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PERFORMANCE OF SQUARE FOOTING ON REINFORCED SOIL UNDER ECCENTRIC-INCLINED LOAD

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ABSTRACT

The foundations may be subjected to inclined loads or eccentric loads or both in many structure such as retaining walls, abutments, columns, stanchions, portal framed buildings, footing located at property line, machine foundation. It's influence on bearing capacity of footing is of great concerned. It is an important aspect in the design of footings to understand the behavior of soil when footings are subjected to eccentric and inclined loads. The eccentric loading resulting into non-uniform pressure below the footing and it increases with the increase in eccentricity and the bearing capacity reduces considerably which result in increase of footing size and making the design uneconomical. The inclined load increases the horizontal deflection of the footing resulting into sliding failure. Hence, this study aims to evaluate the effects of eccentricity, inclination of load along with eccentric-inclined load on performance of footing resting over unreinforced and reinforced sand. The laboratory model load tests were conducted on the model square footing resting over medium dense sand. The parameters studied were load eccentricity ratio, load inclination angle and depth of top reinforcing layer. The eccentricity ratio (e/B) and inclination angle (α) varied from 0 to 0.2 and 0^0 to 30^0 respectively. The effects of depth of top reinforcing layer were studied at 0.2B and 0.4B. The results shows that the bearing capacity decreases with increase in the load eccentricity and load inclination. The load inclination result in decreasing the bearing capacity more than the effects of eccentric load. The horizontal deflection increases with increase in the load inclination angle. The results shows that the bearing capacity on reinforced sand bed subjected to inclined eccentric load were higher than that of unreinforced soil. The maximum reduction in bearing capacity and maximum horizontal deflection was observed at load inclination of 30^0 with an eccentricity of 0.2B.

Keywords: Sand, Square footing, Eccentricity width ratio, Inclined and eccentric-inclined load, reinforced s

I INTRODUCTION

Foundations may be subjected to inclined loads or eccentric loads or both. The problems of footings subjected to inclined loads are frequently encountered in the case of the foundations of retaining walls, abutments, columns, stanchions, portal framed buildings etc. Footing located at property line, machine foundation are some examples where the foundations experience eccentric loading. If the load is eccentric-inclined, the stress distribution below the footing will be non uniform causing unequal settlement at two edges. An inclined load reduces the ultimate bearing capacity of soil. Many studies has been observed using different approaches with analytical, experimental and numerical method for footings on unreinforced soil (Loukidis *et al.*, (2008), Saleh, *et al*. (2008), Joshi and Mahiyar (2009); Nawghare, *et al.* (2010), Dhar and Roy (2013); Ornek (2014).) and on reinforced soil (Singh and Agrawal (2007); Sawwaf (2009); Sadoglu *et al*. (2009); Dewaikar *et al*. (2011)). The literature review shows that load eccentricity and load inclination reduces the bearing capacity of the foundation noticeably. But very limited study was carried out in combined effects of load eccentricity and inclination. The objective of the study was to perform a parametric study to understand the effect of load inclination and load eccentricity on ultimate bearing capacity and settlement behavior of square footing resting over unreinforced and reinforced bed. The various parameters considered for the study were load eccentricity, load inclination, depth of top reinforcing layer.

II EXPERIMENTAL PROGRAM

2. 1 Material and Methodology

Sand used in the present work was locally available Kanhan sand. The sand is available in Kanhan River (Nagpur), Maharashtra. The various properties of the soil were determined in the laboratory and are presented in Table 1.

Geogrid is usually made from polymer materials, such as polypropylene, polyethylene or polyester. Commercially available continuous biaxial geogrid was used for reinforcing the sand bed. The size of biaxial geogrid reinforcement used was four times the size of the footing. The top surface of the sand was leveled and the biaxial geogrid reinforcement was placed.

