NUMERICAL ANALYSIS OF CENTRALLY AND ECCENTRICALLY LOADED SQUARE FOOTING ON GEOGRID-REINFORCED SOIL

MAJOR II PROJECT REPORT

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IN

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CANDIDATE'S DECLARATION

I, Bhaskar Ranjan, Roll No. 2K18/GTE/06 student of M. Tech (Geotechnical Engineering), hereby declare that the Project Dissertation titled "Numerical Analysis Of Centrally And Eccentrically Loaded Square Footing On Geogrid-Reinforced Soil" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title of recognition.

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Date: August 31st, 2020

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CERTIFICATE

I hereby certify that the Project Dissertation titled "Numerical Analysis of Centrally and Eccentrically Loaded Square Footing On Geogrid-Reinforced Soil" which is submitted by BHASKAR RANJAN, 2K18/GTE/06, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi

Date: August 31st, 2020

Dr. ASHOK KUMAR GUPTA

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ABSTRACT

Since Terzaghi gives his hypothesis "Theoretical soil Mechanics (1943)", various researches have been published their works on the ultimate bearing capacity of the foundation. Most of these works are related to vertical centric loading. A few works have also done on eccentric loading. After going through a lot of existing literature, evidence suggested that reinforcement could be an effective method to increase the bearing capacity of foundation in eccentric and centric loading. But a detailed study for eccentric loading for square footing is not done. The purpose of this work is to find the optimum value of depth ratio (u/B), (h/B), width ratio (b/B), the number of geogrid layers (N), and also the effect of eccentricity on bearing capacity of the foundation. To achieve this numerical simulation of square footing (B=3m, D=0.5m) embedded in a reinforced sand bed is carried out using OPTUM G2 software. Mohr-Coulomb material model is used in the simulation. The impact of placement depth of geogrid layer, number of the geogrids, and width of geogrid layer on bearing capacity of footing for the various eccentric load (e/B = 0, 0.05, 0.1, 0.15) are examined. The Test result shows that the optimum value of u/B varies between 0.3–0.4, the optimum value of h/B varies between 0.3-0.4, the optimum value of b/B = 7, and the optimum value of N=3 for square footing.

Keywords: Geogrids, Square footing, Numerical simulation, Eccentric load.

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LIST OF SYMBOLS

B	Width of the footing
D	Depth of the footing
Φ	Angle of friction
c	Cohesion
Q_u	Ultimate load at failure
q_{nu}	Net ultimate bearing capacity
q_u	Ultimate bearing capacity
N_c, N_q, N_γ,	Bearing capacity factor
s_c, s_q, s_γ	Shape factor
d_c, d_q, d_γ	Depth factor
i_c, i_q, i_γ	Inclination factor
γ_b	Bulk unit weight
γ_d	Dry unit weight
γ_s	Saturated unit weight
u	Depth of first the layer of geogrid from the bottom of the footing.
h	Gap between each consecutive geogrid layer.
b	Width of geogrid.
N	Number of geogrids
BCR	Bearing Capacity ratio
e/B	Ratio of eccentricity by the width of the footing
u/B	Depth ratio for first reinforcement layer
h/B	Depth ratio for the second reinforcement layer
b/B	Width ratio

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Foundation is the part of the structure which is constructed first and is in direct contact with soil mass. Most of the time it is constructed below the ground surface. That's why the foundation is also called as a substructure. The load of the superstructure is transferred to the soil directly through the foundation only. So, the foundation should be designed in such a way that it could transfer the desired load without failure. The failure term for the foundation is described by two different criteria. One is shear failure and other one is settlement failure. The footing is generally exposed to a different set of loads such as vertical, horizontal, bending, and sometime torsion also. But it has been seen that most of the theory available is for the centric vertical load. However, there are some cases due to bending moment and horizontal thrust (earthquake) structure like portal framed structure, heavy industrial machines, waterfront structures, abutments, and retaining walls are subjected to eccentric load. Even in residential buildings due to footing located at properties line, columns have to locate at an eccentric location which could lead to the eccentric loaded footing. Whenever an eccentric load is applied on footing it could be analyzed by dividing it into two different loads, one is the vertical load at the center and the second is the moment which is produced by eccentricity.

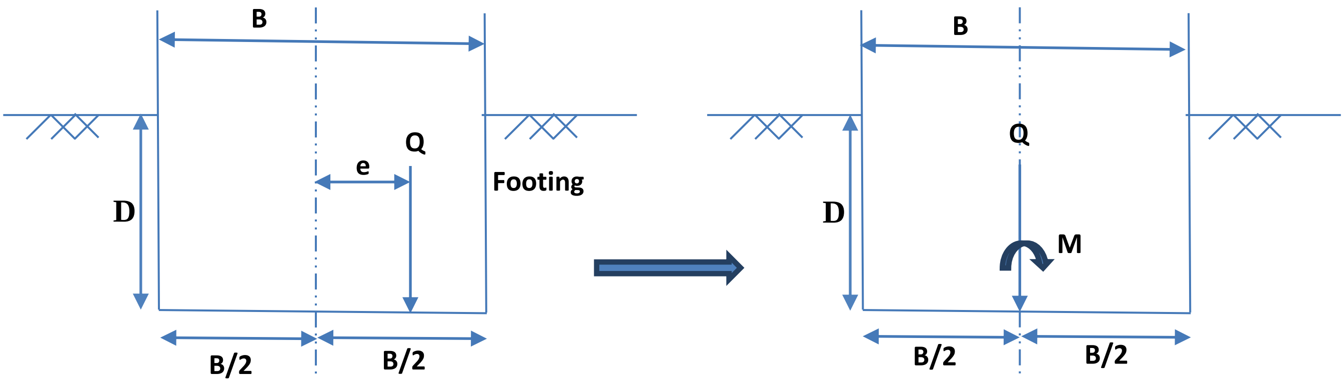

Figure 1.1 Definition of eccentricity in footing

In the case of centrically vertical load, the stress distribution below footing is uniform and both edges experience equal settlement, but in case of eccentric load stress distribution below footing is non-uniform which would lead to uneven settlement and tilting of footing. The tilting will increase with an increase in eccentricity. So, the bearing capacity will reduce drastically with an increase in eccentricity.

In the last two decades, the use of geosynthetics has been increased rapidly. A lot of research has been done on geosynthetics to solve various engineering problems, especially in geotechnical engineering. There is a variety of geosynthetics material available in the market, based on their shapes and use. One of them is geogrid, which I am using for this project. Geogrid acts as reinforcement in the soil mass. Geogrid provides high tensile strength at very low strain uniform along with all directions. We all know that the soil is weak in tension and strong in compression, and by using geogrid we try to improve the tensile strength of the soil. And geoogrid also helps in the distribution of load to a larger area. Now a day's numerical analysis is widely used for determining the feasibility of the new idea. There is a lot of software available for doing numerical analysis. The Numerical analysis gives a relative accurate results within less time frame. The main advantage of using numerical analysis is that we can perform a full-scale model test which gives us a relative accurate result than a small scale prototype. The numerical analysis is based on the fundamental equation of engineering. In numerical analysis the whole domain is subdivided into smaller units called element and then a fundamental equation is applied for the determination of results. The smaller the element size, the lesser error will reflect in results.

1.2 THE OBJECTIVES OF THE STUDY

(a) To perform numerical analysis of square shaped footing for various set of loads.

(b) Determination optimum value of:

- (i) Depth of first geogrid layer from the base of the footing
- (ii) The Gap between each consecutive layer from the second layer
- (iii) Number of the reinforcement layer
- (iv) Width of the reinforcement layer

(c) To determine the Impact on bearing capacity of the soil due to eccentric load.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

After going through a lot of research papers, I have found that in previous decades there is lots of research has been done on bearing capacity of foundation in reinforced and unreinforced conditions. Even researches have worked on different types of loading, shapes of footing, soil types, layered soil strata, and many more. Those researchers used various approaches to analyze the problem like theories based analytical approach or finite element numerical approach or prototype laboratory models. The Researcher has tried to enhance the load carrying capacity of the foundation by using a different type of Geosynthetics material. In this chapter, a brief review of that literature is presented.

