Bearing Capacity of Foundation Soils using Analytical Methods

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ABSTRACT

The proper evaluation of bearing capacity of soil is needed for stability of buildings resting on foundation. The aim of this study is determining the allowable bearing capacity of soils. The computations of carrying capacity of soil were done by collecting the results obtained from laboratory. Some of the index and Engineering properties were investigated. The shear strength parameters were determined using unconsolidated undrained direct shear test. The applied analytical methods for determination of this pressure are Terzhagi, Meyerhof and Vesic bearing capacity equations. The allowable bearing capacity values obtained for typical isolated rectangular footing, (BxL=1mx3m), were calculated by the above mentioned authors. Accordingly, the results for test pit (TP1) are 2537.6, 3527.4 and 3185.8kPa; and for TP2 are 743.9, 946.6 and 1020.6kPa respectively. These values are responsible for supporting high rise buildings.

Keywords: Allowable bearing, capacity, undrained, unconsolidated, direct shear test, Cohesion, *Internal friction angle.*

I. INTRODUCTION

Foundation is an integral part of a building whose stability determines the stability of the entire structure. It acts as a medium through which loads are transmitted to the soil or rock below. The stability of a foundation depends on its proper design based on the structural loads of the building it carries, the geology of the area and condition of the subsoil base. Depending on the depth of load-transfer from the structure to the ground, foundations are classified as shallow and deep foundations. The definition of shallow foundations varies in different publications. [3].The subject of bearing capacity is perhaps the most important of all the aspects of geotechnical engineering. Loads from buildings are transmitted to the foundation by columns, by load bearing walls or by such other load-bearing components of the structures [2].The two basic criteria to be satisfied in the analysis and design of a shallow foundation are stability and deformation requirements. Stability requirement ensures that the foundation does not undergo shear failure under loading, while deformation requirement ensures that settlement of a structure is within the tolerance limit of the superstructure [1]. Where data for characteristics of a soil (cohesion, angle of internal friction, density, etc) are available, the allowable bearing capacity may be calculated from consideration of shear failure. A factor of safety of three shall be adopted [2].

2. LOCATION OF THE SITE

Wolaita Sodo town is found on latitude 6°49' N, longitude 37° 45' E in SNNPRs, Ethiopia. The location of project area is found on (6°49'39" - 6°49'35") N, longitude (37° 44' 39" - 37° 44' 36") E within the compound of Wolaita Sodo University. Figure 1shown below is the area which proposed to serve as a Technology campus.

Chart - 1: Location of the study area.

3. SOME OF LITERATURES REVIEWED

Some of the literatures reviewed are listed below.
Akpila and Eluozo (2012): He made analysis on bearing cap acity of heterogeneous soil found in Niger Delta of Nigeria. For the computation of soil parameters laboratory and field tests (standard penetration test). The soil having high settlement, raft foundation is recommended and put at the interface between clay and sand layer. The net bearing capacities versus breadth of shallow foundations were presented.

Rajeev Gupta and Ashutosh Trivedi (2009): They have determined the bearing capacity and settlement of footing resting on confined loose silty sands. It used laboratory and model test tank method. It checks the effectiveness of model cell diameter, cell height, fines related to confinement and determination the bearing capacities and settlements.

Pravin and Karim (2016): In this research, new approach for determination of bearing capacities of soil using direct shear test and plate loading test. The safe bearing capacities and settlements are determined using analytical methods by IS: 6403-1981.

Otuaga (2015): He was determined the bearing capacity of building and structural design in Owo local area, Nigeria. He presents shear strength parameters and found that the minimum bearing capacities can carry high rise building with little risk.

S.B. Akpila and I.W.Omunguye (2013): They have done research on influence of foundation settlement on bearing capacity analysis of shallow foundation in Niger Delta, Nigeria. They have evaluated the allowable bearing capacity for raft foundation with breadth of 19.3m and 29.5m up to 3m depth.

Magdi and Husam (2016): The prediction of bearing strength of soil from index properties. This was determined by collecting shear strength parameters using CBR test.

Bunyamin and Ja'afar (2016): The evaluation of bearing capacity and settlements of foundations were determined, by using standard penetration test. The analysis was done using analytical method Meyerhofs and plaxis. The values calculated by analytical methods gave acceptable results.

