Behaviour of Surface Strip Footing on Soft Soil Subjected to Eccentrical and Inclined Load

Debasish Kanhar

Department of Civil Engineering
National Institute of Technology Rourkela
Rourkela – 769 008, India

Behaviour of Surface Strip Footing on Soft Soil Subjected to Eccentrical and Inclined Load

A Thesis Submited in Partial Fulfillment of the Requirements for the Degree of

Master of Technology

in

Geotechnical Engineering

by

Debasish Kanhar

(Roll No. 215CE1014)

under the supervision of

Prof. Rabi Narayan Behera

Department of Civil Engineering

National Institute of Technology Rourkela

Rourkela – 769 008, India

May 2017

Dedicated to

My Mother

Department of Civil Engineering
National Institute of Technology Rourkela
Rourkela-769 008 , Odisha , India. www.nitrkl.ac.in

Prof. Rabi Narayan Behera
Assistant Professor

May , 2017

Certificate

This is to certify that the thesis entitled, BEHAVIOUR OF SURFACE STRIP FOOTING ON SOFT SOIL SUBJECTED TO ECCENTRICAL AND INCLINED LOAD submitted by Debasish Kanhar in partial fulfillment of the requirement for the award of Master of Technology degree in Civil Engineering with specialization in Geotechnical Engineering at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

Rabi Narayan Behera

Acknowledgement

First and foremost, praise and thanks goes to my God for the blessing that has bestowed upon me in all my endeavors.

I am thankful to my supervisor Prof. Rabi Narayan Behera, my advisor and guide, for his motivation, guidance, support and patience throughout the research work and above all for his belief in me. I appreciate his broad range of expertise and attention to detail, as well as the constant encouragement he has given me over the course work period. There is no need to mention that a big part of this thesis is the result of joint work with him, without which the completion of the work would have been impossible.

Besides my advisor, I would like to thank Prof. S. K. Sahu, Head of the Department of Civil Engineering for his valuable suggestions. I am very grateful to the friend Vikrant Patel,Soumendra Kodamasingh,(M.Tech students) and my classmates for clarifying many technical doubts and solving the difficulties using software.

Finally, I would like thank my parents from the bottom of my heart for their unconditional love, constant help, moral support and inspiration all throughout my life. Without their support, nothing would have been possible. I am greatly indebted to them.

Debasish Kanhar
Geotechnical Engineering
Roll No. 215CE1014

Abstract

The soil around foundation plays a very critical role during its performance. The strip foundation is one in which inclined or eccentric loads surrounds soil mass beneath footing. The strip form an enclosure in which soil is confined and works as a unit with the overlain foundation to transfer superstructure load to essentially at the level of strip resulting increase in the ultimate bearing capacity of the structure. This present works is an attempt to behavior of strip footing subjected to an eccentric and inclined load on soft soil. The failure mechanism of strip footing located above the soils is studied analytically. The present work focused on the analysis of strip footing subjected to inclined and eccentric load using finite element software PLAXIS 2D.

The various parameter considered for the study were inclined load, eccentric load, inclination angle,width of strip footing(B), depth of footing in terms of height(H), the ratio of eccentricity from applied to the width of footing(e/B), plasticity index of soft soil. Figures involving the load carrying capacity with affecting factors presented. The result indicates the strip foundation had significant effect in improving the ultimate bearing capacity with different plasticity index. The depth of footing does not show any improvement in ultimate bearing capacity.

Keywords**:** - inclined load, eccentric load, strip footing, PLAXIS 2D, bearing capacity, soft soil.

Table of Contents

List of Figures

List of Tables

Chapter 1

INTRODUCTION

1.1 Introduction

The lowest part of structure which transfer its load to the beneath is called foundation. The stability of a structure mostly depend on the performance of foundation. Depending on the depth of embedment, foundation can be classified as shallow or deep. The ultimate load, which can be sustained by the soil, is identified as bearing capacity. Bearing capacity and settlement are two parameter requirements for the design of shallow foundation.

It is essential for engineers to estimate the foundation bearing capacity subjected to vertical loading. However, for some structure such as abutment, retaining wall, portal framed building and water front structure, which are often subjected to eccentric load due to horizontal thrust and bending moment. Settlement of foundation under load due to the movement of soil particle horizontally and vertically below the footing. Tilt of the footing caused by eccentric loading which result to non-uniform stress distribution and unequal settlement below the footing. When centric vertical load subjected to the foundation, uniform stress distribution under the footing and settlement at both edges occurred. The tilt of footing direct proportional to the (e/B) ratio. Stress developed in different layers of soil due to some amount of strain, which causes settlement of the structure.

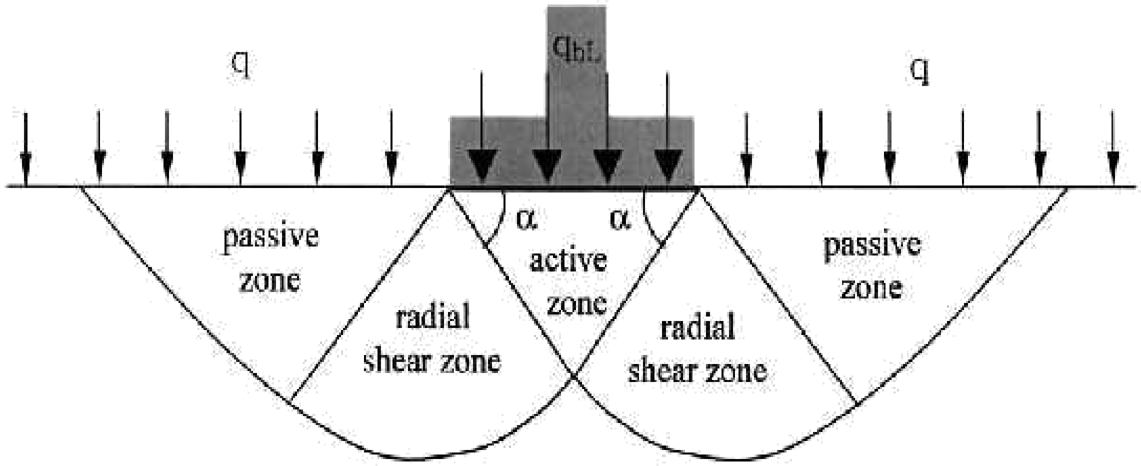

Figure 1.1: Typical Failure Mechanism of Axially Loaded Footing

Footing of the retaining Walls, abutment, industrial machines and portal framed building are not only subjected to vertical or inclined loads but also to moments. Moments on the foundation base mainly caused by horizontally forces acting on the structure. Horizontally forces are the resultant of earth pressure, wind pressure, seismic inclined load on the footing. The general objective of this research is to study the behavior of strip footing under the effect of eccentric inclined loads. The experimental work is directed to study the effect of variation of load eccentricity, load inclination angle, strip length and strip inclination angle. Numerical analysis was carried out using the finite element software PLAXIS 2D, version 8.2. The validity and efficiency of the numerical analysis is evaluated by comparing the load-settlement responses from the model footing test data result.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

The review of literature of literatures briefly represented below for eccentrically and inclined loaded foundation. An overview of numerical analysis is also discussed below.

2.2 Historical review

Meyerhof (1953) was proposed an effective width method for foundation subjected to an eccentric load. Due to an eccentric load on the foundation, the foundation tilts towards the side of the eccentricity and the contact pressure below the foundation does not remain uniform. Thus for a shallow horizontal strip foundation of width B and depth D carrying a vertical load Q with an eccentricity e on the base.

Prakash and Saran (1971) suggested a comprehensive mathematical formulation to estimate the ultimate bearing capacity of a rough strip footing under eccentric load. The failure surface as assumed in a $C-\phi$ soil under a continuous foundation subjected to a load with eccentricity.

Michalowski and You (1998) presented the bearing capacity of eccentrically loaded/footing using the kinematic approach of limit analysis. They found that the effective width method given by Meyerhof (1953) leads to the same bearing capacity as the limit analysis solution for a smooth footing and it underestimated the bearing capacity of footing on cohesive soils with frictional or adhesive soil-footing interfaces. The effective width rule significantly underestimated the bearing capacity for clays (ø=0) only when the footing is boned with the soil and the eccentric is relatively large (*e/B>0.25).*

Terzaghi (1943) theory was proposed first to determine the ultimate bearing capacity of shallow footing. The surcharge $q=\gamma D$ applied on soil above the bottom of foundation. The study of foundation as strip foundation with rough base. As per this theory shallow foundation having the depth less than or equal to width. The zone of failure below the foundation is divided in to 3 parts i.e. 1. Triangular zone 2. Radial shear zone 3. Rankine passive zone due to vertical load. He had provided expression for the different type of footing as below.

$$q_u = cN_c + qN_q + \frac{1}{2}\gamma B N_\gamma$$ For continuous and strip foundation

$$q_u = 1.3cN_c + qN_q + 0.4\gamma B N_\gamma$$ For square foundation

$$q_u = 1.3cN_c + qN_q + 0.3\gamma B N_\gamma$$ For Circular foundation

Where c= cohesion of soil

γ= unit weight of soil

q= Df, Nc, Nq and Nγ are baring capacity factor are given below

Meyerhof (1963) suggested a bearing capacity equation in generalized form for different shape of footing and also the study not considered the shearing resistance across the failure surface in soil above the bottom of foundation. Below equation given for ultimate bearing capacity.

$$q_u = cN_c F_{cs} F_{cd} F_{ci} + qN_q F_{qs} F_{qd} F_{qi} + \frac{1}{2}\gamma B N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i}$$