2.2 LITERATURE REVIEW

Karl Terzaghi (1943) publish a book" Theoretical soil Mechanics" in which he describes how the soil below foundation fails. He also derives the equation to calculate the ultimate bearing capacity of the shallow foundation. The foundation whose depth is less than or equal to the width of the foundation is called shallow foundation. Firstly, he gave an equation for continuous strip footing and later on modified the equation for different shapes of footing. He describes the failure zone under footing as three distinguish part i.e. first is triangle shape wedge which is form just below the footing and two radial shear zone along both sides of the triangle.

$$q_u = cN_c + qN_q + 1/2B\gamma N_\gamma \quad \text{(strip foundation)} \quad (2.1)$$

$$q_u = 1.3cN_c + qN_q + 0.4B\gamma N_\gamma \quad \text{(square foundation)} \quad (2.2)$$

$$q_u = 1.3cN_c + qN_q + 0.3B\gamma N_\gamma \quad \text{(circular foundation)} \quad (2.3)$$

where q_u = ultimate bearing capacity

c = Cohesion

B = size of footing

γ = Bulk unit weight of the foundation soil

N_c, N_q, N_γ = Bearing capacity factor

$$N_q = \frac{e^{2\left(\frac{3\pi}{4}-\frac{\phi}{2}\right)\tan\phi}}{2\cos^2(45+\frac{\phi}{2})} \tag{2.4}$$

$$N_c = (N_q - 1)\cot\phi \tag{2.5}$$

$$N_\gamma = 1.8(N_q - 1)\cot\phi(\tan\phi)^2 \tag{2.6}$$

Meyerhof (1963) further extend the work of Terzaghi. He suggested a general equation for bearing capacity. We could find the bearing capacity of different geometric shapes of foundation (i.e. strip, rectangular, or square) with help of this equation. He also suggested a method to find the bearing capacity in the eccentric loading condition. He named this method as an effective area method. The size of footing is reduced to two times of eccentricity. this reduced area is used for calculation of the bearing capacity. The equation for ultimate bearing capacity is as follows.

$$q_u = cN_cF_{cs}F_{cd}F_{ci} + qN_qF_{qs}F_{qd}F_{qi} + ½B\gamma N_\gamma F_{\gamma s}F_{\gamma d}F_{\gamma i} \tag{2.7}$$

Where N_c, N_q, N_γ = Bearing capacity factor

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

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

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

$$N_q = e^{\pi\tan\phi(\frac{1+\sin\phi}{1-\sin\phi})} \tag{2.8}$$

$$N_c = (N_q - 1)\cot\phi \tag{2.9}$$

$$N_\gamma = (N_q - 1)\tan(1.4\,\phi) \tag{2.10}$$

Huang C.C. and Tatsuoka F. (1990) perform model tests on strip footing in plane strain conditions. The test results show that the bearing capacity can be increase by providing reinforcement below the footing. He performs limit equilibrium analysis on a reinforced sand bed. By doing this he suggests a method to find the bearing capacity. During analysis length of reinforcement is taken equal to the width of the footing.

Khing K.H (1993) perform a laboratory test on reinforced strip footing. For reinforcement he uses geogrid. The result shows that reinforcement should be placed in the active zone. The depth of the active zone is 2.25 times of the width of the the footing. The width of the active zone is 6 times the width of the footing.

Patra C.R. (2006) perform various laboratory tests on reinforced strip footing. These parameters were fixed depth ratio = 0.35, and width ratio = 5, the depth is taken as variable parameter. Depth varies between 0 to B. An empirical relation is established as reduction factor. The reduction factor R_{kR} is

$$R_{kR} = 4.97\left(\frac{d}{B}\right)^{0.12}\left(\frac{e}{B}\right)^{1.21} \qquad (2.11)$$

Where d = depth of the foundation

B= width of the foundation

e = eccentricity

Basudhar P.K. (2008) uses the finite element method to analyze the behaviour of strip load in geotextile reinforced sand bed. Base on test results it has been seen that for single layer reinforcement optimum depth is 0.6B. For a two-layer system, the effect of Poisson's ratio and Young's modulus is greater than reinforcement in settlement reduction.

Sadoglu E. (2009) perform various laboratory tests on geotextile reinforced strip footing. The load is applied as eccentric loading. The result shows that; bearing capacity increase by providing reinforcement. But the effect of reinforcement decrease as eccentricity increases. Also, the Meyerhof approach of the effective area gives low strength than the actual conditions. Which is on a safer side for design.

Latha G.M. (2009) perform various laboratory tests and also perform numerical simulations of same models. The model selected is square footing in reinforced condition. The result suggested to kept the spacing between geogrid 0.4 times the width of footing. He also suggested to use four numbers of geogrid layers for optimum result. Depth equal to two time of width of footing is active zone. Reinforcement should be place in active zone only.

Nareeman B.J. (2012) perform laboratory test on different shaped footing. Result shows that N_γ is a parameter which depend on width of footing. N_γ decrease with size of footing for square and circular footing. N_γ increases as sand comes in denser state.

After going through a lot of research work, I concluded that most of the research has been done for centrally loaded footing. There is only a few research has been done on eccentric loading condition, but these work focus on calculating the bearing capacity of the soil and how the eccentricity impacts the bearing capacity of footing. They work to find out the reduction factor, which helps in finding the loss of bearing capacity of footing due to eccentric loading. Some of the researchers also work on improving the strength of soil in eccentric loading conditions by providing geogrid as reinforcement. They reported that reinforcement is an effective method for improving the condition in eccentric loading, but they do not discuss the parameters of geogrids. And all the research with geogrids for eccentric loading is done on strip footing. A conclusion could not be drawn regarding various parameters (i.e. width, depth of each layer, number of layers, etc.) for different shapes of footing. That’s why I have done this work by accounting all the parameters at once and find out their optimum value for a better understanding of square footing in eccentric loading.

CHAPTER 3

MODEL TEST AND METHODOLOGY

3.1 INTRODUCTION

3.1.1 Finite element analysis

Finite element analysis (FEA) is a mathematical procedure used to get estimated solutions of boundary value problems in engineering. The finite element analysis (FEA) depends on building a complex model into simple blocks, and separating a model into smaller and manageable elements. Application of this basic thought can be found wherever in regular day to day existence problems, as well as in engineering. Steps include in finite element analysis are:

• Divide the model into smaller pieces (elements with nodes).

• Define the behavior of the properties on each element.

• Assemble the pieces at the nodes to form an approximative system of equations for the entire model.

• Solve the system of equations including unknown parameters at the nodes (displacements).

• Compute the desired parameter (e.g., strains and stresses) at particular elements.

OPTUM G2 is a finite element analysis software developed specifically for geotechnical problems. The graphical user interface allows us to easily generate the finite element model of a complex structure. OPTUM G2 is a finite element based software which provides various kind of analysis (i.e. elastoplastic deformation analysis, staged construction analysis, and seepage analysis). OPTUM G2 is a very good software for both purpose research and design as it provides a combination of different analysis. OPTUM G2 contains various different types of finite elements shape, including the 6-node and 15-node triangles. The software makes the modeling very simple as it automatically recognizes the intersections, closed surfaces, etc. It also provides many other features, such as anchors, modeling retaining walls, and geotextiles for even more accurate modeling.

For the simulation of models, I have used OPTUM G2 software. I get this software from internet source https://optumce.com/products/optumg2. I have used the academic version which is free of cost. We can use all the tools for a limited period (i.e. one month) in the academic version. I am using two different methods of analysis in this project first is (i) Limit analysis and second is (ii) Multiplier Elastoplastic analysis. The Limit analysis method is used to analyze the system which is rigid and perfectly plastic. This works on the concept of upper and lower bound theorems. The upper bound theorem is based on the principle of virtual work and the lower bound is based on the principle of maximum dissipation. The upper bound and lower bound limit give the maximum and minimum limit of the load. The Mean of these two will be the closest to the exact value. This analysis is used for finding out the shear criteria of bearing capacity. After analysis two values come up lower bound and upper bound values and the mean of these two is taken as final answer. As the number of mesh element increase the gaps between upper and lower bound values decrease and answer is more accurate.

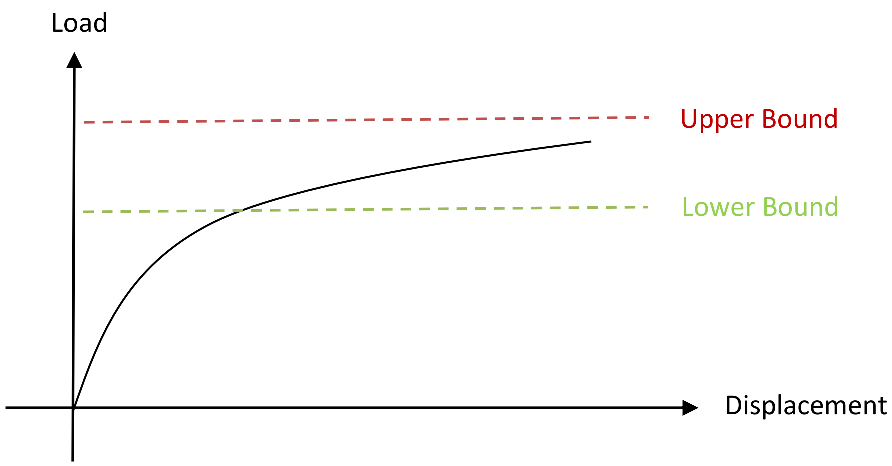

Figure 3.1 Generalize load-displacement curve

Multiplier Elastoplastic analysis is used for finding out the load settlement graph of the system. As the word multiplier suggested, multiple loads is applied from zero till failure, and after computation of data graph is form. This graph could be used for deterring the settlement criteria of bearing capacity.