Table 1: Properties of Sand

Sr. No.	Properties	Values
1	Specific gravity	2.64
2	e_{max}	0.72
3	e_{min}	0.52
4	γ_{max}	17.16 kN/m^3
5	γ_{min}	15.4kN/m^3
6	Relative density (%)	40%
7	Angle of internal friction φ	33.02º
8	Average grain size (D60)	1mm
9	Effective grain size (D10)	0.425
10	Coefficient of uniformity (Cu)	1.088
11	Coefficient of curvature (Cc)	2.35

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12	I. S. Classification	Medium sand, SP

The test tank was made of 2 mm thick M.S. plate having internal dimensions 600 mm x 600 mm in plan and 450 mm high. The bulging effect counteracts by providing sufficient horizontal and vertical bracings at sufficient intervals. The model footing used was made up of a rigid steel plate of dimensions 100mm x 100mm and 10 mm thick. The footing was provided with grooves at required eccentricity to provide eccentric load. The load was applied using screw jack. The wooden wedges were used to provide the load inclination. The details of complete setup is shown in Fig. 1.

For the experimental investigation, the model plate load tests (I.S.1888:1982) were conducted on sand to evaluate the bearing capacity and settlement. The sand bed was prepared using rain fall method in number of layers. The top surface of the sand was leveled and the biaxial geogrid reinforcement was placed at required depth and spacing. After preparation of sand bed, the model footing was placed at the centre of the tank. Two dial gauges were then placed on the flanges of the footing to measure the vertical settlement and one dial gauge was provided to measure the horizontal deflection of footing. The load was applied through screw jack. The load was applied in increments and each increment was maintained constant till the footing settlement had stabilized. The settlement of the footing was measured by taking average readings of the two dial gauges. By gradually increasing the load, tests were carried out to observe the complete load-settlement behavior till the failure. The footing was subjected to increasing central inclined load, eccentric load and eccentric-inclined load at chosen angle of inclination and load eccentricity.

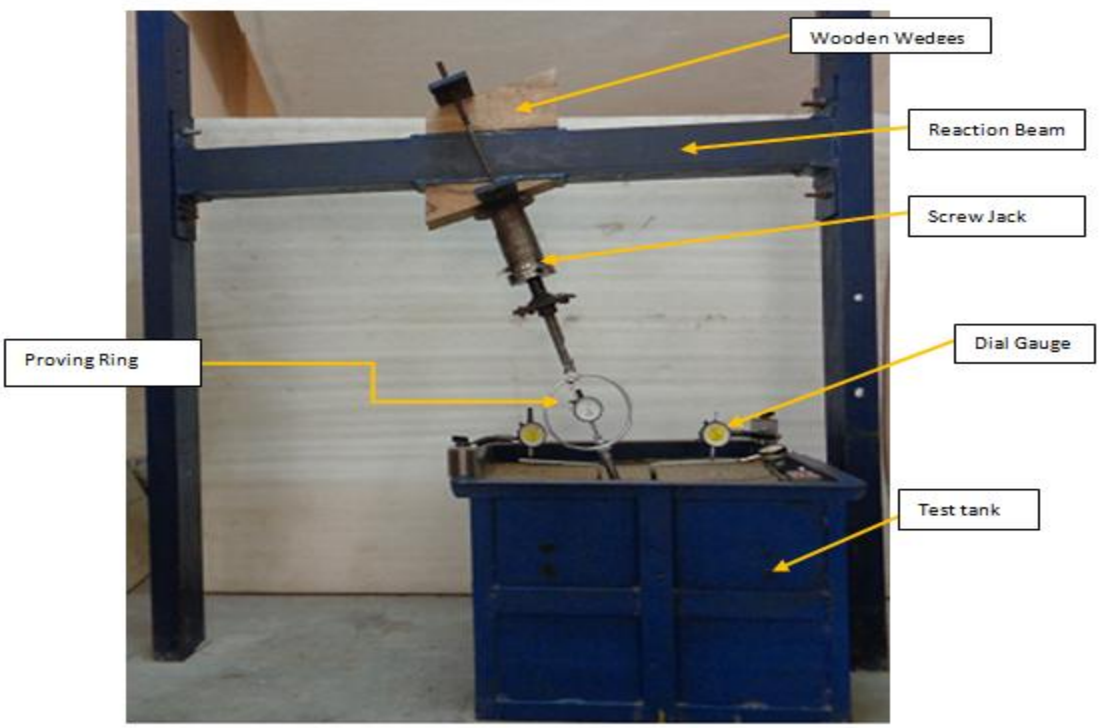

Fig. 1: Experimental Setup

The model plate load tests were conducted for different parameters as shown in Table