$F_{cs}, F_{qs}, F_{\gamma s}$ = Shape factor,

$F_{cd}, F_{qd}, F_{\gamma d}$ = Depth factor

$F_{ci}, F_{qi}, F_{\gamma i}$ == Inclination factor

Bearing capacity factors	**Equation**	**Investigator**
N_c	$N_c = (N_q - 1)\cot\phi$	Terzaghi (1943), Meyerhof (1963)
N_q	$N_q = \left[\dfrac{e^{2\left(\frac{3\pi}{4} - \frac{\phi'}{2}\right)\tan\phi'}}{2\cos^2\left(45 + \frac{\phi'}{2}\right)} \right]$	Terzaghi (1943)
N_q	$N_q = \tan^2\left(45 + \frac{\phi}{2}\right) e^{(\pi \tan\phi)}$	Meyerhof(1963), Hansen(1970), Vesic(1973), Is code(IS: 6403-1981)
N_q	$N_\gamma = 1.8(N_q - 1)\cot\phi(\tan\phi)^2$	Terzaghi (1943)
N_γ	$N_\gamma = 1.5(N_q - 1)\tan\phi$	Hansen(1970)

Meyerhof (1974) the study was based on the ultimate bearing capacity of circular and strip footing resting on sub-soils having two layers of different cases of dense sand on soft clay and loose sand on stiff clay. Bearing capacity ratio of clay to sand, frictional angle, shape and depth of foundation are the main factor which have an influence over sand layer thickness below the footing.

Purkayastha and char (1977) tests were conducted for analysis on stability of eccentricity loaded strip foundation on using the method of slices proposed by Janbu (1957).

Rahaman (1981) study was carried out for understanding the problem of the bearing capacity and settlement by using circular footing on sand bed. Shear strength, frictional angle, relative density of sand surcharge effect on bearing capacity and settlement are investigated. Maximum vertical strain occurs at 0.5 to 0.6 times the diameter of footing, depth increase with decrease in density of sand. Radial deformation increase from center of the footing to a maximum value at a distance of 0.75time diameter and then started decreasing.

Wang and Hsieh (1987) studied the failure load of strip foundation located on strip using finite element method. The foundation is treated as rigid frame, and supportive soil performs as a stiff plastic material. The study shows that when the voids is found at a depth of four times the foundation width, the presence of the voids shows substantially no influence on the performance of footing.

Terzaghi proposed the first relationship for effective stress. He expressed that the term 'effective' means the calculated stress that was effective in moving soil, causing displacement. It represented the average stress carried by the soil. The addition of a surface load will increase the total stress below may be considered constant with depth and equal to the magnitude of the surcharge.

Bransby and Randolph (1999) used the finite element method to study the effect of vertical load under strip and circular foundation. Results indicated that the use of loads the effect with circular footing gave better than obtained from strip footing.

Button (1953) analyzed the bearing capacity of strip footing resting on two layers of clay. He assumed that the cohesive soils in both layers are consolidated approximately to the same degree.In order to determine the ultimate bearing capacity of foundation, he assumed that the failure surface at the ultimate load is cylindrical, where the curves lies at the edges of the footing. The bearing capacity factor used on the upper soil layer and on the ratio of the cohesion of the lower/upper clay layers.

2.3 Scope of the Present study

Based on the existing literature review for the bearing capacity of shallow foundation, it shows that very few attentions have been paid to determine ultimate bearing capacity of eccentrically loaded strip footing. The studied are based on numerical analysis supported by few number of model tests. So, the objective of the present thesis to study the estimate bearing capacity when the foundation is subjected to eccentrically inclined load by varying eccentricity ratio (*e/B*). The assumption is analyzed analytically by using PLAXIS 8.2 finite element program.

Chapter 3

NUMERICAL METHODOLOGY

3.1 Introduction

So as to study the bearing capacity of eccentrically loaded strip footing on soft soil, the analytical program was designed. To fill this need, the analytical model tests were conducted on strip footing load eccentricity (*e*) is varied from 0 to 0.3 at an increment of *e/B= 0, 0.5, 0.1, 0.15,* and the inclination angle (α) varied from 0^0 to 2^0 at an increment of 5^0.

Dimensions of soil structure (width (B) =20m, depth=10m)

3.2. Soil

Analytical modeling of strip footing is done in PLAXIS 2D over soft soil for different loading conditions such as concentric, eccentric, inclined and eccentric inclined. Also different plasticity index are considered in present study.

3.2.1 Characteristics of Soft Soil

Low plasticity: - plasticity index (5-10)

e/B= 0, 0.5, 0.1, 0.15

$\alpha = 0^0, 5^0, 10^0, 15^0, 20^0$

Medium plasticity: - plasticity index (10-20)

e/B= 0, 0.5, 0.1, 0.15

$\alpha = 0^0, 5^0, 10^0, 15^0, 20^0$

High plasticity: - plasticity index (20-40)

e/B= 0, 0.5, 0.1, 0.15

$\alpha = 0^0, 5^0, 10^0, 15^0, 20^0$

3.3 Ultimate Bearing Capacity of Strip Footing

3.3.1 Eccentrically inclined loaded when the line of load application is towards the center line of the footing

Eccentrically inclined load can be applied on the foundation in two ways. It can be referred to as *partially compensated* (Perloff and Baron, 1976) when the line of load application on the foundation is inclined towards the center line of the foundation [Figure 3.1]. In order to investigate the effect of load eccentricity and inclination.

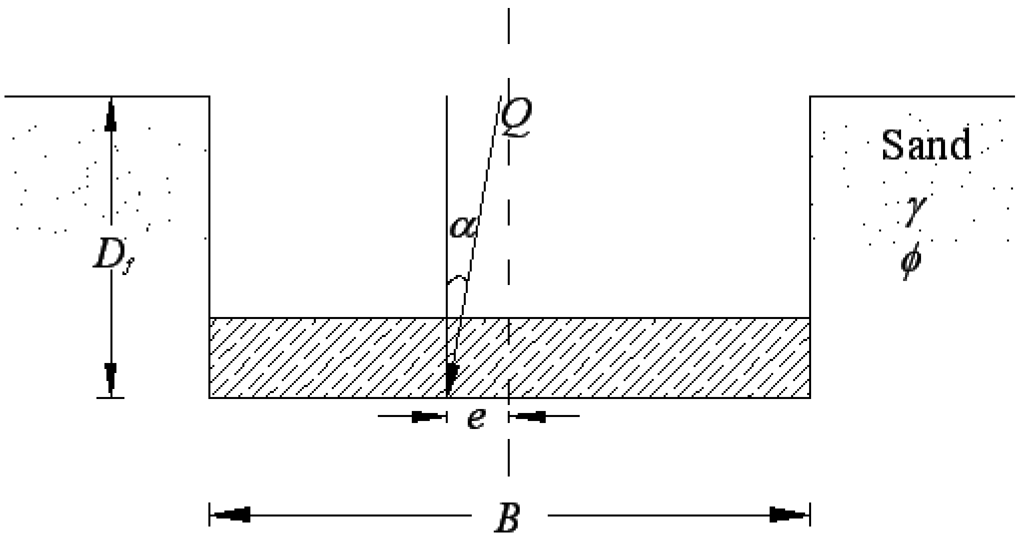

Figure 3.1: Eccentrically inclined load on strip foundation: line of load application towards the center line of the footing

3.3.2 Eccentrically Inclined Loaded When the Line of Load Application Is Away From the Center Line of The Footing

Shallow strip foundations are at times subjected to eccentrically inclined loads. Shows two possible modes of load application. In this figure *B* is the width of the foundation, *e* is the load eccentricity, α is the load inclination, and *Qu* is the ultimate load per unit length of the foundation. In Figure 3.2(a) the line of load application of the foundation is inclined towards the center line of the foundation and is referred to as partially compensate by Perloff and Baron (1976). It is also possible for the line of load application on the foundation to be inclined away from the center line of the foundation as shown in Figure 3.2(b). Perloff and Baron (1976) called this type of loading as *reinforced* case. The results of practically all studies relating to the bearing capacity of a shallow foundation subjected to eccentrically inclined load presently available in the literature, though fairly limited, consider the so-called *partially compensated* case. This chapter deals with the study for the *reinforced* type of loading

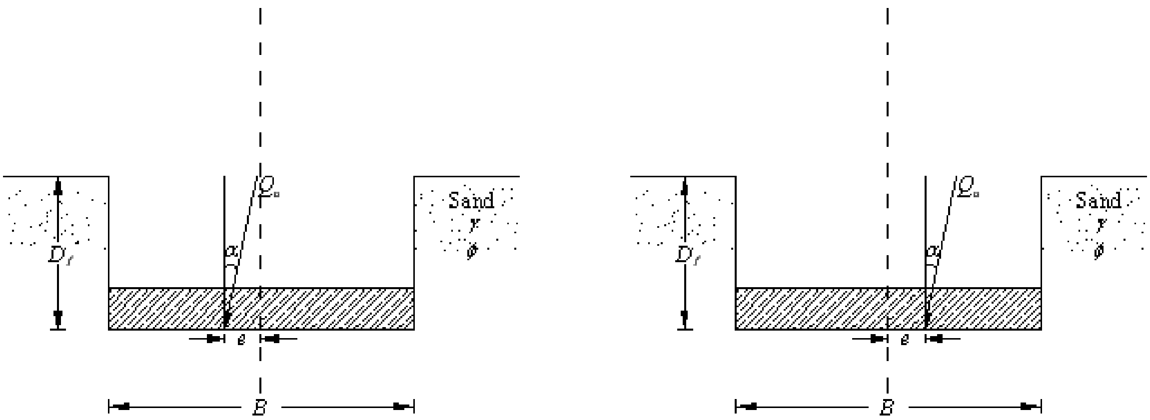

Figure 3.2: Eccentrically inclined load on a strip foundation: (a) *partially compensated* Case, (b) *Reinforced* case