3.2 VALIDATION OF THE SOFTWARE

To validation of the software I am solving a numerical problem of isolated square footing, the result given by the OPTUM G2 software will be compared with IS 6403: 2002 (Code of practice for determination of breaking capacity of shallow foundation.) and IS 1904: 2006 (Code of practice for design and construction of foundation in soils: general requirement.)

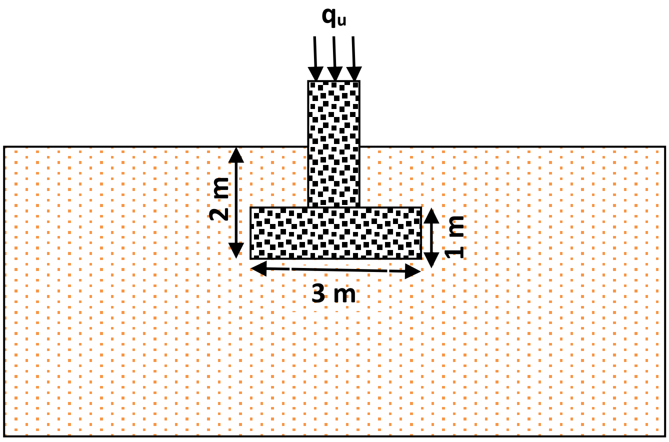

Figure 3.2 Geometry of problem

Properties of soil:

Cohesion = 78 kN/m^2 Internal angle of friction = 15^o

Bulk density = 17.5 kN/m^3 Dry density = 16 kN/m^3

Properties of footing:

Size of footing = 3*3 m Depth of footing = 2 m

Unit weight of concrete = 24 kN/m^3

As per IS 6403

$$Q_{nu} = cN_c s_c d_c i_c + q(N_q - 1) s_q d_q i_q + 0.5B\gamma N_\gamma s_\gamma d_\gamma i_\gamma \qquad (3.1)$$

Q_{nu} = Net ultimate bearing capacity based on general shear failure in kN/m^2

c = Cohesion in kN/m^2

B = Side of square footing

N_c, N_q, N_γ,= Bearing capacity factor.

s_c, s_q, s_γ = Shape factor

d_c, d_q, d_γ = Depth factor

i_c, i_q, i_γ = Inclination factor

γ = Bulk unit weight of foundation soil kN/m^3

For $\phi = 15^o$ $N_c = 10.98$, $N_q = 3.94$,

$N_\gamma = 2.65$ (From IS 6403 Table 1)

For square footing, Shape factors:

s_c=1.3, s_q = 1.2, s_γ = 0.8 (From IS 6403 Table 2)

Depth factors:

$d_c = 1+ 0.2\ D_f/B\sqrt{N}\phi$ $d_q = d_\gamma = 1$ for $\phi < 10^o$

$d_q = d_\gamma = 1+ 0.1\ D_f/B\sqrt{N}\phi$ for $\phi > 10^o$

Where, $\sqrt{N}\phi = \tan^2 (\pi/4 + \phi/2)$

D_f = Depth of foundation in cm

B = Side of square footing in cm

So, d_c = 1+ 0.2*(2/3)*1.3 = 1.173,

$d_q = d_\gamma$ = 1 + 0.1*(2/3)*1.3 = 1.0867

q_n = {78*10.98*1.3*1.173} + {2*17.5* (3.94 -1)*1.2*1.0867} + {0.5*3*17.5*2.65*0.8*1.0867}

= 1305.98 + 134.186 + 60.475

= 1500.641 kN/m^2

$q_u = q_n + \gamma*D_f$

= 1500.641 + 17.5*2

= 1535.641 kN/m^2 ≈ 1536 kN/m^2

So, Ultimate bearing capacity of footing is 1536 kN/m^2 (As per IS 6403: 2002)

3.2.1 Analysis of problem with OPTUM G2

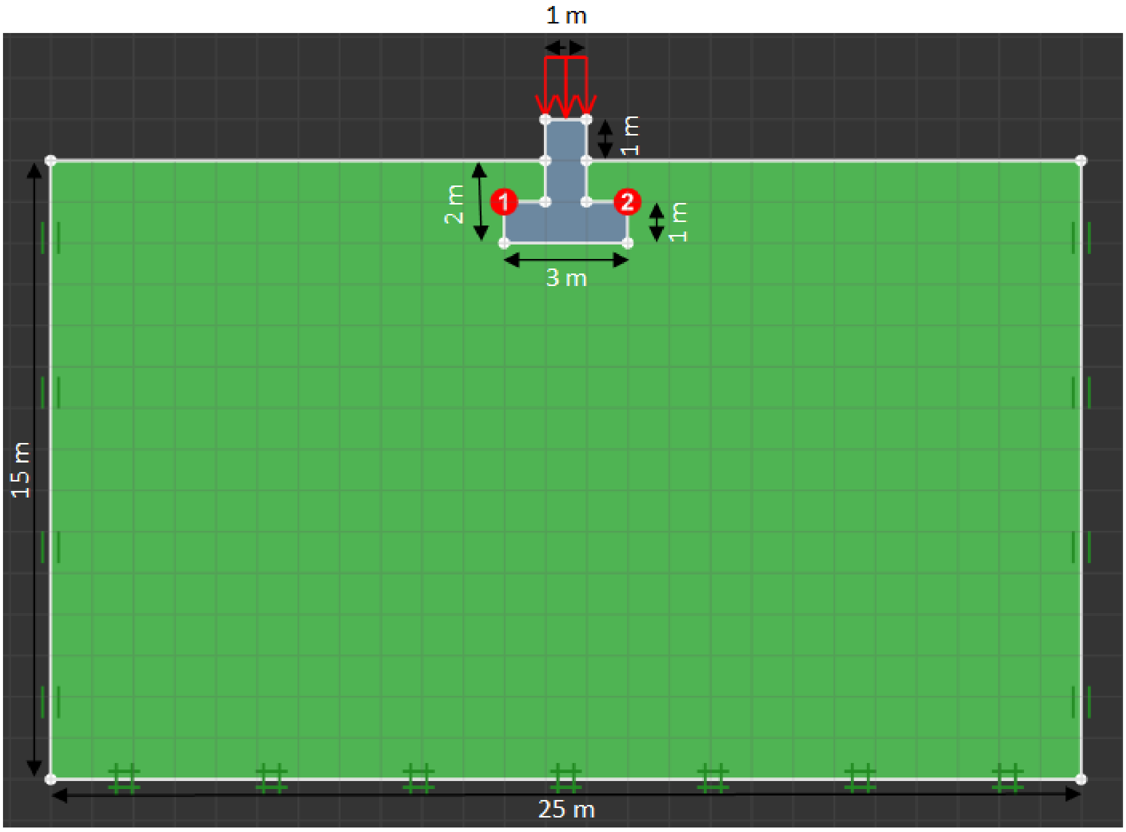

Figure 3.3 Model in Optum G2 software

Properties of soil

Material model = Mohr – Coulomb c (kpa) = 78, ϕ (°) = 15,

γ_d (kN/m^3) = 16, γ_s (kN/m^3) = 19

Properties of foundation

Material model = Rigid γ (kN/m^3) = 24

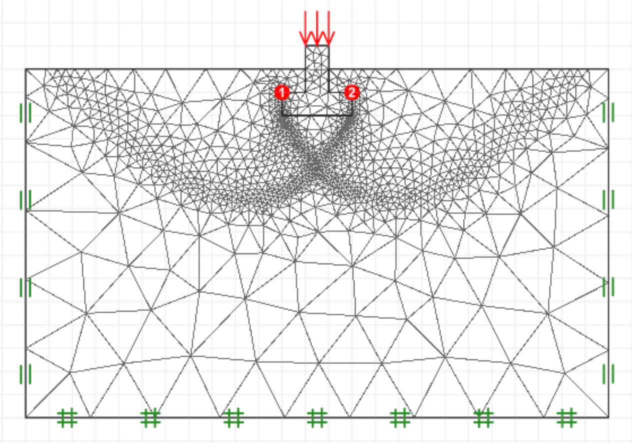

Figure 3.4 Mesh formation of problem

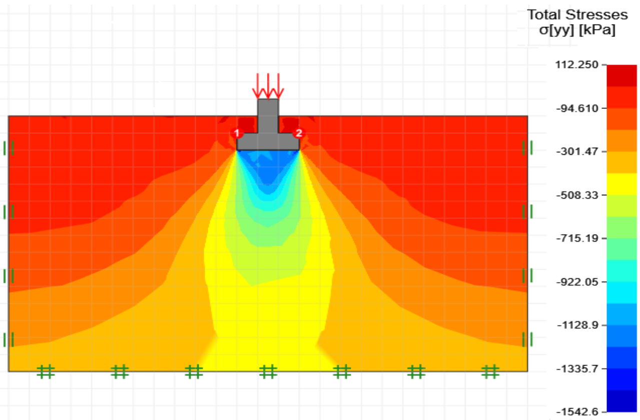

Figure 3.5 Isobar of total vertical stress

Result, From the limit analysis

Lower bound q_u = 1509 kN/m^2 Upper bound q_u = 1687 kN/m^2

So mean of this will be final q_u = 1598 kN/m^2

So, the Ultimate bearing capacity of footing is 1598 kN/m^2 (As per limit analysis) From this, we can see that difference between the ultimate bearing capacity is 62 kN/m^2, which is only 4% higher than the value provided by IS 6403: 2002. The error is within the acceptable range. So, we can say that OPTUM G2 software is validated and we can use it for further studies.