A.Eslami and M.Gholami (2005-2006): It was determined the bearing capacity analysis of foundations. They have used cone penetration tests for data collection. The ultimate bearings were evaluated for footing having a diameter of 0.3 to 3m

4.METHODOLOGY

4.1 Laboratory analysis

The methods used to determine the subsurface condition of the study area was investigated by conducting laboratory tests. The properties of soil were determined samples collected from two test pits at 1.5m depth below ground surface.Finally the soil samples are transported to geotechnical laboratory and bulk density, grain size analysis, shear strength, liquid limit, plastic limit and density of the samples are determined [5]. Determination of shearing strength of a soil involves the plotting of failure envelopes and evaluation of the shear strength parameters for the necessary conditions [2]. The unconsolidated undrained laboratory tests were done. The samples collected within the main Campus with thickness of 25mm, length of 60mm and width of 60mm, were conducted tests using shear box apparatus shown in Figure

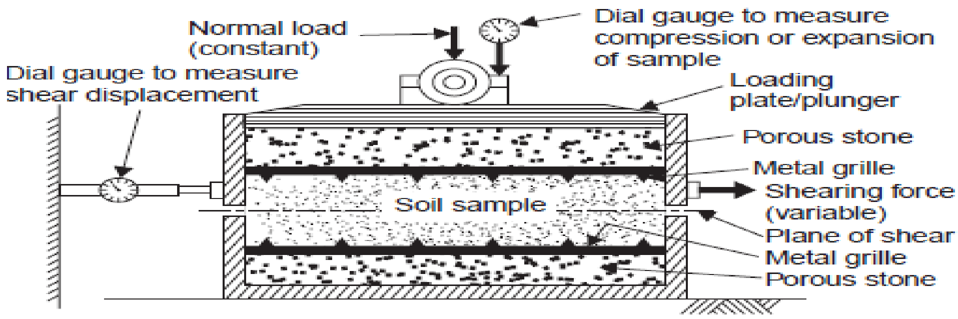


Chart -2: Schematic Diagram for direct shear aparatus [2]

4.2 Bearing capacity analysis

The allowable,q_{all}, bearing capacity of the soil has been evaluated for a factor of safety (F.S) of 3.0. An undrained cohesion (C_u) and internal friction angle (ϕ) were determined for TP1 and TP2 [4]. And the allowable bearing capacity of a model rectangular isolated footing of BxL (1m x 3m, 1.5 m x 3m and 2m x 3m) have been evaluated which placed on 1.5m of the silt layer.

5.RESULT ANALYSIS AND DISCUSION

The prepared soil samples from test pits have been transported from the site to the laboratory. These samples were ready for tests in laboratory.

5.1 Properties of Tested Soil

Then after, the prepared soil sample is taken and analyzed in the laboratory for determination of its various physical and engineering properties i.e. grain size distribution, shear strength parameters i.e. angle of internal of friction (φ), cohesion (c), liquid limit (LL), plastic limit (PL) and Bulk density (γ) etc [6]. The type of soil found in the study area were brownish lateritic.

5.1.1Atterberg Limit Test

According to [8], the laboratory tests performed to determine the plastic (PL), liquid limits (LL) and plasticity Index (PI) of a fine grained soil. The results are presented in Table 1.

Test Pit	LL(%)	PL(%)	PI(%)
TP1	55	37	18
TP2	59	34	25

Table 1: Results of Atterberg limits tests

5.1.2 Grain Size Analysis

The screening processes have been used for coarse grained soils (gravel and sand) by mechanical sieve. But for fine-grained soils (silts and clays), because of their extremely small size, were used a hydrometer test. The behavior of fine-grained soils is strongly influenced by moisture content changes [8]. According to Unified Soil Classification System (USCS) [7], the grouping percent amount of particle sizes classification was done. The results are tabulated in Table 2.

	percentage amount test of particle sizes			
Test Pit	Grave l(%)	Sand (%)	Silt (%)	Clay (%)
TP1	0	9.3	41.4	49.3
TP2	0	13.8	32.7	53.5

Table-2: Results of grain size tests

5.1.3 Soil Classification

Soil classification systems divide soils into groups and subgroups based on common Engineering properties such as the grain-size distribution, liquid limit, and plastic limit [10].