Chapter 4

NUMERICAL ANALYSIS

4.1 Introduction

PLAXIS is a FEM package used for analysis of stability and deformation of structure. It is developed at the Technical University of Delft. At the initial stage, this was used to analysis the soft soil river embankments of the lowlands of Holland. But later a company named PLAXIS BV was formed, and expansion of the program was done to address a wide range of geotechnical issues, it requires advanced and anisotropic behavior of soils and rock for analysis purpose. As soil being a material with multiple phases, some additional methods are adopted to take care of hydrostatics and non-hydrostatics pore pressure within the soil. Here, the modeling of the soil is an important aspect. But many projects require the modeling of structure and the interaction between soil and structure. PLAXIS is a software package well equipped with advanced features to deal with complex problem involved in geotechnical engineering. There are two different type of approach: experimentally, by conducting model and full-scale test; or, analytically, by using methods such as finite element methods. It is used in foundation engineering. Full scale tests are the ideal methods for obtaining data; however, practical difficulties and economic consideration either eliminate or considerably restrict the possibility of full-scale testing. As an alternative model tests may be employed, but they have disadvantages. Boundary condition, the size of the footing, the sample disturbance, the test setup procedure of the testing book usually affected the model tests results. Due to the fortunate development in numerical methods and computer programming, it is advantageous to use these techniques to simulate the condition of model tests to verify the theoretical models. The theoretical study can be extended to cover a wide range of field cases which engineers omitted using full-scale testing.

In the present study, the program “PLAXIS 2D” used for Numerical analysis. It is a finite element based software. The stresses, strain and failure aspects of a given problem can be evaluated by using software.

4.2 METHODOLOGY

The finite elements program PLAXIS 2D, is used to model the tests of strip footing of soft soil. PLAXIS is intended for the analysis of deformation and stability in geotechnical engineering projects. All the finite element calculation was based on the mesh generation process. The boundary conditions were chosen such that the vertical boundary was constrained horizontally and vertically boundary to the base of the models. The parameter used in the analysis are tabulated in Table 4.1.

Table 4.1: - Parameter used in numerical modeling analysis

Sr. No	parameter	Detail of parameter
1	Type of soil	Soft soil
2	Type of footing	Strip footing
3	Type of load	Eccentric / inclined
4	width of footing	2m
5	Depth of strip footing	1m

4.2.1 Procedure

First a geometric model of dimension 20m x10m is created. The footing size (2m width and thickness is 0.025) is placed on the top of the soil model according to the eccentricity. By the box of geometric a fine mesh is to be generated. At the top of the footing a vertical load is applied according to the different loading condition and eccentricity. Then analyzed the loading point of the soil. Calculation process are done until the failure of the soft soil. Load – displacement curve obtained from the calculation. By using different eccentrically and inclined load result gave the ultimate bearing capacity of the strip footing. Different steps shows the general procedure of analysis.

- Creating the geometry
- Giving soil and Material properties
- Generation of mesh
- Selecting the applied load point
- Calculation phase
- Output

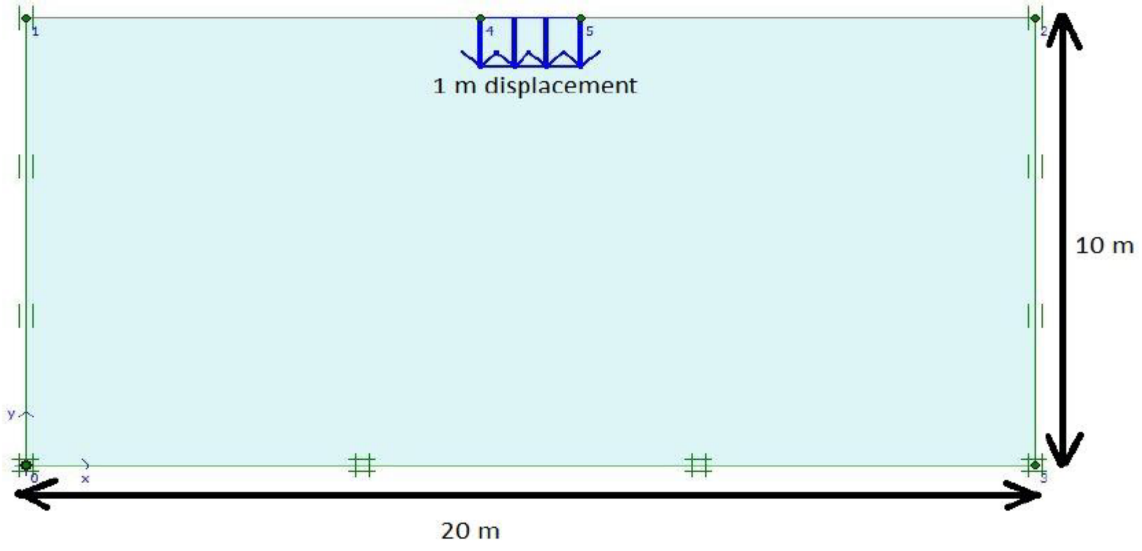

Figure 4.1: geometry model of strip footing for analysis at (*e/B=0*)

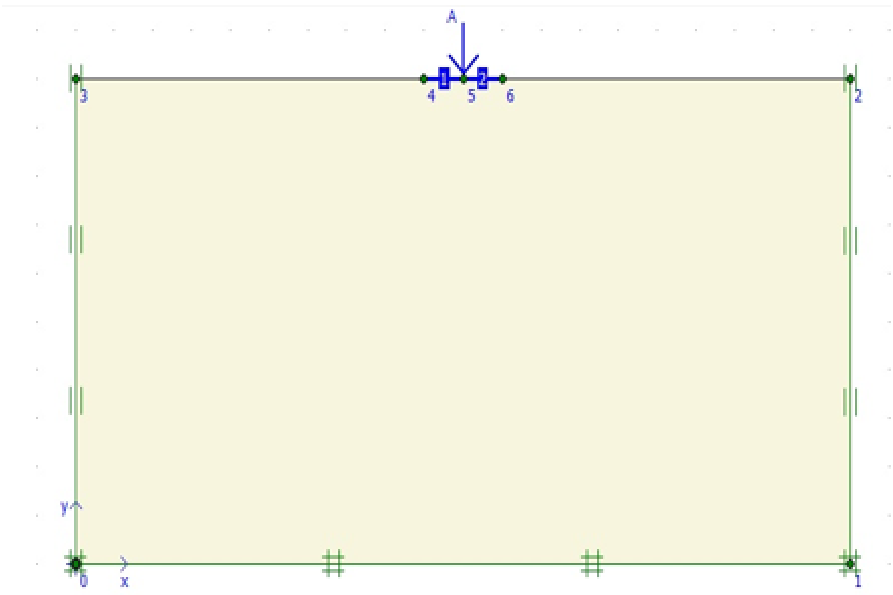

Figure 4.2: geometry model of eccentric loaded strip footing at (*e/B*= 0, angle =0^0)

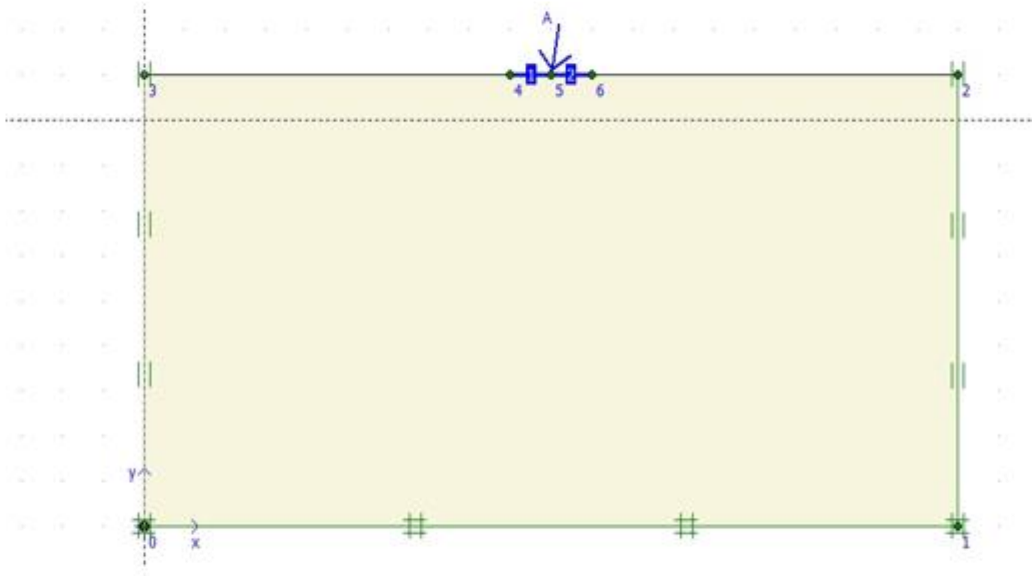

Figure 4.3: geometry model of inclined loaded strip footing at (*e/B*= 0.05, angle =5^0)