3.3 MODEL DEFINITION

3.3.1 Geometry of problem

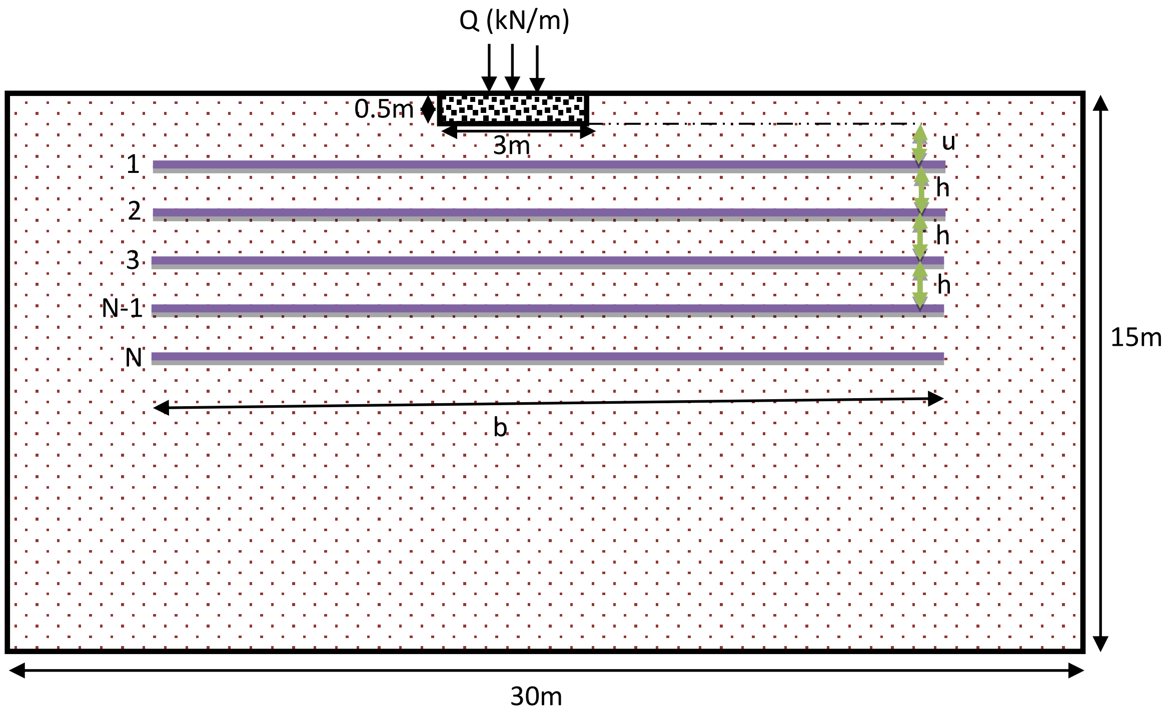

Figure 3.6 Generalized model of the project

To analysis the effect of geogrid this is the model, I am using to perform numerical analysis. A rigid footing of depth 0.5m and width 3m is used. To eliminate the effect of the boundary the dimension of soil mass should be kept minimum five times the width of the footing. So, soil mass of 30m width with 15m depth is used. The

Load is applied as a uniformly distributed load on length of 1m. The footing is embedded in soil mass in such a way that the top level of footing is at ground level.

Parameter those optimum value has to determine:

(a) u = depth of the first layer of geogrid from the bottom of the footing.
(b) h = gap between each consecutive geogrid layer.
(c) b = width of geogrid.
(d) N = number of geogrids.

Table 3.1 Properties of soil:

Material model = Mohr-Coulomb sand	c = 0 kPa	$\phi = 35^{o}$
γ_s = 19 kN/m^3	γ_d = 16 kN/m^3	$K_x = K_y$ = 1m/day
E = 40 Mpa	μ = 0.25	

Table 3.2 Properties of square footing:

Material model = Rigid	γ= 24 kN/m^3
B = 3m	D = 0.5 m

Table 3.3 Properties of Geogrid:

Stiffness = 450 kN/m	Yield force = 45 kN/m
Strength reduction factor = 2	

3.4 MODEL SIMULATION PROCEDURE

The finite element program OPTUM G2 is used in the study to simulate the model. The model consists of shallow square footing embedded in the reinforced and unreinforced sand bed. In this model, the bottom surface of soil mass is restricted to move in both directions, horizontal and vertical. The lateral surface of soil mass is restricted to move in the horizontal direction. This whole fixation is called as standard fixities in software. A 15-node Gauss triangle is used as the shape of element and the number of elements is 2500, which is sufficient to generate the reasonable accurate results. Mess adaptivity option is also introduced during analysis. This option will increase the number of elements in the region where stress and deformation is more as compared to another region. So, near the footing along the slip surface, the element size is smaller and the number of element is more. This will help in much accurate result. The material model used for simulation of footing is Mohr-Coulomb. Mohr-Coulomb model requires these following parameters cohesion, friction angle, hydraulic permeability along both axis, dry and saturated, young's modulus, unit weight and Poisson's ratio.

3.4.1 Test Simulation and Setup

A total 56 number of simulation is analysis in OPTUM G2 software to determine the ultimate load. The ultimate load is calculated on the bases of shearing failure criteria. Eccentricity is defined as the ratio of load eccentricity with respect to the center of load by the width of footing (e/B). For analysis four different eccentricities (e/B = 0, 0.05, 0.1, 0.15) is applied to model footing. Optimum depth ratio for the first layer of geogrid (u/B) is defined as the depth of the first layer to the width of footing. Four optimum depth ratio (u/B = 0.25, 0.33, 0.5, 0.67) is taken under consideration for analysis. Optimum depth ratio for the second reinforcement layer (h/B) defined as gaps between each consecutive layer to the width of footing. As previous, four optimum depth ratio (h/B = 0.25, 0.33, 0.5, 0.67) is taken for analysis. Optimum width ratio (b/B) defined as the width of geogrid to the width of footing. Here also four different sets of optimum width ratio (b/B = 2, 4, 6, 8) is used for analysis. For the starting set of test, the width ratio (b/B) is taken as 5. In previous research work for centric loading, researcher has suggested taking width ratio (b/B) 4.5 for square footing. In this research work, Bearing Capacity ratio (BCR) is used to indicate the improvement offered by geogrid layers on increasing bearing capacity of the soil. Bearing Capacity ratio (BCR) is a dimensionless parameter, which is defined as the ratio of ultimate load in reinforced soil to that of unreinforced soil condition.

$$BCR = Q_u \text{ (reinforced)} / Q_u \text{ (unreinforced)}$$

Where Q_u is the ultimate load at failure of footing due to shear.

3.4.2 Sample Analysis

(i) Let take one case where load is applied as vertical eccentric (e/B) = 0.05 with no geogrid layer.