Table 2: Parameters Investigated

Series	Condition	Varying parameters	No. of Test
A	Unreinforced soil- Inclined load	$\alpha = 0^0, 10^0, 20^0, 30^0$	4
B	Unreinforced soil- Eccentric load	e/B = 0.1, 0.15, 0.2	3
C	Unreinforced soil- Eccentric-Inclined load	$\alpha=10^0, 20^0, 30^0$ e/B =0.1, 0.15, 0.2	9
D	Reinforced soil- Inclined load	$\alpha = 0^0, 10^0, 20^0, 30^0$ u/B=0.2, 0.4	8
E	Reinforced soil- Eccentric load	e/B = 0.1, 0.15, 0.2 u/B=0.2, 0.4	6
F	Reinforced soil- Eccentric-Inclined load	$\alpha=10^0, 20^0, 30^0$ e/B =0.1, 0.15, 0.2 u/B=0.2, 0.4	18
Total			48

III RESULTS

The results of plate load tests conducted on footing resting over unreinforced and reinforced sand bed under inclined load, eccentric load and eccentric-inclined load were used to study the variation of bearing capacity of footing with change in inclination and eccentricity of load.

3.1 Effect of Load Inclination on Footing

The results obtained from tests conducted were used to study the effects of load inclination on footing resting over unreinforced and reinforced sand bed. The load-settlement curve for footing under inclined load with load inclination of 10^0 on unreinforced and reinforced sand is shown in Fig. 2. The ultimate bearing capacity (U.B.C) was found to be 82 kN/m^2 and 102 kN/m^2 respectively. The results obtained from various tests for different load inclination are shown in Table 3.

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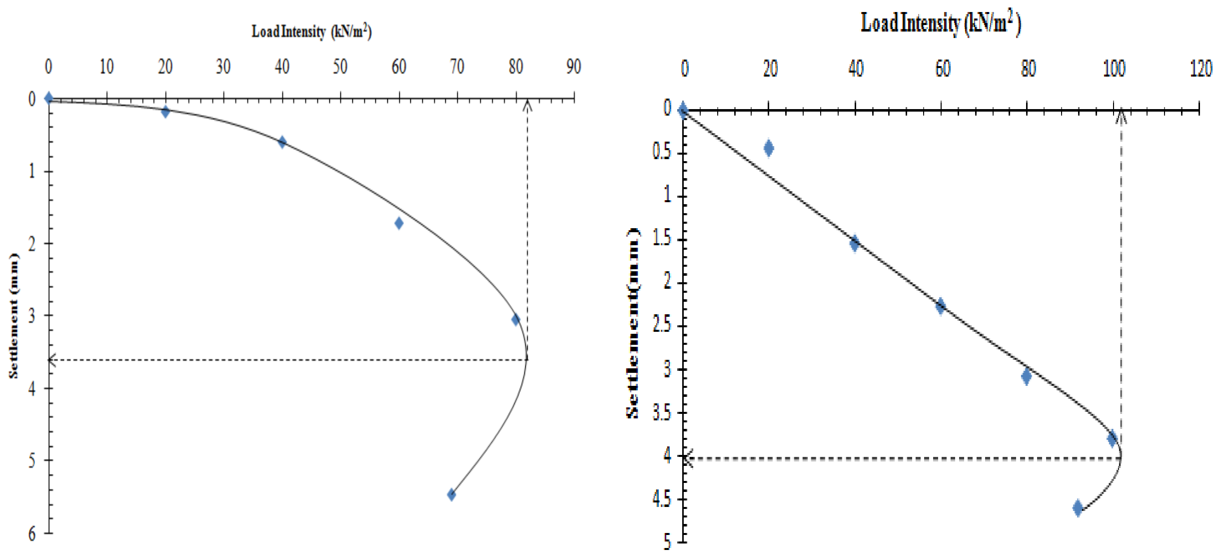


