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Performance of Square Footing Subjected to Eccentric-Inclined Load

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Abstract— The study aims to evaluate the effects of eccentricity, inclination of load along with eccentric-inclined load on performance of square footing resting over sand. The laboratory load tests were conducted on the model footing with eccentric load and/or inclined load. The eccentricity ratio (e/B) and inclination angle (α) varied from 0 to 0.2 and 0^0 to 30^0 respectively. The results shows that the bearing capacity decreases with increase in the load eccentricity and load inclination.

Keywords— Sand, Square Footing, Eccentric, Inclined and Eccentric-Inclined load.

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).) 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. The various parameters considered for the study were load eccentricity and inclination.

II. 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.

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.

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
12	I. S. Classification	Medium sand, SP

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. 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.

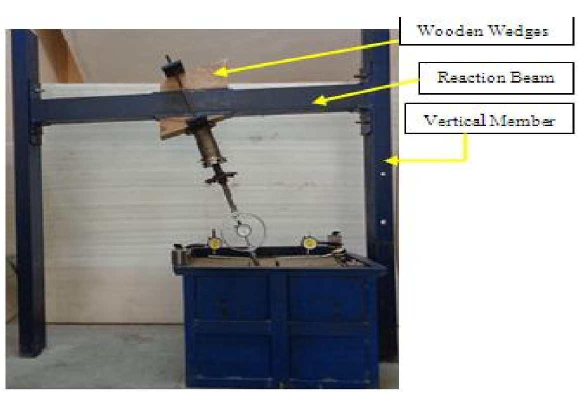

Figure 1: Experimental Setup

The model plate load tests were conducted for different parameters as shown in Table 2. Test in series A were performed only for inclined load. Test in series B were performed only for eccentric load. Test in series C were performed for an eccentric-inclined load.

Table 2: Parameters Investigated

Series	Condition	Varying parameters	No. of Test
A	Inclined Load	$\alpha = 0^0, 10^0, 20^0, 30^0$	4
B	Eccentric Load	e/B = 0.1, 0.15, 0.2	3
C	Eccentric-Inclined Load	$\alpha=10^0, 20^0, 30^0$ e/B =0.1, 0.15, 0.2	9
Total			16

III. Results

The tests results were used to study the variation of bearing capacity of footing with change in inclination and eccentricity of load.

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 sand bed. The load-settlement curve for footing under inclined load with load inclination of 10^0 is shown in Fig. 2. The ultimate bearing capacity (U.B.C) was found to be 82 kN/m^2. The results obtained from various tests for different load inclination are tabulated in Table 3. The results shows that the ultimate bearing capacity decreases with increase in load inclination. The bearing capacity ratio (B.C.R.) was determined for each result which is the ratio of ultimate bearing capacity of test case to ultimate bearing capacity of vertical-concentric load. B.C.R. found to decrease with increase in load inclination.

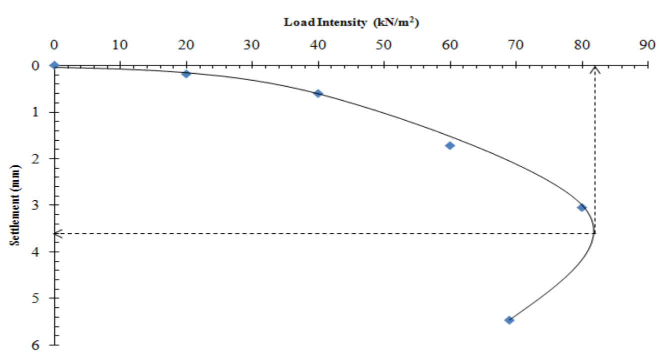

Figure 2: Load-Settlement Curve for Footing under Inclined Load ($\alpha=10^0$)

Effect of Load Eccentricity on Footing

The load-settlement curve for footing under eccentric load with an load eccentricity of 0.1B is shown in Fig. 3. The results shows that the ultimate bearing capacity decreases with increase in load eccentricity. The unequal settlement of footing increases with increase in load eccentricity. The results obtained from tests for different load eccentricity are tabulated in Table 4.

Table 3: Ultimate Bearing Capacity under Inclined Load

Sr. No.	Load inclination	U.B.C. (kN/m^2)	B.C.R.
1	$\alpha = 0^0$	102	1
2	$\alpha = 10^0$	82	0.80
3	$\alpha = 20^0$	40	0.39
4	$\alpha = 30^0$	12.4	0.12

Table 4: Ultimate Bearing Capacity under Eccentric Load

Sr. No.	Eccentricity Width Ratio	U.B.C. (kN/m^2)	B.C.R.
1	e/B=0.1	77	0.75
2	e/B=0.15	54	0.53
3	e/B=0.2	30	0.29