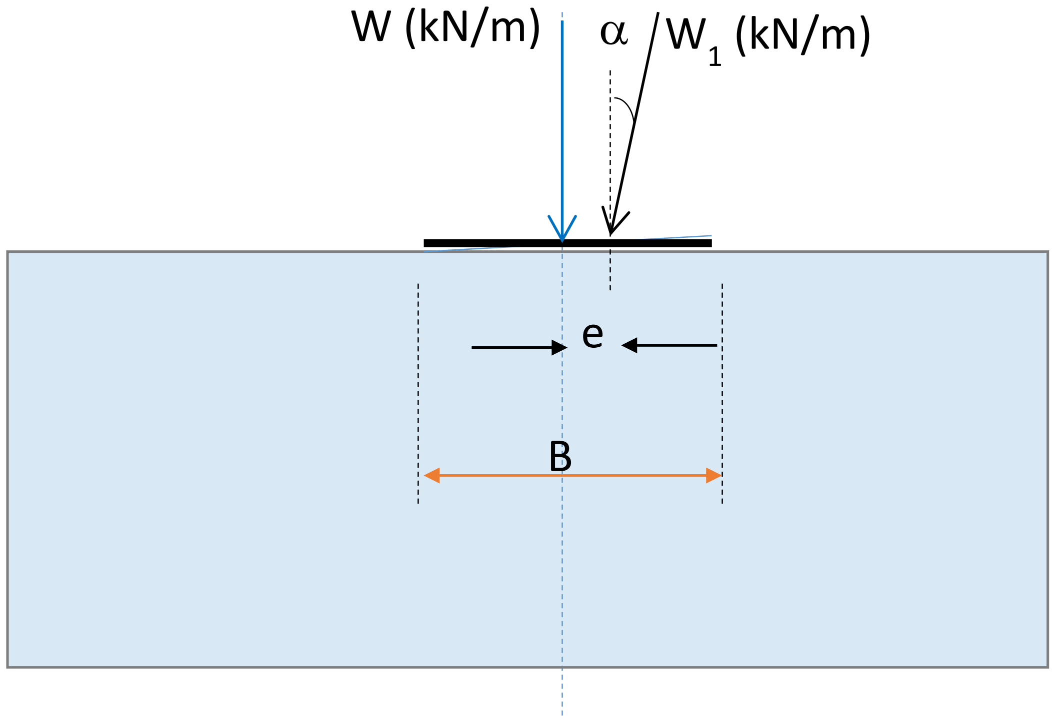

Figure 4.4: Magnified view of geometry model of inclined loaded strip footing at (*e/B*= 0.05, α =5^0)

4.2.2 Soil and material properties

While analyzing slope in PLAXIS 2D, the material properties of soil and footing were required. The soil was considering load as while strip footing of concrete was analyzing. The properties of soil used in analysis are given below in the Table 4.2.

Table 4.2: material properties of strip footing

Sr. NO	parameter	value
1	Type of material	Elasto-plastic
2	Normal stiffness EA (kN/m)	12×10^6
3	Flexural rigidity EI (kN/m2/m)	120000.32
4	Poisson’s ratio	0.15

Table 4.3: material properties of soil

Sr. NO	Parameter	value
1	Type of material	soil
2	Material model	Mohr-coulomb
3	Young's Modulus of soil	5000
4	Poisson's ratio	0.30
5	Frictional angle(□)	15
6	Cohesion(kN/m)	35

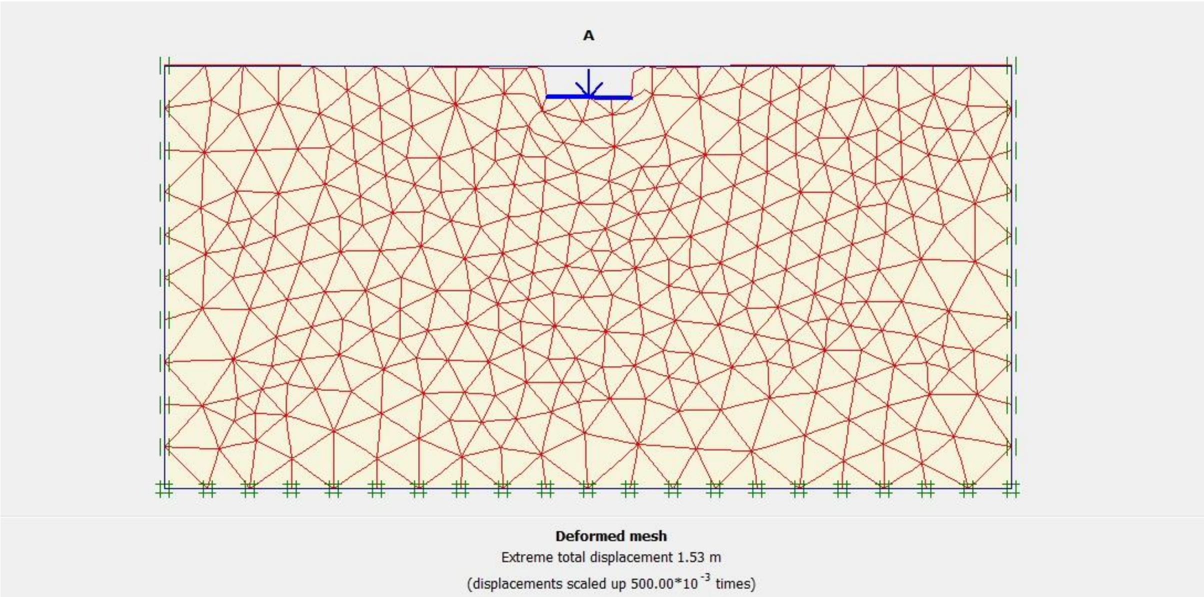

Figure 4.5: deformed mesh at eccentricity (*e/B*=0)

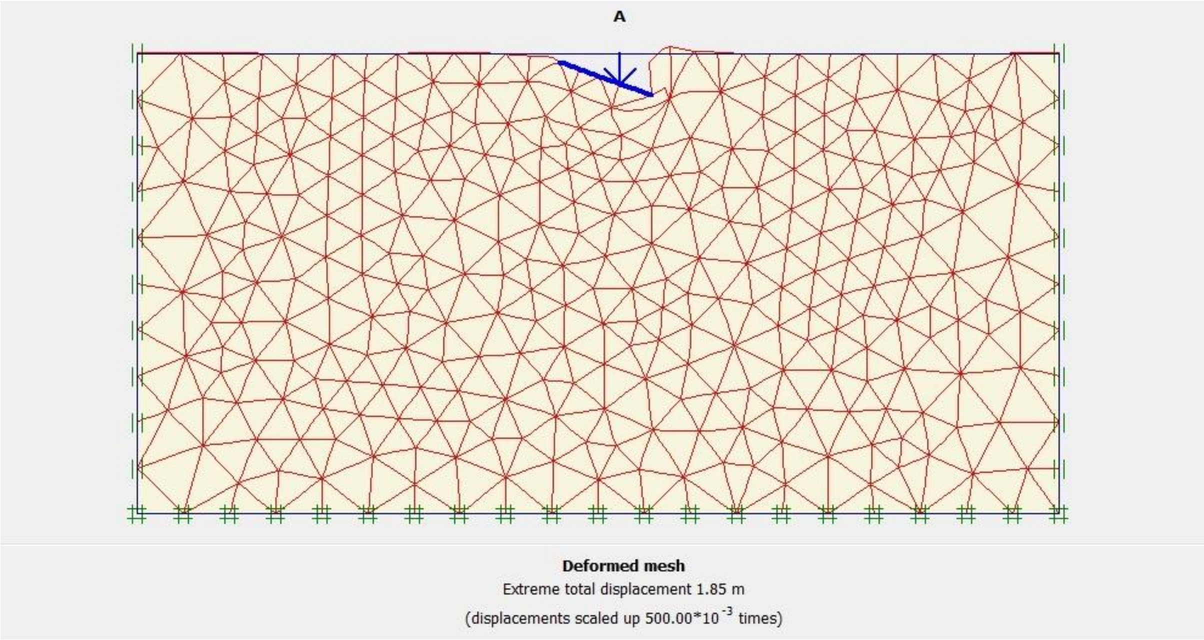

Figure 4.6: Deformed mesh at inclined (*e/B*=0)

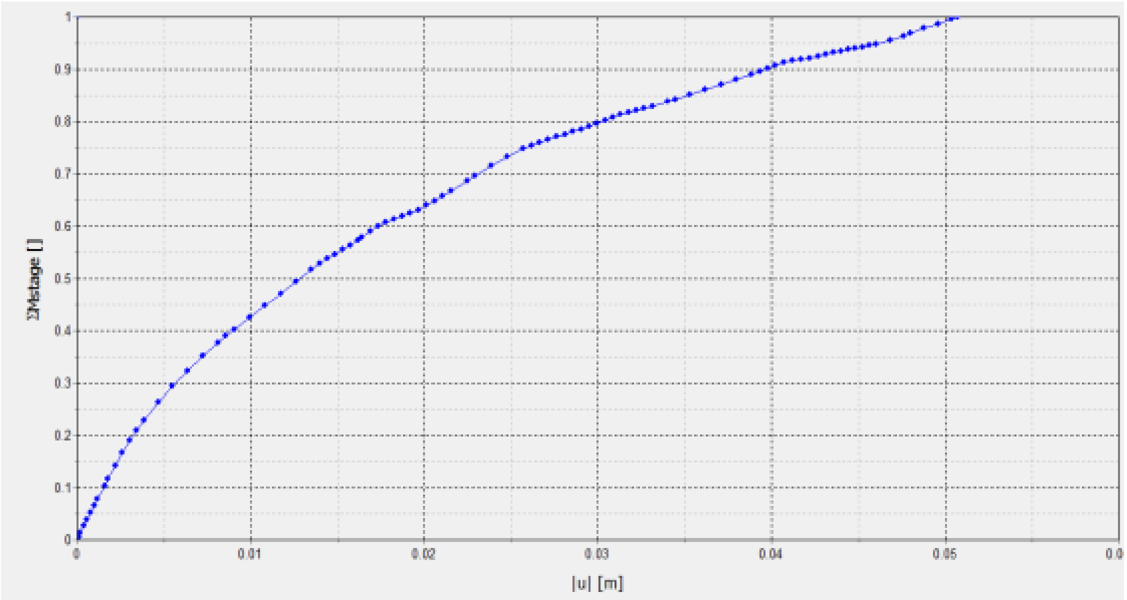

Figure 4.7: load – displacement curve

Chapter 5

Results and Discussion

5.1 Result analysis

Numerical analysis have been done over soft soil with strip foundation by using PLAXIS 2D. Analysis been done for surface case width 2m along with eccentricloads (*e/B*=0, 0.05, 0.1, 0.15). The load – displacement curve for surfaceat different eccentric ratio shown below.

