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An Investigation of Angle Shaped Footing Subjected to Inclined Loading using an Inclined Projection

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***Abstract*— Since the inception of angle-shaped Footing in 2000, a lot of significant work has been done in the previous decade on angle-shaped Footing. The literature review has been found sufficient and necessary for the study. Therefore an analysis of angle-shaped footing under eccentric loading has been carried out in the present study. One side-footing projection having different angles and lengths of the footing projection confines the soil and prevents its lateral moment. It was concluded that eccentrically loaded footing could be designed for no or negligible tilt by giving footing an angle shape. The length and angle of footing projection will depend upon the eccentricity width ratio. The concept of square angle-shaped footing has been extended by the varying angles of projection (β) & angle of eccentric loading (α). The charts were developed for the zero tilt conditions for different α, β, and D/B values by conducting experiments on a model footing plate of size 220 mm x220 mm. zero tilt condition is of uttermost importance, the results and the graphs have been plotted for the same. The readymade package 'ANSYS' has been used for conducting the finite element analysis of the footing.**

***Keywords*-- Angle Shaped Footing, Eccentric Loading, zero tilt conditions, Finite Element Method, ANSYS**

I. INTRODUCTION

Over the years, various researchers (S. Nazeer , R.K. Dutta (2021), Sandeep Nighojkar, Bhagyashree Naik, Dr.U.Pendharkar (2020), Koushik Halder, Debarghya Chakraborty (2020), Zainab Talib Jafaar , Zinah Waleed Abass ,Shaimaa Hasan Fadhil (2020) Tarek Mansouri, Khelifa Abbeche (2019), Sharad Chaurasia, Dr. Rakesh Kumar (2018)) have used reinforcement beneath the foundation for different structures such as building, bridge abutment, electrical transmission tower, and hanging cable car situated on the sloping ground. Inclusion of reinforcement layers below the footing enhances both bearing capacity of footing and stability of the slope. In all of these prior studies, the footing on a sloping ground was subjected to only vertical loading. However, a foundation may be subjected to inclined loading and over turning moment generated due to lateral forces and structural asymmetry.

The idea of confinement has been used here by giving the foosting an angle shape. The horizontal leg is the footing itself and the vertical leg is defined in the study as the footing projection, which is provided toward the loading side. In such footings, the soil particles near the footing projection are prevented from moving laterally. As a result, they cause the footing projection to tilt in a direction opposite the one in which the footing has a tendency to tilt. Thus, tilt of the footing can be reduced to zero by providing a downward vertical footing projection of required depth toward the loading side. Sometimes when the inclined eccentric loads are acting on the footing the tilt developed is minimized by giving inclination to the projection.

A footing when provided with vertical projection which remains embedded in the soil on one side i.e. towards the eccentricity such that it is an integral part of the footing it is called an Square angle shaped Footing.

In an angle shape footing the soil particles near the footing projection are prevented from moving laterally thus footing projection causes footing to tilt in direction opposite the one in which the footing has tendency to tilt. Thus tilt of the footing can be reduced to zero by providing a downward footing projection of required depth toward the loading side By varying two dimensionless parameters namely e_x/B and L/B and Mahiyar H.K.(2000) developed the equation of the following type which is found to be independent of the material of footing and the properties of the underlying sandy soil.

$$\mathbf{D/B = 85.77(e_x/B)^3 - 8.95(e_x/B)^2 + 3.42(e_x/B) - 0.0012}$$

Where,
B = width of footing;
D = depth of footing projection;
e_x = eccentricity along x-axis;

II. LITERATURE REVIEW

S. NAZEER, R.K. DUTTA (2021) Purpose: The purpose of this study is to estimate the ultimate bearing capacity of the E-shaped footing resting on two layered sand using finite element method.

The solution was implemented using ABACUS software. Design/methodology/approach: The numerical study of the ultimate bearing capacity of the E-shaped footing resting on layered sand and subjected to vertical load was carried out using finite element analysis. The layered sand was having an upper layer of loose sand of thickness H and lower layer was considered as dense sand of infinite depth. The various parameters varied were the friction angle of the upper (30° to 34°) and lower (42° to 46°) layer of sand as well as the thickness (0.5B, 2B and 4B) of the upper sand layer.