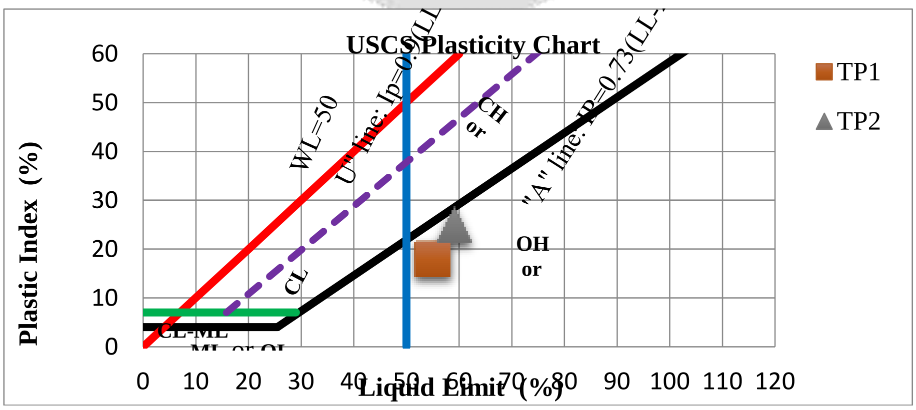


Chart-3: USCS plasticity chart.

The soil classification was accomplished according to USCS [7]. And then, TP1 and TP2 are categorized under Silt Soil (MH).

5.2 Compaction Test

The water content at which the maximum dry density is attained is obtained from the relationships provided by the standard proctor tests. It may be mentioned that compaction methods cannot remove all the air voids, and, therefore, the soil never becomes fully saturated. The water content at which the soil is compacted in the field is controlled by the value of the optimum water content determined by the laboratory compaction test [11]. The results of this test are tabulated in Table 3.

5.3 Shear Strength Test

The unconsolidated undrained direct shear tests were conducted for determination of shear strength parameters presented in Table 3.

Test Pit	Cohesion (c_u), kPa	Internal friction angle (ϕ°)	Maximum Dry density g/cm^3	Optimum Moisture content (%)
TP1	14.3	43	1.42	29
TP2	28	31	1.53	19

Table 3: Results of shear strength test

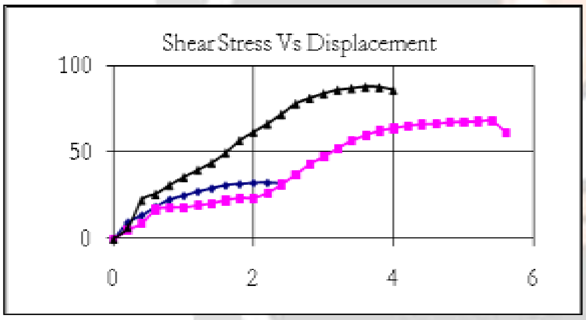
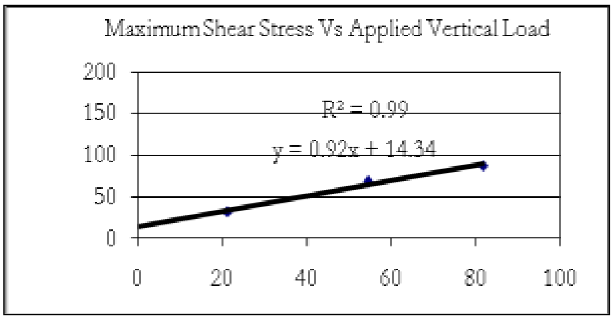


Chart- 4: Shear stress Vs Displacement graph for TP1

Vertical Stress (kN/m^2)	21.25	54.5	81.75
Shear stress (kN/m^2)	32.3	67.77	87.47

Table 4: Results of Direct Shear Test



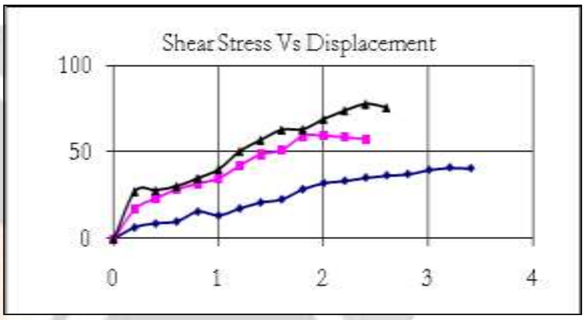


Chart- 5: Maximum shear stress Vs Applied vertical load graph for TP1

Table-5: Results of Direct Shear Test

Vertical Stress (kN/m^2)	21.25	54.5	81.75
Shear stress (kN/m^2)	41.08	59.77	77.55