(a) Unreinforced (b) Reinforced (at u/B=0.2)

Fig. 2: Load-Settlement Curve for Footing under Inclined Load ($\alpha=10^0$)

Table 3 : Bearing Capacity Ratio (B.C.R) for Inclined Load

Sr. No.	Condition	U.B.C. (kN/m²)		
		Unreinforced	Reinforced	
			u/B=0.2	u/B=0.4
1	$\alpha = 0^0$	102	152	140
2	$\alpha = 10^0$	82	102	90
3	$\alpha = 20^0$	40	56	45.5
4	$\alpha = 30^0$	12.4	18.5	15.2

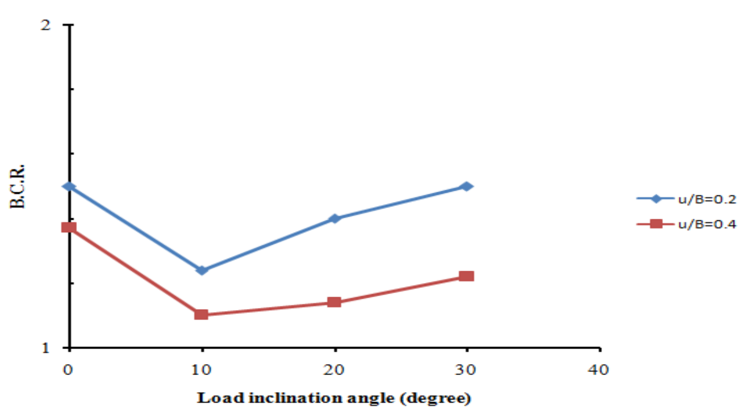


Fig. 3: Variation of B.C.R. at Various Load Inclination Angle on Reinforced

Sand Bed (u/B=0.2 and u/B=0.4)

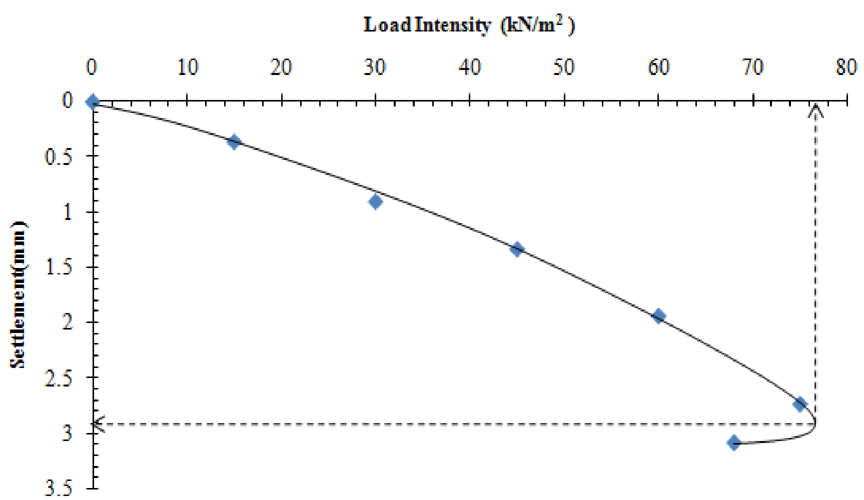
The horizontal deflection of footing increases with increase in load inclination. The horizontal deflection causes sliding of the footing and causes failure due to sliding. The Table 4 shows the values of horizontal displacement for various load inclination angle.