SANDEEP NIGHOJKAR, BHAGYASHREE NAIK, DR.U.PENDHARKAR (2020) Global rise in temperature and lowering of ground water table, significantly affects the behaviour and strength characteristics of foundation soil. It possesses a critical problem of differential settlement of foundations in structures. It is a major concern for foundation designer. Bi-Angle shape skirted footing can be a better alternative to reduce the differential settlement. Skirts, i.e. vertical walls at the base of footing, which helps in confining the under lying soil, generates a soil resistance on skirt sides that helps the footing to resist settlement. Bi-angle shaped skirts are the skirts in which vertical walls are provided under the footing on two adjacent sides. A finite element model is being prepared to study and investigate the behaviour and effectiveness of Bi-angle shape skirted footing resting on clayey soil; using finite element software SAP 2000 VS18.The study has been carried out for two types of soils and footing model are analyzed to find the effectiveness of skirts and their depths in arresting differential settlement of footing. Encouraging results obtained from finite element modelling and analysis shows that the settlement of footing decreases with the increase in skirt depth.

KOUSHIK HALDER, DEBARGHYA CHAKRABORTY (2020) The present study considers the influence of inclined and eccentric loading on the bearing capacity of a strip footing placed on the reinforced cohesion less soil slope by using lower bound finite element limit analysis technique. The effects of other parameters such as soil friction angle, embedment depth of reinforcement layer below the footing, interface friction angle between soil and reinforcement, and vertical spacing between two reinforcement layers are also investigated. Results are presented as the variation between reinforcing efficiency and various combinations of above-mentioned parameters. The bearing capacity of strip footing reduces under combined effects of inclined and eccentric loading. However, with the inclusion of reinforcement layers at the optimum depth, the bearing capacity enhances significantly.

The reinforcing efficacy increases with the increasing value of load inclination. The reinforcing efficiency reduces with the consideration of partial roughness between soil and reinforcement layer. Stress contours are also plotted in the two-dimensional object space to understand the failure mechanism of slopes.

ZAINAB TALIB JAFAAR, ZINAH WALEED ABASS, SHAIMAA HASAN FADHIL (2020) Punching shear failure is one of the most common problems in shallow foundations (pad footings).Therefore, this investigation is conducted to study the effect of increasing of the flexural reinforcement ratios as (0.0036, 0.0047, and 0.0057) and using funnel-shaped punching shear preventers (FSPSP)on the punching shear failure of self-compacting concrete(SCC) pad footing. Four footing specimens were supported on a bed of steel(car)springs and loaded by vertical force till failure. The results show that the first crack load, the ultimate load, the ductility and the punching shear strength were improved by using the FSPSP. The results showed that the first crack load and ultimate load increased with increasing of the flexural reinforcement ratio while the ductility and the deflection are decreased. In contract, the using of the FSPSP showed an improve of the first crack load, the ultimate load, the ductility and the punching shear strength.

TAREK MANSOURI, KHELIFA ABBECHE (2019) Based on the response of small-scale model square footing, the present paper shows the results of an experimental bearing capacity of eccentrically loaded square footing, near a slope sand bed. To reach this aim, a steel model square footing of (150 mm × 150 mm) and a varied sand relative density of 30%, 50% and 70% are used. The bearing capacity-settlement relationship of footing located at the edge of a slope and the effect of various parameters such as eccentricity (e) and dimensions report (b/B) were studied. Test results indicate that ultimate bearing capacity decreases with increasing load eccentricity to the core boundary of footing and that as far as the footing is distant from the crest, the bearing capacity increases. Furthermore, the results also prove. That there is a clear proportional relation between relative densities –bearing capacity. The model test provides qualitative information on parameters influencing the bearing capacity of square footing. These tests can be used to check the bearing capacity estimated by the conventional methods.

SHARAD CHAURASIA, DR. RAKESH KUMAR (2018) Footing subjected to eccentric loading along two mutually perpendicular axes is quite a common field problem. Due to this bearing capacity is reduced considerably as the effective size is drastically reduced.