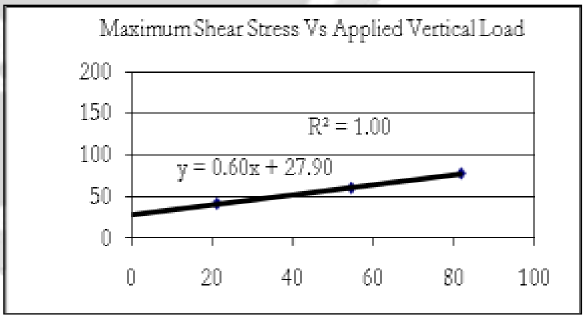


Chart - 6: Shear stress Vs Displacement graph for TP2

Chart-7: Maximum shear stress Vs Applied vertical load graph for TP2

The unit weight of these soils are represented by γ (kN/m^3) and obtained via laboratory test. So that, the values are 19.2 and 20.5 for TP1 and TP2 respectively.From the test result, the cohesion (c) between the soils particles, the angle of internal friction (ϕ), and the unit weight (γ) of the soil are determined. With the information given above, the Bearing capacity of the soil can be determine [9]. The bearing capacities of the brownish lateritic soil have been determined using the model footing presented in Figure 8.

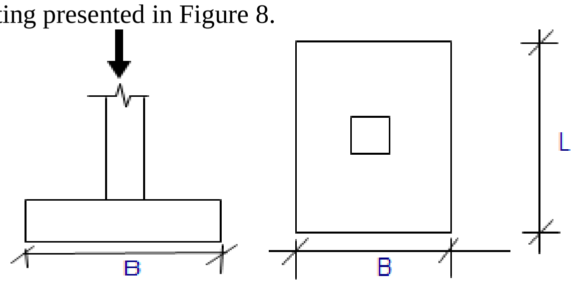


Chart- 8: The model rectangular isolated footing

Terzaghi (1943) suggested the following form of general bearing capacity equation:$q_u = c'N_c + \gamma D_f N_q + 0.5 \gamma BN_\gamma$ Where; Nc, Nq, and N_γ are bearing capacity factors.

Shape of the footing	Strip	Round	Square	Rectangle
s_c	1	1.3	1.3	1+0.3B/L
s_γ	1	0.6	0.8	0.8 or 1-0.3B/L

Table 6.The Shape factors according to Terzhagi are

therefore, the ultimate bearing capacity of soil for vertical load on rectangular footing: $c N_c (1+ 0.3B/L) + \gamma D_f N_q + 0.5\gamma BN_\gamma(1- 0.3B/L)$

5.4 Allowable Bearing Capacity of Soils

The allowable bearing capacity of soils (q_{all}) are calculated using the assumed width of isolated footing =1.0m, 1.5m and 2m; footing depth=1.5m and factor of safety of 3.0.

And then, $q_{all} = \frac{\text{Ultimate bearing capacity of soil}}{\text{Factor of safety}}$

According to Terzaghi, the bearing capacity, factors for TP1 and TP2 for ϕ=43° and ϕ = 31° ; Nc =134.58, Nq =126.5 and N_γ =211.56 and; Nc =40.41, Nq =25.28 and N_γ =22.65 were presented respectively. The values of c_u were presented in Table 3. [10] Meyerhof (1963), presented a general bearing capacity equation which takes into account the shape and the inclination of load. The general form of equation suggested by Meyerhof for bearing capacity is: q_u= cNc.Sc.dc.ic + γDf Nq.Sq.dq.iq + 0.5BγNγSγdγiγ. Where: Sγ, Sc, Sq = shape factors; dc, dq, dγ = depth factor; ic, iq, iγ = load inclination factors and N_γ = (Nq -1) tan (1.4 ϕ).

Meyerhof's (1963), proposed bearing capacities factors for test pit (TP1) and (TP2) for ϕ=43° and ϕ = 31°; Nc = 105.11, Nq = 99.02 and N_γ =171.15 and; Nc = 32.67, Nq =20.63 and N_γ =19.51 were tabulated respectively. [12] Hansen (1970), proposed bearing capacity Equation:
q_u = cNc.Sc.dc.icgcbc + γDf Nq.Sq.dq.iqgqbq + 0.5BγNγSγdγiγgγbγ