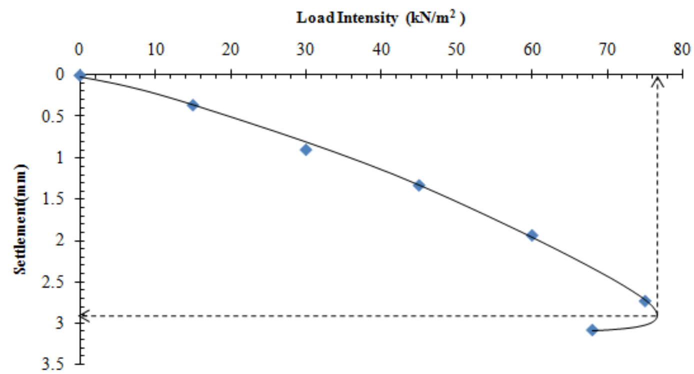

Figure 3: Load-Settlement Curve for Footing under Eccentric Load (e/B=0.1)

Effect of Eccentric-Inclined Load on Footing

The effects of eccentric-inclined load on model footing were studied through model plate load tests for different configurations of load eccentricity and load inclination. The load-settlement curve for footing under eccentric-inclined load is shown in Fig. 4. The results obtained from tests conducted for different conditions are tabulated in Table 5.

The horizontal displacement vs. load intensity curve for footing under different eccentric- inclined load is shown in Fig. 5.

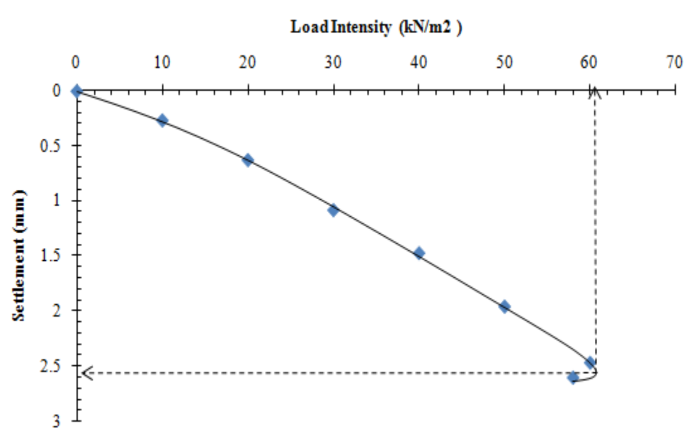

Figure 4: Load-Settlement Curve for Footing under Eccentric-Inclined Load (e/B=0.1 and $\alpha=10^0$)

Table 5: Ultimate Bearing Capacity under Eccentric-Inclined Load

Sr. No.	Condition		U.B.C. (kN/m^2)	B.C.R.
	Constant Parameters	Varying Parameters		
1	e/B = 0.1	$\alpha = 10^0$	60	0.58
2		$\alpha = 20^0$	30	0.20
3		$\alpha = 30^0$	8	0.08
4	e/B = 0.15	$\alpha = 10^0$	42	0.41
5		$\alpha = 20^0$	22	0.22
6		$\alpha = 30^0$	7.5	0.07
7	e/B = 0.2	$\alpha = 10^0$	20.5	0.20
8		$\alpha = 20^0$	12.2	0.12
9		$\alpha = 30^0$	4	0.04

The results shows that the ultimate bearing capacity decreases with increase in load eccentricity and load inclination. The horizontal displacement of footing under eccentric-inclined load increases with increase in load inclination angle. The effects of horizontal displacement may caused due to sliding of the footing leading to failure.

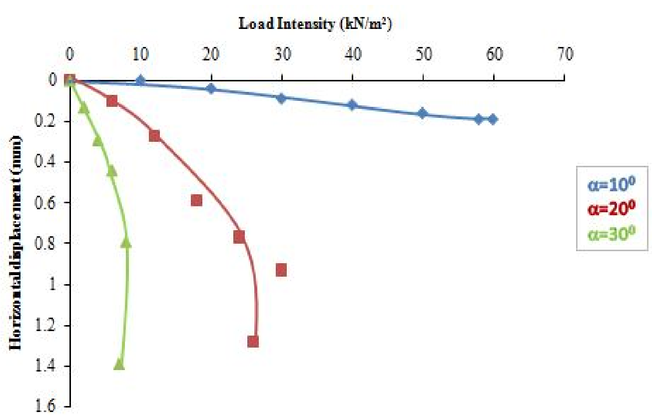

Figure 5: Horizontal Displacement vs. Load Intensity for Footing under Eccentric-Inclined Load at e/B=0.1.

IV. Conclusions

The present work studied the performance of model square footing under eccentric, inclined and eccentric-inclined loading on unreinforced sand.

The model plate load test were conducted to understand the performance. The performance was presented in terms of ultimate bearing capacity, settlement and horizontal displacement. The following conclusion are drawn from the work.

- The ultimate bearing capacity of square footing decreases as load inclination increases.
- The ultimate bearing capacity for inclined load is reduces to 50% even at load inclination of 20^0.
- The ultimate bearing capacity of square footing decreases as load eccentricity increases.
- The ultimate bearing capacity of square footing decreases as eccentricity and inclination of load increases.
- The horizontal deflection increases with increase of load inclination.
- The eccentricity and inclination of load shows impact on ultimate bearing capacity.

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