A footing may be subjected to one way or two-way eccentricity due to many reasons. In the case of footing subjected to one-way eccentricity the common practice is to match the centre of gravity of column loads to centre of gravity of footing area. Strap footings are also commonly used when the footing is subjected to two-way eccentric load. These footings not only resist the eccentric loading without (negligible) tilt but increase the bearing capacity also. Using the idea of angle-shaped footings and bi-angle shaped footing which was a result from the study of partial confinement, another new idea, has been developed. These footings have shape in the form of one vertically downward projection towards the eccentric side of one adjacent edge. In the present paper Square Angle shaped footing which was the experimental work of Dr. H. K Mahiyar has been analysed and then verified by Finite Element Technique using ANSYS software. Secondly rectangular footings subjected to eccentric loadings have been considered and an analysis has been done by taking different points of eccentricity along with varying projection and sizes of footing. Footing under a point load at some eccentricity along diagonal with one vertically downward footing projections of equal length along one adjacent side towards the eccentricity have been analysed. To get the zero-tilt condition of the footing for the eccentric load, the projection has been given certain ratios with respect to the size of the footing. It has been observed that the equation given by Dr. H K Mahiyar was verified and the position of the zero tilt of rectangular angle shaped footing could be achieved successfully.

PANCHAM KUMAR, HEMANT MAHIYAR (2015) The bases of all the civil engineering structures rest on soil/rock. The size of open foundation depends upon the bearing capacity and compressibility of soil/rock. The footings are often subjected to eccentric and inclined loading. The experimental and finite element analysis of Angle Shaped Footings has proved their acceptability under eccentric vertical or eccentric inclined static loading. In Angle Shaped Footings a vertical projection which is an integral part of footing and remains embedded in soil is there if the footing is subjected to eccentric vertical load while the projection is inclined in case the footings are subjected to eccentric inclined loading. However, the quadrant of eccentricity has to be known well before providing such footings as the footing projection is always provided towards the eccentricity. The earthquake is a natural phenomenon the occurrence of which is not in the hand of human being, and the civil engineers have to design the substructure taking care of earthquake force since the effect shall be ultimately transferred to foundation.

Thus the study of foundation under dynamic loading is conducted to assess the behaviour of Angle Shaped Footings under variable parameters of experimental studies. After conducting exhaustive experimental studies on Angle Shaped Footings it has been found that Angle Shaped Footings displaced less in the direction parallel and perpendicular to direction of shaking but the tilt is more as compared to normal footing.

GUPTA N. (2010) has done the cost comparison of materials for both conventional footing and angle shaped footing for a common building plan with multiple stories with multiple earthquake zones'n case of higher eccentricity, more advantageous in case of footing.

KULSHRESTHA R. (2009) worked on inclined angle shaped footing of different Sizes, choosing the other parameters in such a way that the tilt is zero. He also proposed the designs steps of angle shaped footing.

Ghngoriya V. (2008) has done experimental work done on angle shaped footing subjected to eccentric loading. In this the angle is connected to longer direction. He took 12cm x 24cm footing rectangular plate, projection was taken ½ times the width of footing, and load was taken in both directions i.e. clockwise and anticlockwise.

Vrma N. (2007) again worked on experimental study of angle shaped footing subjected to eccentric loading with pile under sand. He concluded that for angle shaped footing subjected to loading toward the footing projection, provision of pile is advantageous.

Verma N. (2007) studied the comparative design of isolated footing and angle shaped footing under eccentric load and moment of a G+9 story building under seismic and static load combination. He conclude that angle shaped footing is more economical field practitioners at nearer the property line.

Nighojkar Sandeep (2006) studied Bi- angle shaped model footing subjected to two way eccentric load under mixed soil condition. He observed that when load is applied tilt increases with increase in depth of footing projection, which means that for resisting higher eccentricities, the depth of confinement should be high.

Rajput D. (2006) studied the angle shaped footing subjected to one way eccentric loading under mixed soil condition. She concluded that the angle shaped footing are very useful for the eccentric loads and can be used in natural condition where the existing soil is cohesive black cotton or yellow by excavating a pit of size equal to little more than width of footing and filling the excavated soil by sand of equal density.