Table 4: Horizontal Displacement for Various Load Inclination Angle

Sr. No.	Condition	Horizontal displacement(mm)	
		Reinforced case	
		u/B=0.2	u/B=0.4
1	$\alpha = 10^0$	0.81	1.06
2	$\alpha = 20^0$	1.8	1.92
3	$\alpha = 30^0$	1.95	0.82

3.2 Effect of Load Eccentricity on Footing

The load-settlement curve for footing under eccentric load with load eccentricity of 0.1B on unreinforced and reinforced sand is shown in Fig. 4. The results obtained from various tests for different load eccentricity are shown in Table 5. The Fig. 5 shows the variation of B.C.R. for various load eccentricity on reinforced sand.



(a)Unreinforced

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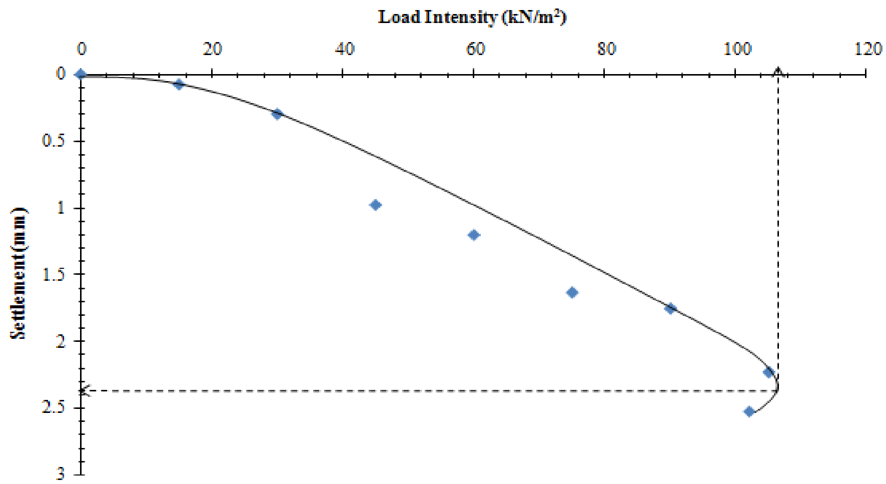

(b) Reinforced

Fig. 4 : Load -Settlement Curve for Footing under Eccentric Load (e/B = 0.1)

Table 5 : Bearing Capacity Ratio (B.C.R) for Eccentric Load

Sr. No.	Condition	U.B.C. (kN/m²)		
		Unreinforced	Reinforced	
			u/B=0.2	u/B=0.4
1	e/B = 0.1	77	106	92
2	e/B = 0.15	54	73	64
3	e/B = 0.2	30	42	36.5

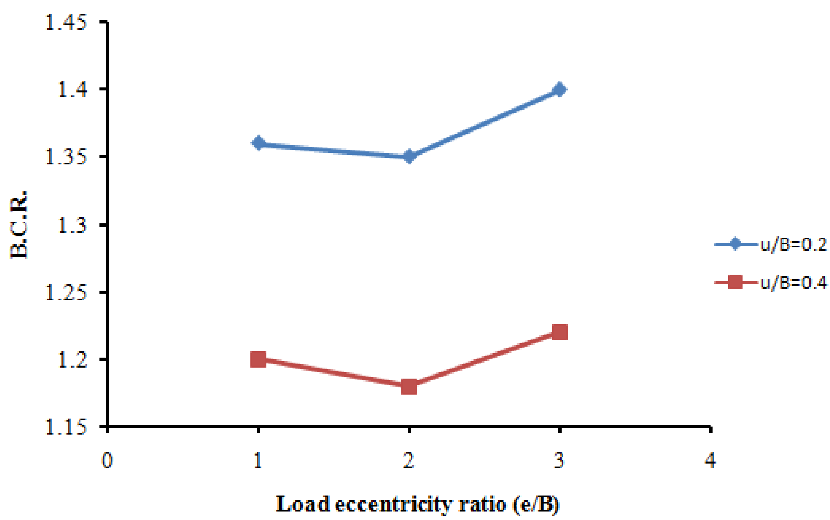

Fig. 5 : Variation of B.C.R. for Various Load Eccentricity on Reinforced Sand Bed