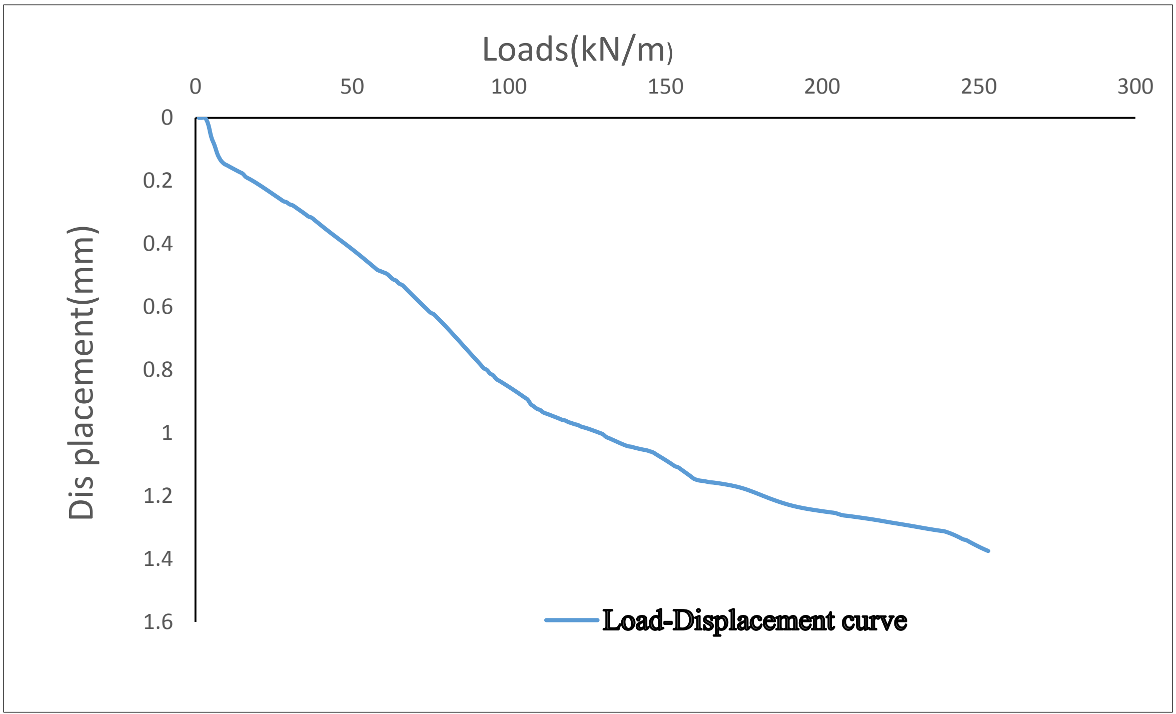

Figure 5.1: Load Deformation for Low plasticity (e/*B*=0, α=0)

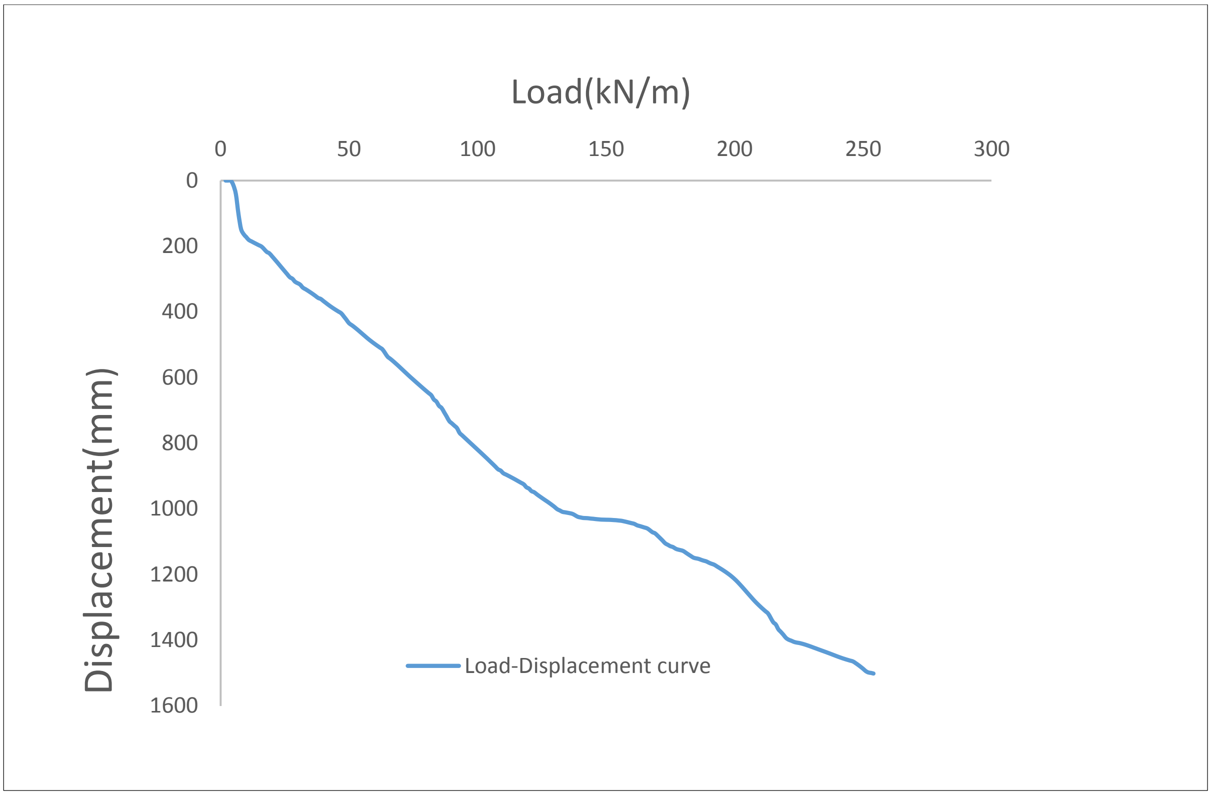

Figure 5.2: Load Deformation for Medium plasticity (e/*B*=0, α=0)

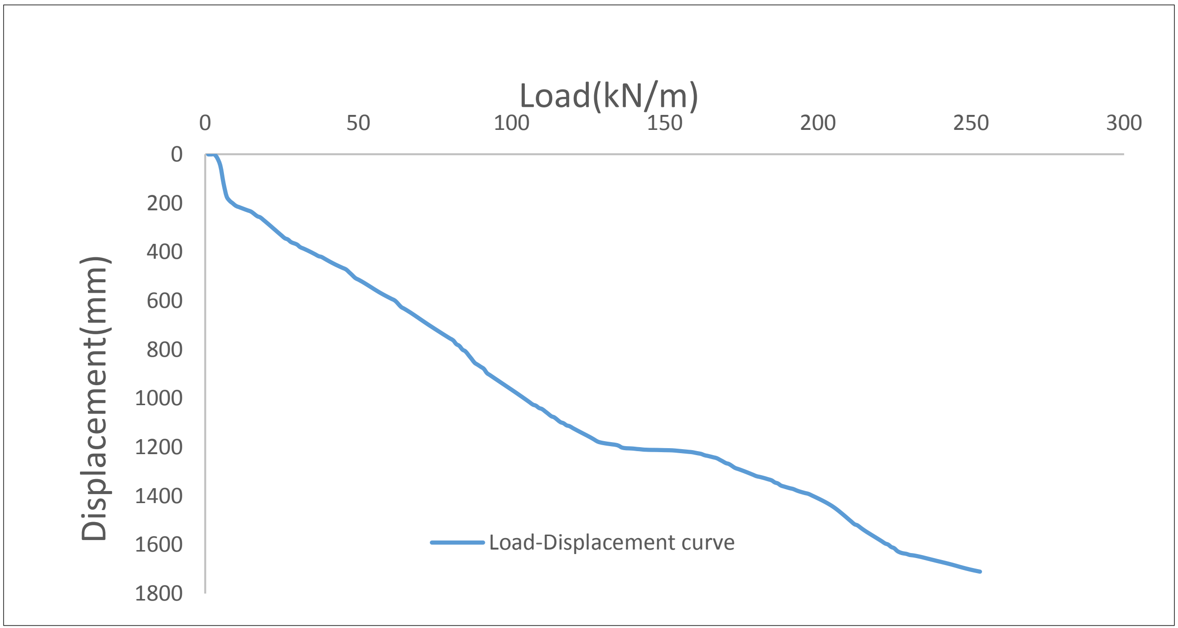

Figure 5.3: Load Deformation for High plasticity (e/*B*=0, α=0)