Atulkar N. K. (2005) has done work on Optimization of angle shaped Footing. In which he concluded that the rigorous analysis of angle shaped footing could be obtained and based upon the analysis the footing can be designed for any magnitude of load. The technical optimization has been obtained by introducing moment in addition to eccentric point load. The analysis and design of such cases also has been done successfully. Based upon the experimental study geometrical optimization has been achieved. It has found that the rectangular shaped footing projections are more effective. Although the percentage bearing capacity reduces but the saving in material (i.e. concrete and steel) is more as compared to percentage reduction in bearing capacity.

Kanungo A. (2004) studied the angle shaped footing in which (e/B) and (D/B) were in accordance with the polynomial equation of third degree which was in terms of D, B and e and was given by Mahiyar H. K. He concluded that tilt was zero. The various sizes of footings were considered and concluded that bearing capacity increases with increase in size of footing and with increase in (D/B) ratio.

Mahiyar H. K. and Patel A. N. (2003) studied the effect of shear parameters on load carrying capacity of angle shaped footing and concluded that load carrying capacity increases with increase in angle of internal friction and tilt was zero at all value.

Joshi D. (2001, 2009) studied angle shaped footing subjected to eccentric inclined loading. The inclination on either side of vertical axis was provided and the angle of footing projection was also varied. He found that footing had the resisting capacity to eccentric inclined load, although the load carrying capacity was less.

Gupta D. (2000) presented his views after studying the angle shaped footing with rectangular shaped in which eccentricity was provided on longer side and shorter side. He found that eccentricity along shorter side and footing projection on longer side is more effective.

CRITIQUES

From the above studies it can be seen that the work has been done experimentally as well as by modelling software on model footing except Kulshrestha R. (2009).

- The foundations are subjected to eccentric loads which create the non-uniform pressure beneath the footing; bearing capacity for normal footing is done by many researchers.
- Minimization of the rotation or tilt for uniaxial loading is to be done by introducing the projection of required length and inclination.
- The concept of square angle shaped footing has been extended by varying angle of projection (β) & angle of eccentric loading (α). The charts were developed for zero tilt condition for different α, β and D/B values by conducting experiments on model footing plate of size 220mm x220mm.
- The earlier studies were the experimental studies on model footings & software modelling on the study had also been done.

III. OBJECTIVES

The objective is to verify the eccentricity width ratio (ex/B) for zero tilt condition for the real size footing of size 1m x1m, using the parameters-

1. Inclination of load (α) = 0^0, 3^0, 6^0, 9^0, 12^0
2. Inclination of length of projection (β) = 0^0, 15^0, 30^0, 45^0.
3. Length of projection = 0.2m, 0.4m, 0.6m.

By using the combinations of above parameters in form of different cases, the objective is clear to determine the following-

- To determine and check the tilt of the footing which should be within permissible limits.
- To determine and check the settlement of footing which should be within permissible limits.
- To compare the results of the work done previously on finite element modelling software.

Modal Analysis Using FEM -

The goal of modal analysis in structural mechanics is to determine the natural modal shapes and frequencies of an object or structure during free vibration. It is common to use the finite element method (FEM) to perform this analysis because, like other calculations using the FEM, the object being analyzed can have arbitrary shape and the results of the calculations are acceptable. The types of equations which arise from modal analysis are those seen in Eigen systems. The physical interpretation of the Eigen values and Eigen vector which come from solving the system are that they represent the frequencies and corresponding mode shapes. Sometimes, the only desired modes are the lowest frequencies because they can be the most prominent modes at which the object will vibrate, dominating all the highest frequency modes. It is also possible to test a physical object to determine its natural frequency and mode shapes. This is called an Experimental Modal Analysis.

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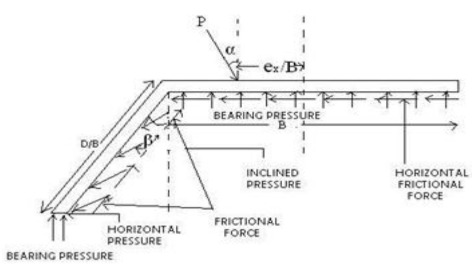
The results of the physical test can be used to calibrate a finite element model to determine if the underlying assumptions made were correct (for example, correct material properties and boundary conditions were used).