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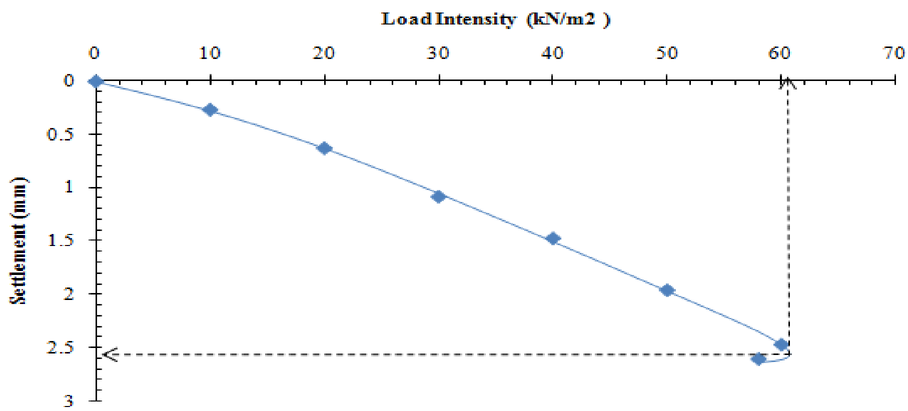
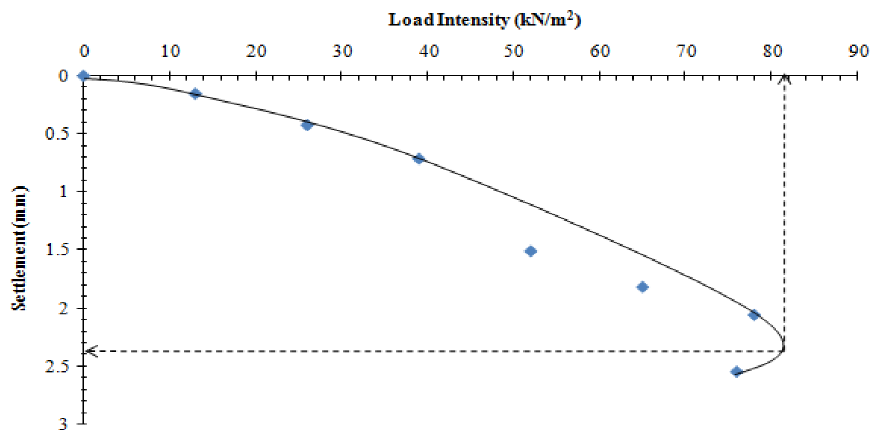
3.3 Effect of Eccentric-Inclined Load on Footing

The load-settlement curve for footing under eccentric-inclined load with load eccentricity of 0.1B and load inclination of 10^0 on unreinforced and reinforced sand is shown in Fig. 6. The results obtained from different configurations of load eccentricity and load inclination are shown in Table 6.



(a) Unreinforced



(b) Reinforced

Fig. 6 : Load -Settlement Curve for Footing under Eccentric-Inclined Load (at e/B = 0.1 and a=10^0)

Table 6 : Bearing Capacity Ratios (B.C.R) for Eccentric-Inclined Load

Sr. No.	Condition		U.B.C. (kN/m^2)		
	Constant parameters	Varying parameters	Unreinforced	Reinforced	
				u/B = 0.2	u/B = 0.4
1	e/B = 0.1	$\alpha = 10^0$	60	82	74
2		$\alpha = 20^0$	30	44	36

3		$\alpha = 30^0$	8	12.8	11.3
4	e/B = 0.15	$\alpha = 10^0$	42	58	48
5		$\alpha = 20^0$	22	36	25.5
6		$\alpha = 30^0$	7.5	12	10
7	e/B = 0.2	$\alpha = 10^0$	20.5	30	24
8		$\alpha = 20^0$	12.2	18.4	15.2
9		$\alpha = 30^0$	4	7.8	6.1

The horizontal displacement vs. load intensity curve for footing under different eccentric-inclined load is shown in Fig. 7 and the Fig. 8 shows the variation of B.C.R. for eccentric-inclined load on reinforced sand bed.