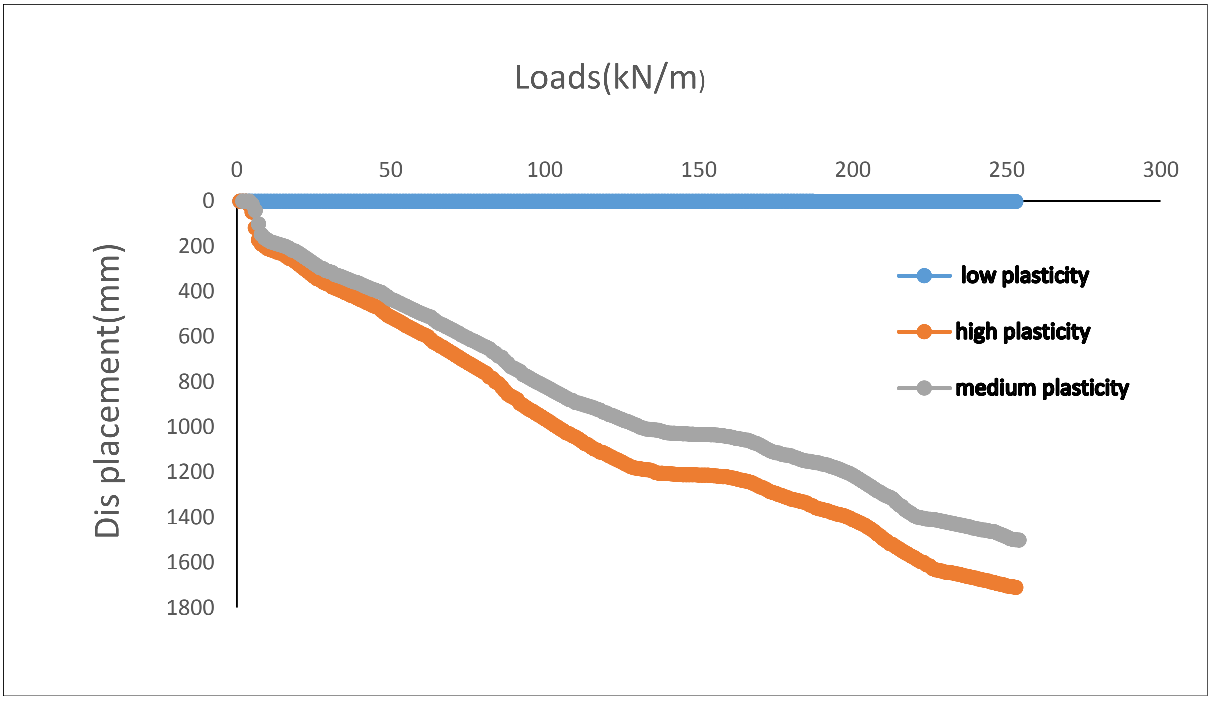

Figure 5.4: Variation in Load - Displacement curve of surface footing (e/B=0, α=0)

5.2 Comparative Study

Some experimental results for strip footing were chosen for comparison with the results of the PLAXIS 2D. The results gave the ultimate bearing capacity of the soft soil. The ultimate bearing capacity differences increases with the change of both eccentrically and inclined load. Figs. 5.5 to 5.12 shows the load displacement curve for numerical analysis by using strip footing. The ultimate bearing capacity obtained different due to soil parameter like elasticity modulus, young's modulus, inclination angle. There is good compatibility of observation among low plasticity, medium plasticity and high plasticity in numerical analysis.

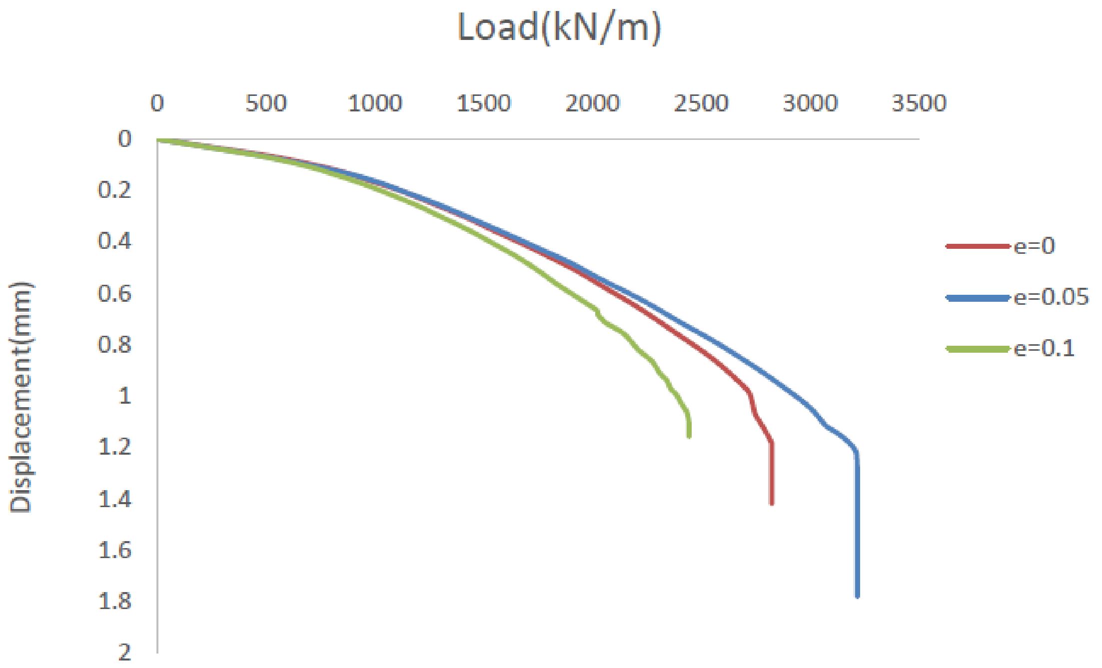

Figure 5.5: Load Displacement curve for Low plasticity (α =0)

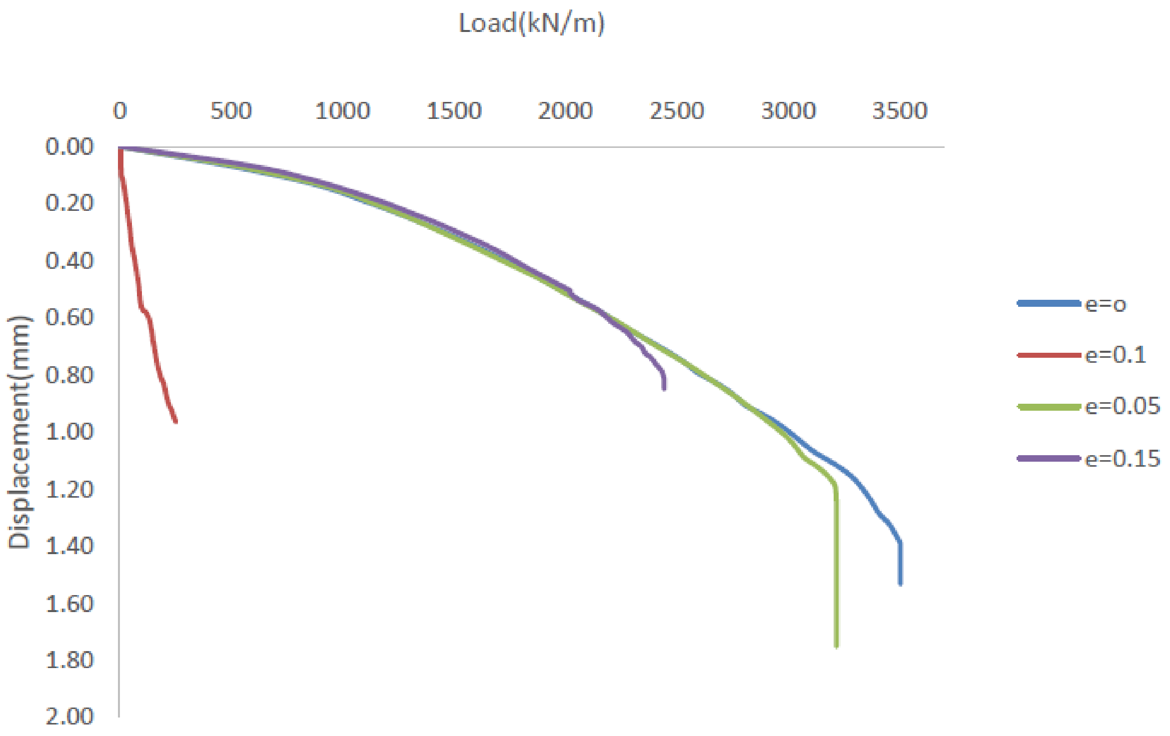

Figure 5.6: Load Displacement curve for Low plasticity (α =10)