ANSYS -

ANSYS, Inc. is an engineering simulation software provider founded by software engineer John Swanson .it develops general purpose finite element analysis and computational fluid dynamics software. While ANSYS has developed a range of computer-aided engineering (CAE) products, it is perhaps best known for its ANSYS Mechanical and ANSYS Multi- physics products.

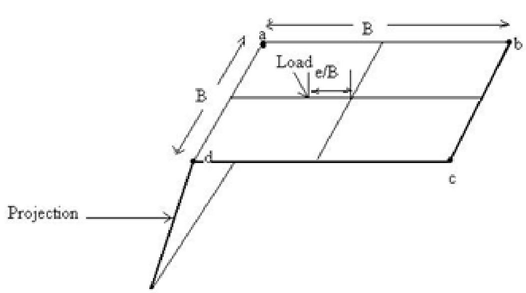
IV. PROBLEM FORMULATION

The combination of above parameters were used for no tilt condition, different cases using above parameters are made and applied at particular eccentricity width ratios (e_x /B) and graphs between e_x /B Vs β ,and e_x /B Vs α for different length of projection (D/B) on the model footing of 220 mm x 220 mm were made, So as to have the zero tilt condition.



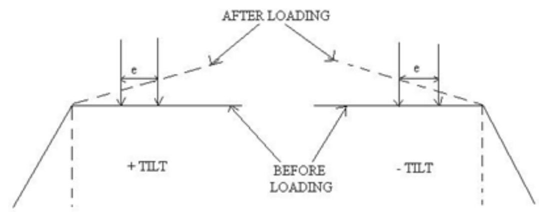
FRONT VIEW OF SQUARE ANGLE SHAPED FOOTING

Figure 1



ISOMETRIC VIEW OF SQUARE ANGLE SHAPED FOOTING

Figure 2



(SIGN CONVENTIONS FOR TILT)

Figure 3

V. OBSERVATION & RESULTS

LOADING INTENSITY OF 150 KN/m^2

PERMISSIBLE DOWNWARD SETTLEMENT=50 mm,

PERMISSIBLE TILT=1.5X10^{-3}

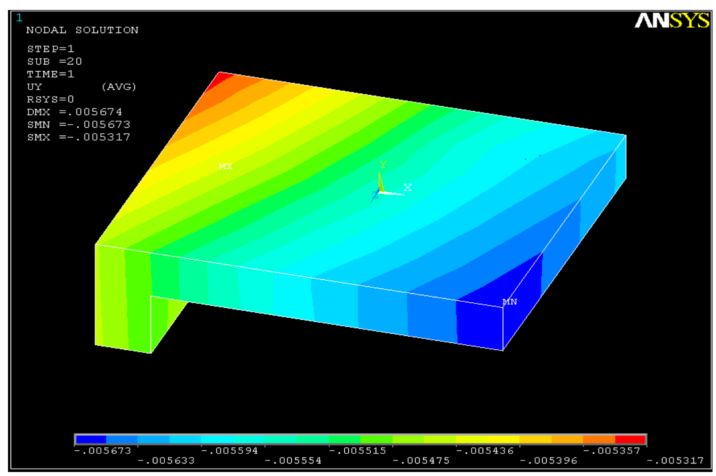
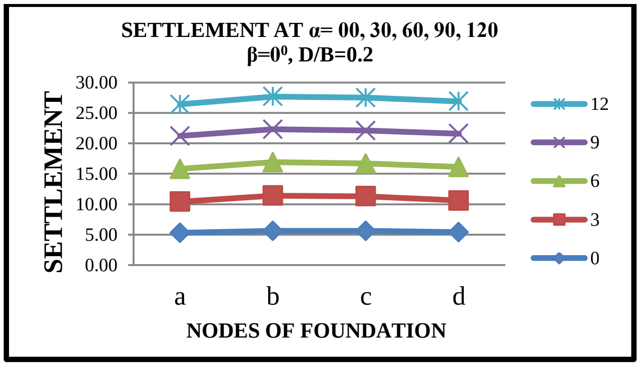