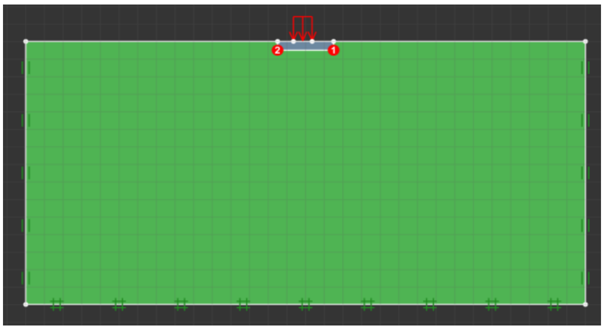

Figure 3.7 Geometry of model
(e/B = 0.05, N=0)

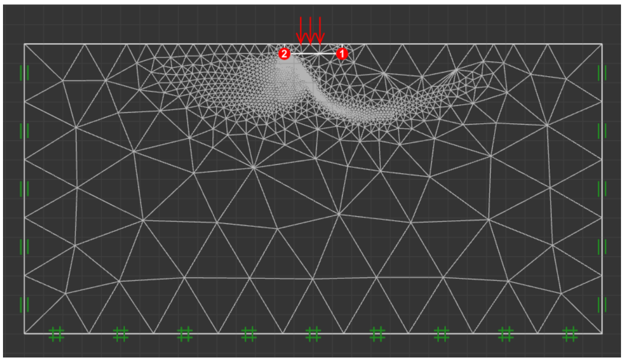

Figure 3.8 Mesh Formation
(e/B = 0.05, N=0)

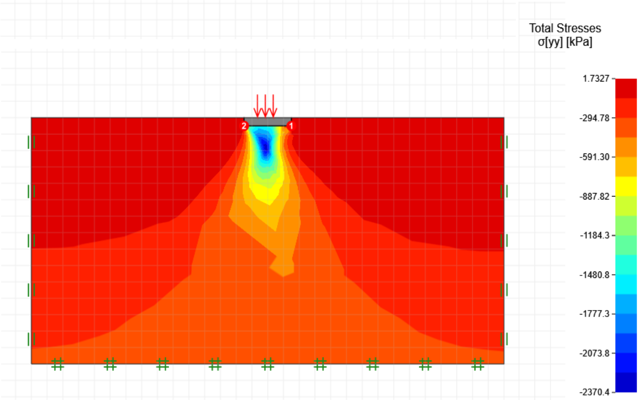

Figure 3.9 Isobar of vertical total stress
(e/B = 0.05, N=0)

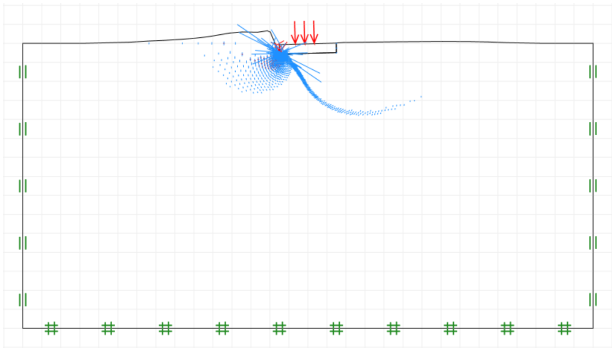

Figure 3.10 Failure surface of model
(e/B = 0.05, N=0)

Result of analysis $Q_u = 3510$ kN

So, BCR = 3510/3510 = 1

(ii) Let take the case when load is applied at eccentricity (e/B) = 0.05, N= 2, u/B=0.33, h/B=0.5

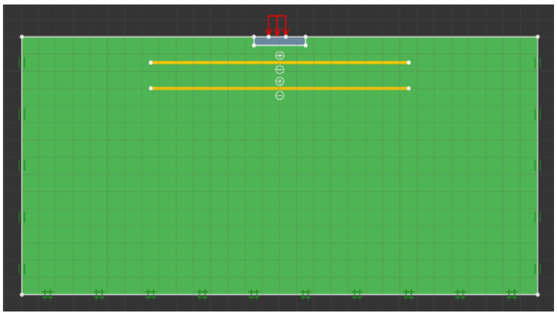

Figure 3.11 Geometry of model (e/B = 0.05, N=2, u/B = 0.33, h/B= 0.5)

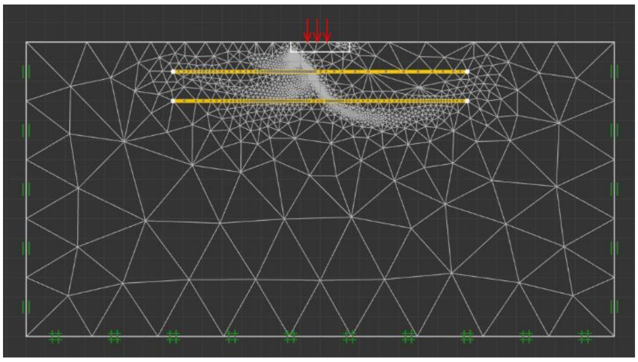

Figure 3.12 Mesh Formation (e/B = 0.05, N=2, u/B = 0.33, h/B= 0.5)

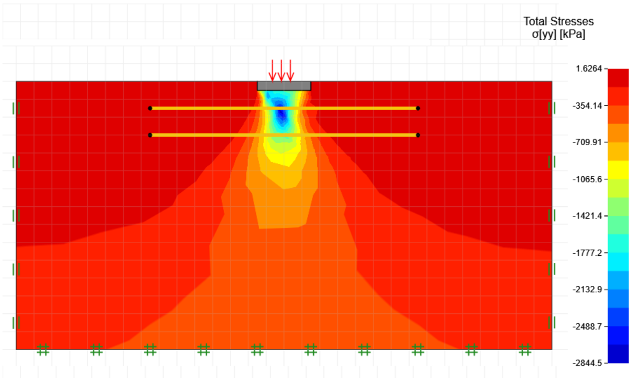

Figure 3.13 Isobar of vertical total stress (e/B = 0.05, N=2, u/B = 0.33, h/B= 0.5)

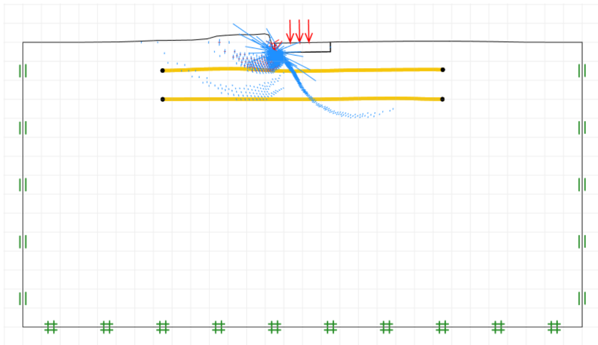

Figure 3.14 Failure surface of model (e/B = 0.05, N=2, u/B = 0.33, h/B= 0.5)

Result of analysis Q_u = 3972 kN

So, BCR = 3972/3510 = 1.132

In this same manner, all the 56 models is simulated and their results are shown in the tabular form below:

Table 3.4 Results of square footing test for e/B = 0, 0.05, 0.10, 0.15 in both reinforced and unreinforced condition.

e/B	No. of test	N	e (cm)	u/B	h/B	Qu (kN)	BCR
0	1	0	0			4082	1.000
	2	1	0	0.25		4367	1.070
	3	1	0	0.33		4379	1.073
	4	1	0	0.5		4311	1.056
	5	1	0	0.67		4208	1.031
	6	2	0	0.33	0.25	4588	1.124
	7	2	0	0.33	0.33	4588	1.124
	8	2	0	0.33	0.5	4523	1.108
	9	2	0	0.33	0.67	4523	1.108
	10	3	0	0.33	0.33	4602	1.127
	11	4	0	0.33	0.33	4645	1.137
0.05	12	0	15			3510	1.000
	13	1	15	0.25		3749	1.068
	14	1	15	0.33		3771	1.074
	15	1	15	0.5		3706	1.056
	16	1	15	0.67		3603	1.026
	17	2	15	0.33	0.25	3930	1.119
	18	2	15	0.33	0.33	3972	1.131
	19	2	15	0.33	0.5	3972	1.131
	20	2	15	0.33	0.67	3814	1.087
	21	3	15	0.33	0.33	3976	1.133
	22	4	15	0.33	0.33	3971	1.131
0.1	23	0	30			2911	1.000
	24	1	30	0.25		3149	1.082
	25	1	30	0.33		3257	1.119
	26	1	30	0.5		3159	1.085
	27	1	30	0.67		3075	1.056
	28	2	30	0.33	0.25	3331	1.144
	29	2	30	0.33	0.33	3354	1.152
	30	2	30	0.33	0.5	3354	1.152
	31	2	30	0.33	0.67	3201	1.099
	32	3	30	0.33	0.33	3379	1.161
	33	4	30	0.33	0.33	3373	1.159

Table 3.4 (continued)

e/B	No. of test	N	e (cm)	u/B	h/B	Qu (kN)	BCR
0.15	34	0	45			2351	1.000
	35	1	45	0.25		2605	1.108
	36	1	45	0.33		2680	1.140
	37	1	45	0.5		2606	1.108
	38	1	45	0.67		2489	1.058
	39	2	45	0.33	0.25	2746	1.168
	40	2	45	0.33	0.33	2769	1.178
	41	2	45	0.33	0.5	2732	1.162
	42	2	45	0.33	0.67	2612	1.111
	43	3	45	0.33	0.33	2788	1.186
	44	4	45	0.33	0.33	2778	1.182

CHAPTER 4

RESULT AND DICUSSION

All the test shows a similar type of failure mechanism. The General shear failure pattern is observed in all the models. It may be due to that the properties of soil used belong to medium dense sand and in dense sand usually general shear failure is observed. The load v/s settlement graph shows the following pattern as firstly with the increment of load rate of settlement is very low, but after attaining a load value the rate of settlement increase rapidly and a clear failure is observed. That point is taken as the ultimate load (Q_u) for that model. A typical sample of load v/s settlement curve is shown below for e/b = 0.05, N=2, u/b = 0.33, h/B = 0.25.