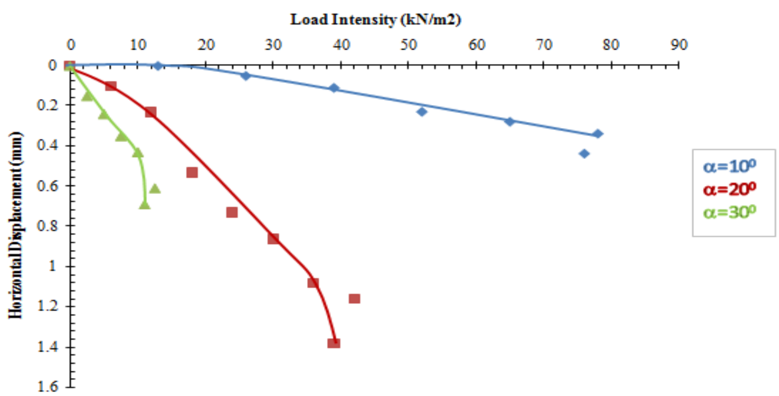
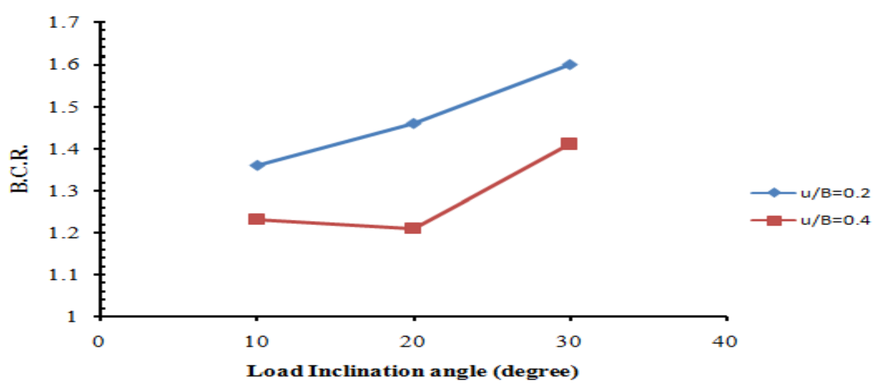


Fig. 7 : Horizontal Displacement Vs. Load Intensity Curve for Footing under Eccentric-Inclined Load (u/B=0.2 and e/B=0.1)



e/B=0.1

Fig. 8 : Variation of B.C.R. for Eccentric-Inclined Load on Reinforced Sand Bed.

IV CONCLUSIONS

The present work studied the performance of model square footing under eccentric, inclined and eccentric-inclined loading on unreinforced and reinforced sand. The geogrid was used as reinforced material for sand. The geogrid was used in three layers having length of four times the width of footing. The reinforcement was placed at u/B=0.2 and u/B=0.4 for studying the effects of position of reinforcement. The model plate load test were conducted to understand the performance. The performance was presented in terms of bearing capacity ratio, settlement and horizontal displacement. The following conclusion are drawn from the work.

- The bearing capacity of square footing decreases as load inclination increases for unreinforced and reinforced soil.
- The bearing capacity ratios for inclined load is minimum at load inclination of 10^0.
- The bearing capacity of square footing decreases as load eccentricity increases for unreinforced and reinforced soil.
- The bearing capacity ratios for eccentric load is minimum at load eccentricity of 0.15 (e/B=0.15).
- The bearing capacity of square footing decreases as eccentric-inclined load increases for unreinforced and reinforced soil.
- The bearing capacity ratios for eccentric-inclined load increases with inclination and eccentricity of the load
- The bearing capacity ratios for inclined, eccentric and eccentric-inclined load is maximum when reinforcement is placed at u/B=0.2.
- The horizontal deflection increases with increase of load inclination.

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