Vesic (1973), used the same form of equation suggested by Hansen. All three investigators use the equations proposed by Prandtl (1921) for computing the values of Nc and Nq wherein the foundation base is assumed as smooth. However, the equations used by them for computing the values of N_γ are different and for Vesic N_γ=2(Nq+l) tan ϕ [14].The bearing capacity factors proposed by Vesic (1973) for TP1 and TP2 for ϕ=43° and ϕ = 31°; Nc =105.11, Nq =99.02 and N_γ =186.54 and; Nc =32.67, Nq =20.63 and N_γ =25.99 were tabulated respectively [14]. The allowable bearing capacities of soil for different width of footing are presented in Table 10.
Table 7: Shape and depth factors for Meyerhof and Vesic [12, 14]

Meyerhof	Shape factor	$s_c=1+0.2k_p\frac{B}{L}$	$s_q=1+0.1k_p\frac{B}{L}$ for $\phi>10°$	$s_\gamma=s_q$ for $\phi>10°$
	Depth factor	$d_c=1+0.2\sqrt{k_p}\frac{D_f}{B}$	$d_q=1+0.1\sqrt{k_p}\frac{D_f}{B}$	$d_q=d_\gamma$ for $\phi>10°$
Vesic	Shape factor	$s_c=1+\frac{N_q}{N_c}\frac{B}{L}$	$s_q=1+\frac{B}{L}\tan\phi$	$s_\gamma=1-0.4\frac{B}{L}$
	Depth factor	$d_c=1+0.4\frac{D_f}{B}$	$d_q=1+2\tan\phi(1-\sin\phi)^2\frac{D_f}{B}$	$d_\gamma=1$ for all $\phi°$

Table 8: Shape, depth and load inclination factors for TP1;ϕ =43° by using Terzaghi (T), Meyerhof (M), and Vesic (V) equations

L/B	3.0			2.0			1.5		
D_f/B	1.5			1.0			0.8		
Author	T	M	V	T	M	V	T	M	V
s_c	1.1	1.4	1.3	1.2	1.0	1.5	1.2	1.7	1.6
s_q	-	1.2	1.3	-	1.3	1.5	-	1.4	1.6
s_γ	0.9	1.2	0.9	0.9	1.3	0.8	0.8	1.4	0.7
d_c	-	1.7	1.6	-	1.5	1.4	-	1.3	1.3
d_q	-	1.3	1.3	-	1.2	1.2	-	1.2	1.1
d_γ	-	1.3	1.0	-	1.2	1.0	-	1.2	1.0
i_c	-	1.0	1.0	-	1.0	1.0	-	1.0	1.0
i_q	-	1.0	1.0	-	1.0	1.0	-	1.0	1.0
i_γ	-	1.0	1.0	-	1.0	1.0	-	1.0	1.0

Table 9: Shape, depth and load inclination factors for TP2; ϕ =31° by using Terzaghi (T), Meyerhof (M), and Vesic (V) equations

L/B	3.0			2.0			1.5		
D_f/B	1.5			1.0			0.8		
Author	T	M	V	T	M	V	T	M	V
s_c	1.1	1.2	1.2	1.2	1.3	1.3	1.2	1.4	1.4
s_q	-	1.1	1.2	-	1.2	1.3	-	1.2	1.4
s_γ	0.9	1.1	0.9	0.9	1.2	0.8	0.8	1.2	0.7
d_c	-	1.5	1.6	-	1.4	1.4	-	1.3	1.3
d_q	-	1.3	1.4	-	1.2	1.3	-	1.1	1.2
d_γ	-	1.3	1.0	-	1.2	1.0	-	1.1	1.0
i_c	-	1.0	1.0	-	1.0	1.0	-	1.0	1.0
i_q	-	1.0	1.0	-	1.0	1.0	-	1.0	1.0
i_γ	-	1.0	1.0	-	1.0	1.0	-	1.0	1.0

Table 10: Calculated values of allowable bearing capacities in kPa of Model footings using Terzagi, Meyerhof and Vesic equations for silt

TP1				
L/B	D_f/B	q_{all} (T)	q_{all} (M)	q_{all} (V)
3.0	1.5	2537.6	3527.4	3185.8
2.0	1.0	2907.2	3889.2	3479.9
1.5	0.8	3076.8	4541.4	3551.5
TP2				
L/B	D_f/B	q_{all} (T)	q_{all} (M)	q_{all} (V)
3.0	1.5	743.9	946..6	1020.6
2.0	1.0	816.5	1003.4	1018.9
1.5	0.8	835.9	1010.1	1034.5

It is seen from Table 9 that most of the allowable bearing capacities of all methods increase with increase of angle of friction. At lower value of angle of friction for instance 0° to 20°, the ultimate bearing capacities are approximately similar to each other but difference of bearing capacity increases with increase of friction angle. Terzaghi's (1943) equation estimates lower value of bearing capacity at higher value of friction angle compare to other authors .