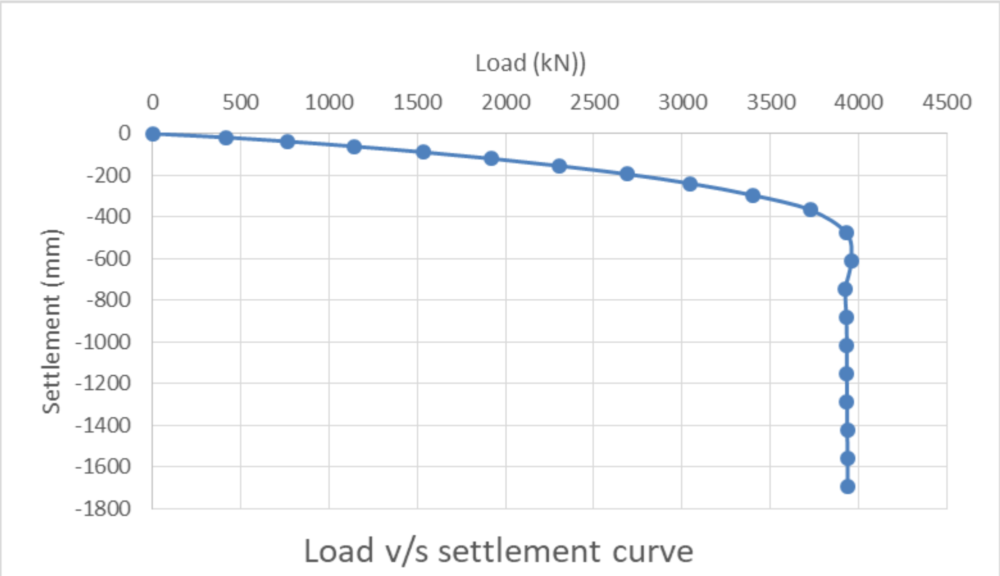

Figure 4.1 Load v/s settlement curve of model
(e/B = 0.05, N=2, u/B = 0.33, h/B= 0.25)

In centric loading system at failure, uniform heaving is observed on both sides of the footing. While in the eccentric loading system on edge settle much larger than others. The eccentric side of footing settles more, so the tilting of footing is observed at failure the stage. The Heaving of soil on the eccentric side of footing is much larger as compared to the other side at the failure stage.

4.1 OPTIMUM DEPTH OF FIRST GEOGRID LAYER (u/B)

One of the important parameters is the embedment depth of the first layer of reinforcement. To find out this parameter different set of the model is tested as e/B varying from 0 to 0.15 and u/B varies from 0.25 to 0.67. For all these cases BCR is calculated and plotted on the graph (figure 4.2), u/B is plotted on X-axis, and BCR is plotted on Y-axis.

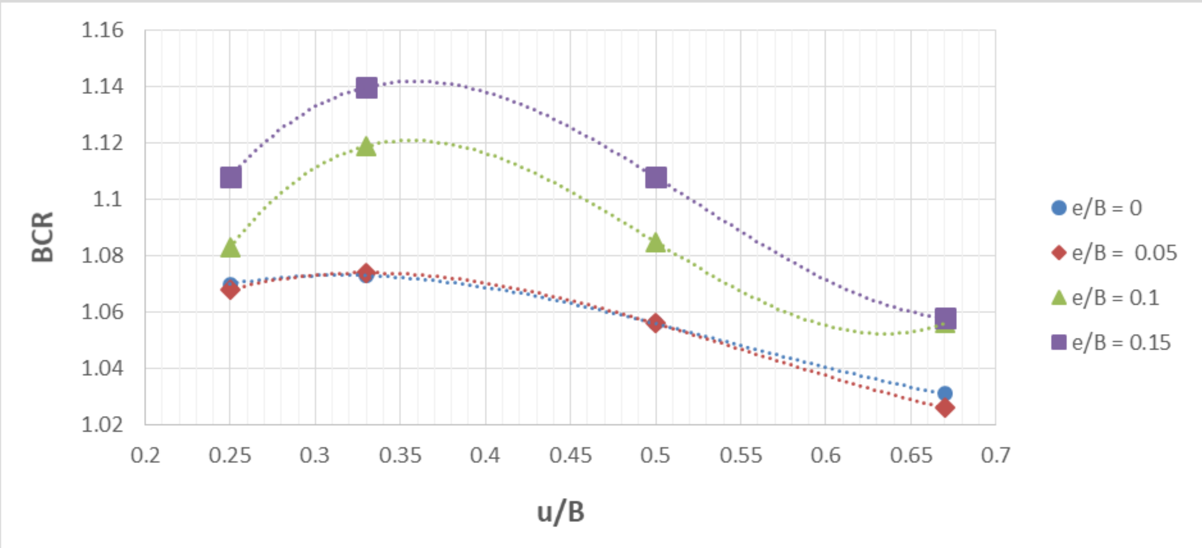

Figure 4.2 Variation of BCR with u/B ratio for first layer of geogrid

Firstly, with an increase in u/B, the BCR value also increase, and then it decreases beyond a point. It's been seen that for u/B = 0.33 gives the maximum value of BCR. BCR value is more and the less same for u/B varies from 0.3 to 0.4. So, I suggest taking the optimum depth ratio (u/B) for the first layer anywhere between 0.3 – 0.4 in square footing for optimum result. I am going to take u/B 0.33 for further simulation of modeling.

4.2 OPTIMUM DEPTH OF SECOND GEOGRID LAYER (h/B)

To find the variation of h/B first we fix the value of u/B at 0.33 and different sets of h/B (0.25, 0.33, 0.5, 0.67) is been used for modeling. The final graph between h/B and BCR is plotted below (figure 4.3). As it can be seen that for both centric load (e/B = 0) and eccentric load (e/B = 0.05, 0.1, 0.15) the value of BCR first increase showing maximum at h/B = 0.33 and the decrease. The variation of BCR between h/B 0.3- 0.4 is more and less the same. So, I suggest taking the optimum depth ratio for the second layer h/B of geogrid between 0.3 - 0.4 in square footing for optimum result. For further analysis of models, I am using h/B = 0.33.

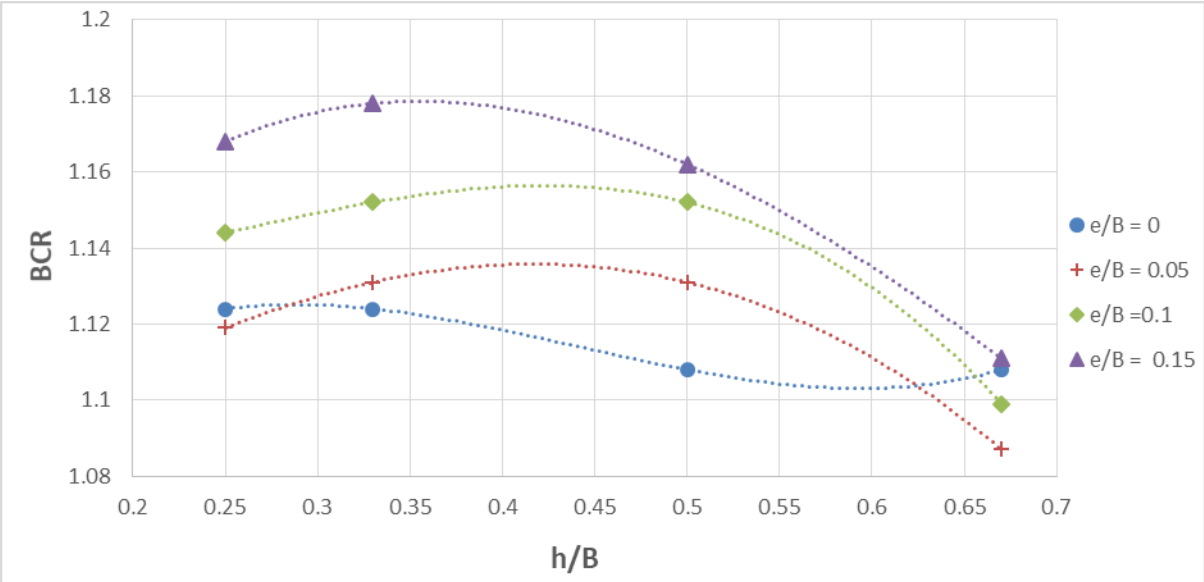

Figure 4.3 Variation of BCR with h/B ratio for second layer of geogrid

4.3 OPTIMUM NUMBER OF GEOGRID LAYER (N)

Several model are simulated with depth ratio (u/B = h/B = 0.33) with different number of reinforcement layers (N = 1, 2, 3, 4) at all eccentricity (e/B =0.05, 0.1, 0.15). The variation of N v/s BCR is plotted on the graph (figure 4.4). For the centric load, the BCR value keeps on increasing with an increasing number of geogrid layers up to four layers. In eccentric loading, it has been observed that BCR values increase with an increase in the number of geogrids layers from N = 0 to 3, and beyond N = 3 layers there is not any further increment in BCR. So, I suggest that N = 3 layers of reinforcement are the optimum value for square footing.