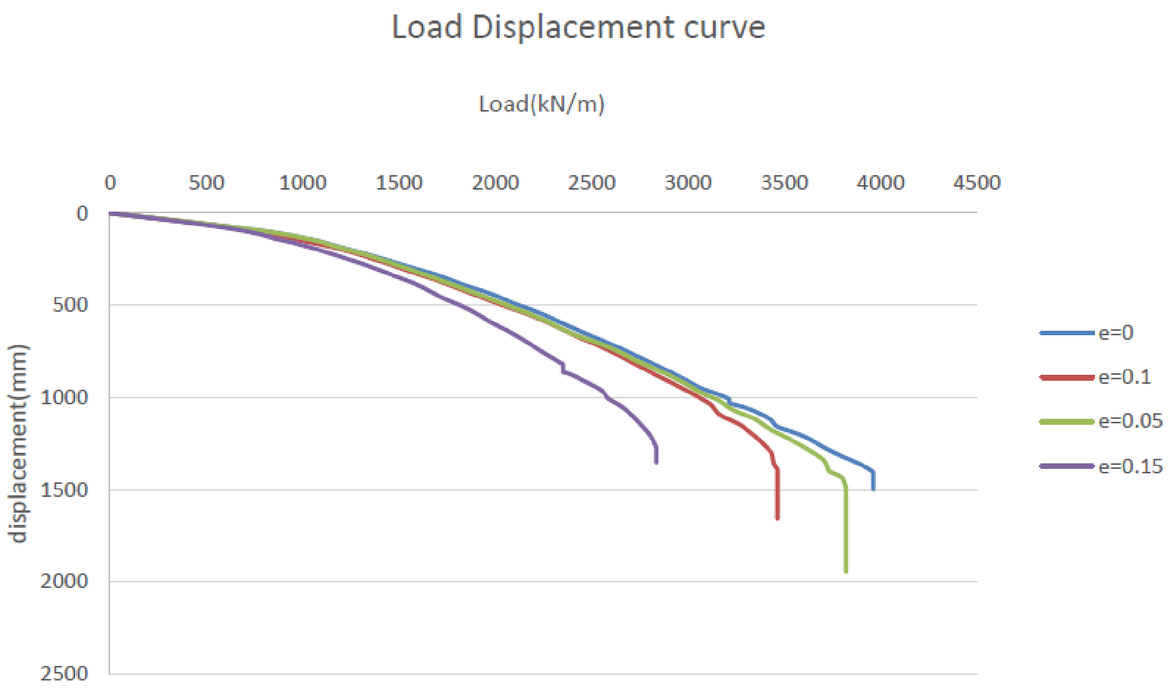

Figure 5.7: Load Displacement curve for Medium plasticity (α =0)

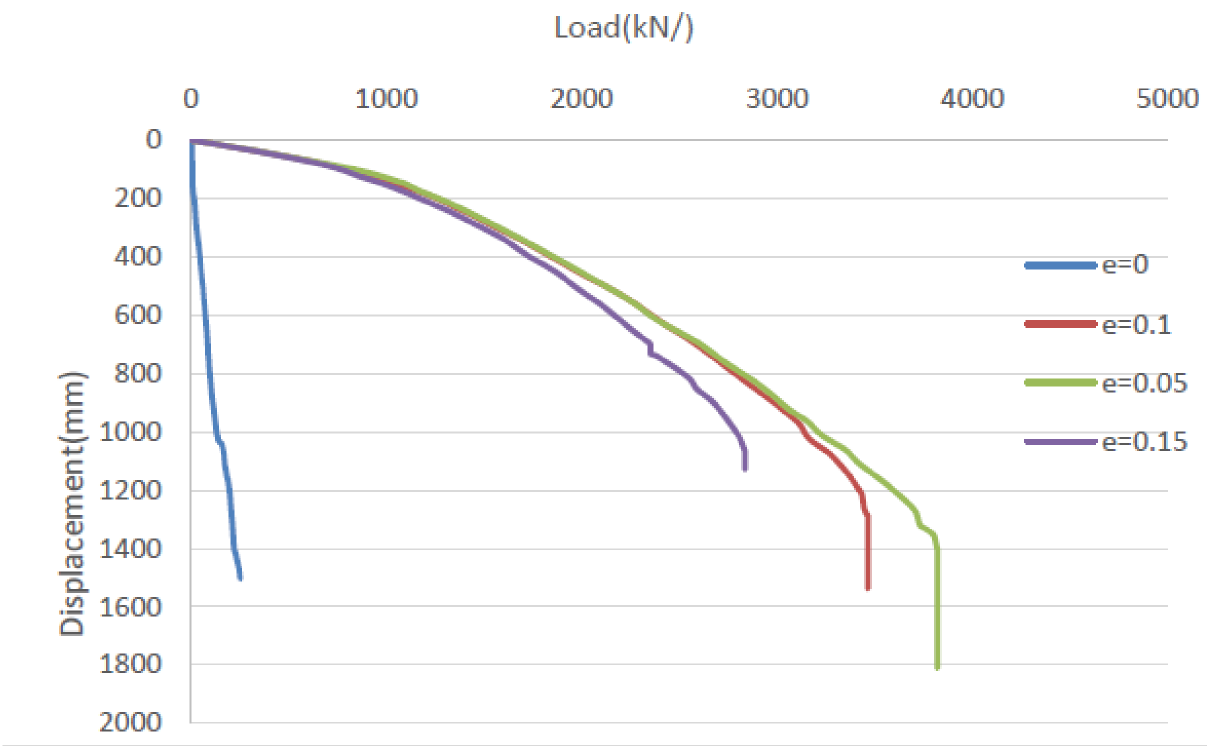

Figure 5.8: Load Displacement curve for Medium plasticity (α =10)

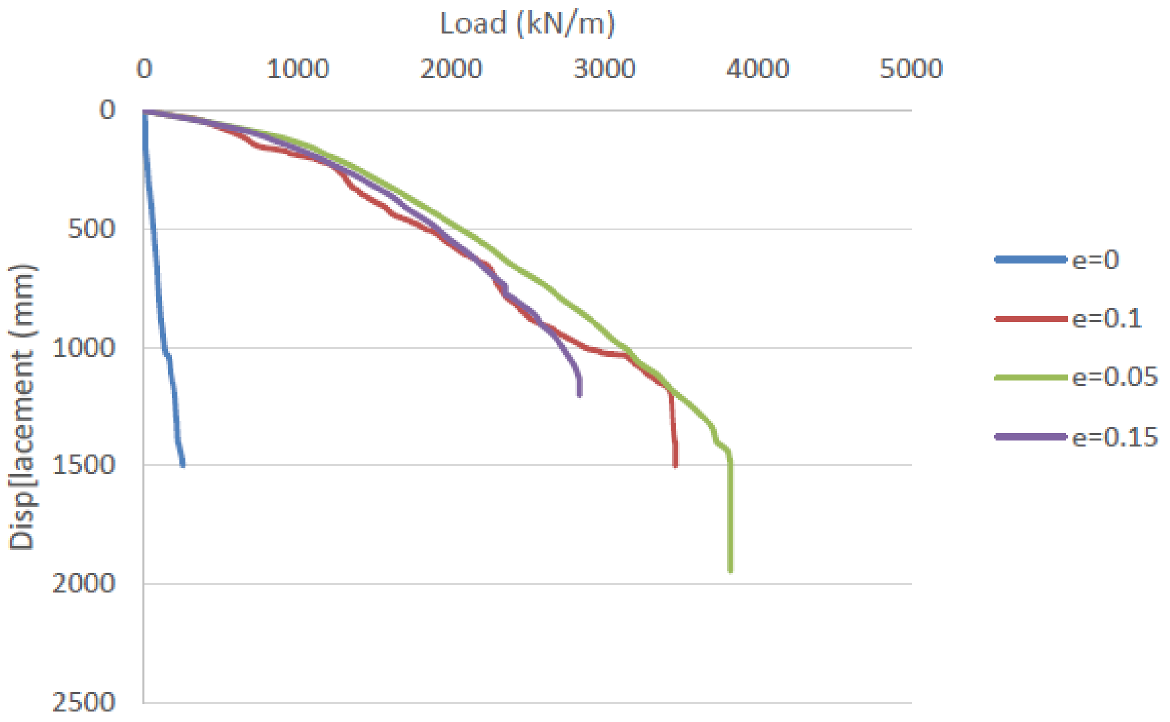

Figure 5.9: Load Displacement curve for Medium plasticity (α =15)

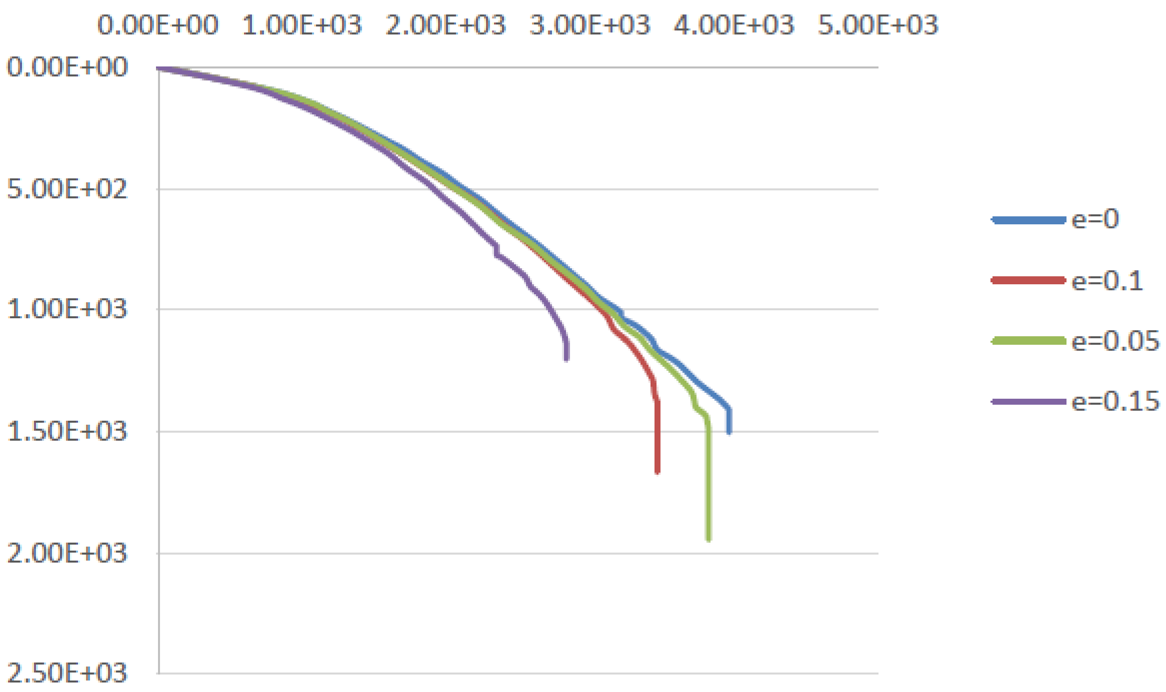

Figure 5.10: Load Displacement curve for Medium plasticity (α =20)