The most excellent technique used for cohesive soils than cohesion less soil for Df /B < 1, is Terzaghi. Whereas for D_f /B>l, Vesic equation is more appropriate. The load applied on absolutely horizontal isolated footing is concentric and vertical. So, the inclination factors are ic=iq=iγ=1. Actually, the carrying capacities of soil depend on the equations proposed by the authors. Though, the shape and depth factors are determined the values calculated and presented in Table 10. Through this process, the allowable bearing capacity values obtained for Vesic are lower than Meyerhof for TP1 having higher internal friction. The bearing capacity values for TP2 under two authors (Meyerhof and Terzhagi) for different width are nearly similar.

6. CONCLUSION

The index property values for liquid limit are 55% and 59%, plastic limit of 37% and 34%, and plasticity index of 18% and 25% for TP1 and TP2 respectively. According to USCS classification [7], the soils found in the study area are silty (MH). The compaction test evaluates the values of optimum moisture contents for TP1 and TP2 are 29% and 19%, and maximum dry density of 1.42 g/cm^{3}and 1.53 g/cm^3 respectively. The allowable bearing capacities of the soil typically for footing width 1m and depth 1.5m were computed. The results obtained from Terzhagi (1943), Meyerhof (1963) and Vesic (1973) equations shows that, for width of rectangular footing (1m) for test pit (TP1) are 2537.6kPa, 3527.4kPa and 3185.8kPa respectively. Similarly, the results obtained from these equations for test pit (TP2) are 743.9kPa, 946.6kPa and 1020.6kPa respectively. In fact, the bearing capacities of these soils are directly proportional to rectangular footing dimensions. So, an increase in the carrying capacity of soil followed with an increase in footing width. These bearing capacity values are ready for carrying for multi-story building with little risk.

7.ACKNOWLEGMENT

The author is grateful to the financial support of Yohannis Haile Building Construction for the tests were performed in the Geotechnical Engineering Laboratory.

8.REFERENCES

[1] Akpila S.B; Eluozo, S.N (2012), Shallow Foundation Analysis on Heterogeneous Soil Formation in the Niger Delta of Nigeria, Nigeria.

[2] C.Ve Venkatramaiah, (2006), Geotechnical Engineering, India.

[3] K. Terzaghi, R. B. Peck &G.Mesri,(1996) Soil Mechanics in Engineering Practice‖. (Third edition). John Wiley & Sons, New York.

[4] Matawal, D.S., Journal of Engineering Research, 1991, 3(1), 1-9.

[5] Mishra A. K., et al. (2010) A New Technology of Marble Slurry Waste Utilization in Roads, Journal ofScientific and Industrial Research, 69; 67-72.

[6] Prof. P. B. Pande, Dr. S.P. Bajad, Dr. S. R. Khandeshwar (2014), The Effect of Degree of Saturation on the Bearing Capacity of Shallow Foundation, India.

[7] ASTM, 2004. Special Procedures for Testing Soil and Rock for Civil Engineering Purpose, U.S. America.

Prof. Muni B. (2011), Soil Mechanics and Foundations, John Wiley & Sons, inc.

[8] Otuaga, Philips M. (2015), Determination of bearing capacity for building and structural design in owo local government area, ondo state, Nigeria.

[9] Terzaghi K. (1943), Theoretical Soil Mechanics. Wiley, New York.

[9] Arora, K.R. (2004), Soil Mechanics and Foundation Engineering, Standard Publishers Distributors, New Delhi.

[10] Meyerhof, G.G. (1963). Some Recent Research on Bearing Capacity of Foundation, CGJ Ottawa, Vol.1.

[11] Hansen J. B. (1970) A Revised and Extended Formula for bearing Capacity. Danish Geotechnical Institute, Copenhagen, bulletin No. 28.

[12] Vesic, A.S. (1973). "Analysis of Ultimate Loads of Shallow Foundations, "JSMFD, ASCE, Vol. 99, SMI.

[13] Mr. SukantaKumer Shill (Ass Pro.), Dr. Md. Mozammel Hoque (Prof.), Copaction of Bearing Capacity Calculation Methods in Designing Shallow Foundations, Gazipur, Bangladesh.