Fig.-4 β=0^0, D/B=0.2 for Avg. Settlement (in mm) & Angular Distortion

Table-1
β=0^0, D/B=0.2 for Avg. Settlement (in mm) & Angular Distortion

β=0^0, D/B=0.2						
ANGLE	**NODE**				**Avg. Settlement (in mm) (a+b+c+d)/4**	**Angular Distortion (in mm)**
α	**a**	**b**	**c**	**d**		
0^0	5.30	5.60	5.60	5.40	5.48	1x10^{-4}
3^0	5.10	5.80	5.70	5.20	5.45	1x10^{-4}
6^0	5.40	5.50	5.40	5.50	5.45	2x10^{-4}
9^0	5.40	5.40	5.40	5.50	5.43	2x10^{-4}
12^0	5.20	5.40	5.40	5.30	5.33	3x10^{-4}



Graph -1 $\beta=0^0$, D/B=0.2 for Avg. Settlement (in mm) & Angular Distortion

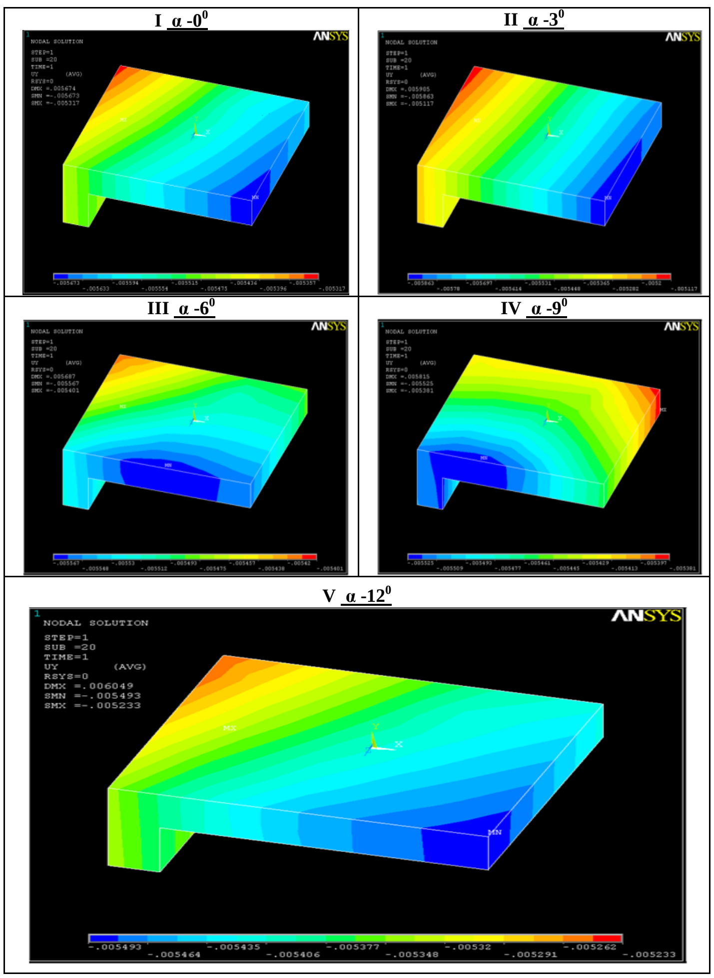


Figure -5. I- α -0^0 II- α -0^0 III- α -0^0 IV- α -0^0 ,V α -0^0 $\beta=0^0$, D/B=0.2 for Avg. Settlement (in mm) & Angular Distortion

VI. CONCLUSION

The verification of the charts by the considered parameters for the real size footing of 1m x1m using the simulation software ANSYS has been done and the results are found to be satisfactory. Following conclusions can be made from the above tabulated results-

1. The eccentricity-width ratio (ex/B) taken from the previously developed charts for the different cases of α, β & D/B ratio were verified using the simulation software ANSYS.
2. The eccentricity-width ratio (ex/B) remains same on the application of 150 KN/m2.
3. Settlements found are within permissible limits as per N.B.C.

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