.15	151	0.55	0.45
0.33	1.1	0.05	323	0.85	0.15
0.33	1.1	0.10	251	0.66	0.34
0.33	1.1	0.15	182	0.48	0.52

Comparison of predicted ultimate bearing capacity of reinforced sand bed with those observed from experiment

B/L	N	d_f/B	e/B	$q_{u(Expt)}$	$q_{u(pred)}$	%Deviation
0.5	2	0.6	0.05	198	197	0.50
		0.6	0.1	165	166	-0.60
		0.6	0.15	132	133	-0.75
	3	0.85	0.05	238	236	0.84
		0.85	0.1	189	191	-1.05
		0.85	0.15	140	142	-1.42
	4	1.1	0.05	314	312	0.63
		1.1	0.1	237	244	-2.95
		1.1	0.15	164	169	-3.05
0.33	2	0.6	0.05	201	197	1.99
		0.6	0.1	171	166	2.92
		0.6	0.15	140	133	5.00
	3	0.85	0.05	242	236	2.47
		0.85	0.1	195	191	2.05
		0.85	0.15	151	142	5.96
	4	1.1	0.05	323	312	3.40
		1.1	0.1	251	244	2.78
		1.1	0.15	182	169	7.14

Summarized results:

A number of laboratory model tests have been conducted to determine the ultimate load bearing capacity of rectangular model footings resting over geogrid reinforced sand and subjected to vertical eccentric load. All the tests have been conducted for footing resting on the surface. Following are the summarized results of present research work.

The ultimate bearing capacity of the foundation for un-reinforced and reinforced soil decreases with the increase in eccentricity ratio i.e. e/B.

The ultimate bearing capacity of the foundation increases with the increase in number of reinforcement layer.

Reduction factor for the footing with B/L=0.5 & 0.33 has been derived separately and then combined to get a simple generalized equation of reduction factor for rectangular footing as shown in Equation.

A comparison of the experiment and predicted ultimate bearing capacity for rectangular footings on reinforced sand bed by using concept of reduction factor is calculated using the derived relation and presented in Table 5.9. The maximum deviation of experimental from predicted is 7.14%.

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