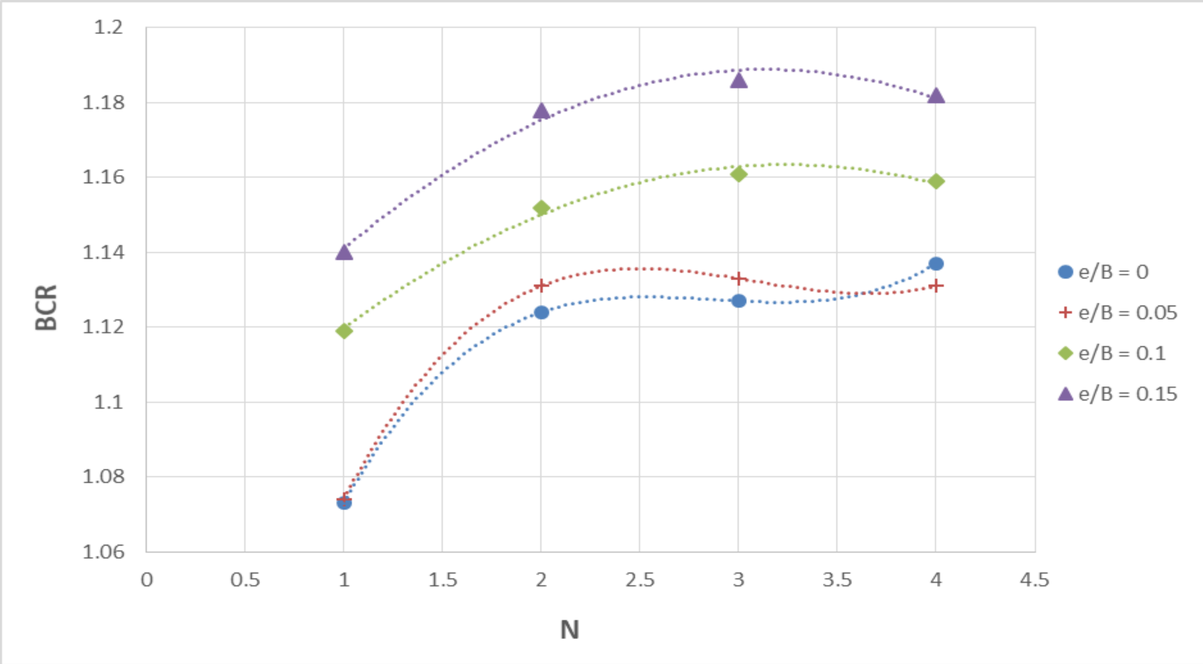

Figure 4.4 Variation of BCR with N for centric and eccentric loadings

There is the surface along which the soil fails for eccentricity (e/B = 0.05, 0.1, 0.15) (figure 4.5, 4.6, 4.7) it is seen that for e/B = 0.05 the failure, surface goes slightly below the third layer of geogrid, for e/B = 0.1 the failure surface goes up to the third layer of geogrid. But as eccentricity increases e/B = 0.15 the failure surface is in between the third and second layer of geogrid. The Conclusion is that as the eccentricity increase the depth of failure surface is reducing. So in all the three cases, the fourth layer is not playing any role in increasing the bearing capacity of the soil, which justifies that the optimum number of geogrid layers is N = 3. If we increase the eccentricity e/B beyond 0.15, it could we observe that even the third layer of geogrid will not add any further strength to the soil.

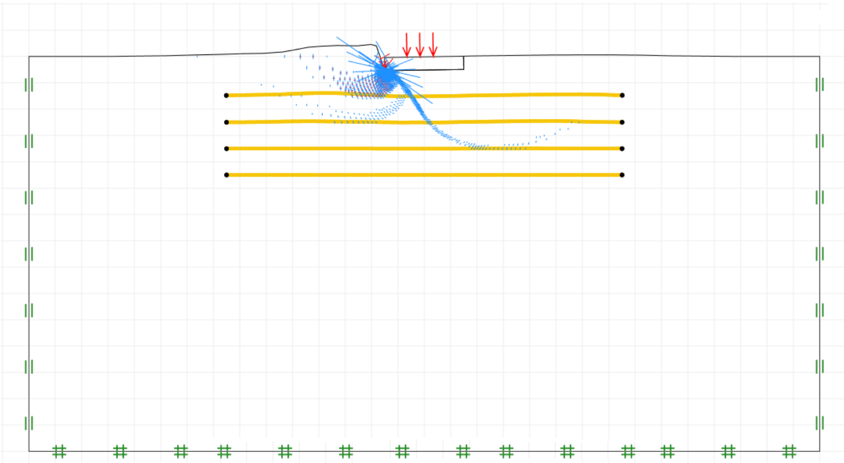

Figure 4.5 Failure surface of model
(e/B = 0.05, N=4, u/B = 0.33, h/B= 0.33)

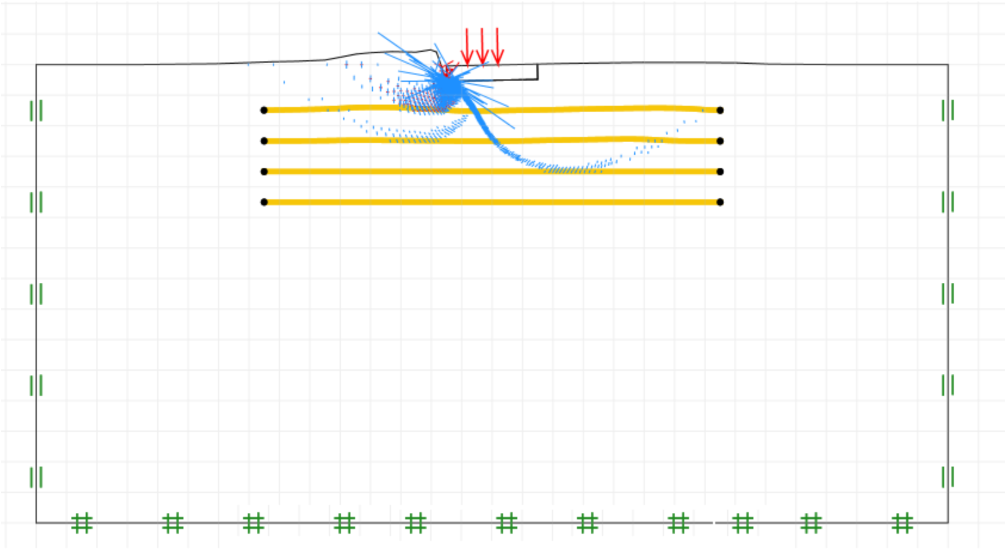

Figure 4.6 Failure surface of model
(e/B = 0.1, N=4, u/B = 0.33, h/B= 0.33)

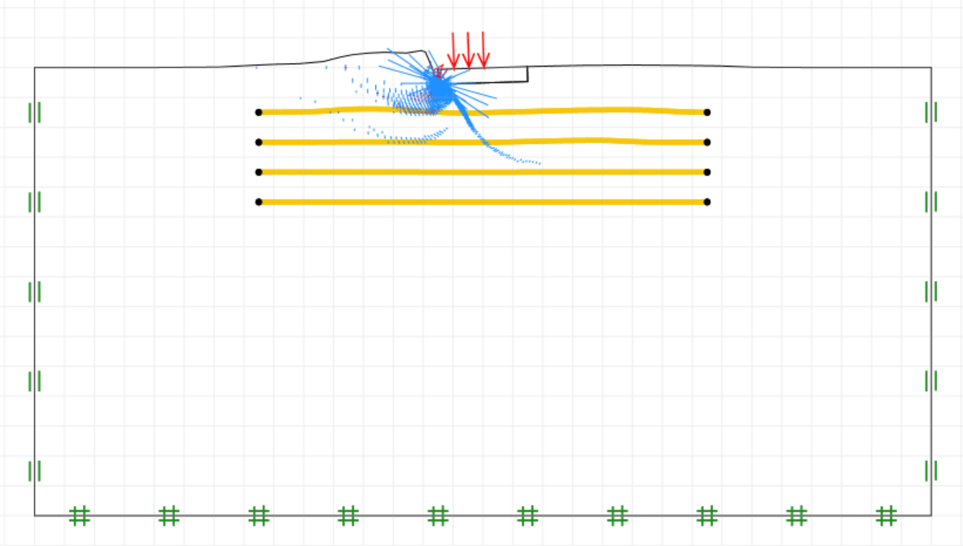

Figure 4.7 Failure surface of model
(e/B = 0.15, N=4, u/B = 0.33, h/B= 0.33)

4.4 OPTIMUM WIDTH OF GEOGRID LAYER (b/B)

For determination of optimum width ratio (b/B) different set of model with width ratio (b/B = 2, 4, 6, 8) with eccentricity (e/B= 0.05, 0.1, 0.15) is simulated. Result of these model is given below in tabular form. Result is also plotted in graphical form (figure 4.8).