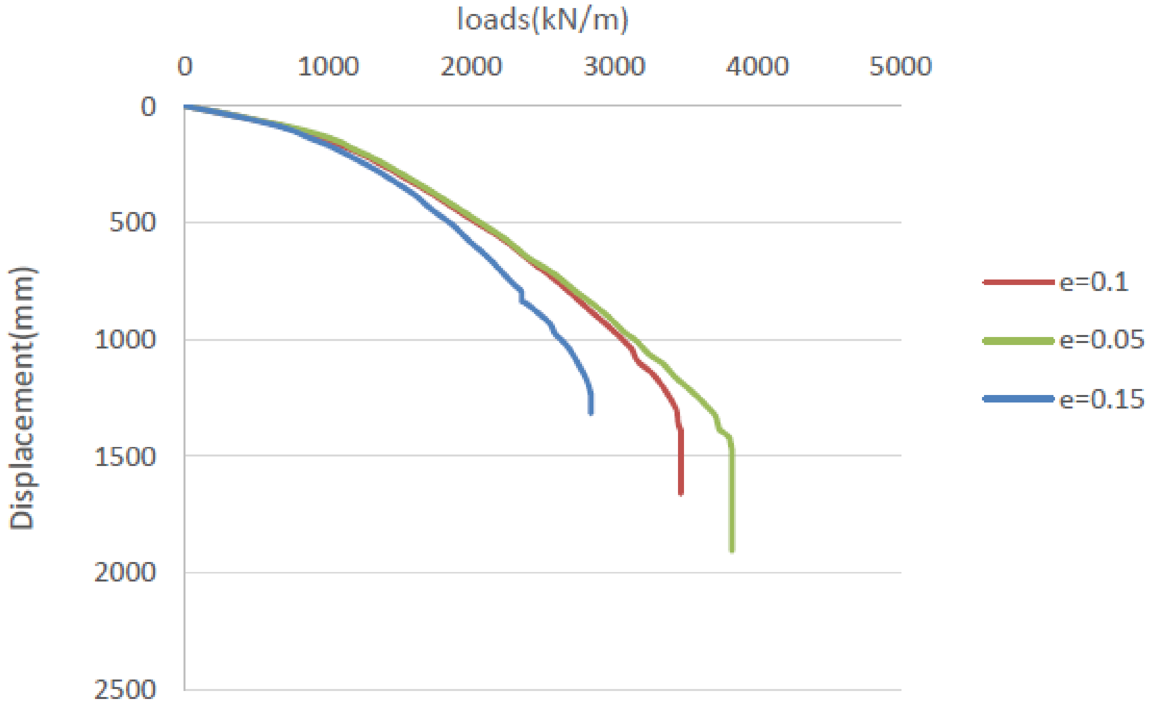

Figure 5.11: Load Displacement curve for High plasticity (α = 0)

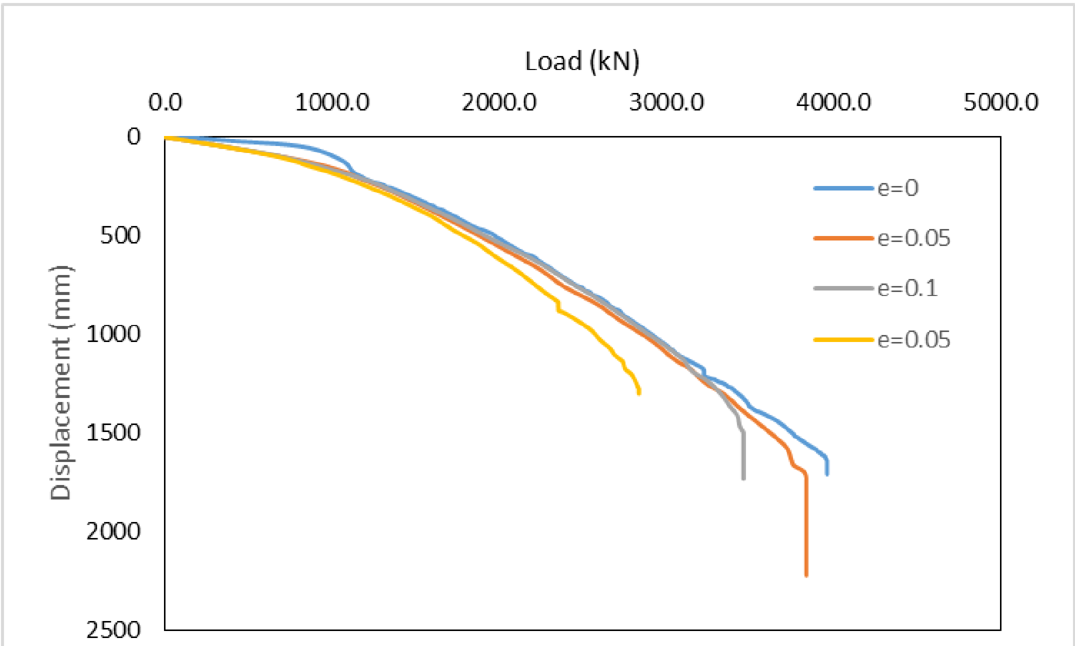

Figure 5.12: Load Displacement curve for High plasticity (α =20)

Chapter 6

CONCLUSION AND SCOPE OF FUTURE WORK

6.1 Conclusion

Based on the limited number of present model test result on the ultimate bearing capacity of an eccentricity loaded strip footing supported by soft soil, the following conclusion can be drawn

1. Increase the inclination angle decrease the ultimate bearing capacity and increase the corresponding displacement. Due to eccentric load on strip footing ultimate bearing capacity is reduced.

2. The finite element software PLAXIS 2D, Version 8.2, gives a good insight and helps in understanding the behavior of soil supporting a strip footing under inclined and eccentric loading condition.

3. The FEM is capable of predicting the load-displacement to a good level of accuracy except at load eccentricity and high load inclination angle.

6.2 Future Scope

The present thesis is relevant to the surface strip footing on soft soil subjected to eccentric and inclined load. The future research work should address the below mentioned points:

1. Present work can be extended to study the behaviour of strip footing of different sizes (Width=B) on soft soil at different e/B ratio.

2. The present study work can be extended to reinforced soil condition for different depth of embedment.

References

Basudhar,P.K.,Saha,Santanu.,Deb,Kousik (2007) “Circular footings resting on geotextile-reinforced sand bed” Department of Civil Engineering, IIT Kanpur Geotextiles and Geomembranes 25, pp.377–384.

Louis’s D, Chakraborty T, Salgado R (2008) Bearing capacity of strip footings on purely frictional soil under eccentric and inclined loads. Can Geotech J 45:768–787.

Meyerhof G.G. (1953) “The Bearing Capacity of Foundations under Eccentric and Inclined Loads” In Proc. 3rd Int. Conf. Soil Mech. Zurich, vol. 1, pp. 440-45.

Meyerhof, G.G. (1953). “The bearing capacity of foundations under eccentric and inclined loads.” *Proc., 3rd Int. Conf. on Soil Mech. and Found. Eng.*, 1, 440-445.

Michalowski, R.L., and You, L. (1998). “Effective width rule in calculations of bearing Capacity of shallow footings.” *Comp. and Geotech,* 23, 237-253.

Patra, C.R., Behera, R.N., Sivakugan, N., Das, B.M. (2012) “Ultimate bearing capacity of shallow Strip foundation under eccentrically inclined load”: part I, International Journal of Geotechnical Engineering 6, no.3: pp. 343-352.

Prakash, S. and Saran, S. (1971) “Bearing capacity of eccentrically loaded footings”, *Journal Soil Mech. and Found Div*., ASCE, 97: pp. 95–118.

Purkayastha, R.D., and Char, R.A.N. (1977) “Sensitivity analysis for eccentrically loaded Footings.” *J.Geotech.Eng. Div*., ASCE, 103(6), 647.

Rahman, M.G., (1981) “Bearing capacity and settlement of circular footing on sand “Department of civil Engineering Ottawa university Canada, pp.1-173.

Vesic, A.S., (1975) “Bearing capacity of Shallow foundations. In Geotechnical Engineering Handbook” Edited by Braja M. Das, Chapter 3, Journal Ross Publishing, Inc., U.S.A.