Table 4.1 Results of square footing test for e/B = 0, 0.05, 0.10, 0.15 for reinforced condition.

e/B	No. of test	N	e (cm)	u/B	h/B	b/B	Qu (kN)	BCR
0.05	45	3	15	0.33	0.33	2	4087	1.164
	46	3	15	0.33	0.33	4	4108	1.170
	47	3	15	0.33	0.33	6	4135	1.178
	48	3	15	0.33	0.33	8	4139	1.179
0.1	49	3	30	0.33	0.33	2	3322	1.141
	50	3	30	0.33	0.33	4	3361	1.154
	51	3	30	0.33	0.33	6	3372	1.158
	52	3	30	0.33	0.33	8	3382	1.160
0.15	53	3	45	0.33	0.33	2	2721	1.157
	54	3	45	0.33	0.33	4	2731	1.162
	55	3	45	0.33	0.33	6	2754	1.171
	56	3	45	0.33	0.33	8	2756	1.172

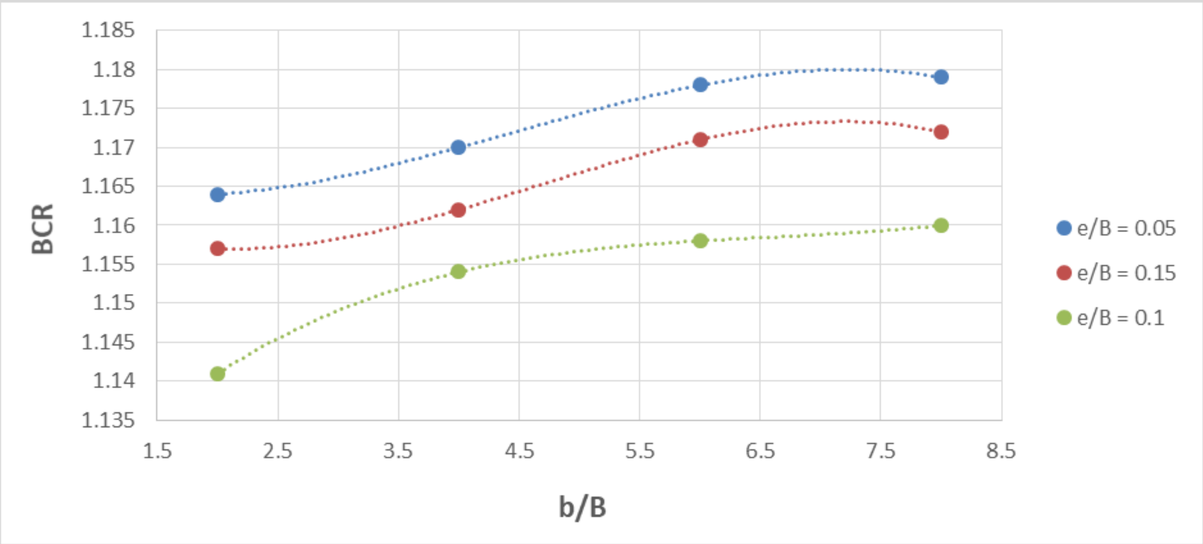

Figure 4.8 Variation of BCR with b/B for eccentric loadings

From the graph, it is observed that with the increase in width ratio (b/B) the value of BCR keeps on increasing till b/B = 7 and after that, there is a slightly downfall in the graph. Which mean that optimum value of width ration (b/B) = 7. So, I suggest using width ratio (b/B) = 7 for the optimum result for eccentric loading in square footing.

4.5 EFFECT OF ECCENTRICITY OF LOAD ON BEARING CAPACITY OF FOOTING

To examine the effect of eccentricity (e/B) on the rearing capacity of square footing in both reinforced and unreinforced condition, a different set of the model is simulated and the result is shown as graph between eccentricity (e/B) v/s ultimate load (Q_u) (figure 4.9).

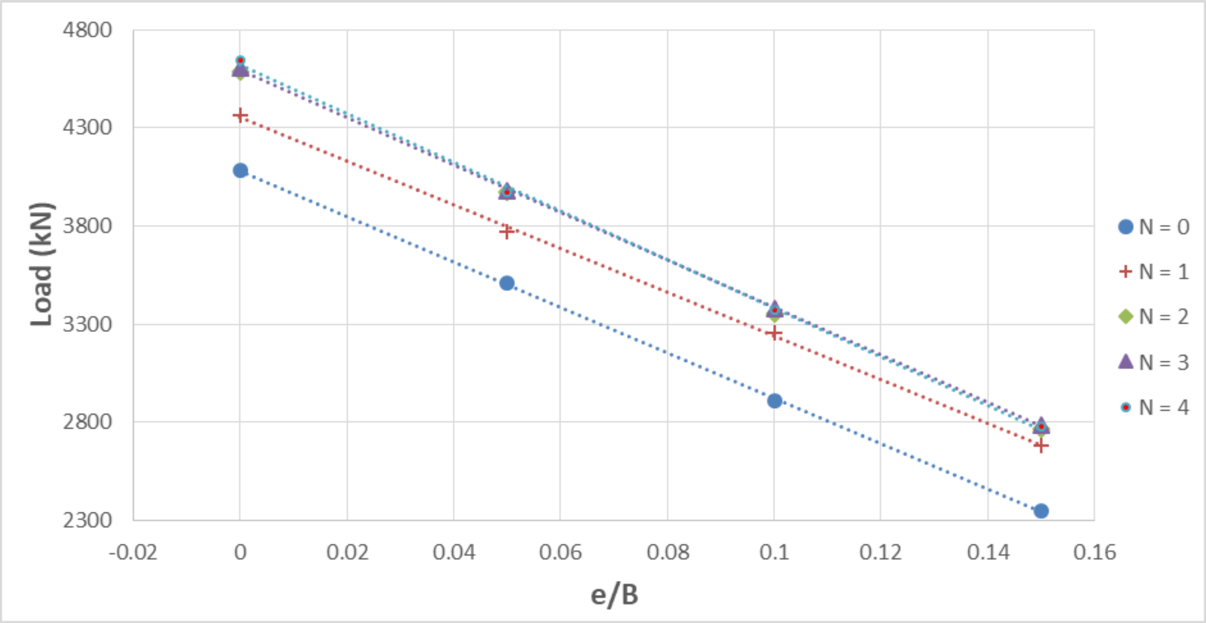

Figure 4.9 Variation of e/B with ultimate load (Q_u) for different layer of reinforcement

The result shows that in all cases with an increase in eccentricity (e/B) the bearing capacity of footing reduce, but in the unreinforced condition, the slope of the line is more than the reinforced condition. This means the rate of decrement of bearing capacity is more in unreinforced soil than the reinforced soil. As the number of geogrid increases the rate of decrement of bearing capacity reduces with eccentricity and for N = 2, 3, 4 the rate is almost same as these lines overlap each other.

CHAPTER 5

CONCLUSION

5.1 GENERAL CONCLUSION

The behaviour of vertical eccentric loaded square footing in unreinforced and reinforced with geogrids on the sand bed are studied, by performing a series of simulation in OPTUM G2 software. Different value of load eccentricity (e/B = 0, 0.05, 0.1, 0.15) are considered for determination of optimum values of geogrid layer parameters, such as u/B, h/B, b/B, and N. Following points can be concluded from this study:

(i) For the maximum utilization of the geogrid these Parameter values should be taken u/B= 0.3-0.4, h/B = 0.3-0.4, and b/B = 7.

(ii) In centric loading condition the bearing capacity increase as we increase the number of geogrid layers (up to N=4).

(iii) It has been observed that the optimum value for N = 3 for eccentric loading in square footing.

(iv) The bearing capacity of soil reduces with an increase in load eccentricity. This reduction can be minimized by using geogrids as suggested above.

5.2 SCOPE OF FUTURE WORK

This research work is oriented towards the effect of eccentricity on parameters of geogrids over the sand bed. Because of time constrain other perspectives associated with square footing could not be considered. Following work should be considered if someone wants to extend this:

(i) Properties of foundation such as depth to width ratio (D/B), embedment depth of footing, the shape of footing could be taken under study.

(ii) The Effect on the settlement could also be taken under consideration for further studies.

(iii) A generalized equation of the ultimate bearing capacity for the reinforced condition could be developed for square footing.

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